Environmental Media Systems:
Innovations at the U.S. Environmental Protection Agency's National Exposure Research Laboratory

by

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ABSTRACT

This multi-sited ethnography analyzes challenges and opportunities in the design and development of digital media systems in the Office of Research and Development (ORD) at the United States Environmental Protection Agency (EPA). Drawing heavily from interviews conducted over the course of three years, primarily with scientists at the ORD's National Exposure Research Laboratory (NERL) in Research Triangle, North Carolina, this dissertation documents and describes the forces behind emergent practices in the communication of environmental science that go beyond the limitations of a transmission model of communication. To describe the practices of my interlocutors, I introduce a model of *science communication as context production*. The contexts of interest are *environmental media systems (EMSs)*, sociotechnical systems marked by diverse forms of expertise and the creation of collaborative, interactive, open, multi-directional, digital spaces. The EMSs I focus on are the National Atlas of Sustainability and the Community Multiscale Air Quality (CMAQ) modeling system. Both projects could be described as virtual laboratories. The Atlas, which is not yet available for public use, will be a publicly accessible, web-based, easily usable mapping application that draws together a multitude of demographic and ecological data sets, along with a number of tools, including an Eco-Health Relationship Browser. CMAQ is an open-source modeling system used primarily to guide regulatory policy on air quality. This dissertation aims to describe and analyze how producers of the Atlas and CMAQ articulate *the matrix of forces* (technological, political, economic, legal, historical, ecological, cultural) that shape and are shaped by the design and effects of EMSs; *the need for innovation* in the circulation of environmental information and in forms of collectivity that enable better design of EMSs; *the design imaginaries or logics* guiding the assemblage of EMSs capable of fostering new forms of environmental and scientific literacy and *the cultural critique* practiced through production of EMSs and imaginaries of (scientific) communication and literacy that challenge traditional notions of what communication is and can do. The EMS producers I engaged with understand their communities of practice—and the publics using the systems they design—as marked by heterogeneous expertise and goals; recognition of this diversity opens up possibilities for collaboration and interdisciplinary problem solving.

1. Introduction

1.1 Summary of the Project

In recent years layoffs of thousands of journalists, the collapse of long standing newspapers throughout the U.S. and other factors have led to an upheaval in traditional forms of environmental journalism (Daley, 2010). Nevertheless, public awareness of the urgency and complexity of many environmental issues has increased dramatically in the past few decades. This is, in part, due to developments in *environmental media systems (EMSs)*—such as web-based tools using geographic information systems (GIS), geo-coded databases on toxics and computer models of the environment—that have enabled the visualization, communication and contemplation of environmental problems in new ways.[1] New opportunities are emerging for the integration of increasingly accessible and usable media technologies such as video cameras, editing software, online mapping tools and a variety of social networking tools with traditional knowledges, skills, artistic practices and forms of collectivity. EMSs are sociotechnical systems marked by diverse forms of expertise and the creation of collaborative, interactive, open, multi-directional digital spaces. The EMSs I focus on in this dissertation are the National Atlas of Sustainability and the Community Multiscale Air Quality (CMAQ) modeling system. Each of these projects is led by producers in the National Exposure Research Laboratory (NERL) within the Office of Research and Development (ORD) of the U.S. Environmental Protection Agency (EPA). The Atlas, which is currently under development and not yet available for public use, is becoming a web-based mapping application that draws together a multitude of demographic and ecological data sets, along with a number of tools, including an Eco-Health Relationship Browser. The Atlas will enable a diverse set of users to view and analyze multiple ecosystem services—such

[1] A number of scholars have written about environmental information systems (EIS) (K Fortun, 2004; Günther, 2001; Tochtermann, 2002). The distinction between EIS and EMS may seem minor, but foreshadows some of the key arguments of this dissertation. Choosing *media* over *information* draws attention to how representations of the environment are always mediated by, and can mediate or transform, the systems they are produced and operate within. Media, and perhaps especially new media, are more easily recognized as contexts with particular forms (a newspaper, radio show, blog, etc.), while information tends to be seen as content. The EIS/EMS distinction is discussed further in this dissertation's conclusion.

as climate regulation, protection from hazardous weather and filtration of pollutants from the air—along with services provided by the built environment in a specific region. CMAQ is an open-source modeling system used primarily in guiding regulatory policy on air quality.

Along with improving public awareness of environmental problems, innovations in EMSs provide scientists with improved modes of internal communication, enhancing mutual understanding, collaboration and coordinated action. Constant advances in modeling and visualization methods are critical in the contemporary moment because the most pressing environmental problems (e.g., climate change, peak oil, biodiversity loss, etc.) exist on a global scale and exceed the confines of disciplinary boundaries.[2] Seemingly more mundane but nevertheless highly complex policy matters, such as a revision to the regulatory standard for ozone pollution, require the collective engagement of diverse experts and technologies. Building assemblages to link scientists with varying expertise, data sets, technologies and policy makers can be a formidable challenge (Reichman, Jones, & Schildhauer, 2011) but is an essential task if we are to successfully confront daunting environmental challenges. A key refrain in this dissertation is the notion of communicationXcreation, where the X (standing in for the Greek "chi") marks a chiasmus. Mike Fortun writes (2010, pp. 13–15):

> The chiasmus cleaves a couplet of terms that are conventionally taken as distinct or even opposed, but that in fact depend on each other, provoke each other, or contribute to each other. . . In cell biology, the chiasmus is the name given to the site where the two copies of a chromosome are joined, become entwined, and, most importantly and productively, *recombine* in the process of meiotic cell division, rather than simply reproduce or replicate. The chiasma of our chromosomes are sites of chance and an emergent future—sites of volatility, change, and, with luck, evolution. . . the chiasmus marks a folding of two things into each

[2]Paul Edwards, in *A Vast Machine*, writes about how modeling is *essential* for making sense of the world's climate because observations must be mediated by models to become global in time and space (Edwards, 2010). Chapter Three of this dissertation, on the CMAQ modeling system, resonates strongly with Edwards's debunking of climate change skeptics' calls for the need to wait for "real data" or "sound science" before action is taken. My material on CMAQ and Edwards's analysis of climate change models reveals how modelers have gradually and carefully crafted modeling systems that provide a useful—though imperfect—basis for making difficult decisions about environmental management.

> other that, like any of a number of M.C. Escher prints, never settles down into a *first this, then that* image, statement, or concept.

The re-combinatorial nature of communication and creation marked by the X resonates strongly with the notion of "informated objectivity" inspired by post-1980 practices in genomics and the environmental sciences.[3] While communication has always been central to knowledge creation, new technologies and growing institutional support are catalyzing experiments in the form of environmental mediation and enabling the production of contexts that assemble diverse environmental knowledge, experts and decision makers.

[3]Kim Fortun and Mike Fortun describe informated objectivity as a matter of (Kim Fortun & Fortun, n.d.-a):

> juxtaposition, addition, and connection rather than reduction. . . the really good [scientists]—the ones we want more of, the ones whose becomings we want to assist if we can—are comfortable with multiplicities, recognizing that the patterns "seen" in large datasets are both meaningful and radically perspectival. They recognize that data does not speak for itself, except through the instruments we provide in conversation with it.

The notion of informated objectivity explicitly draws on, and extends, Peter Galison's work on the personae, practices, image and ontologies that underlie three phases of objectivity: genial depiction (before 1820), mechanical objectivity (1820 – 1920) and judgmental objectivity (1920-1980) (P. Galison, 1999).

Figure 1: Beyondtalk.net. The name of this environmentalist group—focused on "direct action"—is telling. It exemplifies widely circulating notions about what communication is, or is not. I agree that we need to get beyond talk, and direct action on climate change is necessary, I think we also need to get beyond models of talk that see communication as a matter of transmission or injection. Instead, communication can be seen as capable of creating new contexts for generation and action. Communicative contexts in the scientific arena can produce knowledge, but can also circulate and create collaborations, practices and world-views. The organization and performance of direct actions increasingly relies on information and communications technologies (ICTs). Activists employ last-minute mass e-mails, on-the-go text messaging, tweeting and videography as means of organizing collectivity, witnessing police actions and proliferating the activists' mediated view of the action (Donk, 2004; Garrett, 2006).

The EMS producers I interviewed stress that to properly address environmental problems of "broad national significance," policy makers, scientists and the public need better tools—conceptual as well as technological—for visualizing, communicating about and acting on environmental information and knowledge.[4] EMS producers at my field sites tend to imagine their audiences as capable (with the right tools) of developing

[4]In 2009, the Conceptual Document guiding research at NERL called for increasing attention to "problems of broad national significance," like climate change and sustaining ecosystem services (Araujo et al., 2009).

environmental literacy and grasping dense and complex information. These EMS producers are developing systems to provide the scientific and technical means for understanding and modeling causes, effects and relationships across spatio-temporal scales. Interactions with these systems could enable both *ecological* and *future-oriented* thinking and action.

Both in terms of communication to various publics and among scientists, the scientists I interviewed articulate an emergent focus on the development of collaborative, interactive, open, multi-directional, sociotechnical systems, what I call EMSs.[5] Table 1, below, illustrates an analytical dichotomy between the *transmission* and *context production* models of science/environmental communication.[6]

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[5]In this dissertation, I use the term "publics" (in the plural) to move away from the homogenizing rhetoric of "the public," as if "it" was a monolithic entity. Homi K. Bhaba's comments in "DissemiNation" accomplish a similar de-homogenizing move, while noting how collectivity must be continually re-created (Bhabha, 1994, p. 212):

> The boundary that marks the nation's selfhood interrupts the self-generating time of national production and disrupts the signification of the people as homogeneous. The problem is not simply the 'selfhood' of the nation as opposed to the otherness of other nations. We are confronted with the nation split within itself, articulating the heterogeneity of its population. The barred Nation *It/Self*, alienated from its eternal self-generation, becomes a liminal signifying space that is internally marked by the discourses of minorities, the heterogeneous histories of contending peoples, antagonistic authorities, and tense locations of culture difference.

Sidney Verba and Norman H. Nie, in their ambitious *Participation in America*, develop a typology of publics as inactives, voting specialists, parochial participants, communalists, campaign activists and complete activists (Verba & Nie, 1987). Their study on the ways in which citizens participate in American political life points to the need to *constitute* active publics; information can catalyze the transformation of inactives into complete activists, which "rate high on all participation orientations and are involved in conflict and cleavage but also have a sense of contribution to the community at large" (Kasperson & Kasperson, 2005, p. 25). Publics can, of course, include scientists, and many other kinds of experts. A key argument of this dissertation concerns how my interlocutors are imagining their communities of practice as heterogeneous, opening up possibilities for collaboration and pointing the way to understand publics as similarly diverse.

[6]While my interlocutors describe their own impressions of differences in communicative practices over the past few decades, it is important to note that this dissertation does not claim to document a *transition* from a transmission model to another point. While this shift may be occurring, the empirical material collected here represents a snapshot in time and not a historical argument. Thinking of scientific communication as context production is inspired by scholarship on digital artists, especially Victoria Vesna's introduction to *Database Aesthetics: Art in the Age of Information Overflow,* in which she writes that "ultimately, artists working with digital media necessarily work in collaborative groups and are context providers. Indeed, the development of context in the age of information overload is the art of the day" (2007, xii). Vesna contrasts the work of context production with the label of artists as "content providers," simply adding content to pre-defined spaces. Similarly, as I discuss in this dissertation's epilogue, Kathy High and other media artists I have interviewed veer away from the figure of the artist collaborating with scientists as the illustrator or translator of science. High and others may avoid seeing their work as communication because of widely circulating notions of

This dissertation maps recent developments in EMSs and how these innovations are drawn together. I aim to promote understanding of how and why EMS producers in the United States are developing innovative media systems in order to expand scientific and environmental literacy and to generate new scientific knowledge. The conceptual question behind this work concerns what communication can do and could become. Four primary empirical questions cascade from this conceptual question and guide this study, namely how do EMS producers understand and articulate:

1) *the matrix of forces* (technological, political, economic, legal, historical, ecological, cultural) that shape and are shaped by the design and effects of EMSs?

2) *the need for innovation* in the circulation of environmental information and in forms of collectivity behind EMS design and circulation?

3) *their design imaginaries* guiding the assemblage of EMSs[7]?

4) *their cultural critique* of scientific communication and literacy by challenging traditional notions of what communication is and can do and re-working figures of both experts and the public as heterogeneous assemblages?

Engagement with these questions has included three years of participant observation and ethnographic interviews with experts in environmental science communication at the EPA's ORD. The projects I focused on were the National Atlas for Sustainability and the Community Multiscale Air Quality (CMAQ) modeling system. The designers and developers of these projects are distributed across a number of spaces, but are primarily located at EPA ORD's National Exposure Research Laboratory (NERL) in Research Triangle, North Carolina. NERL aims to produce science that (EPA, 2012e):

> leads to improved methods, measurements and models to assess and predict exposures of humans and ecosystems to harmful environmental

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communication as transmission, rather than as the production of productive and provocative contexts for deliberation and dissent. Sections 5.2 and 5.31 elaborate on the model of scientific communication as context production.

[7]Imaginaries, in anthropological discourse, bring together different modes and products of sense making. Kim Fortun and Mike Fortun write that (Fortun & Fortun, 2005, p. 44):

> the study of imaginaries has allowed us to examine how large-scale change happens and is understood at the local level. Focusing on imaginaries is a way to study the forces constitutive of subjectivity and how subjects negotiate those forces. And it is also a way to study how people shape and are shaped by complex technical, social, and political-economic systems.

stressors [which] can include chemical pollutants, microbes and pathogens, physical agents such as land use and processes such as alteration of wildlife habitat. Exposure science also provides the foundation for the development of approaches to reduce these exposures and safeguard human health and the environment.

Figure 2: NERL Headquarters. Inside the NERL's Green Building, Research Triangle Park, North Carolina.

The National Atlas for Sustainability, currently under development at the EPA and slated for public release in late 2012, will be an online space that allows users to use Geographic Information Systems (GIS) to visualize data sets on the benefits provided by

natural and built environments and to graph differences across space and time for criteria such as air quality, carbon sequestration and other ecosystem services.[8] An Urban Atlas component will enable users to zoom in with high resolution to local scales in select areas. The Atlas will provide a space for gathering the necessary information to make a wide array of environmental management decisions. It will also provide a context for gaining a sense of how ecosystems connect elements sometimes thought to be separate, or of a different kind, such as humans and nature, ecosystem services and the built environment, the economy and biodiversity. The Atlas could also be useful for researchers, radically reducing the time it takes to gather data sets. Drawing together a wide array of researchers and data has been essential to the development of the Atlas.

CMAQ is an air quality modeling system designed to model multiple pollutants at multiple scales. CMAQ is used in regulatory contexts to evaluate the impacts of air quality management decisions and predict the effects of alternative future pathways. CMAQ is also used to provide air quality predictions alongside weather forecasts and on sites like airnow.gov. While the Atlas is designed to be useable by the general U.S. population, CMAQ is designed to be used by a highly specialized community of about 3,000 air quality modelers throughout the world. CMAQ is emphatically open-source and many of its users also develop and analyze the model for ongoing improvement. Because of the complexity of the atmosphere and the model itself, CMAQ is reliant upon contributions from scientists in multiple fields. Like the Atlas, CMAQ can be used to make comparisons across space (i.e. between cities or estimating concentrations between monitors) and time (i.e. for predicting pollution concentrations given alternate scenarios), but is much more narrowly focused on the subject of air quality. CMAQ has achieved a relatively high degree of credibility through its transparency and careful development of the model itself as well as—and inseparably—the collective that develops and analyzes it.

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[8]The notion of ecosystem services (or eco services) has been used by ecologists for decades and gained much wider exposure through the massive 2005 United Nations Millennium Ecosystem Assessment (see maweb.org). Eco services refer to myriad ecosystem resources and processes that supply benefits to humankind. As an environmental management paradigm, eco services tends towards assigning economic value to nature. Debates over the eco services paradigm are covered in more detail in Chapter Three on the National Atlas of Sustainability.

This dissertation contributes to the fields of science and technology studies (STS), media studies and cultural anthropology by:

1) Augmenting the ethnographic and historical record on how scientists conceive of communication, their audiences and potential effects.

2) Describing the collective design of online, collaborative, *experimental media systems* (drawing on Rheinberger 1997) or *virtual trading zones* (Peter Galison, 1997) as contexts that can produce knowledge and the unexpected.[9]

3) Looking at the need for innovation in modes of engagement with the challenges and opportunities involved in representing the environment (often portrayed as subaltern other) and its relationship to humanity.[10]

4) Providing new insight into the development of scientific and environmental communication and literacy in an era of new media.

1.2 The Fieldwork

Interviews and fieldwork for this dissertation were carried out from 2009 to 2012. Individually and in team-based settings, over 50 interviews were conducted with EMS producers across my field sites and at other relevant organizations.[11]

The EPA is largely a regulatory agency. It has ten regional offices around the nation and a dozen headquarters offices located in Washington, D.C., such as the Office of Air and Radiation and the Office of Environmental Information. The Office of Research and Development (ORD) has three national laboratories, four national centers and two offices located in 14 facilities across the country. The scientists I spoke with for

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[9]Peter Galison describes the physics laboratory as a "trading zone" where physicists with different "forms of work, modes of demonstration, [and] ontological commitments" come together like two cultures who do not share the same language and interact through trade (Peter Galison, 1997, p. 137). For a trading zone between two cultures to function properly, the trading partners need to "hammer out a *local* coordination despite vast *global* differences" (Ibid., 138). While not sited in a specific physical laboratory, I conceive of the various moments of intra-action within CMAQ and the social spaces around it as virtual trading zones that require their own set of *local practices*, which I focus on in Chapter Four.

[10]"The weaving of contexts and of messages which propose contexts—but which, like all messages whatsoever, have 'meaning' only by virtue of context—is the subject matter of the so-called double-bind theory" (Bateson, 2000, p. 274).

[11]For detailed descriptions of the fieldwork and interviews see Appendix Two.

this dissertation research were primarily located at the National Exposure Research Laboratory (NERL), headquartered in Research Triangle Park (RTP), North Carolina.

My fieldwork began in RTP where we interviewed 22 NERL research scientists as part of a National Science Foundation funded study on interdisciplinarity in exposure science.[12] We conducted interviews in a team-based setting and focused on the communication challenges to creating and sustaining interdisciplinarity and reaching diverse publics. This research trip provided methodological training that would prove invaluable, but also illustrated the magnitude of the challenge of coordinating over 400 scientists in a complex and dynamic organizational structure. This initial foray into the world of EPA research sparked an ongoing interest in how experimenting with forms of diverse collectivity can enable better scientific practice and communication. I had to rapidly pick up dozens of acronyms and technical phrases and found that even researchers within the EPA sometimes find it difficult to navigate the institutional landscape outside of their research group and specialty area.[13] There was something about the researchers at NERL that moved me: they seemed to be driven by a desire to simultaneously create a better world and to do the best science they could. It became increasingly clear that these dual motivations were intimately entwined. There has been surprisingly little written about the ORD, and in the contemporary moment—marked by presidential candidates threatening to "turn the lights off" at the EPA and think tanks calling for the EPA's dissolution—documenting the struggles and the successes of the researchers at EPA's ORD seemed especially timely.[14,15]

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[12]This research trip included Kim Fortun (PI on the NSF grant supporting the research), Mike Fortun and Alison Kenner. We collaborated on researching each interviewee's background and, together, developed a general template of interview questions that would generate material for our separate projects and our shared goal of improving understanding of creating and sustaining interdisciplinarity.

[13]On a few occasions, when researchers with decades of experience at ORD were asked what an acronym stood for, having become so accustomed to using the abbreviated name, they wouldn't remember!

[14]Presidential candidate Michelle Bachmann, in a town hall meeting on the campaign trail, promised to "go to the Department—the EPA—and I will turn the lights off and I'll lock the door… wouldn't it be wonderful to turn those government buildings into for-profit centers and have business come along and buy up a lot of those buildings?" (Bachmann, 2011).

[15] Herman I. Miller, a Fellow in Scientific Philosophy and Public Policy at the Hoover Institution, recently called for the complete dissolution of the EPA, partly based on perceived scientific ineptitude. In an article in the Cato Institute's *Regulation*, Miller argues that the EPA "should be abolished and its essential functions reassigned to other, less scientifically challenged government organizations (Miller, 2011, p. 6).The Hoover Institution's mission statement quotes Herbert Hoover's 1959 statement to the

This initial research trip introduced me to the projects that became my primary field sites. One key project is the National Atlas of Sustainability (which I'll refer to as the Atlas). A number of ecologists we spoke with referred to the ecosystem services (or "eco services") paradigm as the next big thing or the "third wave" in environmentalism (after conservation and sustainability).[16] The Atlas (originally called the National Atlas of Ecosystem Services until a recent re-organization at the EPA) is heavily embedded in the eco services paradigm, aiming to help, as the team leader on the Atlas Annie Neale puts it, "ensure that the balance between things people want (e.g. convenient roadways and plentiful parking), and the functionality that the environment needs to maintain itself are understood and managed in a manner that is sustainable to both" (Neale, 2009a). The Atlas also reflects a broadly articulated need to improve the transparency of research and databases at the EPA and other federal agencies.[17] Mapping was framed by Atlas producers as a fruitful approach to making EPA data more usable by a wider range of stakeholders.[18] The Atlas interface is similar to programs like Google Earth and will help

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Board of Trustees of Stanford University on the purpose and scope of the Hoover Institution (Hoover Institution, 2012):

> Both our social and economic systems are based on private enterprise from which springs initiative and ingenuity. . . Ours is a system where the Federal Government should undertake no governmental, social or economic action, except where local government, or the people, cannot undertake it for themselves.

Environmental sustainability, for this institution, is trumped by a mission to sustain "the American way of life."

[16]In more recent interviews, there has been an increasing focus on sustainability as an emergent paradigm, still very much under negotiation, that is focusing efforts at the EPA.

[17]A recent report by the President's Council of Advisors on Science and Technology (PCAST), "Sustaining Environmental Capital: Protecting Society and the Economy" (U.S. Office of Science and Technology Policy, 2011, p. 2) notes:

> with concern that the vast majority of the 55 national environmental monitoring programs surveyed by PCAST have not yet posted their data sets to Data.gov, the Federal data clearinghouse. Moreover, the report found, some agencies appear to be using overly strict security regimes on ecosystem data sets, making it unnecessarily difficult for policy-makers to take environmental capital into account. "Government agencies over the years have invested heavily in environmental data gathering, but those investments will be wasted if the data are not made available to the public and other agencies in usable formats," said Barbara Schaal, PCAST member and working group co-chair. "By making these data accessible and applying new informatics techniques, we stand to gain answers to difficult ecological and economic questions and can plan wisely for a robust and sustainable future."

[18]STS scholars Virginia Eubanks and Nancy Campbell write about the importance of usability and how, "the democratization of technological citizenship can be best extended not through narrowly construed 'technology training' but through 'popular technology,' an empowering and visionary combination of popular education and participatory design that emphasizes technological literacy as well as producing

make visible the wide range of services that can be provided by different ecosystems such as filtering agricultural runoff and providing outdoor recreation spaces. Another section provides data layers on services provided by the built environment. While the particular communities that will use the Atlas remain to be seen, it appears that it will help a diverse set of users assess a wide range of land-use scenarios. By comparing different spaces, or the same spaces across time, the Atlas allows for a limited number of risk assessments (such as risks from heat waves, air pollution from traffic and contamination of drinking and recreational waters) and comparisons of the relative value of ecosystem services using a modifiable index. Users with asthma, for example, can increase the weight of ground-level ozone—a powerful asthma trigger—in assessing air quality. Asthmatics could then compare spaces using the graphing tools in order to inform decisions about where to live and work. It quickly became clear that the Atlas works by linking the data sets from many governmental organizations in a single public platform. Development of the Atlas is led by the Landscape Characterization and Mapping Team (part of the EPA Ecosystem Services Research Program) but involves many other agencies at the federal, state and municipal levels. The Atlas is also the project that researchers I spoke with at the EPA most often described as a hub that integrates a multitude of data sets and tools. It was this work of synthesizing and developing relays that first jumped out at me, especially after hearing from a number of researchers about the wide range of tools developed at the EPA that remain fairly disconnected. The focus on inter-connection (or experts, models, data sets, etc.) at the core of both the Atlas and CMAQ is a hallmark of EMSs.

While the Atlas was originally designed primarily for public circulation of relatively settled environmental information, researchers at the EPA and elsewhere are also developing EMSs more explicitly designed for the production of new environmental knowledge.[19] On our 2009 NERL trip we spoke with a number of research scientists working on developing, analyzing and deploying the CMAQ model, described on cmaq-

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and decoding cultural representations" (Eubanks & Campbell, 2004, p. 1). Eubanks and Campbell point out how the interface between the user and the medium itself is mediated by broader factors.

[19] This is not to say that the Atlas will not also be a powerful research tool. Circulation and generation of environmental knowledge is inseparable; one of the markers of EMSs is that they provide a space for communicationXcreation.

model.org as "an active open-source development project of the U.S. EPA Atmospheric Science Modeling Division that consists of a suite of programs for conducting air quality model simulations." The primary goals for the CMAQ modeling system are (EPA, 2012b):

> to improve 1) the environmental management community's ability to evaluate the impact of air quality management practices for multiple pollutants at multiple scales and 2) the scientist's ability to better probe, understand, and simulate chemical and physical interactions in the atmosphere.

CMAQ producers tend to imagine a narrower audience than Atlas producers, namely the environmental management community and scientists. CMAQ designers referred to the model as a "numerical laboratory," which I came to see as a virtual space for knowledge communicationXcreation; CMAQ is a space that both contains (and, as it travels, circulates) the state-of-the-science and enables new questions to be asked and answered. CMAQ first caught my attention because of its open source character and the diverse global community of user/producers required to sustain and develop it. When I first encountered CMAQ, I had a copy of Chris Kelty's *Two Bits* in my backpack and the notion of "recursive publics" was ringing in my ears (Kelty, 2005, 2008).[20] The CMAQ network provided an excellent case for examining how modes of collectivity can help enable, and are enabled by, successful EMS production and innovation.[21]

My choice of research projects proved to be lucky. In interviews years later both the Atlas and CMAQ were repeatedly cited by ORD scientists as the best contemporary examples of tools or spaces being crafted that assemble diverse elements and exemplify the logic of assemblage that will be necessary for addressing complex environmental challenges. By and large, my research relied on interviews with the producers of the Atlas and CMAQ. In order to get a better feel for the process of developing EMSs, I

[20]A recursive public is a mode of association in which a group is "constituted by a shared, profound concern for the technical and legal conditions of possibility for their own association" (Kelty 2008, 185).

[21]While my own practices of scholarship seemed far removed, at first, from the production and evaluation of this air quality model, I believe that some of the forms of collective knowledge production in the CMAQ community might inflect practices in STS and anthropology, especially when traditional forms of proprietary publishing could be described as in crisis. I develop these potential connections in the Epilogue.

have also been a participant-observer, as a core designer, on *The Asthma Files***,** a collaborative ethnographic project that provides a context for engaging with complex environmental health issues.[22]

1.3 The Analysis

> *The passage of relays not only implies holding but also giving. For the relay to be taken, it must be given, even if those who give know that they are not masters of what they give, that when a relay is taken it is not a matter of a simple translation but of a new creation. In this regard Félix Guattari evoked a process of "existential catalysis," wherein each "creation" or reconquest is able to generate repercussions in the mode of the "yes, it's possible," able to arouse the appetite that will make another possibility exist elsewhere.*
>
> - Isabelle Stengers and Phillipe Pignarre, *Capitalist Sorcery: Breaking the Spell* (2011, p. 96)

How have EMS producers perceived and acted within the matrix of forces that affect and are affected by projects at the intersection of emergent media technologies and environmentalism? What are the goals and motivations driving their work? What do they think is missing from the environmental media landscape? How do they imagine EMSs could be designed to become more effective? What does it mean for EMSs to be "effective," and how can this be measured or accounted for? How can their practices be understood as cultural critique, especially in light of how they think about and produce new forms of scientific communication and literacy? These are the questions that I

[22] *The Asthma Files* is an electronic archive of text, images, video and audio that illustrate multiple perspectives on asthma and environmental health. Unlike my EPA sites, collaborators on *The Asthma Files* are, for the most part, social scientists and humanities scholars, with backgrounds in the history of genetics, the philosophy of science, science and technology studies, medical anthropology and anthropology of science and technology. A number of the decisions we have made in designing the website have been influenced by my research on the Atlas and CMAQ, such as including a tools section and linking disparate data sets. Beyond working on the overall structure of *The Asthma Files* website, my focus has been on developing the Communicating Asthma section, which includes charts of air pollution correlated to asthma hospitalization rates and maps that convey the extraordinary and uneven prevalence of asthma in different locales. The structure of *The Asthma Files*, as a context in which complex phenomena can be better understood, could travel, proving useful for a number of phenomena beyond asthma.

stayed close to as I prepared interview questions, attended meetings and conferences and sat down to analyze the ethnographic material I collected. Generating and analyzing data was an iterative process, and while writing in a structured way necessarily became increasingly central as the project progressed, I started writing as soon as research commenced and did not stop gathering data and conducting interviews until the writing was nearly finished.

Underlying my research questions are the following basic but sprawling, long-studied but never resolved conceptual-theoretical questions: What is communication? What can it do? What could it become? These conceptual questions have practical stakes. What new images of the political come into view? What new pedagogical strategies or tactics could be invented? These questions were approached ethnographically. I mapped the trajectories of EMS producers (both their career paths and the influences that have affected their EMS production) and examined their ways of thinking about and approaching communication, their audiences, science, technology and literacy. I brought my own constructions of language to this project, inflected largely by reading-effects[23] from my most loved texts, but the ethnographic approach required constant openness to the approaches and conceptualizations of my interlocutors. Following Shoshana Felman (Felman, 2003, pp. 21–22):

> theoretical tools will not function here as a new *meaning* to confer upon the text [or the ethnographic material I collected for this dissertation], but as a new way of *being affected* by the text[24]. . . each text studied will put into question the terminology and critical instruments used to approach it, giving them in the end a different, singular, and renewed meaning. As a result, it is not just the literary texts that will, in light of these theoretical problematics, be opened up to an entirely different reading, the critical terms and theoretical instruments themselves will be rediscovered and reinterpreted.

[23]The Lacanian literary theorist Shoshana Felman uses the term reading-effect to describe how literature can catalyze a mutation in how people read, and even how they situate themselves in the world (Felman, 2003).

[24]In grappling with the question "what can a body do?" Gilles Deleuze writes that "what a body can do corresponds to the nature and limits of its capacity to be affected" (Deleuze, 1992, p. 218). See also Derrida's argument for speech as the means through which actors open themselves up to personal transformation (Derrida, 1988).

1.4 The Text

While much of this dissertation is dedicated to illuminating what I see as novel, exciting possibilities, I actively work against a tendency to fetishize the new and I have tried to retain close attention to how structural factors resist change and continue to have powerful effects. Putting the substantive and design logics of EMS producers in conversation with relevant literatures helps to draw out their cultural critique in ways that highlight the particularities of their practices and forms of collectivity, ideally informing their (and my) future work.

The following chapter, Environmental Media Systems in/as Forceful Contexts situates the EMSs I analyze in emergent historical contexts and points to the potentials and limitations of EMSs with a focus on effects/affects that are often missed in scholarship on environmental and science communication. The chapter maps out conceptual/theoretical and empirical background on public environmental perceptions and literacies; reviews models of environmental risk communication, uncertainty and scientific literacy; gives examples of the roles EMSs, as actively shaping prostheses, can have in shaping environmental subjects and covers recent shifts in mass media, especially in reporting on science and the environment, opportunities and limitations of new media in the environmental sphere, different imaginaries of what media are and can do and different notions of what counts as good evidence and representation.

Chapter Three, on the National Atlas for Sustainability, is about the intersection of ecology and informatics and the knowledge and subject-effects eco-informatics can produce. The science of ecology, which is largely about connectivity, has been characterized by a surprising lack of data sharing among ecologists, not to mention across boundaries with other kinds of scientists, publics and policy makers. Ecologists have often mobilized a limited model of science communication as the sharing of final results, in the traditional form of presentations and publications. The Atlas reflects (and catalyzes) developments in ecological informatics, especially at the EPA, that prioritize sharing and synthesis of ecological data by providing an interface that is accessible and usable by ecologists and non-specialists alike. Designed primarily to help a diverse array of users make better environmental management decisions, the Atlas will also provide a

space for knowledge production and could help circulate a more ecological views of the human/nature relationship.

Chapter Four, "Steps to an Epistemology of Models: Care of the Collective and Sound Science," describes the open-source Community Multiscale Air Quality (CMAQ) modeling system, analyzes a debate over its use in predicting some of the health effects resulting from climate change and characterizes its developers' epistemological stances. I trace how CMAQ has become the "go-to" modeling system for a wide range of air quality issues, both in the scientific community and policy-making spheres, in the U.S. and abroad. CMAQ became widely used and respected not by defeating the competition, but by continually adapting to changing demands in the regulatory arena and developing a diverse global community that contributes to the model's development and analysis. This chapter illustrates some of the unique challenges and opportunities around unstable notions of "sound science" at the EPA, which simultaneously has mandates to produce unbiased science and advocate for public health and ecological sustainability.[25] CMAQ's credibility is largely based on the communication and collaboration required by, and produced by, the modeling system. In this chapter I sketch an epistemology that is simultaneously self-critical and imperfect, scientific and mediated. Practices within the CMAQ community could inform the development of a more nuanced notion of sound science in modeling and the environmental sciences more generally.

My analyses of the Atlas and CMAQ provide insights into conditions that shape EMS producers' articulations of their goals, supporting infrastructure, forms of collaboration and perceived effects. This dissertation's conclusion focuses on how EMS producers at my field sites understand and articulate the key concepts of this study including communication, literacy, subject-effects and collectivity. I return to the project of situating the specific articulations and practices of my interlocutors (which were zoomed in on in the body chapters) *in* broader contexts, while framing the EMSs they

[25]In *Merchants of Doubt*, Naomi Oreskes and Erik Conway chronicle how Fred Singer, with generous funding from the tobacco industry, created the Science and Environment Policy Project in 1990 to promote the notion of "sound science" in environmental policy. Specifically, Singer and colleagues aimed to mobilize the concept of sound science to help industry "promote the science they liked and to discredit discredit any science they didn't," including EPA science on second hand smoke, which was dismissed as "junk science" (Oreskes & Conway, 2010, p. 143)

produce *as* contexts that could make these broader contexts swerve and enable new modes of engagement with environmentalism. I put EMS producers' logics in play with design principles drawn from readings of other practices such as permaculture design principles and the design logics informing *The Asthma Files*.[26] Drawing on the body chapters' engagement with my four primary research questions, the conclusion returns to the underlying conceptual/theoretical questions about what communication in the sciences could become. Table 1 sets up an analytical distinction between communication as transmission and as context production. The figure condenses brief articulations of what I see as emergent practices in science/environment communication (on the right), while keeping in view the staying power of embedded practices and imaginaries of what communication is and can do (on the left). The conclusion concludes with a brief discussion of the kinds of environmental literacy that EMS might catalyze in both scientists and the public and re-visits the stakes of this research.

In the epilogue I reflect on the potential for EMSs to catalyze epistemological literacies and ecologies of mind, discuss the consequences of re-theorizing communication as context production, put EMS in conversation with STS and artistic practices and analyze some of the stakes involved with developing better EMSs in the contemporary moment. Appendix 1 is a timeline covering shifts in conceptions of the environment, key moments in environmental legislation, institutional development at the EPA and developments in environmental media and information technology. Appendix 2 provides brief reflections on the research process and more detail on the fieldwork and interviews for this dissertation.

[26]One of the permaculture design principles, for example, focuses on building in collaboration between diverse elements—geography, ecology, plants, animals—in order to reduce the amount of work required to address agricultural challenges.

2. Environmental Media Systems in/as Forceful Contexts

2.1 Introduction

This chapter discusses some of the key contextual factors that shape and are shaped by EMS design and situates EMSs in relation to broader dynamics in contemporary media ecologies. I map conceptual and empirical background on public environmental perceptions and literacies and analyze a number of models of environmental risk communication, uncertainty and scientific literacy. I also outline some of the opportunities and limitations of new media and show how EMSs can shape environmental subjects, objects and their relations. While I primarily focus on new media, I also discuss recent transformations in mass media because much of the public still relies heavily on the mass media for information on science and the environment; information from the types of EMSs I examine can travel farthest when re-mediated through the mass media and examining the constraints on the mass media as a space of science and environment communication illuminates some of the stakes involved with developing new forms of EMSs. This chapter concludes by discussing theories of communication, different imaginaries of what media are capable of and different constructions of what gets to count as good or sound science. I argue that, compared to transmission models of communication, conceiving of communication as context production both more accurately describes EMSs like the Atlas and CMAQ and could better inform practices in environmental and science communication that leverage (and push) the affordances of new media.

2.2 Informatics and the Environment

This dissertation is a step towards bridging discursive gaps between the *practices* of EMS producers working at the intersection of information technologies and environmentalism and the *theories* of (science) communication produced by scholars in anthropology, media studies and STS. Environmental communication scholar Piyush Mathur notes a lack of a sustained theoretical engagement between the discourses concerning the information society and environmentalism. This is surprising because

many environmentalists in both activist and governmental contexts have embraced the use of information technology. "In general," he writes (2009, p. 119):

> the discourse on the information society has neglected the environmental factor; the environmental discourse, on the other hand, has either maintained its critical distance from the technological visions involving the information society—or it has rejected them. . . eco-critics or eco-philosophers have typically tended to focus on those socioeconomic, political, and cultural tenets that are readily characterized by the term *postindustrialism* rather than, strictly speaking, by informationalization.

Mathur discusses only two authors with book-length exceptions to the separation of information technology from environmentalist concerns. Timothy W. Luke's work characterizes informationalization (of industrial and agricultural production) as largely a project which supports the continued development of transnational commerce and domination of nature (Luke, 1997, 1999). Elizabeth Grossman examines the toxic environmental and health effects of the production and discard of hardware and writes about how the idea of "virtual worlds" fosters the illusion that we have left the material world behind (Grossman, 2007).[27]

While the negative contingencies of information technologies described by Luke and Grossman are important to account for, this dissertation takes a more affirmative tack, showing how information technologies, when designed and developed in particular ways, can become virtual worlds where the materiality of environments (natural and culturally produced) can come into better view. Some EMSs could help users shift from a stance of domination over nature to a more immanent view of the intra-action among humans and their environments.[28]

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[27]For an artistic intervention that seeks to make visible the materiality of the "information age," see Natalie Jeremijenko's project "Stump," in which a (Jeremijenko, n.d.):

> printer queue virus that counts the number of pages consumed by the printer. When the equivalent of a tree in pulp has been consumed the program automatically prints out a slice of tree. Accumulating these pieces of paper 'grows' a stump of the forest that you and your printer have consumed, and a tangible representation of tree debt.

The project intends to dispel the illusion of a clean and paperless digital age.

[28]Physicist and feminist theorist Karen Barad uses the term "intra-action" to describe a relationship between objects in which the objects do not precede their interaction; rather, they emerge through particular, "material-discursive," intra-actions (Barad, 2007). The chiasmus described above is a useful material-semiotic figure for intra-active sites.

While Mathur demonstrates a general lack of attention to the intersection of IT and environmentalism, scholars in the fields of environmental communication and risk communication do, of course, work on these issues. But Mathur argues, and I agree, that there are serious lacunae in these fields, largely due to legacy models of communication and the domination of a limited number of questions that receive the lion's share of attention in these fields.

2.3 Transmission and Context in Environmental Communication

In the journal *Environmental Communication,* Asa Boholm writes that in the fields of risk and environmental communication, **"**despite some change of scope and orientation over the past 30 years, two theoretical ideas have persisted: the subjective/objective risk dichotomy and the transmission (also known as code) model of communication" (Boholm, 2009, p. 225). Boholm argues that these theoretical legacies make *context* a blind spot. In Boholm's characterization of the transmission model—also known as the conduit metaphor, the syringe theory or the code theory—there are two stages of communication: that of sending and that of receiving a signal (Boholm 2009, 338 and see (Sperber & Wilson, 1996, pp. 1–9):

> The sender translates a message into a signal using a code (a 'language'); the receiver interprets the message by decoding the signal according to the same code… words and sentences have meanings in themselves, independent of context or speaker… Thoughts are transformed into words that 'travel,' by means of speech or writing, from a sender to a receiver who can 'understand' the thought 'behind' the linguistic expression.

In *Communication as Culture,* James W. Carey, a communications theorist, media critic and journalism instructor, writes about how the transmission model of communication is linked to a 19th Century notion that binds communication with transportation, and ultimately an industrial model that situates communication as "the transmission of signals or messages over distance for the purpose of control" (Carey, 2008, p. 12). Antonio López, a scholar of environmental communication, points out that "it is well worth considering a critique of 'control over distance' when a host of ecological

advocates. . . are arguing that local solutions are the antidote to the globalized crisis" (López, 2010, p. 102).[29]

Education can be framed as planned attitude and behavioral change, induced by technocratic expertise. The pedagogy of the projects I analyze in this dissertation is better understood as one involving diverse participation and involvement in environmental decision making and multi-directional co-operation among different publics, policy makers and scientific experts. As Boholm suggests above, going beyond the transmission model can entail paying more attention to context, including literacies, cultural formations and ontological presuppositions. In pragmatics, context is understood as an assemblage of the premises, assumptions and meanings shaped by the information, expectations, beliefs, memories and attributions possessed by participants in the communicative process. This linguistic definition of context as discursive assemblage is expanded in this dissertation to include the technologies that mediate communication among various stakeholders in the communication and generation of environmental science.

While still marked by the transmission model, the EMSs I analyze tend towards emergent articulations and practices that are described more accurately by a model of communication as context production. In this model, multiple codes or languages can co-exist and new ones can be created. Like the trading zone, local languages are "hammered out" (Galison, 1997). In the Atlas, multiple publics can use the platform in myriad ways, bringing their own questions and goals. CMAQ similarly braids together multiple ways of understanding the atmosphere and provides a new context that can be useful for different actors in different ways. In both projects, pre-existing languages or codes are not sufficient; difference is made productive. The point is not to transmit an

[29]Anna Tsing has helped me think through globalism and scale. She writes that scale (Tsing, 2004, p. 58):

> is the spatial dimensionality necessary for a particular kind of view, whether up close or from a distance, microscopic or planetary. I argue that scale is not just a neutral frame for viewing the world; scale must be brought into being: proposed, practiced, and evaded, as well as taken for granted. Scales are claimed and contested in cultural and political projects. A "globalism" is a commitment to the global, and there are multiple, overlapping, and somewhat contradictory globalisms; a "regionalism" is a commitment to the region; and so on.

already known message, but to create new questions and ways of grasping the environment as an epistemic object.

Science communication, as transmission, is frequently portrayed in popular accounts as outside or after the more serious and difficult work of creating (or discovering) scientific knowledge and facts. But science communication as context production, in the cases discussed below, involves crafting spaces that can be used both for locating and producing knowledge. STS scholars have consistently and convincingly argued that, especially in interdisciplinary projects, communication among communities of practice is increasingly central to the creation of new and usable knowledge. Classic texts in STS are based on fieldwork at, or historical analysis of, the "sites" of knowledge production and provide thick description of laboratory life (Latour & Woolgar, 1986; Traweek, 1992) and other spaces of knowledge production (Shapin & Schaffer, 2011). This dissertation examines digital contexts for scientific knowledge production, even as face-to-face interaction among designers of these virtual sites remains crucial. In a sense, embodied relationships among EMS producers enable the production of digital spaces that broaden access and usability to the knowledge and expertise produced in these communities of practice. The sites of EMS production (including institutional and political-economic contexts) can have powerful effects on the digital spaces that are produced.[30]

2.4 Public Perceptions and Literacies of Environmental Problems

In *The Social Contours of Risk,* Roger E. Kasperson and Jeanne Kasperson provide a condensed history of some of the legal and cultural forces affecting increasing demands for better environmental and risk communication (Kasperson & Kasperson, 2005, p. 19):

> a time of community right-to-know laws, burgeoning liability claims and expectations for citizen participation imposes new societal obligations for communicating about risk. The growing obligation for communication

[30]Based on my interlocutors' description of CMAQ as a "numerical laboratory," I have begun to think of the Atlas as a "visual laboratory." Both can be seen as "experimental systems" and "graphematic spaces" (Rheinberger, 1998; Rheinberger, 1997).

> reflects not only an increasing public concern over hazards of technology, but also a long-term movement for public participation (which has its roots in the civil rights and environmental movements of the 1960s) and the Freedom of Information Act and right-to-know requirements of specific health and safety regulations.

How do we, as a society and as scholars, make sense of public understanding of the (science of) the environment? Large polls can be useful for tracking general trends with a large sample size, but the results can be contradictory depending on who conducted the study and what specific questions were asked. The questions tend to be either very broad or focused on relatively instrumental technical knowledge. They can also reinforce the idea of environmentalism as a zero sum game, i.e. "what is more important to you, the environment or the economy?"

In *Environmental Communication and the Public Sphere*, J. Robert Cox, Professor of Communication Studies and the Curriculum in the Environment and Ecology at the University of North Carolina at Chapel Hill, writes, "at first glance, there appears to be little need for persuasion and debate about environmental issues. Since the first Earth Day in 1970, U.S. opinion polls have reported that the public is concerned about environmental problems and strongly supports environmental values" (Cox, 2009, pp. 3–4). A 2000 Gallup poll found that 83% of Americans "readily agreed with the broadest goals of the environmental movement" (Guber, 2003, p. 3). Even with the recent recession, a plurality of Americans say that protection of the environment should be given priority, even at the risk of curbing economic growth, according to a poll by CNN/Opinion Research (Goldman, 2008). But the 2010 Gallup Environment poll found "historically low levels of public worry about environmental problems (particularly global warming) and support for environmental protection" (Dunlap, 2010).[31] While 74 percent of the public felt that the problem of warming the Earth's atmosphere was either "somewhat" or "extremely" serious, considerable differences exist among individuals over how society should solve environmental problems (Guber, 2003).[32] Robert Cox

[31]Specifically, the poll shows a "10-point overall increase in those claiming to be neutral or unsympathetic toward the [environmental] movement (from 28% to 38%)" over the last decade (Dunlap, 2010).

[32]This statistic is from a study by the World Wildlife Fund Respondents were split almost evenly between those who favored government regulation (37%), those who supported free market options (32%) and

notes that "the complexity of issues such as global warming makes the finding of a public consensus difficult" (Cox, 2009, p. 4).

The statistics above are based on broad surveys, standard and relatively visible modes of accounting for public awareness and understanding of the environment and science. It is fairly common to hear statistics on how many Americans believe in anthropogenic climate change in the mass media. Much of risk communication (RC), environmental communication (EC) and public understanding of science (PUS) scholarship and practice sees the task of communication as using ready-made vehicles (often the mass media) to transmit the correct facts, in one direction, from experts (who have the science) to the rather ignorant and homogeneous public.[33] "Traditionally," Cox writes, "scholars have evaluated the effectiveness of particular communication strategies for conveying technical information about health risks to potentially affected populations" (Cox, 2009, p. 18). Presumably, once members of the public are enlightened with factual science they will see the light, grasp their plight and take better

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those who felt they lacked enough information to choose (30%) (Guber, 2003, pp. 30–31).

[33]Piyush Mathur writes that (P. Mathur, 2009, p. 124):

> The privileging of the professional communicator within the analytical framework (of EC) is also witnessed in literatures related to science communication (especially science journalism), except that the scientist here shares the podium (sometimes competes for it), so to speak, with the reporter. Rather predictably, the literature of EC is rife with lines of inquiries such as the following: How best to communicate (presumably complex) concerns relating to the environment to the public at large? What problems are encountered in the process of this communication? What politics or scientific disputes does an environmental journalist or reporter get caught into while discharging his or her duties? How to determine empirically public's awareness of a particular environmental issue—what methodologies to employ, how to draw conclusions from such a study for improving a given environmental communication?

What might we be able to see if, temporarily, we de-center the professional communicator in our analysis of the goals and procedures of risk communication? Privileging the subject position of the professional communicator—whether inhabited by a scientist, reporter or both—results in some questions being privileged while others fall away. In *The Social Contours of Risk*, Kasperson and Kasperson write that (Kasperson & Kasperson, 2005, p. 20):

> conflicts emerging in public participation efforts often centre upon means/ends differences in expectations… Different individuals bring different expectations to the participation (or risk consideration) enterprise. The public official tends to see an instrumental role for public participation—it is a means to accomplish particular ends, often those included in an agency mandate (protect health and safety) or those associated with bureaucratic objectives (e.g. build a base of support for agency plans, protect the agency from outside attacks). Thus, agency-designed participation efforts characteristically recognize goals such as "correcting misperception," "educating the public," "reducing conflict," "easing implementation" or increasing legitimacy.

care of their environment, making decisions based on science instead of ignorance or politics. Asthma communication and education campaigns, for example, are almost always targeted narrowly at asthmatics and reduce a complex environmental health condition to its technical fix, in the form of the inhaler, devoid of broader context. Traditional methods of environmental and science communication frequently carry traces of the transmission model of communication that I describe above.

Landy et al. argue that framing environmental decision-making as narrowly focused on technical questions of safety, "the EPA hindered meaningful political debate about critical environmental choices" (Landy et al., 1994, p. 8). They see "civic education" as one of the key tasks for the EPA, a task that they suggest has much room for improvement. Landy et al. write that any given policy issue will have its own set of interested publics, which (Landy et al., 1994, p. 8):

> can be conceived of as a set of concentric circles. The innermost ring is composed of the relevant specialists in lead agencies and legislative communities. Surrounding them are staffers from other agencies (including oversight units like the Office of Management and Budget), members of interest groups, and other legislators. Farther removed are journalists, state and local bureaucrats, local opinion leaders, and activists. Most distant still is the citizenry at large.

Going beyond the transmission model, Landy et al. argue that a key task is to enable meaningful political debate by providing "civic education that strengthens the capacity of citizens for successful self-government" (Landy et al., 1994, p. 7). Rather than see public and expert communities as homogeneous and separate, they share space in the concentric circles of different publics around any policy decision and while "the authority of experts may pose a danger to democracy," their expertise "is crucial if citizens are to understand what is possible and what is mere wishful thinking" (Landy et al., 1994, p. 7).

In the arena of environmental problem solving, public opinion is, of course, only part of the story. Beyond conveying environmental and scientific information from scientists to the public, advances in EMSs could enable 1) better linkages among different kinds of scientists (a crucial development as contemporary environmental challenges demand increasingly interdisciplinary collaboration) and 2) the production of tools that enable individuals and communities with little scientific training to develop

and communicate their own understanding of local environmental challenges. Communication is central to both internal production and external circulation of environmental knowledge, but, as much STS scholarship has shown, the line between lay and expert can be far from clear, though it has powerful effects and deserves careful interrogation.

2.5 From Literacies to Subjectivities: EMSs and the Shaping of Environmental Subjects

Landy et al. write about how "pluralism," the "mode of political analysis that has dominated the postwar period," has led to a kind of muddling through that takes problems to be zero-sum games and sees compromise as the goal (Landy et al., 1994, p. 12):

> Like economists, pluralists treat individual desires as fixed and given. Such desires determine the ends the state is to serve. The state in turn is but a handy organizing device, a traffic cop, helping the free market to function efficiently. Perhaps because it so complicates the analysis, pluralists seldom acknowledge that experiences change individuals, that is, the value someone places on preserving nature may depend on whether they have ever hiked in the wilderness. The pluralists would reject our whole discussion of civic education, especially the ethical dimensions of such education, as at best irrelevant and at worst a recipe for tyranny.

I would add that experiences that can affect perceptions and desires around the environment need not be as picturesquely "natural" as hiking in the wilderness; experiences with various media can powerfully shift desires and subjectivities as well. Films like *Food Inc.* have changed the way people think about their relationship to the food they consume. I would argue that in the space of the Atlas, the very form of the medium—infused by its ecologist-producers with an aesthetic of layering and connection-building—could have reading-effects on users that travel to various parts of their lives, potentially affecting how they "read" the environment around them and their relationship to it.

Conveying technical information can be a challenging and productive goal in some contexts, but how else do EMS producers understand scientific and environmental literacy? How else do they imagine it might it be measured and improved?

Developments in EMSs have provided new ways to visualize and act in and on the environment, sometimes with ambiguous effects. EMSs configure access to knowledge, manage uncertainty and develop particular modes of subjectivity. Well-designed EMSs can help people make new connections among aspects of their environment and health that are not immediately apparent. EMSs can help people make connections between their own local environments and seemingly distant contexts and develop an eye for patterns and comparative perspective.

While my focus is on producers (and not consumers) of EMSs, the potential for EMSs to have various subject-effects, even when initially designed and used for instrumental goals, is a key driver of my interest in these systems. Furthermore, how EMS producers imagine and experience their audiences—including students, scientists and policymakers—and their potential for new ways of seeing and knowing their environment will clearly affect their design logics. The process of design and development can also have subject-effects on the producers of these systems. The new ways of seeing that could be catalyzed by the EMSs I've examined, especially the ecological perspective presented by the Atlas, resonates with Isabelle Stengers' version of a humorous and immanent style of critique (Stengers, 2000, pp. 65–67). Humor, for Stengers, following Deleuze, signals an immanent relation among subject and object. The media described in Historian of science Gregg Mitman's *Reel Nature*, in contrast, take on a more ironic affect, portraying nature as radically removed from humanity, showing humanity as transcending nature (Mitman, 1999). Immanence (vs. transcendence) has frequently been invoked in feminist studies of science and technology. Distinguished STS scholar and feminist theorist Donna Haraway, for example, writes that "feminist objectivity is about limited location and situated knowledge, not about transcendence and splitting of subject and object. In this way we might become answerable for what we learn how to see" (Haraway, 1988, p. 587).

Diane Wilson's book, *An Unreasonable Woman*, illustrates the extraordinary capacity for environmental information to animate new kinds of literacy, inquiry and subjectivity (D. Wilson & Ausubel, 2006). In 1989, based on the first year of reporting from the Toxic Release Inventory (TRI), a local newspaper reported that Calhoun County, Texas, population 15,000, was the most polluted county in the U.S. Wilson

describes how reading the article catalyzed a process by which she learned about not only the details about the pollution in her beloved San Antonio Bay, but also how to "read" how specific and local environmental conditions are embedded in a complex web of international laws, information politics, local economies and grassroots campaigns. The Atlas, with its ability to zoom between different scales, could prove to be a powerful tool for connecting local experiences to broader trends.

Similarly, Mitman has written about how pollen maps, produced in the U.S. in the 1930s, while heavily biased and developed to increase pharmaceutical sales, introduced a panoramic, ecological view of the world (Mitman, 2007). Mitman makes the case that an ecological perspective can foster a better understanding of the changing relationships between health and environment and can cultivate more intelligent and careful engagement with complex problems. Developing an ecological perspective could involve a shift away from anthropocentric views of the world and a greater appreciation for how immanently and intimately entwined various components of ecosystems are, and how the relays that connect diverse elements could be re-shaped to produce healthier environments. As Stengers et al. point out, it is important to ask what connections are *not* being made, what elements are *not* being cared for, what is left off the map (Stengers & Pignarre, 2011).

2.6 EMSs as Subject-, Community- and Object-Shaping Prostheses

In addition to subject-shaping reading-effects, EMSs can have object-shaping "observer effects" (as in quantum physics) at multiple scales.[34] Beyond delivering technical information for instrumental uses, EMSs can actively re-shape cultural formations, material ecologies and environmental governance. Scholar of GIS and political geography Sarah Elwood's research on the adoption of GIS technologies by a neighborhood association in Minneapolis shows how GIS shifted the power dynamics between the state and the community in "progressive" directions, challenging exclusion

[34]The concept of "observer" effects gets precisely at the inseparability of, intraaction between and tangled agencies of subject and object. See Barad (Barad, 2007) on the impossibility of separating phenomena from their observations and measurements.

from a state rehabilitation fund, but also had an ambiguous impact within the community, allowing those with greater technological facility to gain disproportionate control (Elwood, 2002). In other cases, GIS could help balance access to ecological information by making it accessible to users that had previously lacked the requisite technological literacy to navigate difficult interfaces. Atlas designers and developers aim for the Atlas to be usable by a very wide range of users, albeit differently, depending on prior experience and expertise with GIS and ecological data. The potential for EMSs to shape, or even create, communities is exemplified in both the Atlas and CMAQ projects, but is perhaps most clearly condensed in the institutionalization of the Community Modeling and Analysis System (CMAS).

Ways of seeing and making sense of the world can also have profound effects on the environments portrayed in these systems. An STS scholar and Professor of Digital Anthropology, Lane DeNicola shows how mapping and visualization technologies can transform the physical world with their gaze (DeNicola, 2007). In the remote sensing technologies he examined, trees that take up more pixel space from aerial views were planted prolifically in order to meet certain requirements, such as "coverage," despite the fact that other trees could have been much more effective on the ground. Similarly, ecosystems that can more easily fit the ecosystems services paradigm and the visualization system of the Atlas may gain priority in land-use decisions over landscapes that provide services that are less quantifiable. Richard Kerr writes about how the Gravity Recovery and Climate Experiment (GRACE) satellite mission has "put a solid number" on the rate at which groundwater is being depleted in India and Pakistan (Kerr, 2009).[35] The quantitative data produced by GRACE scientists, using an impressive system linking satellite technology and modeling software, may prove to be crucial for animating effective and legitimate policy. GRACE enables powerful and sobering articulations like "54 cubic kilometers of groundwater is lost each year from the world's most intensively irrigated region hosting 600 million people." This broad, national, view

[35]In addition to impressive numbers, evocative images can be similarly mobilizing. Satellite images of the Deepwater Horizon Oil Spill are a case in point. David Meek writes about the proliferation and extensive usage of remote sensing technologies and asks "how do these technologies, and their usages, inform our understanding of the 'production' of environmental disasters, their (re)mediation, and the assignment of blame?" (Meek, 2010).

of Indian groundwater involves big numbers and a grand scale; it could be used to supplement the local knowledge of farmers on the ground. When new technological ways of seeing and knowing enter a field, is it important to account for the knowledges they may displace, but also the promises they may hold to supplement existing ways of knowing.[36] As we will see in Chapter Four, putting a number on environmental degradation and human health effects can be powerful, but is also likely to be highly contested and compete with other numbers, such as those marking the current state of the economy.

2.7 Environmental Risk Communication and the Politics of Uncertainty

The question of what (environmental) risk and science should be communicated, and why, is inseparable from the questions of to whom and by whom? Much scholarship in environmental communication focuses on representations in news media that are almost always limited to one directional communication to the public. Traditional modes of risk communication tend to configure the public as uneducated or even—resonating with the figure of the public described above by Landy et al. as having fixed and given desires—incapable of learning (Fortun 2004). The figure of the hysterical subject of environmental risk, easily panicked over threats, conditions—and constrains—communication strategies in government initiatives (Covello & Allen, 1988), industry (Harrison, 1992) and journalism (Bate, 2000).

Bate is concerned that "contentious theories. . . are often given undue prominence [in the media]. . . because of prejudice, time pressure and ignorance" (Bate, 2000, p. x). But contention is an irreducible and central aspect of contemporary environmental problems, which tend to be both politically and scientifically complex. In their preface to *Communicating Uncertainty*, Friedman et al. even claim (Friedman, Dunwoody, & Rogers, 1999, p. vii):

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[36] As Haraway puts it, "Partial perspective can be held accountable for both its promising and its destructive monsters;" "seeing from below" is far from straightforward: "*how* to see from below is a problem requiring at least as much skill with bodies and language, with the mediations of vision, as the 'highest' techno-scientific visualizations" (Haraway, 1993, pp. 87–88).

> perhaps the most common outcome of the scientific process is not facts, but uncertainty. Ambiguity about what is true and what is not is so ubiquitous that one could define scientific expertise not so much in terms of accumulation of knowledge but by the skill of recognizing and managing uncertainty.

In *Science in Public*, Jane Gregory and Steve Miller argue that while improving the public understanding of science is an admirable goal, what should be communicated, and why, is far from clear (Gregory & Miller, 2000). They claim that when science is "in-the-making," and the "right" answer is unavailable, the scientific literacy enterprise, in terms of knowledge or understanding, becomes "irrelevant." Yet, in the environmental arena, much science is uncertain and still demands action in the present. Scientists using the CMAQ model, for example, have made claims about possible effects of climate change on asthma incidence due to ozone exposure, even as they point out uncertainties in the model and the need for better inputs (Knowlton et al., 2004).[37] Clearly these kinds of speculative scientific endeavors cannot be adequately judged using standards and epistemological frames developed for, say, clinical trials of drugs that use double-blind placebo experiments (the gold standard in pharmaceutical research). Future-oriented or spatially predictive sciences demand the invention of novel forms of accounting for and defending good science.

Debates over uncertain science always occur in particular (and often highly contentious) political contexts. Bate argues that "scientific uncertainty is no match for a politician with a plan, and often policy proceeds as though correlation were indeed causation" (Bate, 2000, p. xiv). Bate, like many politicians and U.S. citizens in the neoliberal moment, is concerned with overregulation of industries by the government on environmental issues. But a "politician with a plan" can also take advantage of the difficulty of proving and communicating causation, a notoriously difficult task, especially in cases when many different factors can have cumulative effects that are

[37]On much shorter time scales, people with asthma can get daily updates that predict air quality and ozone in order to plan their activities. An even more common-place modeling practice is the ubiquitous weather forecast, though even this familiar information service is infamous for uncertainty. Linking climate change to health effects is especially important in the light of recent research that suggests people are more likely to listen when climate change becomes a health issue (Maibach, Nisbet, Baldwin, Akerlof, & Diao, 2010).

difficult to disentangle, and particularly in the U.S. legal context, which tends to place the burden of proof firmly on those aiming to show causation between, say, pollution and health effects. Politicians wishing to delay or block "progressive" regulatory policy can take advantage of this difficulty in proving causation.[38] Many politicians today, despite the state-of-the-science, for example, refuse to recognize a robust causal relationship between human activity and climate change. Working for the tobacco industry, Fred Singer's assault on EPA science as "junk science" largely relied on claims that the EPA "could not rule out other factors… such as diet, outdoor air pollution, genetics, prior lung disease, etc." (Oreskes & Conway, 2010, pp. 143–144).[39] The very rules of what counts as "causation" are constructed in power-laden contexts; there is no a priori definition of standard of proof. As I will show in Chapter Four, CMAQ producers have developed an approach that focuses on careful collective examination of the processes that make up the model.

2.8 Recent Shifts in the Mass Media and Effects on Science and Environment Reporting

A narrow range the U.S. population reads reports generated by scientists; these reports tend to take the form of dense articles, with a narrow scope, published in journals that have yet to become open access. Various news media have traditionally played an important role in disseminating scientific perspectives on the environment and shaping

[38]The precautionary principle is far more common in the European Union (EU), where legislation known as Registration, Evaluation and Authorization of Chemicals (REACH), unlike the Toxic Substances Control Act (TSCA) in the U.S., requires companies to develop information on chemicals' effects on human health and the environment. As a report from the U.S. Government Accountability Office (GAO) puts it (United States Government Accountability Office, 2007):

> TSCA places the burden of proof on EPA to demonstrate that a chemical poses a risk to human health or the environment before EPA can regulate its production or use, while REACH generally places a burden on chemical companies to ensure that chemicals do not pose such risks or that measures are identified for handling chemicals safely.

[39]In their evaluation of Singer's accusations, Oreskes and Conway write that (Oreskes & Conway, 2010, p. 144):

> The EPA scientists *had* considered and ruled out other factors. That is what it means to do epidemiology. No one had denied that genetics and lifestyle played a role in health and disease, but the statistical evidence was overwhelming that [second hand smoke] was an *added* risk. It is not plausible to suppose that Singer did not understand this—he was a highly educated and intelligent man—but the reality wasn't convenient to his motivation.

public environmental and scientific literacy. But the news media landscape has shifted radically in recent years, especially when it comes to coverage of science and the environment. Fairness and Accuracy in Reporting (FAIR) concisely sums up a broad critique of the contemporary mainstream media landscape as increasingly co-opted by large corporations, limited in the range of viewpoints that are given a voice and failing the public interest (Fairness and Accuracy in Reporting, n.d.):

> Independent, aggressive and critical media are essential to an informed democracy. But mainstream media are increasingly cozy with the economic and political powers they should be watchdogging. Mergers in the news industry have accelerated, further limiting the spectrum of viewpoints that have access to mass media. With U.S. media outlets overwhelmingly owned by for-profit conglomerates and supported by corporate advertisers, independent journalism is compromised. Ultimately, FAIR believes that structural reform is needed to break up the dominant media conglomerates, establish independent public broadcasting, and promote strong, non-profit alternative sources of information.

The Pew Research Center's "State of the News Media" shows a 26% drop in newspaper advertising revenue in 2009, including online (Pew Project for Excellence in Journalism, 2010). This rapid decline in revenue is contributing to the recent layoffs of thousands of journalists, the collapse of long-standing newspapers and what John Daley, a member of the Society for Environmental Journalists, describes as an overall "meltdown" of environmental journalism (Daley, 2010). Daley describes how "9/11 plus competition from Fox, MSNBC" drastically changed the landscape of environmental journalism in the U.S. For his article published on the *Yale Forum on Climate Change and the Media*, Daley interviewed former CNN producer Camille Freanny to provide "a window into the evolution of CNN's science team, from thriving to extinct, which parallels larger industry trends" (Daley, 2010):

> In its heyday in the late 90s, she says, CNN had a team of roughly 12 full-time journalists, plus interns, covering technology, climate change, wildlife, alternative energy, and more. It traveled the world to do groundbreaking stories and over time produced four CNN magazine programs on environment, science, and technology. The team lost its key supporter after CNN merged with Time Warner and the network's legendary founder Ted Turner, an ardent supporter of environmental causes and environmental journalism, became much less of an influence. Later, Freanny says, the 9/11 terrorism attacks and the Iraq war changed

> the focus dramatically. "We became the technology experts of war," she said, "7All of a sudden everything was about the war and if you could not justify your work, you had a hard time getting your stories on the air."

In 2008, CNN laid off its entire science and technology staff.

Climate activist, author and educator Bill McKibben (a founder of the climate change website 350.org) argues that the dearth of public understanding about climate change cannot be sufficiently explained by recent shifts in mainstream science and environment journalism. "Public opinion lagged scientific knowledge when newspapering was in its salad days. Journalists have done a truly bad job on this, at least in this country. . . It was the issue that showed just how awry the 'on the one hand, on the other hand' style of objectivity could go" (McKibben quoted in Daley 2010).[40]

Traditional journalism's limitations and shifts exist alongside (and perhaps motivate) promising new models and partnerships, and not just in new media. Daley describes an emerging media ecology in which journalists can link up with websites like Spot.Us where reporters seek donations to fund their stories. If a news outlet buys exclusive rights, donations are reimbursed. The process by which Spot.us democratizes the media is similar to a proposal by Edward Woodhouse, a political scientist working in STS, in which each citizen would get a standard number of vouchers that they can use to vote for particular kinds of stories to be covered.[41] A model that sounded a bit like a democratic pipe dream only a few years ago is becoming a reality with rapid shifts in the economic and sociotechnical landscape. Perhaps a similar model, based on vouchers and voting, could help the EPA get better public feedback on research and regulation priorities.

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[40]McKibben's stance reflects the idea that if the public could only have the right (scientific) knowledge, their opinions (and actions) would become environmentalist. There is some truth to this, of course, but the question of what style of objectivity is up to the task of communicating (and making sense of) environmental issues is still very much open. The communication of complex environmental problems, like climate change, call for fresh approaches to objectivity in journalism and new literacies about what counts as sound science.

[41]The Spot.Us model does not, of course, account for wide disparities in income, and for this reason is actually far from the kind of democratized media envisioned by Woodhouse. Income disparity and the heavy influence large corporations can exert on mainstream media content are some of the many economic factors that make environmental communication difficult. Publicly sponsored investigative news journalism is another emerging model, spearheaded by some Scandinavian countries, which may be more in line with democratic values.

2.9 New Media: Opportunities and Limitations

New media technologies have opened up a variety of possibilities for making environmental communication more multi-directional and providing contexts in which local knowledges can, in theory, be generatively re-combined with various forms of expertise. On the ground measurements and citizen-generated observations can, for example, increasingly be added to government data sets and scientific modes of understanding the environment. Opportunities with new media are legion as the internet has exploded contemporary media ecologies into countless channels, but there are also serious limitations to these technologies in practice.

New media have great potential to increase connectivity among people and platforms. But disciplinary and institutional boundaries, national borders and other barriers to collaboration across difference can limit cross-project hybridization. Professor of Informatics Antony Bryant takes issue with the frequent use of metaphors of "free flow" to describe new media and warns against fetishizing new media as an automatic path to stronger democracies (Bryant, 2006, p. vi):

> Social realities of our time stand in stark opposition to the sanguine and cheerful portrait painted by the "communications fetishists." The powerful flow of information is not a confluence of the river of democracy, but an insatiable intake intercepting its contents and channeling them away into magnificently huge, yet stale and stagnant artificial lakes: the more powerful the flow, the greater the threat of the river bed drying up.

The politics of changing technological infrastructure, including struggles over net neutrality, the geo-politics of broadband access and the availability of the means of producing and distributing new media, powerfully shape the landscape of environmental information. Manuel Castells writes in *The Information Society* that the multimedia world will be populated by "the interacting" and "the interacted," those who can select their multidirectional circuits of communication and those who are provided with a few prepackaged choices (Castells, 2000).

The stark scenario painted by Castells is sobering, and analytically useful, but in practice the line between the interacting and the interacted is not so clear. Consumption (of information, in this case) can still be interactive and productive (de Certeau, 2002)

and people appropriate technologies in local contexts in myriad ways. Peter Manuel, for example, demonstrates how the proliferation of inexpensive, portable sound recording equipment in India enabled broader participation in cultural production in new ways (Manuel, 1993). Rather than buy into the dichotomy of new media as either liberating or oppressive, scholars are increasingly mapping how contextual particularities constrain and enable media production and use in specific ways. As this philosopher Giorgio Agamben puts it "we need a logic of the field, as in physics, where it is impossible to draw a line clearly and separate two different substances. The polarity is present and acts at each point of the field" (Agamben & Raulff, 2004, p. 612). This dissertation draws on the work of Manuel and others on new opportunities opened up by increasing accessibility of media technologies and adds insights for the digital age in the context of environmentalism. There are particular, and underanalyzed, challenges to grapple with when media engage with complex and contested scientific issues. Access to more information is clearly not a straightforward path to a safer environment. My interlocutors have, on many occasions, talked about how many EMSs, while technically *accessible*, are hardly *usable* by those who could most benefit from their use. This work contributes to scholarship on the digital divide by insisting on the centrality of intuitive and compelling human-computer interfaces (HCI) and mapping some specific ways in which to achieve such usability.

How do different groups use the tools and resources at hand to develop projects that meet their own challenges and goals? And how are the tools that previously were available only to elites becoming more accessible and usable? How could this extension be furthered in order to help bridge the digital divide and democratize media and information production? The Atlas, for example, can be seen as a project that makes (limited) GIS capabilities and ecological data much more available and usable by a wider audience, but the degree to which users might engage in citizen science, adding their own data alongside that of EPA, remains to be seen and will be constrained by EPA's communicative policies. There are, however, many examples for Atlas producers to draw on as they work through these constraints and possibilities. In "New Cartographers: How Citizen Mapmakers are Changing the Story of our Lives," Christine McLaren writes about how maps portraying data, and not simply locations or

destinations, are becoming common. Fraser Taylor, one of the world's leading cartographers and director of the International Steering Committee for Global Mapping, told McLaren that "the map user has now become the map creator" and argues that contemporary cartography is marked by a massive cultural shift "from a previous era when the mapping of our cities (or countries, or world, for that matter) was placed mainly in the hands of government mapping authorities" (Mclaren, 2012).

Taylor, who sees concern over mapping citizen and governmental data as a trend that extends far beyond the EPA, is experimenting with developing "a crowdsourcing framework that automatically creates metadata (data about the data), thus enabling the merging of crowdsourced data with that of authorities and hard science" (McLaren 2012). Taylor told McLaren that he thinks:

> As of yet there is still a resistance on the part of both government and national mapping agencies to this information. They're always saying, "What is the quality of this information? Is this stuff reliable or not?" But increasingly people are coming around to realize that there are ways of dealing with the so-called reliability issue and the accuracy issue in a way which can lead to an enrichment of society and an enrichment of their own products.

This resistance to merging citizen-produced data with governmental data sets is clearly apparent in the case of the Atlas, where EPA rules on communication, which can be especially strict for online content, constrain the possibilities for sharing data on the Atlas platform.

2.10 Advocacy and Objectivity at the EPA

Questioning the reliability of information, especially when it is displayed publicly on EPA websites, is an ongoing task for NERL scientists. The EPA faces significant challenges due to its double-positioning as a scientific research institution and a policy making and enforcement agency. Producers of the Atlas and CMAQ spoke of how the EPA's image as a regulator and advocate could taint perceptions of objectivity at the ORD. As Boyd and Crawford point out, "claims to objectivity suggest an adherence to the sphere of objects, to things as they exist in and for themselves" (2011, 5). Research at the ORD cannot exist in and for itself, as it is, by design, plugged into a

governing apparatus with a mandate to protect human and ecosystem health. Bernard Goldstein, a former Assistant Administrator for ORD and currently a Professor of Environmental and Occupational Health, asks "should the EPA have an ORD?" and contrasts the tight coupling of the EPA/ORD organizational structure with the relative separation between the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH). Goldstein describes differences in the way ORD and NIOSH are funded and reviews and argues that (Goldstein, 2011, p. 298):

> The advantage of the OSHA-NIOSH relationship is that it protects NIOSH scientific and technical staff from being too closely beholden to OSHA's political needs. This pressure clearly exists at EPA—sometimes overt, sometimes subtle, but never totally absent. In my experience, such pressure rarely impacts the scientific and technical advice given to EPA regulators, but it is not uncommon for opponents of EPA's actions to publicly attack EPA on the basis of its science or scientists being too closely linked with the position of EPA's leadership.

After reviewing differences between the EPA/ORD and OSHA/NIOSH organizational structures, Goldstein (298-299) concludes that "in their forty-year histories, EPA has done a far better job in establishing chemical specific guidelines aimed at protecting the health of the public than OSHA has done with regard to workers. . . the organizational structure of science and technology within EPA likely deserves some credit for EPA's relative effectiveness." CMAQ producers, for example, speak of how meeting every few weeks with regulators is essential for developing a modeling system that is useful in regulatory applications (see section 4.2). The close proximity and intra-action among ORD and EPA could actually produce *greater* credibility and relevance. In Chapter Four, for example, I show how close communication and relationships among CMAQ developers and regulatory stakeholders (especially the Air Quality Modeling Group in the Office of Air and Radiation) enables state-of-the-science to inform regulatory decisions. Rather than disavow the entanglement of science and politics at the ORD, it could be publicly acknowledged that EPA researchers are quite attuned to the highly contested and political nature of the science and react by ensuring that ORD's science can stand up to the strongest of criticisms use this science to advocate for human and ecosystem health.

2.11 Media Imaginaries from Tactical Media

Along with (and partially catalyzed by) advances in technologies for sensing our environment and circulating information, media producers and scholars have developed new imaginaries of what communication and media are and can do, beyond the ideals of transparent and clear information delivery. Reading about tactical media helped me stay attuned to moments when EMS producers went beyond the transmission model of communication to articulate how the projects they produce could help users—including the producers, in the process of developing these systems—develop new ways of thinking and acting in the world. Rita Raley, an Associate Professor of English studying new media art in relation to neoliberal globalization, draws parallels between tactical media and guerrilla warfare. Raley cites John Robb, a theorist of Fourth-Generation Warfare, on the strategy of attacking the "systempunkt," aiming for "disrupted flows" resulting in a "destabilization of the psychology of the marketplace that will introduce severe inefficiencies and chaos" (Raley, 2009, p. 11).[42,43] There are few similarities, at first glance, between the tactical media described by Raley and the EMSs produced at the EPA. But reading these seemingly disparate approaches together can generate new insights for both the practice and analysis of EMSs. Framing, aesthetics, interactivity and attention to scale are a few of the sites of productive overlap and tension among tactical media and the projects I analyze.

While an image of the EPA striving to produce "chaos" is somewhat absurd, the destabilization central to tactical media is a key logic behind the Atlas, which is designed to interrupt standard ways of accounting for (or externalizing) value in the environment

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[42]The term tactical media was coined in 1997 by media theorists David Garcia and Geert Lovink. They write that tactical media are what happens when (Lovink & Garcia, 1997):

> cheap "do it yourself" media, made possible by the revolution in consumer electronics and expanded forms of distribution (from public access cable to the internet) are exploited by groups and individuals who feel aggrieved by or excluded from the wider culture. Tactical media do not just report events, as they are never impartial they always participate and it is this that more than anything separates them from mainstream media.

[43]"In *global guerrilla warfare* (a combination of open source innovation, bazaar transactions, and low tech weapons), the point of greatest emphasis is called a *systempunkt*. It is the point in a system (either an infrastructure or a market), always identified by autonomous groups within the bazaar, where a swarm of small insults will cause a cascade of collapse in the targeted system" (Robb, 2004).

that are supported by ecologically dangerous "psychologies of the marketplace."[44] Predictive modeling using CMAQ, similarly, can intervene in the short-sightedness of markets and profit-based decision-making logics. Shaking habits of thought (like anthropocentrism) and practice (like ignoring environmental factors in economic decisions) is disruptive, but also, by creating space for new patterns, generative; shaking can be a gesture of care, as in pedagogies that aim to shake students up and catalyze critical thinking. A number of the projects described by Raley share in common with the Atlas and CMAQ a strategy of "rendering economic and political complexity in the form of a basic cartography" (Raley, 2009, p. 4). The capacity of media to shape subjectivities is a central and explicit theme in much tactical media that could inform production of the Atlas and other EMSs. As the Critical Art Ensemble put it, tactical media "offers participants in the projects a new way of seeing, understanding, and interacting with a given system" (Raley, 2009, p. 7). Tactical media scholars and EMS producers share an interest in questions such as: What new connections can be seen with the lens of (or from within the space of) this media? What new modes of understanding (and acting) can be catalyzed? What is lost and gained in the always necessary cuts, rendering, reduction and compression of information?

2.12 Design Logics and Beautiful Evidence

In his magisterial, exquisitely illustrated and self-produced *Beautiful Evidence*, Edward Tufte writes that (Tufte, 2006, p. 9):

> science and art have in common *intense seeing*, the wide-eyed observing that generates empirical information. *Beautiful Evidence* is about *how seeing turns* into *showing*, how empirical observations turn into explanations and evidence. The book identifies excellent and effective methods for showing evidence, suggests new designs, and provides analytical tools for assessing the credibility of evidence presentations.

[44] Absurd, that is, to the audience likely reading this dissertation, but exactly the image of the EPA circulated recently by many tea partiers and Republican presidential candidates that see environmental regulation and economic growth as diametrically opposed sides of a zero-sum game. Ironically, EPA Administrator Lisa Jackson recently referred to "the mission to strengthen the American economy" as "the defining mission of our time in office" (Lisa Jackson, 2012). As an agency tasked with protecting human and environmental health, placing the economy over issues such as climate change and peak oil is a bit surprising.

As Tufte makes clear with countless examples, design choices are not simply aesthetic, much as communication is always already "beyond talk." Rendering evidence beautiful, for Tufte, involves making complex phenomena easier to understand and navigate. In artistic and design practice and education, choices about making cuts (as in video editing) or framing (as in photography) are explicitly acknowledged. Some STS scholars have, at times, criticized scientists, technologists and engineers for being reductive. More recent scholarship in STS shows how reduction is a necessary part of any process of invention, as any good historian or other knowledge-maker knows; it is the character of this reduction, and the degree of reflexivity in the process, that is important (see (Barad, 2007).

While Tufte's opus provides many inspiring examples that could be worked into EMS design, his approach is far from a sufficient or comprehensive guide for developing EMSs that could grapple productively with the messiness and uncertainty that mark contemporary environmental sciences. For Tufte, ethics in representation are largely a matter of clean design, of honest representation. This tack resonates with Austin's values of conventional procedure, correctness, and completeness, which Jacques Derrida associates with the widely circulating notion of "an exhaustively definable context, of a free consciousness present to the totality of the operation and of absolutely meaningful speech master of itself; the teleological jurisdiction of an entire field whose organizing center remains *intention*" (Derrida, 1988, p. 15). When novel challenges, like developing the Atlas and CMAQ, call for experimentation, and the complexity of problems make completeness impossible, intention is hardly a workable guiding design principle.

Tufte's work is flavored by what Mathur calls "the refining-representing nexus," which tends to paint the environment as a given, external object (P. Mathur, 2009, p. 123):

> The pragmatic notion of forever refining or perfecting (environmental) communication privileges a mimetic view of environment and reserves a representative role for the communicator and communication. For all practical purposes, this view maintains that the environment (or its disfiguring) can and should be truthfully represented, and that it is such a representation that ought to be the motive and content of serious communication. It is possible that this discursive disposition has by default prevented many researchers of ecological communication from acknowledging the possibility of *a constitutive, interactive, and*

participatory role for the media and other communicative channels within environmentalism

This discursive disposition, and associated models of communication such as the transmission model, has constrained the imagination and practice of producers of EMSs. If a transparent, honest, complete representation of the environment is the ideal, there is little room for creative mediation. Similarly, if the ideal environment is pristine and pure, then the best we can do is reduce our impact, minimizing the effects of human subjects on the natural object *par excellence*: the environment. But there are other imaginaries at work within the cultures of EMS production I describe in detail below. Even when my interlocutors *articulate* fairly traditional notions of what communication is and can do, their *practices* sometimes tell a different, more expansive, story. Their projects have a lively language of their own.

3. Synthesizing Collaborative Cartographies: Articulating Ecological Literacy, Subjectivity and Collectivity with the National Atlas for Sustainability

We're drowning in information while starving for wisdom. The world will henceforth be run by synthesizers, people able to put together the right information at the right time, think critically about it and make important choices wisely.

- Quote from biologist E.O. Wilson tacked to a bulletin board in the office of Laura Jackson, a core producer of the Atlas

Interdisciplinary work, so much discussed these days, is not about confronting already constituted disciplines. . . it's not enough to choose a "subject" (a theme) and gather around it two or three sciences. Interdisciplinarity consists in creating a new object that belongs to no one.

- Roland Barthes, "Jeunes Chercheurs," quoted in James Clifford's Introduction to *Writing Culture* (Clifford & Marcus, 1986)

3.1 Introduction

This chapter examines the development of an online, interactive National Atlas for Sustainability (hereafter the Atlas), illustrating recent developments in the design of environmental communication technologies and techniques. This is primarily a story about the development of EMSs in ecology. I describe the forms of collectivity co-constituted with the creation of the Atlas, challenges and opportunities involved with integrating citizen science and the reading-effects the Atlas might be capable of catalyzing.

The Atlas is designed to help a wide range of users see the many kinds of value that ecosystems and the built environment provide for humans, as well as the accelerating effects of human actions such as loss of biodiversity. The team leader on the Atlas, Annie Neale, is an ecologist working in Research Triangle Park, North Carolina, in the Landscape Ecology branch of the EPA's National Exposure Research Laboratory

(NERL). I first met Neale on my initial visit to NERL in the summer of 2009. In our first interview, she talked about how the Atlas emerged out of a trend towards the paradigm of ecosystem services—it was originally called the National Atlas of Ecosystem Services—and is highly motivated by recent EPA imperatives towards transparency and reaching different publics (Neale, 2009a).[45,46] The Atlas could also become a powerful research tool and acts as a space for both the circulation and production of ecological knowledge. Designing and developing the Atlas, for Neale, is exciting and, at times, overwhelming, pushing her and her many collaborators to go beyond the skills and strategies in which they were trained. There is no pre-existing map for the Atlas producers to follow; they are, by necessity, experimenting with new goals, design logics and collaborations.[47]

After providing a brief overview of the Atlas project, this chapter provides a genealogical sketch of Neale's evolution from field ecologist to EMSs designer and producer and describes how her current fieldwork involves a great deal of travel and networking to assemble the stakeholders and data sets that make the Atlas possible. Tracing shifts in Neale's career also helps situate the Atlas in the history of ecological informatics. Next, I describe the Atlas designers' design logics (such as a focus on enabling interactivity and making limits visible) and motivations (situating the Atlas in broader institutional and economic contexts, including the challenge of valuing ecosystems services). The chapter concludes by drawing out the cultural critique

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[45]See, for example the proceedings for the May 2010 "Environmental Information Symposium: Enabling Environmental Protection through Transparency and Open Government" (EPA Office of Environmental Information, 2010).

[46]As the EPA re-organizes around a growing sense that sustainability will be the key concept driving research at the ORD, it is useful to note historical shortcomings in the EPA's willingness to explicitly acknowledge polyphony of key terms and the labor of interpreting them in particular contexts. In the case of the ozone standard revisions under Carter, Landy et al. write that (Landy, Roberts, & Thomas, 1994, p. 79):

> instead of pointing out the difficulties lurking in the words "sensitive groups" and "adequate margin of safety," its statements tended to obscure these points. EPA thus repeatedly reinforced the view that safety was both possible and desirable, something that medical experts could define without regard to social and economic concerns.

What difficulties lurk in the word "sustainability?" What troubles could the EPA walk into if these contingencies are not explicitly dealt with? Whose job should it be to do this discursive homework?

[47]Joining with scholars such as Schuurman and Pratt (2002), this chapter pushes against portrayals of cartographers (and scientists more generally) as positivists. Instead, my interlocutors are described as experimenters, reflexively (at their best) working their way through unprecedented challenges.

practiced by the Atlas designers, including their articulations and practices of scientific communication, scientific and environmental literacy in the digital age and the stakes involved with the Atlas project.

3.2 Overview of the Atlas

The Atlas will be a publicly usable website built on GIS technology that pulls together a multitude of geo-coded data layers on services provided by ecosystems and the built environment. Designed to help users navigate oceans of data and make better decisions about environmental management and land use, the Atlas will have an interface similar to Google Earth or Google Maps, but with many more data layers, and will help make visible a wide range of services that can be provided by different ecosystems, such as riparian buffers that help protect streams from agricultural runoff and parks for relaxation and recreation. The eco services paradigm is, its champions contend, increasingly being used to account for, value and care for these services and the ecosystems that sustain them.[48] Users of the Atlas will be able to zoom to their geographic area of interest and focus on relevant services to better understand impacts of changes in land-use on ecosystem services. Currently, the categories of ecosystem services to be included in the Atlas are: clean water for drinking, clean water for recreation and aquatic habitat, adequate water supply, food, fuel and fiber, recreation, cultural and aesthetic amenities, climate regulation, protection from hazardous weather, habitat and the maintenance of biodiversity and clean air. In addition to ecosystem services, the Atlas will contain a section with data layers on services provided by the built environment and a section on "drivers," or factors that can erode ecosystem services. The Atlas will make these elements easily visualizable and layerable, comparable across space and sometimes time, for the first time.

In order to have a standard unit of analysis, the Atlas presents data summarized by 12 digit hydrologic unit codes (or HUCs) of which there are about 83,000 in the U.S.

[48] As actively shaping prostheses, the ways in which the eco services paradigm and the Atlas frame and make sense of the environment will have material effects. "Accounting tools. . . do not simply aid the measurement of economic activity, they shape the reality they measure" (Boyd and Crawford 2011, p. 3).

The Atlas will allow users to simultaneously view and compare multiple ecosystem services across multiple HUCs and/or different time periods with a suite of graphing tools (see Figure 3). An Urban Atlas component will have much higher resolution "initially for 50 cities and towns of varying size, location, demographic makeup, and environmental and health risks" (EPA, 2011b, p. 1). This component is slated for release in 2013, "with subsequent releases following as more data become available. In future years an additional 100 to 200 cities will be included, depending on available funding and program success" (EPA, 2011b, p. 2). The Urban Atlas will be especially focused on connecting human health and well-being with environmental factors. A suite of metrics, such as availability of green space and heat stress caused by the built environment, will be explored and related especially to vulnerable sectors and populations.

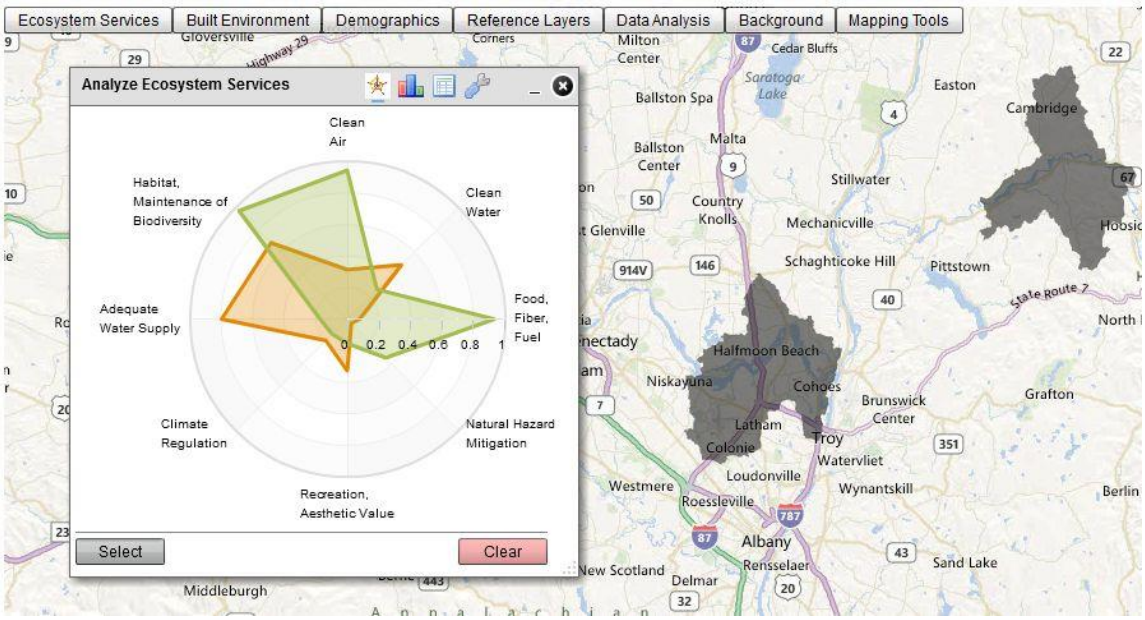

Figure 3: Radar Graph in the Atlas comparing eight ecosystem services between two HUCs in upstate New York.

The imagined users of the Atlas range from non-profit groups focused on land conservation to agencies at the federal, state and municipal levels. Users will be able to quickly find out about ecological services in different locales. The Atlas can be thought of as a database, but its interface differs greatly from traditional EPA databases, as it is

explicitly designed for communicating ecosystems research to stakeholders outside the EPA and without ecological expertise.

The Atlas currently resides in the Sustainable and Healthy Communities Research Program, after previously existing within the Ecosystem Services Research Program.[49] While the core developers of the Atlas are ecologists at the EPA, the scale of the project requires many collaborators, including the National Geographic Society, the U.S. Geological Survey, the City College of New York and others. The science necessary to quantify ecosystem services and develop the Atlas draws from landscape ecology, hydrology, zoology, forestry, agronomy, soil science, demography and ecological economics.[50] The Atlas will serve as a kind of user-friendly container for the state-of-the-science in these fields and will develop indicators of ecosystem services production, demand and drivers for the nation.[51] The Atlas will be connected to many data sets, tools (such as i-Tree) and modeling systems (including CMAQ) developed at the EPA and elsewhere.[52,53]

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[49]NERL (and EPA at large) is going beyond a focus on ecosystem services to a broader focus on sustainability, human health and well-being. The Environmental Justice 2014 document released in 2011 by the EPA states (EPA, 2011a, p. 113):

> The new Administration at EPA and in particular in ORD recognizes that fragmented research programs cannot solve 21st century environmental challenges including disparities in environmental health. ORD is leading the way by integrating 12 research programs that were mostly media-specific into four transdisciplinary programs aligned with EPA's new Strategic Plan. As part of this re-structuring, ORD is fully establishing and supporting a new integrated transdisciplinary research program on environment and community health known as "Sustainable and Healthy Communities."

While the emphasis of the Atlas is still on ecosystem services, it is expanding to include sustainability aspects of the built environment. The shift towards a focus on sustainability has largely been driven by Paul Anastas, the EPA Assistant Administrator for Research and Development.

[50]A great deal of social scientific work in recent decades has also focused on quantification schemes and their effects. Recent work has examined the ubiquity of numbers in representations of global realities, how quantitative approaches order communities across bureaucracies and people's everyday lives and the limits of "neoliberal natures" (Bakker, 2010; Feingold, 1999; Ong & Collier, 2005).

[51]Containing far-flung ecological knowledge and data is a key contribution and goal of the Atlas, but the metaphor of "container" here is misleading because it is an *active* sub-stratum that enables *new* knowledge to be produced. If it is a container, it is perhaps akin to glassware in a chemistry lab: a test tube or experimental beaker, or a medium (as in cell-culture),

[52]The i-Tree toolkit, developed by the U.S. Department of Agriculture's Forest Service (EPA, 2011b, p. 2):

> calculates multiple benefits of urban forest cover on a tree-by-tree basis. The use of this tool will help identify the extent to which trees and other natural infrastructure meet community needs and where the number of trees falls short. It will also help decision-makers understand the additive benefits of natural resources, and how their loss or degradation may be contributing to cumulative burdens on community health and well-being.

[53]Robin Dennis, who has a Ph.D. in physics and works at the intersection of air quality modeling and

It is important to note that the Atlas, which was originally driven by demands for better *circulation* of ecological knowledge, and transparent communication of research results to the public, may also be a research tool for *producing* knowledge by providing a space for previously disparate data to be visualized together in new ways. The "broad scale questions the Atlas will answer" are 1) "What is the current supply/stock of ecosystem services in coterminous US? 2) What is the current supply/stock of ecosystem services compared to the potential and 3) What services can we expect to gain/lose under multiple future scenarios" (Neale, 2009b). Many other questions could be generated and worked through with the Atlas, making the initial data gathering steps required for ecological research far more efficient. Neale states that (Neale, 2010c):

> a really important benefit of the Atlas is the ability to make data much more available to the research/academic community. This has the potential for fast-forwarding research projects that would otherwise have had to spend a large amount of time compiling data.

The Atlas can be seen as a kind of "visual laboratory," catalyzing new modes of knowledge creation.[54] Circulating, layering, folding and re-combining extant information and knowledge, in the form of these data layers, could help produce fundamentally new insights. With the data download function, the Atlas designers plan for a "clip and ship" feature where the user could download all the data for a particular area. More advanced GIS users, for example, may want to conduct spatial analyses on their own, going beyond the built-in visualization functions of the Atlas. Researchers can download data from the Atlas to develop their own empirical models on, for example, bird diversity as an endpoint. Key data sets for bird diversity, like the breeding bird survey, are not part of the Atlas, but can be combined productively with landscape variables that are already calculated in the Atlas, and readily downloadable. Given that it can take researchers

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ecosystem research, explains some of the interplay between CMAQ and ecosystem modeling (Dennis, 2009):

> The deposition to the Earth's surface is a major loss process, part of the budget of where pollutants go. That becomes a source for ecosystems impact, so we use the CMAQ model to look at the deposition, and link the CMAQ output with ecosystem models, such as watershed models. So a lot of my work is getting the watershed people to use the CMAQ deposition outputs as inputs. That's where we get into issues of crossing paradigms that are very difficult to do.

[54]The phrase "visual laboratory" is mine, but riffs on CMAQ developers' description of the air quality model as a "numerical laboratory."

months simply to gather all the data necessary for a study, the Atlas could greatly accelerate research in ecology. Once in the space of the Atlas, researchers could also come across data sets that were not part of the original study design, or come up with unanticipated questions. The next section traces the evolution of Annie Neale's career in order to provide some background on how the Atlas fits into a genealogy of informatics in ecology.

3.3 Informating Ecology/Situating the Atlas in Shifts in the Labor of Ecology

Over the course of many conversations Annie Neale became a key informant in my research, teaching me about recent shifts in the labor of ecology and the techniques of ecological informatics and visualization.[55] Neale's story also is a way into a genealogy of the conditions that support the Atlas development. This section largely helps illuminate the Atlas *in* context, but also foreshadows some of the affordances of the Atlas *as* a context for the circulation and creation of ecological knowledge, literacies, subjectivities and collectivities.

Ecologists continue to rely on traditional modes of surveying and monitoring to better understand the ongoing dynamics of particular ecosystems and the national ecology, develop general theories about how different ecological elements interact at different scales and guide decision-making over land use; they still get their boots muddy, conducting fieldwork on the ground for basic research. But the production of contemporary ecological knowledge is also increasingly fueled by, and in turn catalyzes, the development of corridors among different scientific fields, information technologies and publics.[56] The turning points Neale's career described below are illustrative of shifts

[55]This section is largely about the information practices of one researcher, Annie Neale. It is partly inspired by the work of Tiffany Veinot (Veinot, 2007), who followed a single vault inspector at a hydroelectric utility company and "reframed the definition of 'information practices' away from the usual focus on early-adopter, white-collar workers, to spaces outside the offices and urban context" (Boyd & Crawford, 2011, p. 8). While Neale is a solidly white collar worker, zooming in on her inter-personal practices is a way to richly illustrate the micro-scale, embodied labor that is sometimes occluded in studies of the "digital age" and "big data" in the sciences.

[56]In ecology, wildlife corridors connect populations separated by anthropogenic activities like roads, buildings or logging. Corridors make exchanges of individuals between populations possible, helping

in the ecological sciences, at least at the EPA, towards a greater use of information technologies, remote-sensing, modeled knowledge and interdisciplinarity. The becoming (more) public of ecology that, Neale and her colleagues hope, will go hand in hand with these transformations could have wide-ranging effects. By drawing together communities of expertise, data sets and audiences that have previously been relatively separate, Neale and the Atlas team are embedding an ecological perspective in the Atlas itself and enacting the development of connectivity in the process of its production.

3.3.1 First Phase of Ecological Fieldwork: Databasing Measurements and On the Ground Observations.

> *Ecology is an integrative, collaborative discipline, amplifying the need for open access to data. The field has rapidly matured over the past century from small-scale, short-term observations and experiments conducted by individuals to include large-scale, long-term, multidisciplinary projects that integrate diverse data sets using sophisticated analytical approaches. Ecological investigations often require interactions with adjacent disciplines (e.g., evolution, genomics, geology, oceanography, and climatology) and disparate fields (e.g., epidemiology and economics). This broad scope generates major challenges for finding effective ways to discover, access, integrate, curate, and analyze the range and volume of relevant information.*
>
> - (Reichman et al., 2011)

Neale began work with the EPA as a contractor in the 1980s when, she says, ecology at the EPA was focused on huge field surveys. Her first project was an acid deposition survey in the north-east corner of the U.S. From there she worked on field-based projects all over the country. Neale became a full time EPA employee in 1991 when she was working on a monitoring program with the Nuclear Radiation Division. This first phase of Neale's work was distributed among many different projects, but all primarily entailed on the ground data collection and measurements. The Environmental Monitoring and Assessment Program (or EMAP), for example, collected field data from

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to prevent the negative effects of inbreeding and reduced genetic diversity that can occur within isolated groups.

1990 to 2006 and developed, as the project website states, "indicators to monitor and assess the condition of ecological resources. . . by randomly selecting sites and by obtaining a representative sample of biotic assemblages along with physical and chemical measures."[57] EMAP has become an important and widely used resource and is spoken about by EPA scientists as an example of work that generates new information, but also crafts tools for future research—monitoring and assessing the status and trends of national ecological resources—and protocols for circulating information.

The data archiving and sharing that marks EMAP is reflective of gradual shifts in ecology over the past century towards greater collaboration and synthesis. While ecology is a science of connection, many ecologists have, ironically, worked more or less alone in small niches. Databasing and circulating data in ecology has not traditionally been a priority. Reichman et al. (Reichman et al., 2011) estimate that less than 1% of the data collected by ecologists is accessible after publication of associated results. Interpretations of distilled data are transmitted through presentations and publications, rather than producing contexts (like the Atlas) that enable researchers and others to access and use primary data, perhaps for purposes unforeseen by the original data collectors. Reichman et al. argue that this is partly due to a lack of incentives for sharing data. Researchers in ecology have traditionally been rewarded only for gathering their own data and publishing the results of analysis in the static form of peer-reviewed journals. But this may be changing. The Ecological Society of America (ESA)'s "Data-Sharing Initiative," for example, is a response to the need for better information circulation among ecologists. This initiative, EMAP and the Atlas, are reflective of, and could help drive, the growing value placed on the scholarly and scientific labor of sharing and curating data in ecology.[58]

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[57]The metrics and sampling methodologies developed in the EMAP program are key precursors of the Atlas. Environmental monitoring data from multiple spatial and temporal scales were translated into assessments and metrics that were more easily comparable. Much of the work of developing the Atlas involves a similar development of metrics for quantifying services provided by ecosystems and the built environment.

[58]By providing data for researchers in an easily accessible format, the Atlas enables, or makes easier, a form of ecological research that resembles the model of "authorship as selection," described by Lev Manovich, in which (Manovich, 2002, p. 130):

> an author puts together an object from elements that she herself did not create. The creative energy of the author goes into the selection and sequencing of elements rather

Sharon Kingsland, in *The Evolution of American Ecology: 1890 – 2000*, writes about how a 1991 report from the ESA, "The Sustainable Biosphere Initiative: An Ecological Research Agenda," stressed "the need to focus research so as to aid environmental decision making" (Kingsland, 2008, p. 237; Lubchenco et al., 1991).[59] Key to addressing the pragmatic concerns outlined in the ESA report (especially climate change and threats to biodiversity) was the creation of sustainable ecological *systems.* This entailed better management of resources and improved conservation measures, but also interdisciplinary cooperation, a theme that was threaded throughout the report. Kingsland writes (2008, 237):

> Large-scale and long-term experiments, use of remote sensing technologies, and growth of large-scale data sets held out the promise for better synthesis of ecological research as well as closer cooperation between scientific disciplines. . . The report called for collaboration between ecologists and a wide range of social scientists, policymakers, and planners. . . However, the report concluded that neither the funding nor the infrastructure in the United States was sufficient to address the research needs that the scientists had identified. Moreover, the report recognized that achieving success depended on communicating information to citizens and especially to political leaders.[60]

The contemporary EPA, with programs like EMAP, has provided a space where Neale and other ecologists do have more incentives for pooling and sharing information, especially with the agency's recent focus on problems of broad national significance.

> than into original design. . . the practice of putting together a media object from already existing commercially distributed media elements existed with old media, but new media technology further standardized it and made it much easier to perform. . . and, by encoding the operations of selection and combination into the very interfaces of authoring and editing software, new media "legitimizes" them.

A lack of integration and synthesis does not just cause missed opportunities for knowledge generation. There are also political effects. See John Kineman on how isolated studies, removed from the holistic orientation of ecology, can be re-interpreted quite easily, sometimes being used for intentions that are diametrically opposed to the original intent (Kineman, 2011).

[59]Strangely enough, despite noting that as early as 1897 American scientists recognized that "the key to success was better organization of government work in science and more cooperation between government divisions" (2008, 82), Kingsland does not mention the EPA in her book, reflecting a wide neglect of the EPA, and especially the ORD, as an object of concern for historians and other social scientists and humanities scholars.

[60]EMAP may be an excellent example of developing and circulating ecological data for ecologists, but the EPA's EMAP website does not provide a clear picture of the overarching findings for a lay audience and the interface to the data is quite difficult to navigate (EPA, 2010). One function of the Atlas will be to make data from projects like EMAP much easier to visualize and use by a wide range of citizens and policy makers.

EMAP was a large, data rich, distributed project that set the groundwork for, and ran in parallel with, shifts towards landscape ecology that combined on the ground observations with emergent forms of prosthetics for seeing and understanding the environment.

3.3.2 Second Phase: Remote-Sensing and Modeling

In the mid-90s, Neale's work began to focus on linking environmental endpoints (such as water quality and bird diversity) that were observed in projects like EMAP to "landscape level" metrics and indicators, which refer to information at a larger scale than Neale's earlier work, produced by drawing on the ground observations, but also folding in remote-sensing techniques (including satellite imagery and aerial photography) and computer models designed to generate knowledge by aggregating and analyzing large data sets. In 1998 Neale published one of the first papers linking on the ground measurements of water quality to metrics that had been calculated using land cover data from remote-sensing.

Neale describes how the introduction of increasingly powerful remote-sensing techniques has enabled new modes of ecological knowledge production and visualization (Neale, 2009a). Drawing on satellite imagery and refined classification methods, for example, the second version of the National Land Cover Dataset (NLCD) was released in 2001, providing land cover data on a national scale. Data sets like the NLCD, created by the multiresolution land-cover consortium, a group of federal agencies contributing expertise and resources, are some of the primary informational inputs used to produce the Atlas project.[61] While the camera has long been one of the most important tools for ecological research, "providing a quick way of taking in data about the broad features of the landscape" (Kingsland 2008, 121), aerial photography and remote-sensing technologies provide unprecedented points of view on the national-scale landscape. These new modes of visualizing the environment, combined with computer models that help automate the characterization of different types of land cover,

[61]While the NLCD is an important step, aggregating dispersed data remains a key challenge in ecological informatics (Reichman 2011)—a challenge the Atlas is poised to address.

are key technological developments that enable national-scale understanding of ecosystems and the built environment.

Modeling the environment using computer models and remote-sensing is still an emergent technique and, beyond the development of technical tools, demands the creation of new modes of reading the informational ecologies we inhabit. Even the NLCD, which Neale says "everybody uses… cannot be correct about every pixel every time" (Neale, 2010c). Neale explains that while there are far more supporters than critics, some "more traditional" biologists and wildlife scientists feel that without on the ground monitoring, "you cannot really know a landscape," yet, "the problem is—I mean it's obvious—you can't monitor everywhere. So at some point you have to put some faith into modeled information" (Neale, 2010b). As I will discuss in the next chapter, modeling literacy demands new forms of engagement and connectivity.

3.3.3 Stage Three: New Modes of Fieldwork. The Networking and Informating of Ecology in the Atlas

Neale has moved from on the ground fieldwork to landscape ecology to the development and design of the Atlas which will enable better connectivity among ecologists and various stakeholders. The Atlas is a space of circulation and production that both requires and produces new forms of collectivity and literacy in the sites of overlap, or ecotones, among different institutional, scientific and technological niches.[62] Neale writes that the Atlas is "conceived as a collaborative effort for implementation by multiple Federal agencies and other organizations" (Neale, 2010d). Agencies involved include the U.S. Forest Service, the U.S. Geological Survey (USGS) and the Centers for Disease Control and Prevention (CDCP).

These days, Neale has traded in her water testing kit for a laptop and spends much of her time traveling around the country with a slide show presentation on the Atlas. She is working to collect input on the design of the Atlas and promote the Atlas to groups ranging from the U.S. Department of Agriculture to the CDCP to universities to

[62]Ecotones are spaces at the edges of convergent biomes and are often marked by high biotic diversity and productivity.

NGOs focused on conservation. This was not part of the Research Ecologist job description. But the decades spent working at the EPA, with its frequent institutional reorganizations and constant need to interface with people outside her field of expertise, seems to have prepared Neale well for this new phase of her work. Compared to industry and academia, scientists at the EPA, especially within NERL, are highly focused on team-based projects and interdisciplinarity.[63] I would also argue that three decades of work as a research ecologist have sharpened Neale's ability to think ecologically about, and develop, connectivity; Neale has gracefully negotiated the step from analyzing ecosystems to producing new assemblages of heterogeneous elements.

Neale has presented the Atlas all over the U.S. in order to enroll new collaborators and gather feedback from a variety of experts and a wide range of potential user groups.[64] Much of Neale's current work involves creating relays with other federal agencies, government organizations at the state and municipal levels and many different publics. The Atlas, while spearheaded by the EPA and especially the National Program Director for Ecology Rick Linthurst, is necessarily interdisciplinary—like CMAQ—due to the expansive range of expertise necessary for it to function. Neale says that "we're really just leading the effort, we have conceptual ownership of it, but it was conceived to be a highly collaborative effort, because no organization would have the expertise to be able to complete all the necessary elements" (Neale, 2010a).

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[63]Bowker (2008, 125-126) writes that:

> although technoscientific work is inherently collaborative, management structures in universities and industry still tend to support the heroic myth of the individual researcher. Many scientists turn away from collaborative, interdisciplinary work—precisely the kind of work that is most needed in order to develop policies for sustainable life—because they are risking their careers if they publish outside their own field. There is significant institutional inertia, whereby an old model of science is being applied to a brave new world.

[64]Neale tells me that "what I've done, to date, has been really pretty informal, as far as getting user feedback. Where I'd like to go next is really starting to get what I would call formal documented feedback. A feedback loop has been built into the Atlas application and forms have been developed to collect user feedback at stakeholder workshops" (Neale, 2011). As I describe in the next chapter, CMAQ developers assert that formal feedback, in the form of external peer review by a diverse committee, is essential for the development and analysis process. A formal peer review of the Atlas could help illuminate areas in need of development and provide insight on features that different communities would find useful. I coordinated a review by the students in a graduate seminar at RPI, Asthma Politics, but future reviews could draw on the expertise of a more diverse group and be directed by specific questions from the Atlas producers.

What this diverse team is pulling together, exactly, remains to be seen. It is already clear, however, that the contours of the Atlas will be shaped by Neale's ambitious work to draw together feedback from a multitude of potential stakeholders, including both producers and users. Neale's social and institutional networking parallels the Atlas's role as a space of synthesis for diverse data sets, often provided by the various communities of experts Neale works to draw together.

Linking different kinds of data at different scales requires forms of collectivity that can leverage interdisciplinarity. It was when Neale was asked about how she negotiates disciplinary differences that I first heard about the Atlas. Neale says that the Atlas "couldn't be more transdisciplinary because it involves wildlife science, hydrology, biology, certainly wetlands ecology, demographics, etc. so it's great that I've got this group of people who I can really draw on to pull this together" (Neale, 2009a).[65] In eco-speak, "connectivity" is the measure of how connected or spatially continuous a corridor, network or matrix is. A forested matrix with less gaps in forest cover will have higher connectivity, resulting in greater biodiversity. Developing connectivity among her own team, policy makers and different publics is a clear goal of Neale's fieldwork, which can be seen as a kind of multi-sited ethnography. The Atlas is the object she follows across different scales, institutions and disciplinary boundaries. The object, of course, does not sit still; Neale is acutely aware of how her fieldwork is shaping the object of concern, giving it new contours. That, after all, is the point. Neale's experiments with different forms of representation are reminiscent of the "experimental moment" in ethnography, which pays close attention to the reading and writing practices—the textuality—of anthropological interpretation and representation (see Clifford and Marcus 1986).

By conducting fieldwork among potential user-groups, Neale is collecting data on, and in-process improving, the interpretative literacies of her stakeholders. In her work developing the Atlas, Neale is taking on the challenge of crafting multiple spaces of interpretation and mediation—one for "light" users and one for those with more

[65] The types of expertise Neale has enrolled in the Atlas are largely those from the "hard" sciences. How might the Atlas look different if anthropologists, sociologists and STS scholars were involved in its design from early stages?

experience. The next section gets into a more detailed description of the Atlas itself, as well as the contexts in which it is produced and the ways it may function as a new context for users.

3.4 The Atlas as/in Context

3.4.1 The Atlas as Context: Design Logics

3.4.1.1 Providing a Context for Visualizing and Creating Connections

Neale and the rest of the Atlas team are designing a system that provides users with tools and lenses that can make interconnections among various components of ecosystems more visible in order to inform decision making. Neale spoke about how "looking at [the environment] like we are," as ecologists, can help people see patterns and unintended consequences (Neale, 2010b):

> With the Atlas you're able to take what I call a "30K feet view," because if you're on the ground you don't see the patterns that are there, but if you're looking at it like we are, with a lot of the metrics that we're including, from about 30,000 feet, the patterns of land cover emerge.[66]

The Atlas producers' articulations about what the Atlas is for and could do at times reflect a fairly instrumental view of communication. They sometimes describe the Atlas as a way to deliver information, largely fitting with the transmission model of communication. Yet their *practices,* building a tool, as a new *form* of information delivery device, and Neale's articulations above, edge more towards communication as context production. In the context of the Atlas,

[66]Boyd and Crawford warn that "Big Data tempts some researchers to believe that they can see everything at a 30,000-foot view. It is the kind of data that encourages the practice of apophenia: seeing patterns where none actually exist, simply because massive quantities of data can offer connections that radiate in all directions" (Boyd & Crawford, 2011, p. 2). While Neale and the other producers of the Atlas have extensive training and experience that could temper the danger of apophenia, it may also be important to build safeguards into the Atlas for less experienced users. At the same time, "seeing patterns where none actually exist" could be a way of imagining and prefiguring the relays in ecologies to come. As Stengers et al. put it, "it would also mean not affirming that 'everything is connected' but knowing that every connection is a creation, a 'putting into' relation, an event creative of the plane that it will inhabit" (Stengers, Pignarre, & Goffey, 2011). Environmental communication could go beyond the "refining-representing axis" and take on a more active, generative, mediating role (P. Mathur, 2009).

users can experience a parallax shift, taking on a new point of view, one that more readily recognizes the "patterns that connect" (Bateson, 2000).

The Atlas can be seen as an information *delivery* device, but it is also an interactive *space* for circulating and producing new content. The online, interactive nature of the Atlas is key to its potential to enable new interfaces and visualizations of the world by users that may not have ever experienced an ecologist-eye-view. The Atlas provides a context for the recombination of data to guide decision-making, but also to see new connections and patterns, as well as the chance to see how assembling distributed scientific claims can add up to the "requisite precision," a phrase Lawrence Reiter, a dynamic former Director or NERL, uses to describe knowledge that is useful despite its imperfections (Reiter, 2009).[67]

The "hubs and corridors" data layer of the Atlas maps the connectivity of wetland and forested habitat for the entire nation. When I asked if it was compelling to look at, Neale responded (Neale, 2011):

> What I think is really compelling is when you overlay it onto a stream network, because you can look and you can say "if I restore the riparian habitat on this stream, not only could I possibly improve the water quality. . . I'm also reconnecting these two separate patches of habitat." When you just look at it by itself it's just a bunch of colored pixels with a legend, but when you realize what it's portraying and you combine it with other data layers, I think it's pretty compelling.

Visualizing data, and possible re-combinations, in ways that are usable by different communities is becoming a key mode of scientific communication (see (Fox & Hendler, 2011). The Atlas's strength is in its ability to layer, visualize and juxtapose many different kinds of data across space and time.[68] Neale's perspective on the Atlas is that it

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[67] The concept of requisite precision is an example of the kinds of new narratives called for in this dissertation's Introduction. Precision, or good science, for Reiter, is dependent on the specific context in which knowledge is taken up and mobilized. The Eco-Health Relationship Browser, discussed below, is a response to the need for systems that visualize the state-of-the-science on particular connections between ecosystems and human health, helping people evaluate the strength of the science themselves.

[68] See James Clifford (1981) on "ethnographic surrealism," a key inspiration behind the "juxtapositional

becomes interesting and useful when data layers are combined, when relays are made. The magic happens in the connections. This is a basic premise of GIS. Ecologists and others with the requisite training and resources have been able to use GIS software to layer different kinds of information and see new connections for decades. The Atlas puts these powerful ways of seeing and understanding in the hands of a much wider audience which could result in GIS being experimented with and put to new uses. Users, for example, could rapidly layer data on demographics, air quality and disease rates to make claims about environmental justice and the uneven distribution of pollution and health issues.

3.4.1.2 The Technology and the Interface

The ability of the Atlas to catalyze a future-oriented approach, described below by Laura Jackson, the lead on the Urban Atlas, is made possible by a shift from maps as static representations to GIS techniques enabling modeling between geographic and temporal sites. Developments in the technologies of the geographic sciences, including satellites for remote sensing after World War II and improved data management and cartographic software, were brought together in GIS in order to produce powerful visualizations. With GIS, maps went from static representations of spatial contents to being capable of modeling dynamic phenomena with spatial components.

The Atlas assembles GIS software, high resolution remote sensing technologies[69] and a suite of graphing tools in an interface that will allow users to build ecosystem service maps and graph differences over space and time. The GIS software used in the Atlas, ArcGIS, as proprietary software designed primarily for ecologists and other GIS specialists, has not traditionally been available to, never mind usable by, a lay audience. The richly-detailed maps will help users visualize multiple scales (e.g., national scales down to local political boundaries) for the United States and allow decision makers to

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logic" employed in *The Asthma Files*.

[69] Still higher resolution is one of the recurring requests Neale has heard in her feedback-generating tours. She has stated that the Atlas will not work for people trying to decide about a building permit because it does not currently get closer than 30 meters resolution. The Urban Atlas component, however, will have a much higher resolution for the areas that it covers.

use data sets that can help in considering land-use impacts beyond their own jurisdictions or natural boundaries.

The interface of the Atlas is missing some of the complex functionality that ArcGIS usually contains. But this very constraint is also enabling. It provides a sleeker, simpler medium that can be less intimidating to a broader range of users. The work of the Atlas designers to contextualize the ArcGIS components in a broader system is marked by actions typically associated with new media production: re-assembling, a focus on both figure and ground, curating as condensation and reduction and generating modifiable contexts. The Atlas adds value by framing the GIS software in a contextualizing interface. Neale explains that ArcGIS Server is being developed with flex technology, allowing for many charts and graphs in the same space. The table of contents, for example, includes categories of many ecosystem services—such as water quality, climate regulation and habitat maintenance of biodiversity—and is modifiable by the user (Neale, 2009a). The interactive index allows users to weight the inputs used to generate comparable indices of ecosystem services based on their own conceptions of what should count more heavily. Users with asthma, for example, may weight particulate matter or ozone, powerful triggers of asthma attacks, heavily in determining the air quality index, so that they can compare different cities when deciding where to work or live.

3.4.1.3 ArcGIS

The technological foundation of the Atlas is ArcGIS, a software suite developed by Environmental Systems Research Institute (Esri). Articulations from Esri producers provide a glimpse of the history of GIS, resonate strongly with Atlas producers and illuminate some of the potentials of GIS software as a communications medium. The Esri website states that “Esri is built on the philosophy that a geographic approach to problem solving ensures better communication and collaboration.” In a video on the website, Jack Dangermond, Esri president and a graduate of the Harvard Laboratory for Computer Graphics and Spatial Analysis, states, “GIS is becoming a kind of medium for people to communicate with. Computerized mapping, computerized visualization. . . they help people make decisions, they help them communicate. It’s a wonderful medium

for society today." Clint Brown, director of software products for ESRI adds that GIS helps users organize different sets of information as layers on the surface of the Earth. Bringing these layers together in the context of GIS can help users work on, and communicate about, complex environmental problems. It is important to Brown that GIS can be used to create *interactive* maps. Users can click objects on the map and drill down to the various data sets. Like many of the Atlas producers I spoke with, Brown talks about how GIS is "a great vehicle for understanding problems in a more holistic way" and can be used to "visualize what might be possible in the world."

The history page on the Esri website describes how layering ecological information over geographic base maps has previously existed in other forms. Esri originally produced map-based analyses that used U.S. Geological Survey (USGS) topographic maps as the foundation. Then these maps would be overlaid with gridded Mylar sheets containing data on, for example, geology, soils and topography. After the values of each gridded cell were entered on keypunch cards, they would be run on a mainframe computer and maps would be printed with a pen plotter. The shift to digital technologies, and especially web-based GIS platforms, has radically expanded the circulability and usability of GIS technology. Esri claims to strive for openness, which resonates with the Atlas producers language of transparency described below. Arcgis.com was recently released and provides some GIS capabilities free of charge. ArcGIS.com allows users to create and share their own maps. But its use is quite limited for research purposes. Users cannot drill down to the data in maps and compare across different areas or times. The proprietary nature of ArcGIS may also limit the openness of systems like the Atlas, making it more difficult to support citizen science and users uploading and sharing their own data.

3.4.1.4 The Urban Atlas and Environmental Justice

The National Atlas will include an Urban Atlas component with a suite of finer-scale, higher resolution metrics and imagery for a number of areas, primarily those with populations above about 100,000 people. Land cover data for the Urban Atlas will largely come from aerial photography, which gives a resolution of 1-3M as opposed to the 30M data from the thematic mapper imagery (satellite imagery) that will be the basis

for the National Atlas. The effort to develop the Urban Atlas is being led by Laura Jackson, an ecologist focused on human well-being and based in the ORD's National Health and Environmental Effects Research Laboratory (NHEERL). Jackson explains that the National Atlas, for many of its metrics, uses hydrologic unit codes (HUCs), which can be fairly coarse. A medium sized town like Portland, Maine, may have only two or three HUCs. The Urban Atlas zooms in to Census block groups, which Jackson says, "are practically neighborhoods, smaller areas, because that's where you have concentrated populations… a focus on the cities really teases out relationships between ecosystem services, the built environment, public health and well-being. You've got to go where the people are" (Laura Jackson, 2011a).

While ecology has traditionally focused on the environment *without* humans, drivers such as the institutional mandate to work on problems of broad national significance have resulted in a shift, at least in part, to include humans, and their interactions with the environment, as objects of study. The EPA, with its historical mandate to focus on human and ecosystem health, enables this trend towards a broader notion of ecology. The Urban Atlas could help disrupt commonplace notions of the environment as a faraway pristine landscape; instead, the Atlas provides a view on environments that includes dense urban centers and problems associated with anthropogenic sources, such as near-roadway and industrial pollution.

Humans are not only thought of in the Urban Atlas as receivers of ecosystems services. There will be metrics for services provided by both the "natural" and "built" environment, such as air pollutants removed by vegetation, energy savings due to shading of buildings, carbon storage benefits, storm water runoff benefits, water quality benefits and near-roadway removal of pollutants by vegetation (Neale, 2009b). Under development are metrics for a heat island index, indices of green places (parks), number of days exceeding air quality standards and a nighttime lights index.

The EPA frames the Urban Atlas as part of initiatives in environmental justice (EJ). The Plan EJ 2014 document states that the Urban Atlas is a response to calls by the EJ activists for easy-to-use GIS tools. The 100-250 areas that will be zoomed in on with the Urban Atlas were selected for diversity in size, location, demographics and environmental and health conditions. It will include not only areas that are easily

recognizable as "urban," but also small towns, rural communities and Tribal lands. The document states that (EPA 2011a, p. 115):

> By mapping the current availability of "green" infrastructure and applying existing models for pollutant removal, water storage, and other functions, ORD's National Atlas will estimate the extent to which ecosystem services contribute to the basic needs of populated places. Additionally, the Atlas will reveal under-served areas where management to enhance specific ecosystem services would benefit community health and well-being.

The Urban Atlas will include demographic mapping capabilities that are quite easy to use, enabling users to make visually compelling claims about how certain populations are disproportionately underserved by "green infrastructure" or overburdened by pollution and degradation (EPA, 2011a). EPA regions and ORD's Human Health Research Program are "interacting with communities" to identify and rank priority issues of health and well-being while building capacity for "working with mapping tools to inform risk evaluation and management decisions" (EPA, 2011a).

Development of the Urban Atlas is largely driven by a need to inform stakeholders about how natural resources are important community assets and how their degradation can create burdens on vulnerable populations. Developers see the multi-media approach of the Atlas as enabling users to see the multiple benefits (or burdens) that can result from specific decisions about environmental contaminants or eco services. Interactions with "communities" will initially be conducted through EPA programs such as Community Action for a Renewed Environment (CARE) and the Environmental Justice Showcase Communities program, as well as partnerships with other groups such as the Department of Housing and Urban Development (HUD) and the Department of Transportation (DOT).

3.4.1.5 Connecting Ecosystems to Human Health and Well-Being

Embedded in the tools section of the Atlas is an Eco-Health Relationship Browser (see Figure 4) that helps users to navigate the state-of-the-science connecting ecosystem services to a variety of human health and well-being endpoints. The browser has a visual interface that documents where linkages among ecosystems and human health and well-being have been published, the strength of the association and the

sample size. Summaries of the literature connecting different elements pop up when the user hovers over the connecting lines. If a given element (i.e. air filtration or water regulation) is clicked, it shifts to the center, opening up new connections by pulling new elements on to the screen.

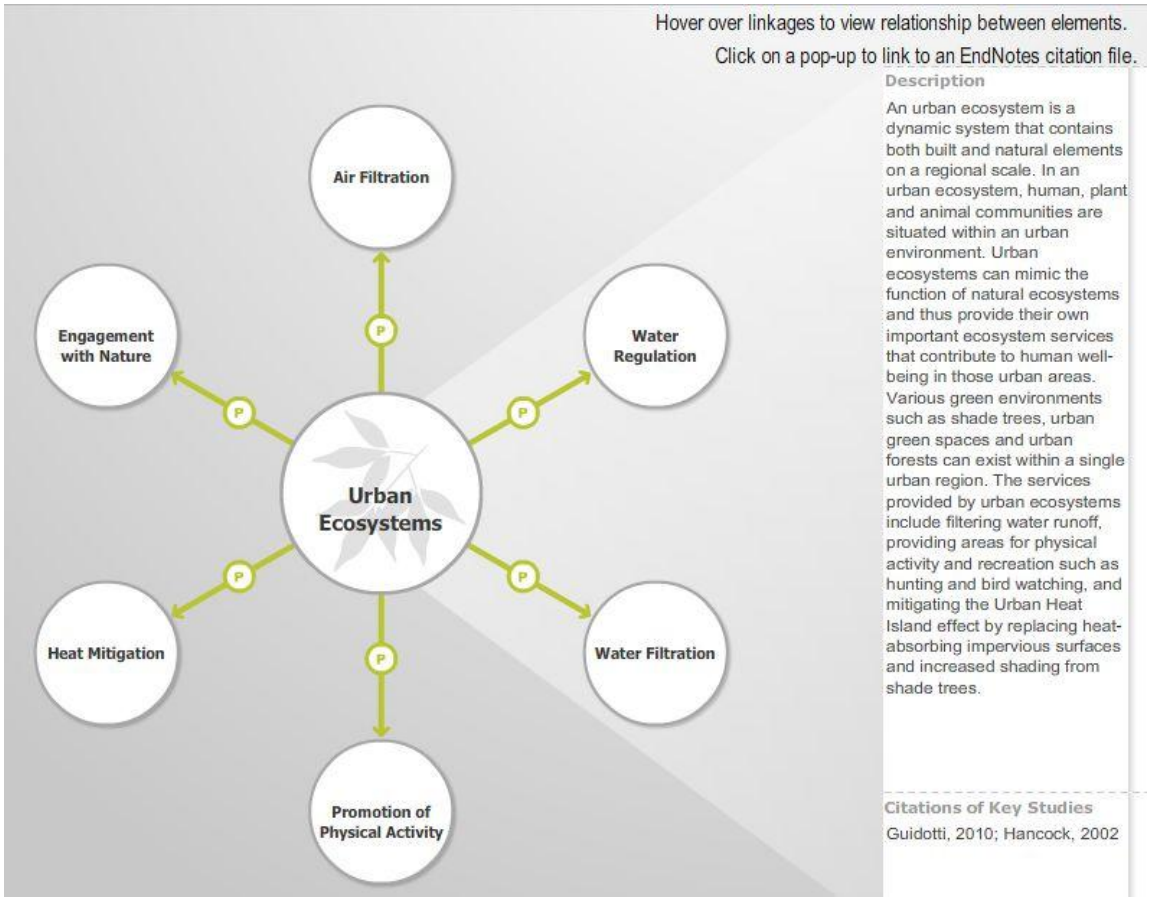

Figure 4: The Eco Health Relationship Browser. The image above is a screenshot from a preliminary version of the Browser. Clicking one of the circles will send it to the middle of the screen and cause a number of new circles to appear. Hovering over connections between circles results in a pop-up window with a brief summary of some of the relevant research connecting the circles.

Jackson, who leads development of the Eco-Health Relationship Browser, says that she has encountered "a tremendous amount of skepticism" from health scientists at the EPA (Laura Jackson, 2011a). Researchers focused on health at the EPA are rarely trained in public health; they are much more likely to have backgrounds in toxicology and focus on highly controlled laboratory experiments. Jackson explained that

connections among human health and well-being and real-world environments do not reveal themselves well in the artificial space of laboratories. The idea that "a window in your apartment could increase your lifespan or raise your IQ," Jackson says, "sounded like some kind of a joke" to many of the health scientists at the EPA (Laura Jackson, 2011b). After spending several years "knocking on closed doors," Jackson decided to create the Browser; with this tool, she can say "hey don't take my word for it, look at what's in the literature" (Laura Jackson, 2011a). The browser includes research from veterinary science, behavioral psychology, city planning and many other widely dispersed fields. The Browser pulls together these disparate ways of knowing and provides a context intended to lend some legitimacy to the research on the eco-health relationship.

Jackson's difficulties in reaching health scientists who take seriously the effects of everyday environments on health and well-being, even at the *Environmental* Protection Agency, speak to the subalternity of environmental health conditions.[70] Well-being, as opposed to health, is even harder to talk about in the context of the EPA, which is explicitly guided by a concern for human health. Environmental health does not fit neatly into disciplinary boundaries. Goldstein writes that "public health fits well with a systems approach to issues, as it is inherently a multidisciplinary field" (2011, 305). The EPA has recently added an Environmental Public Health Division (EPHD) within NHEERL. The EPHD looks at systemic connections among ecosystems and human health, as well as implications for public health care. It is no surprise that the Atlas, guided by ecological principles of synthesis and connectivity, has become a venue for hosting the state-of-the-science on the connections among ecosystem health, public health and human well-being. EPA Administrator Lisa Jackson recently acknowledged that (Lisa Jackson, 2011):

> not everyone will immediately connect EPA with public health. There is a perception that our job is to protect the wilderness and endangered

[70]Jackson's story above resonates with some of the substantive and design logics behind *The Asthma Files*. A seminal event behind the formation of *The Asthma Files* was an "interdisciplinary" conference in which in-body studies, based on biomarkers, seemed to trump research being done in exposure science at a more zoomed-out scale. *The Asthma Files*, like the Eco-Health Relationship Browser, is designed to pull together diverse perspectives.

> species. Those things are important, to be sure. But the truth is that EPA's protection of human health is the first priority of our agency—and has been since day one.[71]

Laura Jackson hopes that by circulating the state-of-the-science and pulling together separate studies the Eco-Health Relationship Browser will allow users to make qualitative, and sometimes quantitative, statements about particular places and human health and well-being. These tools, used in tandem, will enable articulations about how, for example, particular populations do not have green space within a mile of their home (easily visualized with the Atlas) and strong relationships have been reported in eight different studies (pulled together in the Browser) that having green space within a mile of your home decreases your Body Mass Index (BMI) score, improves mood, reduces depressive episodes and lowers the risk of cardiovascular disease.

Aggregating qualitative statements, the Atlas designers hope, could enable users to make strong claims. Many studies, though each may have its imperfections, can add up to a compelling articulation.[72] But, for the producers of the Atlas, quantitative statements, are the gold standard. The Atlas will be able to make some quantitative statements soon after its release. Drawing together tools built by the U.S. Forest Service and the EPA's Office of Air and Radiation, for example, users will be able to put a number on the benefits of the urban canopy for capturing ambient air pollution or the benefits of trees that shade buildings and reduce energy costs. Linking other services to human health and well-being outcomes may be further off, partly due to lacunae in the literature. The Atlas may actually *drive* advances in research in this area; by providing a venue for this work to have effects, the Atlas could provide incentives for more work in this area, which Jackson says can sometimes go unnoticed or dismissed because it may not be reaching the right audiences (Laura Jackson, 2011a). This potential to incentivize research, along with mapping the extant research in order to identify gaps and prioritize

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[71]Yet, in the same year, Administrator Jackson asserted that the "the mission to strengthen the American economy" is "the defining mission of our time in office" (Lisa Jackson, 2012).

[72]This tactic of synthesizing disparate data in order to say something new resonates with the modeling techniques described in the next chapter, the model of "informated objectivity" (Fortun & Fortun, n.d.-a) and new media practices (Manovich, 2002).

future research, are some of the ways in which the notion of communicationXcreation is exemplified in these projects.

A significant obstacle preventing more quantitative claims from being made, Jackson says, is the lack of data on human outcomes, from educational criteria to health issues, in different environmental contexts. This is in part because the data can be highly confidential. Jackson says "it's difficult to do this work because either the data are protected or they're just not even collected and maintained in a consistent way across large areas" (Laura Jackson, 2011b).[73] The Atlas and Browser, by collecting and curating such data, may make future work connecting environmental factors to human factors much easier. Besides circulating, in accessible and graphable ways, geocoded data on ecosystem factors that could affect human health and well-being, the Atlas and the Browser offer a map that condenses the state-of-the-science, various interpretations of the kinds of data in these EMSs. It is notoriously difficult to prove causal relationships in environmental health studies, but the Atlas could help bring into visibility cases where future research could help move from showing correlation to causation. Jackson explained that (Laura Jackson, 2011a):

> If we do find hot spots where we have correlations popping up that, we really don't know if they're spurious, but we see them in several places—between ecosystem services and health and well-being endpoints—they can suggest areas for more structured, designed research. Where we see correlations, is there something real here?

In some cases such "hot spots" may become sites from which to make causal claims; in other cases they may be areas deserving of focused research effort and future experiments.[74]

In order to generate new knowledge on the relationships among ecosystems and human health and well-being, Jackson will need to contend with some of the EPA

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[73]This challenge of maintaining data, in a consistent fashion, from wide-ranging sources, resembles some of the primary "data challenges in ecology" put forth by Reichman, Jones and Schildhauer (Reichman, Jones, & Schildhauer, 2011).

[74]The Atlas can be seen as an experimental system to the extent that it goes beyond testing well worked-out hypotheses—what Hans-Jörg Rheinberger calls a testing device—to generating new questions and bringing into view areas that previously have lacked close attention (Rheinberger, 1997). Whereas communication as transmission is akin to a testing device, the production of contexts can have the effects of an experimental system.

communication policies and privacy issues discussed below in the context of citizen science. Jackson grapples with the privacy issues around data (especially in regards to human health) and is interested in the possibility of community groups uploading their own data, perhaps in ways that would be private. Jackson states that preliminary work among the Atlas producers and potential communities of users has made it clear that "everybody wants to bring their own data" (Laura Jackson, 2011a). To Jackson, it seems unlikely that citizen-generated data will go into the Atlas in a way that is publicly viewable; it is more likely that users will have private accounts that will hold their data, which can be compared to all the data that comes pre-packaged with the Atlas (Laura Jackson, 2011a). Although citizen-generated data may not be share-able with the general population, by anonymizing it, Jackson and her colleagues may still be able to do association research. Test scores, individual medication regiments, etc. are highly private, but if communities post aggregate information, by census tract, for example, Jackson and her colleagues could associate such metrics with the availability of parks, trees near residences or distance to agriculture. Attention to scale is clearly an ongoing concern for the Atlas designers. On the one hand, zooming in to higher resolutions and finer scales, in the Urban Atlas, is necessary for users to make sense of how their particular environments might be affecting their health and well-being. On the other, it may be necessary to zoom out or confine analysis to larger populations in order to protect privacy and generate new knowledge using aggregate information.

3.4.1.6 Synthesis, Collectivity and Collaboration[75]

The primary logic the Atlas embodies—perhaps better than any other project at the EPA—is *synthesis*. Synthetic logic drives the designers to spend a great deal of energy on assembling collectivity and collaboration among the core team and a number

[75] A key implementation strategy for Neale is "reliance on extramural participation" (Neale, 2009b). Other strategies include (Neale, 2009b):

> reliance on existing monitoring and remote sensing data, literature, models, and tools while conducting additional research and keeping eye on future developments; staged implementation; use of existing future scenarios (ICLUS, FORE-SCE, IPCC) and incorporating alternative management scenarios.

of contributing partners.[76] Synthesis can refer to the end result of dialectic. But can also mean folding together elements in order to produce something new, as in protein synthesis or synthetic chemistry. The Millennium Ecosystems Assessment, which played a large role in propelling the eco services paradigm and, in turn, the Atlas, lists a number of emergent findings that, as their website states, "can only be reached when a large body of existing information is examined together." Synthesis can help us see what we know, and what we do not. It can illuminate change over time. It can also help us understand non-linear changes and predict future trends.[77]

The Atlas is somewhat unique in its national scale, breadth of content and the wide range of collaborators and stakeholders it mobilizes. As I describe above, Neale and others have spent great effort enrolling a range of federal stakeholders, as well as participants from state and local agencies. The Atlas depends on linking data from diverse governmental organizations in a single public platform. Media producers with the National Geographic Society (or NatGeo) have also joined the collaboration. "Simply stated," Neale comments, "this collaborative effort combines EPA's ability to develop the science necessary to quantify ecosystem services with National Geographic's world-renowned expertise at delivering information to the public in a way that generates interest and is easily understood" (Neale, 2010a). When I asked Neale to elaborate on the relationship between the Atlas team and NatGeo and if she would characterize the relationship as one of "trading," she responded that Nat Geo is incorporating data layers from the EPA on their website, landscope.org, which puts the data in terms that are even simpler than the Atlas's presentation; in many areas, Landscope currently only displays a data layer called Protected Areas of the U.S., which

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[76]The Atlas clearly illustrates Reichman et al.'s (2011, p. 705) comments on how recent advances in ecological synthesis are changing attitudes to data sharing in ecology.

[77]Paul Edwards writes that "thinking globally," perhaps akin to Bateson's "ecology of mind," means (Edwards, 2010, pp. 1–2):

> seeing the world as a knowable entity—a single, interconnected whole—but in a sense that lacked the secure stasis of maps, parlor globes, or pre-Darwinian cosmologies. Instead, it meant grasping the planet a dynamic system: intricately interconnected, articulated, evolving, but ultimately fragile and vulnerable. Network, rather than hierarchy; complex, interlocking feedbacks, rather than central control; ecology, rather than resource: these are the watchwords of the new habit of mind that took Earth's image for its emblem.

shows parks and land conserved by NGOs. In turn, NatGeo will provide some data layers for the Atlas. Neale said "integrating is a better word [than trading]… our main objective is just getting the information out so decisions can be made in a better way. We don't care whether it's on our server or an NGO's server" (Neale, 2011).[78] Synthesizing the resources from radically different organizations—the EPA and NatGeo, among others—will synthesize not only data sets and types of expertise, but audiences that may have remained largely separate up until this collaboration.

3.4.1.7 Mapping Potentials and Limitations of the Medium

> Now when I was a little chap I had a passion for maps. I would look for hours at South America, or Africa, or Australia, and lose myself in all the glories of exploration. At that time there were many blank spaces on the Earth, and when I saw one that looked particularly inviting on a map (but they all look that) I would put my finger on it and say: when I grow up I will go there.
>
> - Joseph Conrad, Heart of Darkness"

The primary entry point for users of the Atlas will be an interactive map. Maps and globes can fascinate even young children, spurring an imagination for unseen territories and a desire to experience new places. But maps can also be one of the most densely packed communications media of any sort and it could be argued that the recent combination of GIS technology with Web 2.0 interactivity has resulted in a fundamentally new medium. Contemporary ecologists and geographers can use GIS to layer dozens of data layers over a map, enabling the visualization and contemplation of both environmental problems and possibilities in new ways. Maps can simultaneously *circulate* geographical knowledge and *produce* a desire to navigate and learn more about spaces.[79] Maps, and especially data-rich atlases, can simultaneously crystallize the

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[78] While I believe Neale's indifference to whether EPA is credited for the data displayed by NatGeo and other organizations stems from a kind of selflessness, it may be important for EPA researchers to take into account how they could improve the overall public reputation of the EPA as a communicating body and public agency, especially at a time when conservative politicians are threatening to practically dismantle the EPA.

[79] In *Mapping the Invisible Landscape*, Kent Ryden writes that "cartography was one of the most important and respected arts in medieval and Renaissance Europe, serving both to summarize the current state of

"state-of-the-science," both in terms of content and form, and catalyze new science and action. Maps can be powerful tools for swerving cultural imaginaries of the environment and our places within it.[80] Combined with new ways of mediating databases that make them *usable* (and not just accessible) by different publics, mapping projects can provide up-to-the-minute information customized for a user's specific locale.

Compared to a dense spreadsheet or table, the form of the online and interactive atlas/map, with its flexibility in terms of visualizing only the data layers of interest, may be easier (and more fun) for many users to make sense of. The Atlas is explicitly performative in a way that a spreadsheet is not; or, rather, is performative for a different audience, for different reasons, in different ways. Neale clearly has a love of maps. "Maps are just phenomenal," she says, "and they allow you to look at multiple layers at one time, and to summarize information spatially. Maps are just fantastic, they're absolutely fascinating!" It is important to note that, beyond instrumental uses, the map form has a potential for affective mobilization, for fascinating users.

But the Atlas designers are also wary of the map form. The Atlas project will need to provide meta-information for a wide range of potential users on how to read and use the Atlas.[81] Neale is concerned that the map may perform a kind of transparency, or certainty, or seem to tell the whole story, cover the territory. Neale talked about how users that may not be used to looking at maps could think that values on the map are absolute. An area of the map, for example, could be colored a particular color to indicate the amount of atmospheric deposition occurring in that area. "In reality," Neale says, "it has some error bounds around it, and it's important for a user to know what that level of uncertainty is, otherwise it could potentially be misused." The Atlas producers are trying to include certainty analysis for each data layer, perhaps in the form of confidence

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geographic knowledge and belief and to spur explorers on to ever-wider-ranging voyages of discovery" (Ryden, 1993, p. 20).

[80] On maps and environmental imaginations see Italo Calvino's *Invisible Cities* (Calvino, 1978). On "map knowledge and place sense," see Lawrence Buell's *The Environmental Imagination*, an account of Thoreau's synthesis of mathematical mapping of Walden Pond with symbolic tales of its false bottoms and mysterious depths (Buell, 1996).

[81] See above note on the literacy required to use the Atlas, jumping off from Barzyk (2011), and going beyond the technological. Also see Bowker (2008), who stresses the importance of metadata, especially when attempting to link different data sets.

interval maps.

Neale's recognition of the importance of making the limits of the medium (maps) visible, on the surface, resonates with tactical media producers who use media technologies to comment on and critique those very technologies, and the contexts in which they are usually used, sometimes through parody, in order to help their audiences think critically about the mediumXmessage.[82] Neale says that "every data layer, especially the ones we have national coverage for, I mean every single data layer is flawed in some way. So I want to make sure that the user is aware of that." For Neale and the rest of the Atlas team, "transparency" is not simply a buzz word; they want to design the Atlas to be transparent about its flaws. They imagine users that are capable, with the right tools and documentation, of dealing with uncertainty and learning to gain new literacies around uncertain science.

3.4.1.8 Affirmative Approaches

When I hear the word environment—when I do not immediately picture bucolic landscapes far from the urban spaces I inhabit—I tend to think of pollution, toxics, chemicals with unknown effects, frogs with five legs, etc.[83] The Atlas will map some of these aspects of the environment, but it will also highlight opportunities for creatively designing intelligent systems and ecologies. Crucially, the Atlas will focus on both environmental problems and opportunities. The fact that many of the students I have worked with at Rensselaer Polytechnic Institute have shied away from the environmentalist label is indicative of the negative flavor associated with environmentalism today, as when it is opposed to economic growth.

The students I have worked with, largely engineers, are problem-solvers. Helping them think about tradeoffs and unintended consequences—a central goal of Atlas

[82]In a critical media literacy training program I taught with, for example, we helped youth make stop-motion animations in order to learn about the "power of the edit," how particular ways of framing and cutting could be used to manipulate viewers into seeing things in certain ways. The media were used to critique the media. Bio-artists, similarly, use living media to provoke discussion around our bio-tech futures.

[83]See James Rowe's dissertation, "'Love the Earth'—Nietzschean Pathways for Progressive Politics," for some hypotheses about why "popular movements" are, often, not particularly popular (Rowe, 2011).

producers—has been a key part of my job, and deserves much more attention, but EMSs that focus exclusively on the ugly side of the environment (like Scorecard's exclusive focus on toxics) need to be supplemented with spaces that enable and motivate creative action. A "use cases" section of the Atlas could provide a wide variety of success stories—like the one above on developing a systemic solution that avoided huge refrigeration costs for dealing with agricultural runoff—enabled by the Atlas.

3.4.2 The Atlas in Context: Substantive Logics

3.4.2.1 Ecological Perspective in Decision Making

The Atlas is designed to interrupt a perceived tendency to set the cost of environmental degradation and the value of ecosystem services to zero, by default, in decision-making. When asked about her motivations for designing the Atlas, Neale immediately brought up the *form* of the Atlas and how its "holistic" perspective could increase the likelihood that environmentalist concerns will be taken into account in land-use management decisions. The developers of the Atlas are concerned that decisions over natural resources are made in isolation of each other. A decision about water quality, for example, could easily miss other benefits that might be obtained as a result, or other services that could be impacted.

When asked what it might look like for the public to have a more ecological perspective on the environment, Neale thought it could politicize and activate people. Neale says that an ecological world view is fundamentally attuned to how "everything is connected, and I hope that [the Atlas] will show that connectedness" (Neale, 2010b). People with an ecological world view, Neale claims, are more likely to support environmentalist NGOs, more likely to write letters to representatives and more likely to "get involved," perhaps moving along the spectrum from "inactives" to "complete activists" (Ibid.; Verba & Nie, 1987). By showing the public how "ecosystems are protecting things that are *critical* to our ability to continue living on this plant like clean water and air," and not just providing spots for recreation, Neale contends that the Atlas "could contribute to changing the way people use ecology" (Neale, 2011). Neale thinks of the potential users not as simply a remote and homogeneous public, but also more

proximate, even including other researchers at the EPA that could benefit from the more ecological or holistic view that the Atlas provides. Neale told me that "there are people here within EPA who work specifically on very targeted research looking at one chemical and its impact on the human body and I think they probably need as much convincing as, say, a plumber downtown… I mean they could really benefit from viewing the larger picture" (Ibid.).

Neale provides an example of the kind of success story she hopes will proliferate on the Atlas and inspire users to think and act more ecologically (Neale, 2009a). In Portland, OR, about ten years ago, the effluent from a sewage treatment plant was warming a stream, significantly degrading fish habitat. The county was faced with huge costs of refrigeration units to cool the water before it went into the stream. This kind of technological fix approach is precisely *not* the ecological approach advocated by the Atlas producers, but is all too common. Luckily, some ecologically literate planners became involved and convinced the sewage authority to pay farmers along the stream to leave the portion of their land bordering the stream fallow. Trees were planted along the stream that filtered runoff and the temperature of the water dropped perfectly. The farmers were getting paid more than what the land was worth for agriculture, the county was saved from much higher refrigeration costs and the amount of phosphorous running into the stream from the agricultural runoff decreased significantly, improving the habitat for fish, birds and the functioning of the ecosystem as a whole. Neale imagines that the Atlas will help a wide array of users to make similar connections among land-use decisions, agriculture, water quality, biodiversity, remediation expenses, economic incentives and a variety of forms of expertise.

3.4.2.2 Institutional Context: The EPA

Economically, even with budget reductions in recent years, the EPA has vastly greater funds than a typical non-profit environmentalist organization, enabling large-scale projects like the Atlas. The EPA's places high value of the Atlas project, which is described by high-level administrators I spoke with as a shining example of the transparency and communications strategies called for by institutional initiatives and guidance documents. Neale, even in the current climate of budget cuts and tea party

logics, has little fear of funding being pulled, although she does imagine that it could perhaps be reduced, resulting in the project being slowed down.

The EPA also has the benefit of an established infrastructure and knowledge base from which to build. Although the Atlas will continue to acquire and incorporate new data layers even after it is released to the public, a key challenge during the years I conducted this research was to design an interface that is usable by the intended audiences.[84]

The Atlas is largely driven by explicit agency demands for better communication of environmental information to different publics. Neale told me that the Atlas is part of initiatives by the National Program Director for Ecology and the new EPA Administration (Neale, 2009a):

> placing an emphasis on stakeholder involvement, transparency, and the need to be able to communicate results to the public in ways which are consumable rather than buried in science journals. While publishing in the scientific literature is still critically important, there is frequently a long lag time between the publishing and the mainstreaming of the information published. Some critical information never gets mainstreamed.

The Atlas is also acknowledged as part of an initiative for greater transparency at the EPA. Transparency is one of the three core values guiding the EPA FY 2011-2015 Strategic Plan, along with science and the rule of the law. OMB Watch reports that (OMB Watch, 2010):

> The "Expanding the Conversation on Environmentalism" strategy ties directly into the Obama administration's open government efforts to improve participation and collaboration at agencies. . . EPA Administrator Lisa Jackson stated that EPA "will take broad steps to expand the conversation on environmentalism to communities across America, building capacity, increasing transparency and listening to the

[84]The Atlas, like any map or database, will, of course, leave much out. Taking a cue from feminist STS scholars, close attention should be paid to what is excluded, and by what rationale (Haraway 1997; (Singleton, 2012). Bowker (Bowker, 2008, 127) writes that:

> Exclusion from databases has drastic consequences for entities, to say nothing of "systems and services" in current environment-speak; you can only protect through policy interventions that which can be named, that which can be shown to have been important in the past. . . thus it is critical at this juncture that we pay close attention to the ontologies and politics of our databasing life.

> public." EPA will work to ensure that "science is explained clearly and accessibly to all communities, communicating and educating in plain language the complexities of environmental health, policy, and regulatory issues."

But communicating complexities, it turns out, is highly complex. Transparent communication and clear language quickly gets murky when well-planned EMSs are exposed to the broader context of environmental politics. EPA's language above, with its calls for expanding the conversation and greater collaboration, implies opening the door to more voices and not simply turning up the volume on credentialed experts. The challenges of listening to the public, in the form of citizen science, are not easily resolved and require working within constraints, even as these might be loosened a bit in the process.

3.4.2.3 The Challenge of Citizen Science at the EPA

There is great interest within the Atlas development team, in other areas of the EPA, and the stakeholders Neale has spoken with, in developing channels for the public to contribute *to* projects like the Atlas. Citizen science is the term used by Atlas producers. Neale tells me "[we want] to have transparency in everything we do and make it as open as possible. It's very much an 'everybody's welcome' philosophy. Anybody that's interested in working on it: I'm more than happy to have them participate" (Neale, 2009a). But EPA communications policies, which are especially stringent for online content, may significantly limit feasibility of public participation.[85] When asked about the possibilities for curated user-generated content, Neale was excited, but unsure of how institutional rules (set partly by the Office of Environmental Information in Washington, D.C.) as well as technological logics might constrain or enable that aspect of the project.

Technical affordances of the ArcGIS platform on which the Atlas is built could potentially limit initiatives for citizen science. The ArcGIS server allows a lot more

[85] An example of the stringency of EPA communications policies, especially for online content, is the case of two EPA employees that were allegedly asked, under threat of "disciplinary action," to take down a Youtube video they posted on the weaknesses of cap and trade legislation and carbon off-setting (Public Employees for Environmental Responsibility, 2010).

analysis capabilities (vs. Google Earth and other popular systems) but its portability is limited because it can't be used on an iPhone. Neale clearly has an imagination for how a portable version of the Atlas could enable citizen science initiatives. She became highly animated, for example, when talking about the possibility of recreational fishers submitting geo-coded data on what they caught.

Neale reports a "loud and clear" desire among potential users of the Atlas, including the Center for Disease Control, to enable citizen science (Neale, 2009a). Stakeholders want to add their own data. Neale imagines two possible strategies. Allowing users to load their data into the Atlas, but keeping it private and client-based, would be "far easier in the EPA world." "What people *really* want," Neale says, "is the ability to add their data to the application and then share it with other users. That's harder because that means you're taking data from outside, from an unknown source, and putting it into an EPA application without it really being vetted" (Neale, 2011). The work of vetting the information that is associated with the EPA "brand" is taken very seriously. This is not surprising given the uneasy position of the EPA as simultaneously a research organization and a regulatory agency. EPA scientists walk the line of science and policy, subjective and objective concerns, research and advocacy. Neale speaks of a "huge number of security and other challenges" and has a feeling that "before we get to where we can have people all sharing data we'll have many bureaucratic bumps in the road" (Neale, 2011).

3.4.2.4 EPA Communications Challenges at the Nexus of Advocacy and Objectivity

The EPA's publicly uneasy credibility as a research institution (at least in the eyes of some, see Chapter Two) may contribute to their strict communication policies. Rules on the enforcement side can affect the process of science in ORD. If there are "policy implications" in the Atlas, for example—and that not largely the point?—the review (by the Office of Environmental Information and other non-ORD players) may take significantly longer, delaying its public release. Neale points out that the strict communication and publication rules within the EPA are both constraining and enabling. Because of her position at a government agency, Neale feels the need to be extremely

careful about what she puts out on the internet. This can slow the process, and constrain possibilities such as citizen-collected data sharing, but the rigorous review process, Neale says, does give projects like the Atlas and CMAQ greater credibility. Unlike CMAQ, the Atlas is not designed and reviewed primarily for regulatory applications, but it could have a variety of policy implications. While Atlas producers are wary of putting dollar-values on ecosystem services, the metrics they are developing could be used to quantify the economic value of different spaces.

3.4.2.5 Ecosystem Services: the Third Wave of Environmentalism or Neoliberal Encroachment on Ecologies?

Definitions of ecosystem (or eco) services are diverse. Put bluntly, eco services are the benefits that nature provides to people. But most definitions of eco services are more ecologically styled than this one-way characterization might suggest, speaking of interdependence (if not immanence of or intra-action) among human lives and ecosystem-based processes. Thinking in terms of eco services, in theory, helps connect people to nature, but the paradigm also, at least potentially, could separate and stratify, with human well-being as the only marker of value, in the final analysis. This is hardly an ecological stance.

One of my interlocutors described eco services as the third wave of environmentalism, after conservation and sustainability. The eco services paradigm is not, of course, at least yet, replacing sustainability or conservation. Rather the three (and others) mix and layer. [86] Rhetoric and practices of eco services are increasingly supplementing other discourses of environmentalism and are used to navigate issues in sustainable development and tradeoff assessments.

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[86]Goldstein (2011) argues that the major shift that EPA and ORD need to focus on in order to deal with complex environmental issues is from a paradigm of risk to one of sustainability. He points to the 1992 meeting in Rio de Janeiro of the UN Commission on Environment and Development as a major event in international adoption of sustainability, but argues that two decades later the EPA still is in transition from risk to sustainability. He writes, "for EPA to include sustainability as a major driver within its existing legal mandates, EPA will need to transform its culture from its current focus on reducing risk to one that maximizes benefits" (Goldstein, 2011, 307). Accounting for benefits as well as costs, solutions as well as problems, would seem to fit well with the ecosystems services paradigm. The Atlas could serve as a tool that could help measure costs and benefits across the environmental, economic and social dimensions of agency actions at a number of scales.

The Atlas does not explicitly place a dollar-value on eco services, but it is designed to help users place numbers on the relative value of ecosystems (through metrics) and will be a useful tool for market-based approaches to environmental governance. Developers of the Atlas necessarily negotiate a key tension in contemporary environmentalism: a price *should be* put on nature (because otherwise it will be zero) and a price *shouldn't be* (because of nature's immeasurable value and because reductive quantification can reinforce problematic assumptions and frameworks). Environmentalism necessarily exists in this complex space where it certain goals can be accomplished by playing into neoliberal, human-centered, profit-based, imaginaries and market-based "solutions" and yet other goals—perhaps inspiring publics with a sense of awe and humility—can rely on a higher, transcendental ideal of a pristine, transcendental, sublime, pure nature that exceeds all metrics.

While there is no clear moment when the eco services paradigm was born, the Millennium Ecosystems Assessment (MA) was a key development. The MA was a massive undertaking, akin to the United Nations Intergovernmental Panel on Climate Change (IPCC). In 2000, the United Nations secretary general called for the MA to assess the impact of ecosystem change on human well-being. The MA report includes scientific assessment of how to improve conservation and the sustainable use of ecosystems while maintaining a focus on human well-being. Over 1,360 scientists from around the world collaborated on the MA and the findings were published in five technical volumes and six synthesis reports.

During my initial research at NERL in 2009, eco services seemed to be turning up everywhere. Despite its rapid uptake, the paradigm has been critiqued from many directions. Notions of value, despite my interlocutors' tendency to avoid assigning explicit numerical value to eco services, inevitably are coupled with economic questions and analysis. In a classic paper in the eco services literature, Costanza et al. contend that, for the entire biosphere, "the value (most of which is outside the market) is estimated to be in the range of $16 – 54 trillion/yr., with an average of $33 trillion/yr. Because of the nature of the uncertainties, this must be considered a minimum estimate" (Costanza et al., 1997, p. 253). At the time of their estimates (1997), global GNP was around $18 trillion/yr. The wide range given by Costanza and colleagues suggests serious

informational challenges and knowledge gaps within the ecosystems services paradigm. Given the explicit intent by many eco services practitioners to guide environmental and economic policy, better public access to (and construction of) ecological knowledge is a pragmatic task with high stakes.

Other critiques of the eco services paradigm center on its alleged anthropocentrism, reductionism and narrow notions of value. Over a series of interviews, Laura Jackson explained that she can relate to arguments that claim the eco services paradigm, "in trying to nail a price tag to nature, reduces its importance, reduces its essence, neglects the existence value argument" (Laura Jackson, 2011a). Despite the discomfort Jackson feels with putting things in such human-centric terms, she feels that "we're at a point where we're in crisis. The environment continues to decrease in importance to people and so I've made the switch to 'okay, let's show what's in it for you'" (Laura Jackson, 2011a). As Goldman writes "the appeal of ecosystem services for conservation is the connection to people and people's well-being and how that appeal translates into new and increased interest in conservation across a wide range of resource management issues" (Goldman, 2008). The need for experimenting with different tactics, because older ones just aren't working, has led Jackson to mobilize what might be called a tactical (or strategic) anthropocentrism. Eco services, for Jackson, are "the last ditch argument for conservation" (Laura Jackson, 2011a). Paradoxically, it seems to Jackson, the only way to get people to care about the non-human environment, the context outside of oneself, is to appeal to human and ego-centered individual concerns. Jackson contends that most people do not make changes in their lives for "some far away butterfly;" they tend to be interested in themselves, their families and their health; conservation for idealism's sake is rarely effective. Jackson believes that (Laura Jackson, 2011a):

> When push comes to shove, people care about the birds and the bunnies but not enough to maybe think about their selection of where they're going to live, or what kind of car they're going to drive, and so forth. But when it starts getting into children's health, learning ability, obesity, longevity, trips to the hospital and out of pocket expenses, that starts to get people's attention.

Jackson's conception of the typical environmental subject in the U.S. is that she or he is

continuing to put less value on the environment and will only engage in acts of conservation if their own self-interest is spelled out clearly. This vision resonates with the standard economic model of the self-interested individual. But Jackson departs from standard economic conceptions and practices in a number of ways. Jackson told me that a problem with the economic paradigm that eco services is plugged into is that "things become more valuable the scarcer they are," so if "you have just a wonderful abundant supply of something it's devalued… it's all about rates and flow and not about constants" (Laura Jackson, 2011a).[87]

Even in a human- and services-centered approach, close attention should be paid to the *virtual potential* of processes or goods that may not yet be related to valuable and scarce services, but could prove to be highly valued in the future. A future-oriented approach can help people plan for radical changes that might result from climate change, peak oil and other pressing environmental issues. Unfortunately, market-based solutions, which the eco services paradigm is tightly, if uneasily, entwined with, are—to say the least—not always competent at accounting for the future. Laura Jackson hopes the Atlas will improve predictive capacity in decision making by showing potential change over time. Users, for example, would be able to, see what Lyme disease risk would be under different land use scenarios (Laura Jackson, 2011b):

> What if we preserved a bunch of green infrastructure for water quality reasons, how would that affect Lyme disease risk? What if the area developed following business as usual with the trends of the past? What if there was a really high growth, high sprawl scenario from the IPCC?

Dorsey Worthy, Branch Chief of Landscape Characterization at NERL and an early pioneer in developing aerial photography systems, is wary of the eco services

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[87]The problems with thinking in terms of rates and flow, in the economic paradigm Jackson puts forth here, and abstracting value from a somewhat "invaluable" nature, resonate with Jean Baudrillard's commentary, reading Marx, on the commodity (Baudrillard, 1988, pp. 22–23):

> Marx already denounced the obscenity of the commodity, which is linked to the principle of its equivalence, to the abject principle of free circulation. The obscenity of the commodity derives from the fact that it is abstract, formal and light in comparison with the weight, opacity and substance of the object. The commodity is legible, as opposed to the object, which never quite reveals its secret, and it manifests its visible essence—its price.

paradigm because of how *goods* can be left out of the story. He tells the story of how one of the earliest papers on eco services originally coined the phrase "ecosystem goods and services," with a footnote that said "hereafter ecosystem services," and somewhere along the way, "goods" fell away, with important effects (Worthy, 2009). James Wickham, a Senior Research Biologist at NERL and collaborator on the Atlas project, shares Worthy's concern with the disappearance of "goods" and points out that the communications strategy of reduction and compression can sometimes backfire (Wickham, 2009):

> "Ecosystem goods and services" is a concept that was first articulated nearly 40 years ago (Westman, 1977). Its reinvention as "ecosystem services" has abstracted the concept, which has made it more difficult to communicate. Biodiversity is a good example. It's not a service. It's an asset or a good, and it is from this asset that services arise. It is altogether proper and appropriate to take a paragraph, instead of a sentence, to explain what needs to be explained.

Wickham is frustrated with what he sees as a "dumbing down" of complex issues in attempts to communicate with the public. The Atlas—as a context in which users can take the time to explore the connections among various goods and services, examine unintended consequences of different decisions and drill down to examine the sources of information—could provide a model for public engagement that goes beyond the "sound bites" Wickham critiques and does justice to the complexity of environmental problems and potential solutions.

3.5 Conclusion: Cultural Critique in the Atlas

3.5.1 Atlas Makers as Experimenters and Context Producers

Motivated largely by a desire to open up more collaborative possibilities, I aim to push against reductive portrayals of cartographers, GIS experts and scientists more generally as reductive positivists. I figure EMS producers as experimenters muddling their way through uncharted territory, crafting and modifying maps as they go. The Atlas is an unprecedented project in terms of its scale and in terms of the difficult, and perhaps dangerous, line it walks between challenging and reinforcing standard economic schemes for the valuation of ecosystems. Taking a cue from the Atlas producers, I have

increasingly noticed the diversity of expertise and goals within my own field and within the communities I have built connections with.

The Atlas producers' mapping practices are creative and risky acts.[88] The eco services paradigm which the Atlas draws on and extends is far from perfect. It has been criticized for undervaluing ecosystems, playing into the neoliberal marketization of everything under the sun and implying that economic values should be the only ones that count. Anything that can't be counted, quantified, can have a hard time being accounted for in the eco services model. Yet, currently, the value of ecosystems defaults to *zero* in many cost-benefit analyses used in land-use planning initiatives. The Atlas producers I spoke with believe that standard ways of accounting (or not) for environmental factors are clearly not working and experimentation is called for, even if that means playing into paradigms that need to be continually questioned and perhaps re-worked from within.

The Atlas critiques notions of knowledge production as isolated experiments with repeatable results and performs informated scientific approaches with collaborative goals and processes. Adding data to shared databases is increasingly valued in the sciences, if not quite as highly as the publication of scientific papers (Bowker, 2008). The Atlas project shows that, in addition to developing data for databases, the creation of new tools (often database driven) or contexts is increasingly seen as an admirable goal in science, especially in the environmental sciences with their generally applied orientation and at the EPA with its public mandate.

3.5.2 Literacies and Sensibilities

How might the Atlas catalyze new literacies and sensibilities? Could including a fact sheet with every data layer, describing the sources and uncertainties in the data, provide a kind of training in users' epistemological literacy? What about ontological

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[88] As Haraway (1993, 97) puts it:

> Bodies [in this case including bodies of water, ecosystems, and the Atlas itself] as objects of knowledge are material-semiotic generative nodes. Their boundaries materialize in social interaction. Boundaries are drawn by mapping practices; 'objects' do not pre-exist as such. Objects are boundary projects. But boundaries shift from within; boundaries are very tricky. What boundaries provisionally contain remains generative, productive of meanings and bodies. Siting (sighting) boundaries is a risky practice.

shifts? Neale imagines potential effects of interaction with the Atlas beyond simply having, quantitatively, more information. When I asked her if she thought seeing the world through the lens of the Atlas could affect the way users think about the environment and their relationship to it, their fundamental ecological ontologies, she responded in the affirmative, but was wary of making a strong claim for new literacies until she has seen the Atlas "in action," with a diverse array of users. "I would hope," she said, "that it would let users see how much we've already used up and how much is left and think about things a bit differently" (Neale, 2010b)

In *The Invention of Modern Science*, Isabelle Stengers distinguishes between humorous and ironic approaches to scholarship, defining humour as "the capacity to recognize oneself as a product of the history [and, I would add, ecology] whose construction one is trying to follow" (Stengers, 2000, pp. 65–6). Irony appeals to transcendence while humour is an art of immanence (see also (Vann, 2010). The bird's eye view of the Atlas, and the ecosystems services paradigm it is largely based on, at first seem to be highly ironic, enacting a sharp subject/object divide, separating the viewer from the environment, floating above it, enabling decisions about how to use nature-as-raw-material and re-enacting a separation between nature, which provides benefits, and the human, which receives the benefits. But the Atlas is designed by ecologists, who describe a general shift over the past few decades from thinking of ecology as "the world without us" to the study of natural systems, including humans and their effects. When I first heard about the Atlas it was focused entirely on ecosystems services and did not yet have the section on the built environment.[89] The Urban Atlas component situates people as part of the environment by including services from the built environment alongside ecosystem services. The built environment is put on the

[89]Linking "natural" ecosystems with the "human" built environment is also addressed in "systems architecture," described as (Armstrong, 2010):

> a new model for the generation of sustainable architecture that combines the discipline of the study of the built environment with the scientific study of complexity, or systems science, and adopts the perspective of systems theory. Systems architecture offers new perspectives on the organization of the built environment that enable architects to consider architecture as a series of interconnected networks with embedded links into natural systems.

The Atlas could become an important element in the systems architect's toolkit.

same "plane of immanence" as the services provided by ecosystems (Deleuze & Guattari, 1996).[90] The Urban Atlas is especially focused on the challenge of linking ecosystems services to human health and well-being, but the entire Atlas can be seen as engaging in an uneasy strategic anthropocentrism. Environmental health, after all, has come to mean human health as affected by the environment, rather than the health of the overall environment, including effects from humans. Despite its human-centeredness, the discourse of environmental health can still highlight modes of care that go beyond the individual human body (such as using inhalers to treat asthma attacks) to care for the shared environment (such as reducing asthma triggers like particulate matter and ozone, with many added benefits for wider populations).

Jackson told me about how she and her colleagues have been working to connect ecosystem services to aspects of human health and are looking into different indexes of what well-being means around the world. This latter work is a sharp departure from widely circulating notions that the Gross Domestic Product is, far and away, the most important metric for how well a nation is performing. Jackson's work links aspects of the ecosystems humans inhabit to mortality, sub-lethal morbidity, mental health and cognitive development. The biophilia hypothesis, popularized by E.O. Wilson, is a recurring concept in Jackson's work (E. O. Wilson, 1984). Jackson believes that "just being organic creatures that we are—we're still animals from millennia ago—we may actually require exposure to natural landscapes and living plants and animals for our own proper cognitive and physical development" (Laura Jackson, 2011b). The notion of biophilia contests a sharp dichotomy between humanity and nature. The notion that "we're still animals" rings with renewed attention in recent years to what constitutes the human, how humanity is constructed against notions of animality and the emergence of multi-species ethnography (Kirksey & Helmreich, 2010). But it also relates to strategies built into the Atlas itself. The Atlas doesn't blur species boundaries so much as it highlights them as sites of exchange. The boundary between (human) built and natural environments is also problematized by showing how both can serve similar functions. Rather than simply trying to reduce humanity's footprint, the Atlas could show how

[90]Also see discussion, below, of Bateson's views on immanence as marking "the correct way of thinking."

relations of care could be developed. A kind of designed symbiosis, underlying permaculture and other green praxis, could be catalyzed by the Atlas.

The scale-ability of the Atlas may also help users bridge divides between subject/object and human/nature. While holding a space for the global dimensions of our current crisis is surely crucial, scaling down to a landscape perspective, or even a neighborhood scale, could provide a more inhabitable scale of perception. Félix Guattari writes about how television, perhaps more than other media, "turns the environment into an abstract concept" with the result of categorizing ecological issues within people's minds as "outside their everyday experience and thus well beyond their sphere of influence in terms of bringing about change" (Guattari, 2005, p. 20). Getting at globally-scaled phenomena, such as climate change, through scales of everyday life is a challenge and orientation shared by STS scholars and anthropologists. The ubiquity of this challenge is also hinted at in bumper-sticker phrases like "Think Globally, Act Locally."[91]

If users of the Atlas can get a taste of what it's like to have an ecologist-eye-view of the world, which is fundamentally based on an underlying unity and connection among all elements of the ecosystem, they may be able to move a step closer to an ecology of mind and the sensibilities required to negotiate what Gilles Deleuze and Félix Guattari called "the magic formula we all seek—PLURALISM = MONISM" (Deleuze & Guattari, 1996, p. 23) Collaborative cartographies like the Atlas have great potential to enable better visualization and use of environmental knowledge for instrumental land-use decisions. They may also have a more radical potential to contribute to counteracting the underlying causes of the ecological crisis, including deeply rooted notions of human exceptionalism and transcendence.

[91]The phrase "think globally, act locally," was coined by David Brower, founder of Friends of the Earth. Paul Edwards writes about how, "according to rumor," the phrase condensed Law Professor Lawrence Tribe's characterization of the first photographs of Earth from space as the "'fourth discontinuity,' as massive a perspectival shift as those brought on by Copernicus, Darwin, and Freud" (Edwards, 2010, p. 1)

4. Assembling a Numerical Laboratory: The Community Multiscale Air Quality Modeling System as a Context of Collaborative Development and Evaluation

> *There are no defensible epistemological grounds for challenging reliance on climate modeling results in global-change policy deliberations. Models of data and simulation models are not mere heuristic devices. Models of data are intrinsic to the nature and collection of data both in today's remote-sensing modeling science and in traditional controlled experimentation. If climate change modeling is to be challenged legitimately, it will have to be on the basis of how good specific models are, and whether the application to the debated issues is appropriate.*
>
> - Stephen D. Norton and Frederick Suppe, "Why Atmospheric Modeling is Good Science," (Norton & Suppe, 2001, p. 104):

> *It's critical that we practice open communication in our modeling development, its evaluation and its application so that all can contribute to building scientific credibility.*
>
> - Kevin Teichman, the ORD's Deputy Assistant Administrator for Science, at the tenth annual meeting of the Community Modeling and Analysis Center (CMAS)

4.1 Introduction

Very few people have direct experience using air quality models. Most of us, however, make decisions based on weather reports that use some of the same meteorological modeling that is foundational for air quality modeling systems.[92] We acknowledge that forecasts are always imperfect, but often useful. We joke about how frequently the forecast is wrong, but still decide when to have a picnic based on rainfall

[92] In interviews with its producers, "CMAQ" slid between a "model" and a "modeling system," but there really is no model outside of the system. The model condenses and extends a system of other models, human user/producers, programming subroutines and knowledges from a number of disciplines. CMAQ is also an experimental system in Rheinberger's sense, providing a space for generating new questions (Rheinberger, 1997, 1998).

predictions. This double-vision can be understood in light of the double-bind (Bateson 2000), caught between two conflicting messages, one negating the other: we should trust the forecast, we should not. The stakes are high when, instead of planning a picnic based on a weather forecast, policy decisions must be made about an ozone standard, based on conflicting stories, told in multiple ways, by a variety of experts, from publicly-funded scientists to industry-endowed think tanks. Gregory Bateson, who worked on the "patterns that connect" across anthropology, linguistics, semiotics and cybernetics, contends that double-binds can contribute to pathologies, like schizophrenia, but can also catalyze creativity and innovation. Model developers at the EPA, which simultaneously seeks to produce objective knowledge and advocate for public health, have created modes of evaluating the CMAQ modeling system that are informing its use around the world.

CMAQ is designed to aggregate data from a variety of other models and apply, digest and interpret data to help scientists and policy makers determine how changes in air emissions, under proposed or existing regulations, would impact air quality and benefit public health. In their engagements with double-binds around modeling, designers and developers of the CMAQ modeling system have catalyzed imaginaries and collective practices that could inform the development of a more nuanced notion of sound science in modeling and knowledge production beyond the context of air quality.[93] Science communication, in regard to CMAQ, takes the form of producing a sociotechnical context that draws together the myriad forms of expertise that are necessary for producing, evaluating and lending credence to the model. Developers in

[93]Mapping and developing narratives for defending sound science, or good science, is critical in order to counter industry-led attacks on science at the EPA. A classic example is the tobacco industry's handbook *Bad Science: A Resource Book,* which Oreskes and Conway (2010, 144) describe as a "how-to handbook for fact fighters. It contained over two hundred pages of snappy quotes and reprinted editorials, articles, and op-ed pieces that challenged the authority and integrity of science, building to a crescendo in the attack on the EPA's work on secondhand smoke." The sound-bites included in *Bad Science* include: "too often science is manipulated to fulfill a political agenda," government agencies "betray the public trust by violating principles of good science in a desire to achieve a political goal" and "no agency is more guilty of adjusting science to support preconceived public policy prescriptions than the Environmental Protection Agency" (Oreskes & Conway, 2010, pp. 144–5). This dissertation contributes to a thread of STS focused on analyzing layered, historically shifting notions of what counts as good science (Fortun & Fortun, 2005; Haraway, 1997; Haraway, 1993; Shapin & Schaffer, 2011).

the CMAQ community talk about peer review and transparency—instead of comparing to a pre-established quantitative measurement—as the best ways to test, display and improve the accuracy of the model. The distinction between internal and external communication around CMAQ blurs considerably. Sound science, for CMAQ developers, depends on systematic and well-documented modes of collectively developing, using and evaluating the model in ways appropriate to their contexts of use. The articulations and practices of CMAQ developers analyzed in this chapter reinforce the argument that recognition by ORD researchers of heterogeneity within their communities of practice enables the development of EMSs—sociotechnical contexts for creatively confronting environmental challenges. By highlighting the active role of CMAQ producers, I seek to contribute to a thread in anthropologies of science on how science is produced, created and constructed; but not in order to debunk scientific knowledge. My account, rather, reflects and reinforces recent scholarship that rejects framing the debates central to the so-called "science wars" as zero-sum games between science as fiction *or* fact, merely metaphorical *or* radically realist.

Following a description of the CMAQ modeling system and the history of its development, this chapter turns to a debate over its use in predicting some of the health effects associated with climate change and ozone exposure. This particular debate was chosen because modelers focus on the value of the modeling system they have assembled as a *context* that could prove useful in future research applications. The argument against the modelers focuses on the emissions *inputs* used in this particular case. CMAQ producers point out how caring for the processes within the model contributes to the capacity of CMAQ to suggest possible limits of inputs and to illuminate areas for prioritizing future research. The chapter concludes by examining the process-based epistemological orientations of CMAQ developers and reflecting on how these stances might be taken up in other fields of knowledge production. This analysis is in conversation with a growing body of ethnographies of the future that contributes to our capacity to trace how non-natural truth, mediated in myriad ways, still produces "hard-won evidence that could save our lives" (Latour, 2004, p. 227).

The ORD's Deputy Assistant Administrator for Science, Kevin Teichman, has called CMAQ "one of the shining stars, within the EPA, of research results being used to

inform policy-making" (Teichman, 2011). CMAQ crystallizes the state-of-the-science in diverse areas and has become the go-to air quality modeling system in academia and regulatory agencies around the world. But it still has its critics and developers are continuously working to improve its credibility. Debates over CMAQ's forecasting ability can illuminate challenges and opportunities surrounding unstable notions of scientific credibility in the environmental arena and beyond.

Given that modeling can simultaneously be an essential tool for understanding environmental futures and a highly contested technique, we need to develop better conceptual infrastructure around the criteria that make modeled knowledge scientifically robust. CMAQ producers argue that good modeling is accomplished by creating contexts—technological and social—that draw together the best available science and expert communities capable of producing and evaluating that science. The focus is on *processes*: the scientific processes that make up the model "itself" and the social processes that make collective development and evaluation possible. Models are increasingly used in myriad contexts, ranging from neoliberal and participatory models of economic development (Janes 2004) to modeling childhood diarrhea in rural Mexico (Ryan and Martinez 1996). While this chapter focuses on modeling in the environmental arena, collective practices around the CMAQ modeling system and articulations about how the model is deemed to be "fit for purpose" could help inform literacy around modeling more generally. Of course modeling literacy should not be confused with acceptance of modeling as an automatic route to truth; rather, modeling systems (and contemporary sciences more generally) demand reading practices that can account for both the knowledge produced and the specific and situated processes and forms of collectivity that are, perhaps increasingly in an era marked by interdisciplinarity, central to knowledge production.

How do various actors talk about and make sense of uncertainty in modeling and ways of evaluating its validity and promise? How do model developers produce contexts in which modeling systems can be created and used in the face of scrutiny by regulated industries and others? Drawing primarily on participant observation in CMAQ meetings and ethnographic interviews with CMAQ users/producers conducted between 2009 and 2012, this chapter sketches epistemological stances and scientific practices that value

modeling as simultaneously interpretive and scientific, imperfect and useful, humble and bold.[94] For the CMAQ community, scientific credibility is largely based on building a system of open communication and what I call a "care of the collective" that develops, analyzes and applies the model in a number of arenas.[95]

4.2 CMAQ as/in Context

The following description of CMAQ crisscrosses between the two takes on the role of communication and collaboration in the production of scientific knowledge condensed in Table 1. The "transmission model" sees communication as largely a task of transporting the "correct" knowledge, in a unidirectional flow, to "the public" (Boholm, 2009; López, 2010). The focus is on delivering content. In contrast, thinking of communication as "context production" reflects the ability of new media to act as forums for interactive, distributed generation and re-combination of content. In communication as context production, the forms of communication, the media, are re-worked and experimented with, in collaborative processes. Thus communication and collaboration are inseparable. The production of new contexts for interdisciplinary problem solving, and collective evaluation of our prostheses for sensing the environment, and the knowledge we generate with them, will be necessary in order to effectively address the complex socio-environmental challenges of the future. As discussed below in section 4.3, entrenched expectations of science communication as content delivery can make it difficult to articulate the value of experimenting with new configurations of technologies, expertise and data sets.

The CMAQ modeling system is an open source, modular platform intended to encourage collaborative development and analysis of a suite of programs for conducting

[94]The conferences I attended included meetings of the Community Modeling and Analysis System (CMAS), the Air Quality Modeling Evaluation International Initiative (AQMEII) and the U.S./U.K. Collaboration Group.

[95]In the case of CMAQ, collectivity and care are tightly intertwined. Annemarie Mol writes that "care is not a (small or large) product that changes hands, but a matter of various hands working together (over time) towards a result. Care is not a transaction in which something is exchanged (a product against a price); but an interaction in which the action goes back and forth (in an ongoing process)" (Mol, 2008, p. 18). Thus, while care "of the" collective implies a one directional process, Mol shows that practices of care themselves require (and perhaps produce) forms of collectivity.

air quality model simulations. Its open-source character facilitates free distribution and application by the air quality modeling community. CMAQ is used by environmental managers to evaluate the impact of air quality management practices for multiple pollutants at multiple scales. Scientists use CMAQ to probe, understand and simulate chemical and physical interactions in the atmosphere, especially in the context of alternative regulatory scenarios and environmental futures. CMAQ is also used to produce air quality predictions that are delivered to the public through a variety of media such as television weather forecasts, airnow.gov (see Figure 7) and a daily e-mail service called EnviroFlash, among others.

CMAQ provides a context for structuring a variety of data and relays among various modeling system components and data sets. In the 1970s the EPA produced models of the atmosphere in a pollutant-by-pollutant fashion. There was an acid deposition model, one for predicting ozone and one for particulate pollution. As an EPA press release for CMAQ put it, "the 'one-atmosphere' reality, with all of its complexities, was yet-to-be incorporated into EPA's suite of air quality models" (EPA 2009). Between 1992 and 1994, EPA meteorologists and modelers laid the foundation for a "super model" framework that would become the CMAQ modeling system, pulling together data from disparate models in order to facilitate analyses of how various management and regulatory scenarios could impact air quality.

CMAQ was initially released for public use in 1998 as a result of a concentrated development effort by researchers at the EPA, the National Oceanic and Atmospheric Administration (NOAA) and the academic and private sectors (Ching and Byun 1998), but it would take a number of years before it would gain credibility and become the most popular model for many applications. S.T. Rao, a leader in CMAQ development for decades and Director of AMAD, played a key role in ensuring its uptake in policy arenas and helping it gain widespread credibility. Before working for the EPA, Rao was a faculty member in Atmospheric Science at the State University of New York at Albany and worked for the New York Department of Environmental Conservation which, Rao says, "is like state-level EPA" (Rao, 2011). These experiences in academia and at the state level, along with years of interaction with the regulatory side of the EPA, made Rao especially well-positioned to expand the CMAQ user community since his arrival at the

EPA in 2001. Robert Dyer, a neurotoxicologist who spent most of his career in the ORD's National Health and Environmental Effects Research Laboratory (NHEERL) and recently retired from his post as interim director of NERL, gives Rao a great deal of credit for making CMAQ useful to the air office. "CMAQ is a great program," Dyer told me, "it has produced something that's been of real value to the air office. It wasn't always so before [Rao] took over. . . he made it useful by his interactions with the Office of Air Quality Planning and Standards (OAQPS)" (Dyer, 2012).

The development of CMAQ is a labor of context production; developers speak of their work as crafting a "numerical laboratory." CMAQ can be seen as an experimental system, establishing "a space of representation. . . for engendering things that otherwise cannot be grasped as objects of epistemic action," namely unknowable environmental futures (Rheinberger, 1997, 108). In a review of the governing equations, computational algorithms and other components of CMAQ, referred to by CMAQ developers as "the science document," core CMAQ developers Daewon Byun and Ken Schere note that the creation of a collaborative context, a space of synthesis and model development, is the most important driver of CMAQ development. "The main goal of the Models-3[96] CMAQ system," they write (Byun & Schere, 2006, p. 4):

> is continuous development of its science through community modeling participation. Advancements in air quality model technology could not be easily shared between models due to the incompatibilities of the models. Models-3 CMAQ intends to facilitate collaborative development and linking of models for meteorology, emissions, air quality, and health effects through an open-source advanced modeling system.

The main goal of the modeling system, according to Byun and Schere, is not in its applications but rather in the prioritizing of developments in the science. Improving the science in the models is accomplished by "facilitating collaborative development" and linking models. CMAQ does not simply produce knowledge; it provides a context for drawing together a) experts with various training and b) numerous other models. It acts as a trading zone where actors with fluency in different languages and imaginaries can

[96]Models-3 refers to the CMAQ Chemical Transport Model (often simply referred to as CMAQ) along with models for emissions and meteorology. "CMAQ," "the CMAQ modeling system," and "Models-3" often stand in for each other in my interlocutors' articulations.

collaborate (Peter Galison, 1997).

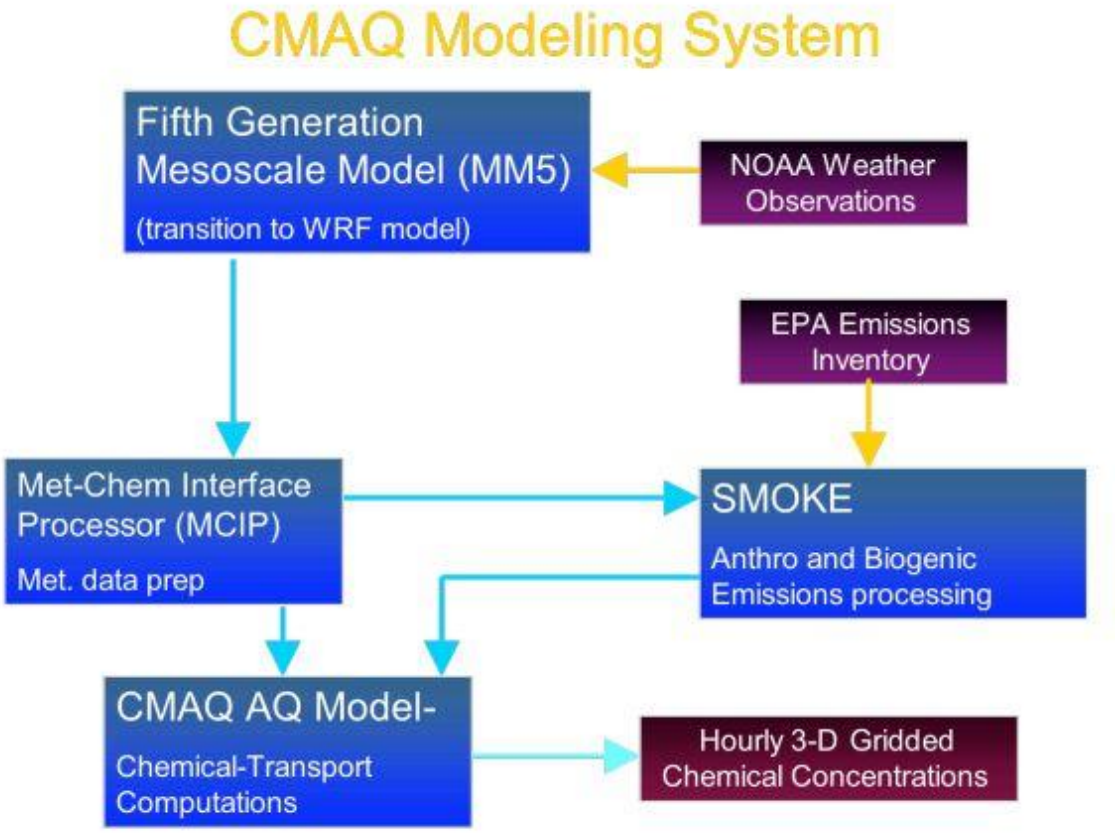

Figure 5: A Configuration of Models Incorporating CMAQ. Models for meteorology and emissions provide the inputs for the CMAQ air quality model. Image is from a presentation to a CMAQ peer review panel by Jonathan Pleim (Pleim, 2006).

What is it actually like to work within the CMAQ modeling system? Compared to the Atlas, which is designed to be usable by the general population, CMAQ has a much less user-friendly interface and requires training in computer programming. My colleague Erik Bigras told me that, upon arriving at the training site (Bigras, 2012):

> it quickly became apparent that knowledge of chemistry and meteorology would *not* be required. Instead, the basic knowledge required for the course was largely programming skills and a basic knowledge of the Linux operating system because CMAQ does not possess a graphical interface and operating it requires writing code and navigating Linux folder structures. As a student computer engineer, I had learned C++ and

DOS, which were close enough structurally to the JAVA and Linux of CMAQ that I did not have many difficulties operating the system.[97]

In order to run CMAQ, emissions and meteorological data, already processed through models, are drawn together in a sub-routine called the Meteorology-Chemistry Interface Processor (MCIP). From there, as Erik Bigras explains (Bigras, 2012):

> Several other sub-routines must be compiled and executed: ICON sets the initial conditions in which the simulation will take place, BCON sets the conditions at the geographical boundary of the simulation, and JPROC processes the photolysis rates of the various chemicals. It is interesting to note that all of these processes must be individually programmed, compiled, and executed by the person wishing to use CMAQ… Only once these operations are performed can the modeler finally meet what usually imagined as being CMAQ… The CMAQ Chemical Transport Model uses the following equation:

$$\frac{\partial C_i}{\partial t} + \frac{\partial (u C_i)}{\partial x} + \frac{\partial (v C_i)}{\partial y} + \frac{\partial (w C_i)}{\partial z} =$$

$$\frac{\partial}{\partial x}\left(K_H \frac{\partial C_i}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_H \frac{\partial C_i}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_V \frac{\partial C_i}{\partial z}\right) + R_i + S + L_i$$

Figure 6: The CMAQ Atmospheric Diffusion Equation (ADE). The ADE is a complex mass balance equation where each side of the equation represents a given state of the atmosphere. As the equation is written above, many of the symbols represent sub-equations. Improvements to the model, drawing on advancements in physics, air chemistry and meteorology, can be folded into this equation (image from Bigras 2012).

After accepting inputs, linking them together and processing them using various subroutines, the output of the modeling system often takes the form of visualizations. The image gallery on the CMAS website juxtaposes four maps of the continental U.S.

[97] I conducted fieldwork at the 2011 CMAS conference with Erik Bigras, a fellow RPI STS graduate student writing about CMAQ for his dissertation. After the three day conference concluded, I attended the U.S./U.K. collaboration meeting and AQMEII meeting, by invitation from S.T. Rao, while Bigras, drawing on his background in computer science, completed the training for using CMAQ. I have benefited greatly from his insights about the nuts and bolts of the CMAQ system. We helped each other work through the extremely detailed technical language of the conference. It was surprising to both of us how quickly we learned at least enough of the CMAQ language to understand the general thrust of the presentations, which focused on new features in CMAQ 5.0 or ways of evaluating the model.

that use CMAQ to display one-hour surface ozone forecasts (from the National Oceanic and Atmospheric Administration, or NOAA), EPA AirNow Current PM2.5 (see Figure 7), a Respiratory Index from the Weather Channel and a National Weather Outlook from the National Weather Service.

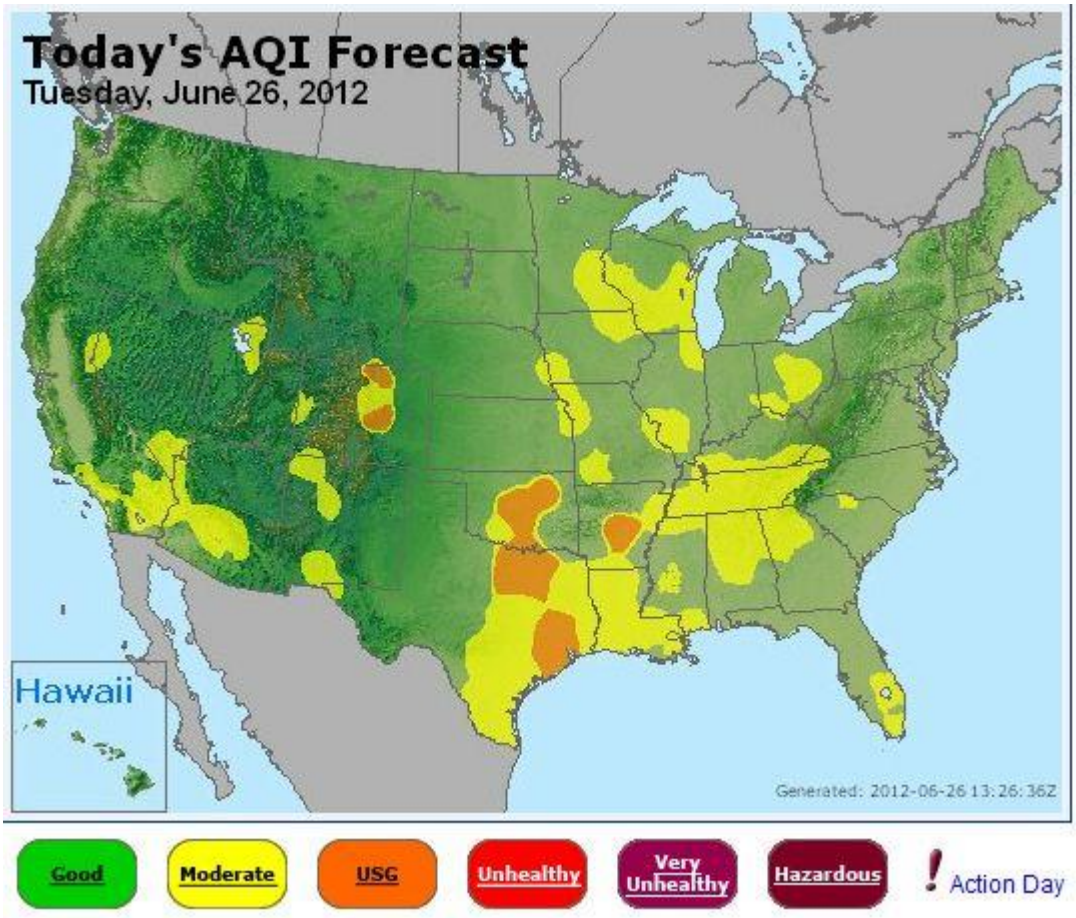

Figure 7: Air Now. Airnow.gov provides daily air quality forecasts, drawing on CMAQ.

Given the EPA's mandate to protect human and environmental health, attention to how knowledge circulates and is evaluated in policy-making and other arenas is critical. Communications projects under development at the EPA, often guided by top-down calls for transparency and open government, are designed primarily for circulating environmental information in the public sphere (Greenwire, 2009; OMB Watch, 2009). Researchers at the EPA also develop media that are more geared toward the *production* of new environmental knowledge. With CMAQ, circulation and production are

inseparable. Careful attention to internal communication among user/producers (and among various modeling system components)[98] is a prerequisite for producing models and knowledge capable of withstanding close scrutiny, especially in contentious policy-making arenas marked by highly uneven access to economic and informational resources (Dosemagen, Warren, & Wylie, 2011). The mass balance equation above is far from comprehensible for most citizens, and many policy makers, interested in air quality. Translation and interpretation are essential aspects of making CMAQ, and the knowledge it helps produce, useful. CMAQ, for example, may reveal or predict a plume of ozone, but may not, on its own, provide an explanation of why it is there, if it is worth worrying about, for what populations or to what degree.

Collectivity is central to both circulation and production and CMAQ requires and produces a multitude of social linkages.[99] CMAQ is largely produced by scientists in the EPA's Atmospheric Modeling and Analysis Division (AMAD), but thousands of non-EPA user/producers also contribute to the modeling system's development and analysis. Developing and advancing CMAQ requires a great deal of collaboration and peer-review and this labor is recognized by the CMAQ development and analysis community as key to the modeling system's credibility. CMAQ requires (and enables) coordination among various researchers, with different kinds of data, at different scales.

The way CMAQ requires and produces collectivity troubles distinctions between CMAQ *in* context and CMAQ *as* context. The context of CMAQ has a double and looping character: CMAQ is produced in a social context that actively shapes, or mediates, the form of the model, which in turn provides a new context for the circulation and creation of knowledge, social connections, epistemologies and material effects.[100] At

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[98]Rohit Mathur, Associate Director for Science for AMAD, explains that one of the important developments in the new release of CMAQ 5.0 is the "coupling of chemical transport models with dynamical calculations in an online manner," enabling "high frequency communications between the dynamical and components and the chemical transport components" (R. Mathur, 2011). This update helps users approach finer spatial scales.

[99]Can a model *produce* anything? Does it have agency? Does it think? Bateson writes, "in no system which shows mental characteristics can any part have unilateral control over the whole. In other words, *the mental characteristics of the system are immanent, not in some part, but in the whole*" (Bateson, 2000, p. 316).

[100]Bigras described his CMAQ training as marked by a "feeling of being disciplined" (Foucault, 1995) in which he "had to construct each sub-routine from scratch, run it, and then incorporate it into the

its best, articulations enabled in the context of CMAQ could shift the broader discursive context in which decisions are made about how to value, fund and act on the development of modeling systems and the knowledge they produce. CMAQ producers at the ORD negotiate the demands of producing a context, or numerical laboratory, that is robust, objective and assembles the state-of-the-science in a number of fields while working within a research context that is directly connected to the regulatory apparatus.

The EPA faces significant challenges due to its double-positioning as a research and a regulatory institution (see section 2.10) and CMAQ producers sometimes express anxiety over how the EPA's image as a regulatory agency might taint public perceptions of objectivity and credibility with respect to the ORD. ORD has strict rules on communication and a vetting process for communications that can be both constraining and enabling. A research scientist at the ORD told me that "making sure that all the i's are dotted and the t's are crossed" can be a long process, "but the flip side of that is that that gives it a lot of credibility. . . because it's very carefully reviewed." Reviewing and continuously improving CMAQ, in order to meet the EPA's demands for platforms that can stand up to rigorous critique, requires the creation of a diverse collectivity. CMAQ producers do not exist in a static institutional context that shapes their work; instead, they actively interpret and re-shape the context they work within, creating and institutionalizing communicative spaces that negotiate the tensions produced by their positioning in the broader context of the EPA and a political climate marked by contention over environmental regulations and potential economic effects.

The C in CMAQ does not refer to a community-scale approach or a generic public; rather, it refers specifically to the community that uses and contributes to CMAQ. An expert community both *produces* CMAQ and, in a sense, is produced *by* CMAQ, in the form of collaborations among EPA scientists, academic researchers and

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chemical transport model in order to obtain mappable results. In effect, I was a computer program involved in bringing CMAQ into existence," even as the CMAQ system brought his subjectivity as a program into existence, shifting his "worries from interpretive to technical ones so that [he] would focus all [his] attention on the model itself as opposed to the meaning of the result. CMAQ was making me into a modeler" (Bigras, 2012).

others working in air quality modeling. An EPA "science feature" article states that (Environmental Protection Agency (EPA), 2009):

> After the initial release of CMAQ it became clear that long-term support for CMAQ's community of users, developers, and partners worldwide would be crucial to sustaining and improving it. . .. To support the CMAQ community, EPA entered into a cooperative research agreement with the Institute for the Environment at the University of North Carolina at Chapel Hill, to start the Community Modeling and Analysis (CMAS) Center.

The institutionalization of collectivity in CMAS, and the support of the user/developer community it fosters, has enabled the modeling system's continued re-production, uptake around the world and continual development. CMAS runs the training program for CMAQ and helps to extend the CMAQ network well outside both the EPA and UNC Chapel Hill to include a global community of user-producers with the expertise required to expand and make improvements to the model.[101] Beyond distributing CMAQ and information on its use, CMAS provides a context for collecting and layering information about the user community and development processes around CMAQ. In response to the peer review of CMAQ 4.6, CMAQ developers wrote (Aiyyer et al., 2007, p. 10):

> CMAS conducts outreach using multiple outlets that encourage users and stakeholders to provide feedback on their modeling needs and concerns. The CMAS website, annual CMAS conferences, *CMAS Quarterly* newsletters, trainings and workshops, and other electronic outlets provide opportunities for the CMAS user community to interact with CMAS and comment on their needs. Through a survey form on the CMAS website, information is collected about the modeling community. The survey asks website users to provide details about how they are using the models, the types of educational opportunities that interest them, and any comments that they have regarding the models and/or services supported by CMAS.

[101] At the 2011 CMAS users' forum, Talal Adman argued that while the younger generation is equipped with programming skills, the models are getting increasingly more complex, "so a training course targeting model development in contrast with the current course which focuses on model use would stimulate community participation in model development." The CMAS Wiki states that "the Linux operating system exemplifies mass collaboration in computer programming. For environmental modeling, peer production is a way to decentralize model development, allowing researchers to freely develop and share new software modules without the constraints of a development agenda" (CMAS, 2009b). The Linux system's open character is in stark contrast with the proprietary ArcGIS software on which the Atlas is built.

The website also provides a suggestion box that acts as a catch-all for all comments submitted.

CMAS personnel include a director and outreach coordinator, research coordinator, applications support and training coordinator, software development coordinator and events coordinator. CMAS maintains a highly active listserv and facilitates an annual meeting of CMAQ users that includes participation from people working in government, industry, academia, research, consulting and stakeholder groups.[102] At the Tenth Annual CMAS Conference, Adel Hanna, the soft-spoken director of CMAS reported 3,500 CMAQ users worldwide.

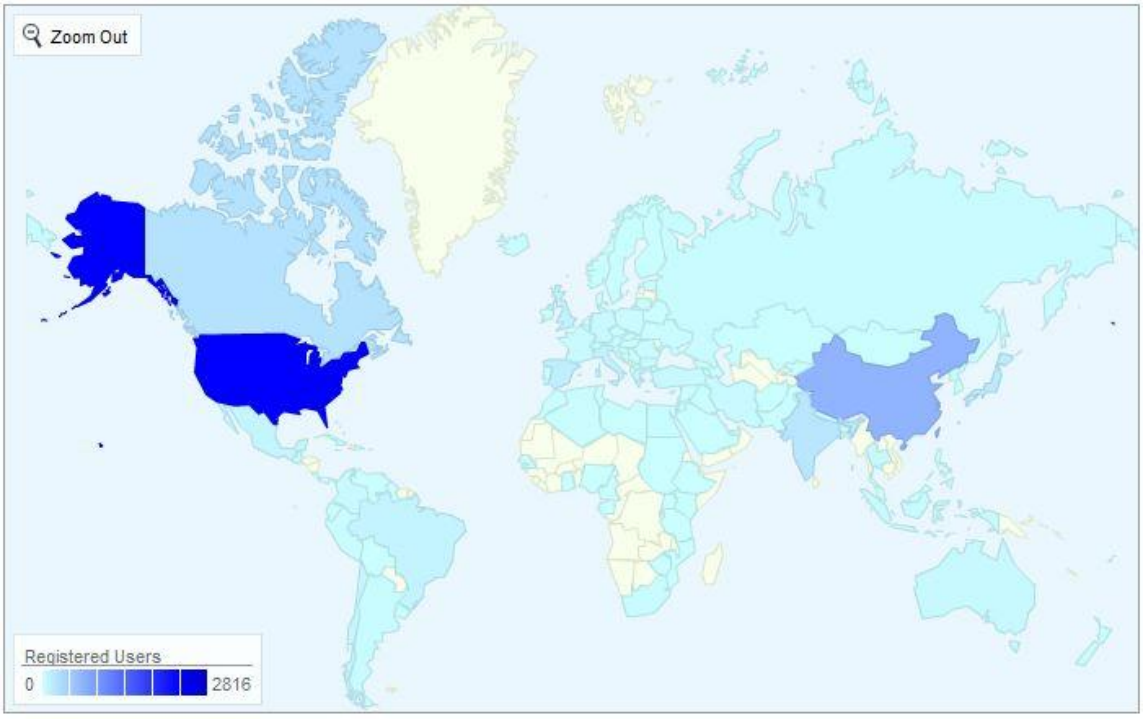

Figure 8: CMAS User Map (CMAS, 2012).

The complexity of the modeling system is one driver of collective process and institutionalization within the CMAQ community. At the 2011 CMAS conference, there

[102]While CMAS has played an essential role in drawing the CMAQ community together, the CMAS Wiki states that "mechanisms to promote peer production are still being developed by CMAS and are an area where more community guidance is needed" (CMAS, 2009b). Perhaps such mechanisms could inform, and draw inspiration from, research platforms for peer production in the social sciences and humanities such as *The Asthma Files*.

was a push to expand the training program to go beyond teaching people how to use the model to teaching people some of the skills required to contribute to the model.[103] Because it is open-source, developers with a variety of backgrounds and strengths can point out "bugs" in CMAQ, or develop new features, which can be incorporated into the next official release. Although there is currently no class in contributing to the model, CMAS does publish detailed Software Development Guidance online, recommending steps to follow to meet the "minimum level of coding and testing practices to be adopted by software developers wishing to contribute code for release to the community" (CMAS, 2009a). CMAS also convenes an annual ad hoc meeting for developers during one of the evenings of the CMAS conference. "Open to anyone," the CMAS Wiki states that "the purpose of the meeting is to bring together community members who are interested or actively engaged in model development and want to provide some guidance about how to optimize how the CMAS Center can facilitate community modeling" (CMAS, 2009b). The CMAS Wiki features a Model Development Center with "interactive pages and discussion forums related to community-based air quality and emissions model development" and community forums to help connect members of the modeling community.

A beta version of CMAQ 5.0 was circulated months before the official release was finalized, materializing an impressive collaborative effort. Rohit Mathur says that this version was released in part so that the modeling community could take a look at the code and provide feedback (R. Mathur, 2011). More importantly, the community was able to add its own contributions. S.T. Rao explained, "we wanted to take advantage of the scientific expertise that is available outside of the EPA. There are many scientists in academia and industry who would like to contribute their science to EPA's air quality modeling system" (Rao, 2011). The processes of contribution and vetting are carefully structured; suggestions and contributions pass through a review in which the core

[103]CMAS may usefully be understood as a recursive public which sustains and advances the technological means of its cohesion as a community (Kelty, 2008). As an open-source project, CMAQ relies on its global community of user/producers, as well as external reviewers, to lend the model its credibility.

CMAQ developers at NERL, acting as curators, test them out before they are incorporated into the next official release.[104]

Partly because of the computationally intensive nature of developing, analyzing and using CMAQ, the global modeling community takes seriously the tasks of coordinating development efforts and choosing valuable test-cases for evaluating the modeling system. S.T. Rao told me that decisions about where to focus development are primarily guided by the question: "Does it make a difference from a policy perspective? That is, if we implement a change in the model, would the policy maker make a different decision?" (Rao, 2011).[105] Determinations about what differences to prioritize are made in participatory face-to-face meetings among CMAQ developers and policy makers. Frequent workshops on CMAQ draw the broader scientific community together to discuss research directions and develop partnerships. A recent retreat assembled program officers from EPA's regulatory groups and top scientists in the modeling community to brainstorm and develop a three to five-year research strategy for developing and analyzing the modeling system. This strategy was made available on the CMAS website, publicized and peer-reviewed by the wider scientific community.

The modeling system's synthesizing approach *as* a context (drawing together communities and a number of models, much like the Atlas draws together various experts and a multitude of data layers) is coupled with close attention to a systems-based view of the modeling system *in* context (assembling collectivity that enables interdisciplinary knowledge production and the collaborations among producers and users that produce a *usable* model). The social synthesis catalyzed by the model

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[104]This example of circulating the model in advance of its release, enabling it to develop contours based on contributions from a wide array of contributors, is a clear example of the communicationXcreation enabled by EMSs.

[105]Some advances, such as ensemble forecasting and the two-way interaction between WRF and CMAQ, are given priority not because policy makers might make different regulatory decisions, but because air quality forecasting could be improved, helping people make decisions that could reduce exposure to ozone and particulate matter (Aiyyer et al., 2007, p. 16). Goldstein describes how ORD "needs the ability to act on issues that, though they cut across all of the program offices, are not looked upon by any one office as a particularly high priority" (Goldstein, 2011, p. 302). Goldstein argues that this situation calls on senior EPA officials to look across short and long-term agency needs and participate in setting the research agenda. Ideally, he writes, "ORD staff involved in translation of existing research findings to EPA leadership and to the program offices will also be heavily involved in setting the research agenda through an iterative process in which crucial uncertainties will be identified" (Ibid., p. 303).

(bringing together air quality researchers, meteorologists, chemists, computer scientists and policy makers around the world, circulating a "modeler" position from which to think) is mirrored by its synthesis of the state-of-the-science in many areas of expertise, enabling a systems-based approach to air quality issues.[106] The majority of improvements in each model release are based on advances in meteorology and air chemistry, but there is also a place for computer scientists and programmers in caring for the model. The peer review panel that assessed CMAQ 4.6 wrote that a high priority should be "increasing the computational efficiency of CMAQ, cleaning up some parts of the code, making it more robust (e.g. rechecking mass conversion issues and greater efforts in insuring the portability to new computational environments, etc.)" (Aiyyer et al., 2007, p. 16).

The need for collaboration and collectivity goes beyond the development community; CMAQ developers also work to create relationships with the modeling system's users. In interviews and at conferences, CMAQ developers talked about how they feel a responsibility to help regulators interpret the results of the modeling system and know its limits.[107] CMAQ comes with a great deal of documentation on the work that led to its development as well as its external review. Despite these efforts, there is recognition among CMAQ developers that there is more work needed in terms of communicating what the modeling system is designed for, what its shortcomings are and how best to use it. CMAQ developers recognize that as the user base has grown and diversified, the model has evolved and become stronger. This evolution has been welcomed, but also creates new challenges. Developers feel an increased interpretive responsibility and need to communicate that there are better and worse ways of using the model.[108] S.T. Rao argues that "we need to inform users on what the model is designed

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[106]Goldstein explores the "increasing importance of systems approaches, including the role of public health and sustainability, to provide EPA with the credible base for achieving its goals of protecting health and the environment" (Goldstein, 2011, p. 295).

[107]One way to "communicate CMAQ strengths and shortcomings to the community for each application," suggested by the Third Review, is for AMD to "convene a workshop of experts to develop improved evaluation methods" and conduct "formal model comparisons" (Aiyyer et al., 2007, p. 19). AQMEII has drawn together a number of these workshops since 2009.

[108]See Daston and Galison on atlas producers' shifting interpretive responsibility to users in conjunction with epistemological shifts towards "mechanical objectivity" (Daston & Galison, 1992). What falls within the domain of interpretation for CMAQ developers is, from a social science perspective,

for and how best to use it. If we don't, people tend to misapply it or misinterpret the results or their expectations on the model keep rising, and we will not be able to meet those expectations" (Rao, 2011). The model evaluation framework document is one step in this direction. But rather than simply coming up with one fixed guidance document, CMAQ developers at ORD meet every couple weeks with regulators that use CMAQ to talk about the current performance evaluation, developmental plans, regulatory applications, etc. "That regular dialog," Ken Schere asserted, at a 2011 U.S./U.K. Collaboration Meeting, "helps them to understand our current thinking on the best way to apply CMAQ. That dialog is key in terms of proper regulatory applications." During a discussion at the same meeting, Rohit Mathur expressed ambivalence about the labor required to make CMAQ usable by a wide range of users. "It's a double-edged sword," he said:

> We put a lot of effort into making the model accessible, but that comes at a price. Anybody can come to our website and download it. We provide data sets to run the model, we provide tools to analyze the data. . . but if people don't have enough guidance on how to interpret the numbers [and the uncertainty involved] that can be a problem.

Communication about how to "supplement" the model with interpretation is central to the labor of making CMAQ credible, a requisite condition for its usability.

Careful documentation of CMAQ has, from the beginning, been essential for enabling its community-based, open source character. In a tribute to Daewon Byun, Jason Lee, a mild-mannered visionary behind CMAQ, spoke about how Dr. Byun, a much loved developer who named the CMAQ modeling system, was keenly aware of the stakes involved in providing thorough documentation. "If we enter into an open system, a science-based, for policy system," Byun realized, "then we really need to

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relatively narrow. They see their work as fairly technical and generally avoid participating in public discussions about social and economic decisions. As Landy et al.'s review of the process of revising the ozone standard in the 1970s makes clear, failing to ask explicit questions about social, economic and ethical factors (such as "just who it is that the standard is trying to protect and against what types of harm") constrained opportunities for deliberation and public debate (Landy et al., 1994, p. 79). "By failing to explain what was at stake," they write, "EPA short-changed its educative functions… most importantly, the important strategic considerations raised by all of these particulars went resolutely unacknowledged. The relevant conceptual, empirical, and ethical difficulties simply were not discussed publicly in ways that improved the citizenry's grasp of these matters" (Landy et al., 1994, p. 79).

document it. Without the documentation it's just another modeling system. It has to be a live system and a growing system." Dr. Byun led the effort to produce the first documents on CMAQ and they have continued to evolve, including careful documentation of use-cases for the model. A technical support document is issued with each regulatory analysis and describes the configuration of the model for that particular case along with the inputs used. This essentially freezes the configuration for that particular case. ORD scientists recommend a particular configuration of the model to the regulatory body for each use and then conduct a thorough evaluation of this configuration. The work of developing the technical support document is a lengthy, complex process, but is seen as crucial by the CMAQ development community for developing the credibility that the model needs to stand up to its detractors. In the following section I briefly present a debate over CMAQ's credibility in predicting some of the health effects of climate change under different scenarios and discuss the stakes involved in establishing the model's credibility.

4.3 Linking Models, Climate Change, Ozone Exposure

Goldstein points out that it is not just "all-encompassing environmental problems such as global climate change" that require collaboration across different forms of scientific and technical expertise (2011, 305). Goldstein argues that we need "cooperative interaction among scientific and technical experts in order to understand and provide the basis for understanding any environmental issue," including the control of a specific air pollutant like ozone (305). My analysis of the following debate focuses on the value of context-production in the environmental sciences. While modeling technologies have improved significantly in recent years, there is still a great deal of uncertainty, and debate, over how they should be used in guiding policy. Yet problems like climate change, by their very nature, demand that future-oriented, speculative modeling techniques guide action and policy in the present. CMAQ modelers are constantly negotiating uncertainty and credibility with other scientists, policy makers and the public in order to improve the model and its ability to grapple with actionable problems. As Paul Edwards makes clear, claims like, "global warming is a myth. It's all model predictions, nothing but simulations. Before you believe it, wait for real data,"

miss the point that *without models, there are no data*" (2010, xiii).[109] And without communication and collaboration among diverse experts, this dissertation shows, there are no models.

In 2004, Kim Knowlton and an interdisciplinary team of air quality modelers and public health researchers published a paper in *Environmental Health Perspectives* titled "Assessing Ozone-Related Health Impacts Under a Changing Climate" (Knowlton et al., 2004). This paper showed how CMAQ, in conjunction with a suite of other models, could be used to link future climate change scenarios to potential changes in ozone related mortality in order to inform adaptive planning. Noting a lack of reliable projected emissions inventories for the U.S., the paper's primary contribution was methodological, showing how modeling systems, linked in a novel configuration, might provide a context in which to examine potential health outcomes given different future environmental scenarios.

In a response to Knowlton et al.'s paper, Joel Schwartz, from the American Enterprise Institute for Public Policy (or AEI), and Patrick Michaels and Robert Davis, professors of environmental sciences, wrote a response titled "Ozone: Unrealistic Scenarios" (Schwartz, Michaels and Davis 2005). AEI has received millions of dollars from ExxonMobil and was criticized in 2007 for offering $10,000 to a number of scientists and economists to write articles emphasizing the shortcomings of a report from the IPCC. The AEI asked for essays that "thoughtfully explore the limitations of climate model outputs" (Sample, 2007). According to sourcewatch.org, Michaels is "a largely oil-funded global warming skeptic who argues that global warming models are fatally flawed and, in any event, we should take no action because new technologies will soon replace those that emit greenhouse gases" (SourceWatch, 2012).

In their critique of Knowlton et al.'s paper, Schwartz et al., who "declare that they have no competing financial interests," attempted to debunk the outputs of the

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[109]Edwards writes that, today (2010, xiii):

> no collection of signals or observations—even from satellites, which can "see" the whole planet—becomes global in time and space without first passing through a series of data models… nor is there any such thing as a pure climate simulation… the models we use to project the future of climate are *not* pure theories, ungrounded in observation. Instead, they are filled with data—data that bind the models to measurable realities.

model by focusing on the model inputs as "unrealistic scenarios" (Schwartz, Michaels and Davis 2005: A86). They claim that Knowlton et al. did not account for recent and predicted reductions in ozone and take issue with the their claim that, given the inputs they used (Knowlton et al. 2004: 1557):

> considering climate change alone, there was a median 4.5% increase in ozone-related acute mortality across the 31 counties. . . including population growth and anthropogenic ozone precursor emissions increases—much greater changes in summer mortality are projected: Regional summer ozone related mortality would increase by a median 59.9% in the 2050s compared with the 1990s.

Despite the many caveats included in Knowlton et al.'s paper on uncertainty and the limits of the inputs, their quantitative claims, taken out of context, could be misleading and easily critiqued. "The nondiscriminating reader" (Schwartz, Michaels and Davis 2005: A86):

> might be impressed by the downscaling of a general circulation model using a regional mesoscale model to predict localized differences in future air-pollution related mortality, but the complexity of the models is irrelevant in the face of Knowlton et al.'s failure to temper their theoretical exercise with real-world data. Had Knowlton et al. accounted for observed historical health and pollution trends and future emission-reduction requirements, they would have arrived at a markedly different story.[110]

Given a human fascination with numbers, how might CMAQ users make the limits of their analysis more visible?[111] How can scientists focused on context production draw attention to methodological or tool-building contributions that may be missed due to the power of entrenched models of communication, namely the transmission model as a legacy system? Schwartz et al.'s critique shows how imperfections with numerical inputs (which will always exist) can be zoomed in on as a

[110]Drawing attention to improvements in air quality, driven largely by regulation such as the Clean Air Act, seems to be a double-edged sword. On the one hand, it could be argued that current regulations are sufficient, and, therefore, continued reductions in Ozone are unnecessary. On the other, it shows that regulation can work, improving human health and well-being. S.T. Rao informed me that the main reason for doing long-term simulations is that "we know, because of the Clean Air Act, although not many people give credit to it. . . air quality is much better today. So that's what we want to test, accountability" (Rao, 2011).

[111]See Martin (1995) on T cell counts standing in for complex health conditions.

tactic to diminish the credibility of the whole system. In their response to Schwartz et al., Kinney et al. reiterate that the main goal of their study was not to produce realistic estimates of mortality, but to show that such a study design was possible and has the potential to predict health outcomes of climate change scenarios, given the future availability of more robust scenarios for emissions inventories (Kinney, Knowlton and Hogrefe 2005). Knowlton and colleagues conclude their response to Schwartz et al. by stating "we hope that even discriminating readers will be impressed by the utility of this new modeling system… and will be motivated to use this system to evaluate alternative inputs and their potential impacts on future climate and air quality" (Kinney, Knowlton and Hogrefe 2005: A87). Thus, they hope the form of their study will "travel" and be useful for a variety of inputs.

Knowlton's original paper states that the IPCC A2 emission growth scenario they used, given a lack of US projections, (Knowlton et al. 2004: 1559):

> might be overly pessimistic given enacted or contemplated US emission control programs, whereas by using these emission growth factors for the CMAQ modeling, we maintain internal consistency with the global and regional climate modeling in which the A2 greenhouse gas emissions were used. Therefore, rather than attempting to predict "realistic" air quality in the 2050s, our simulations investigate the overall effect of the A2 scenario, a possible (although pessimistic) trajectory into the future.

Maintaining "internal consistency," like CMAQ developers' prioritization of peer review of the processes and science in the model, actually produced a somewhat unintended contribution: the original article spawned a new context—the publicly accessible debate—in which it became clear, in this case, that emissions inventories were the limiting factor in producing realistic models of the future. The debate made these limits publicly visible and could help set priorities in future research and accounting. Improvements to model inputs and processes will provide a new space for future model applications with a more delimited range of possible outcomes.

By creating a new assemblage of models focused on different scales, Knowlton et al.'s main goal was to improve the media we use to make sense of and communicate about environmental futures. Their focus was on the form of the argument, the integration of a modeling framework, rather than the quantitative outcome, which in this case served largely as a place-holder until better emissions inventories became available.

Schwartz's critique highlighted the outputs' status as an *insufficient* placeholder, but left the credibility of the modeling system's internal processes and configurations, intact. Critique coming from an organization (the AEI) aiming to "explore the limitations of model outputs" was limited to criticizing a single input and didn't touch on the uncertainties of the modeling system itself or the science it contains. This strategy of critique may point to the powerful reputation that CMAQ has developed over the past decade and a general trend towards accepting modeling systems as valid modes of making substantive claims about environmental futures ((Norton & Suppe, 2001). The form of response, highlighting processes of assembling models and experts in new configurations, supports the contention that the CMAQ community places high value on assembling new sociotechnical contexts for knowledge production, what I call EMSs.

Both Schwartz and Knowlton wrote of the "impressiveness" of the newly assembled modeling system. Inputs aside, how are we to make sense of the truth-making ability of the modeling systems themselves? Should we be impressed? These are highly practical questions in light of, among other things, the 2011 ruling by the Obama administration against EPA recommendations to tighten air-quality standards for ozone. The EPA had proposed that ozone standards be tightened to a range of 60 to 70 parts per billion (ppb), down from 75 ppb adopted under President George W. Bush and the 84 ppb that most states currently adhere to. The EPA had used an assemblage of models to estimate that the tighter standard would save 12,000 lives each year. Obama stated that while remaining committed to public health and clean air, "I have continued to underscore the importance of reducing regulatory burdens and regulatory uncertainty, particularly as our economy continues to recover" (Solomon & Tracy, 2011).[112] A White

[112]Yet, one might ask, what is the economy recovering from? Perhaps a lack of regulatory burdens are part of that story? The very language of the economy "recovering" is indicative of widespread trends to anthropomorphize and reify the economy. The economy is framed as a "thing" or even a "being" that needs to be protected from regulation as it recovers, rather than as contingent social relations that are up for debate and change. During the 1970s revisions to the ozone standard, Senator Edmund S. Muskie spoke out on the CBS news program *Face the Nation* about his concern that "EPA had based its decision on economic factors, thereby violating the law that he had largely written" (Landy et al., 1994, p. 76). The Clean Air Act, according to Muskie (Landy et al., 1994, p. 76):

> clearly prohibits the use of economic considerations in the setting of health standards… if the standard is… unnecessarily harsh, from a health point of view and only from a health point of view… the Congress should have a chance to modify it… it is the heart

House official, on a call with environmental groups, said that the EPA is "under unprecedented assault right now" and that Republicans have made the EPA "the focus of their efforts" (ibid). A recent survey found that "politically conservative Americans have lost trust in science over the last 40 years while moderates and liberals have remained constant in the stock they put in the scientific community" (Pappas 2012).

Developing assemblages of models capable of predicting the health effects of climate change, and improving the available inputs for these models, may be key factors in mobilizing public concern about climate change, which has slipped recently in the U.S. Canadian activist and author Naomi Klein (Klein, 2012) reports that "in 2007, 71% of Americans believed in climate change and in 2009 only 51% believed—and now we're at 41%." Are modeling systems a good area to focus effort in informing publics about climate change? Goldstein recounts (2011, 305):

> I was [Assistant Administrator] AA for ORD in 1984 when the first funding was received by EPA specifically on the issue of global climate change. ORD's proposal was for the Corvallis laboratory to use its greenhouses to study the impact of increased carbon dioxide levels on ecosystems. Instead, the funding was given to the Office of Air and Radiation which primarily used it to develop computer models related to carbon dioxide accumulation and temperature. In my view this typifies what mistakenly has been a relative overemphasis on understanding the global geochemical processes at the cost of studying the impact of global climate change. Both are needed—but it is unreasonable to expect the American public to respond unless it is aware of the impact.

While Goldstein is correct about the need to demonstrate the impacts of climate change, investing in the capacity of models to better understand geochemical processes may actually, in the longer term, enable scientific articulations on the human health impacts of climate change, which recent research suggests could be more mobilizing for the American public than learning about effects on ecosystems (Maibach, Nisbet, Baldwin, Akerlof, & Diao, 2010). In the case of Knowlton et al., understanding processes and climate change impact go hand in hand and require the development of new configurations of experts and technologies.

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of the Clean Air Act.

4.4 Peer Review and Processes: Modeling Future Epistemologies

With ever-changing demands from stakeholders, evolution and development are crucial to ensuring CMAQ's continued use. S.T. Rao asks "when are you done building these models? Why are you going from one version to another version to another version? What difference does it make? How do you quantify that? It boils down to expert judgment. And that's where we bring in the peer review" (Rao, 2011). The value put on peer review and multiple perspectives was echoed in the everyday language of the tenth annual CMAS conference (2011), where phrases like "correct me if I'm wrong" were repeated countless times in both informal chats and the official colloquia and presentations.

Rao told me that the peer review panel is usually made up of about seven experts from different fields, representing government, academia and industry. Because of the diversity of expertise that goes into the model and CMAQ condenses the state-of-the-science from different disciplines into one conceptual computational model, "no one person, even the developers of the CMAQ model, has expertise in all the relevant processes included in the model" (Rao, 2011).[113] Reviews typically start with inviting key scientists to participate who then review relevant reports and articles. The panel then convenes for about three days in Research Triangle Park, North Carolina, with a number of the CMAQ developers and are provided with previous reviews and comments so that they can systematically analyze how previous recommendations have been addressed in the new version. The panel prepares a comprehensive report on their findings and recommendations, including a review of the peer review process itself (Aiyyer et al., 2007, pp. 17–18). Reflecting an ethos of openness and transparency, the report from the external review committee and EPA's response are posted publicly on the CMAS website.

[113]Rao's reflections on how no one person, even amongst its creators, can fully grasp the CMAQ modeling system resonates with Barthes on interdisciplinarity and "creating a new object that belongs to no one" (see the epigraph in Chapter 3).

Industry involvement in the collective review of CMAQ might at first seem off-putting to environmentalists, but because credibility is valued so highly by air quality modelers, they spoke to me about how having industry on board (even on the peer review committee of only seven reviewers) helps make CMAQ more powerful in the regulatory arena.[114] The review asks questions about the science in the model, but the organization of collectivity around CMAQ is also evaluated. Reviewers ask "What are the strengths and weaknesses of the science being used within components of the CMAQ model development program?" and "What are your perceptions of the integration across different elements of the CMAQ modeling program (links among model development, applications, evaluation)?" Reflecting the pragmatism among CMAQ developers, reviewers also are asked "What is your perception of the usefulness of the CMAQ modeling program to the EPA, states, other customer needs and the research community?" (Aiyyer et al., 2007).

Peer review is essential for building the credibility and relevance CMAQ requires in policy making arenas and has been key to CMAQ's uptake in regulatory arenas around the world. At the 2011 CMAS conference, the 275 attendees came from 30 different countries, up from 70 participants from four countries in 2001. It is not simply the model "itself" that is taken up in other countries; the forms of collectivity and evaluation, the whole sociotechnical system, travels with CMAQ. Although the system will evolve as it adapts to new contexts, the EPA has helped a number of organizations to work through what Peter Taylor and Anthony Cheng call "structural choices" presented when "participants must decide how to adapt organizational structures to shifting actors, objectives and rules of interaction without abandoning two organizational characteristics largely responsible for their past successes: effectiveness and legitimacy" (Taylor & Cheng, 2012, p. 110).

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[114]Another case of hybridity between the EPA and industry is the Health Effects Institute (HEI), funded equally by the EPA and the automobile industry. Goldstein writes about the HEI "has often provided specific reviews of controversial scientific subjects" and is an example of funding processes that "provide a buffer between EPA's research selection process and those of the scientific community" (2011, pp. 299-300). David H. Guston uses the HEI as an example of a successful "boundary organization," arguing that "because both government and industry fund HEI, neither party could productively accuse it of being captive to the other. Supplemented by two peer-review committees, HEI has been relatively successful in constructing a reputation for objectivity" (Guston, 2001, p. 403).

After evaluating a number of air quality models, the United Kingdom recently chose to use the CMAQ model in the regulatory arena, largely because of the EPA's documentation, development process and support community.[115] In conjunction with the quality of the science in the model, the ability to reference the EPA's extensive evaluation of the model was a major factor in its selection in the U.K. In a 2011 U.S.-U.K. collaboration meeting in the NERL building at the EPA offices in North Carolina, representatives from the U.K. learned a great deal about the sociotechnical system by which CMAQ is used in the regulatory arena. The value of producing a technical support document, for each regulatory use of the model, was discussed at length. The collaboration meeting addressed broad questions with high stakes: How should research scientists interact and communicate with regulators and policy makers? What are the interpretive responsibilities of the CMAQ producers? What are the markers of sound science in the modeling arena? How do you know when you have achieved the requisite precision?

Bernard Fisher, Principal Scientist at the U.K. Environment Agency explained that, in evaluating various model configurations for various use cases, it wasn't a matter of finding the best or worst model, but finding one that was fit for purpose. At some point, he said, "a judgment will be made. . . I think it's hard to determine objectively that a model is good enough." Yet Fisher still wanted to know how to set a pre-determined quantitative standard for model performance. When results from the model are compared to observations from monitoring networks, how close is close enough? Should the numbers be better than 5% off? 10%? CMAQ developers at the EPA pointed out that this kind of quantitative approach, by itself, can result in ad-hoc changes that can throw the system off in unexpected ways. Ken Schere, a Senior Science Advisor at the EPA, points out that prior to the development of CMAQ, the regulatory side of EPA:

> did set up, years ago back in the 80s, early 90s, a set of criteria to use in which the mean bias and error had to be within certain limits in order to

[115]The peer review of CMAQ 4.6 "emphasized an assessment of the meteorological/physical/chemical process aspects of the CMAQ modeling program, as well as applications and evaluation of model performance" (Aiyyer et al., 2007, p. 3). Thus both the state-of-the-science on material processes and the social processes that care for the model were given close examination.

> use the model in a regulatory application. The effect of having those acceptance criteria was such that model developers were essentially tuning their systems to meet those criteria. However, in that process, they destabilized many of the inputs. So for instance NOx emissions were boosted up in order for the Ozone to meet the criteria. And you ended up with a model that might have apparently met the criteria but when you used it in a control strategy your chemical environment was nothing like reality.

The old system described by Schere, based solely on "ground-truthing" or "bench-marking" was too rigid for model evaluation and development. While accounting for mean bias and error is an important aspect of the analysis process within the CMAQ community, over time they realized that the criteria for credibility should be more like a portfolio, giving a new sort of flexibility to sustain collective and honest engagement with research that aimed to approach reality, even as the possession of a pre-ordained set of rules was eschewed. Rather than meeting quantitative criteria regarding how closely modeled concentrations of a single chemical, such as ozone, matched observations, CMAQ developers focus on the whole modeling system and how well its *processes* can engage with and account for the complexities of atmospheric chemistry and meteorology. Internal consistency, careful documentation, reflexivity and engagements with the world trump judgments about what is true or false. As the previous section of this chapter shows, focusing on internal consistency can result in a model that can show that truth from monitors and measurements is also revisable and imperfect. CMAQ developers valorize the assemblage of diverse and are concerned with how experimenting with specific configurations of expertise and computational algorithms can enable better knowledge production. These questions of assemblage and configuration, material and social processes, are behind the generation of differences that make a difference.

After some discussion it became clear to the U.K. delegation that the consensus of the scientific community and the external peer review process are key criteria lending the model its credence in the policy arena. David Mobley, Associate Director of AMAD, explained that:

> We can elaborate on our evaluation criteria, but one thing I would like to add to your list [of discussion points], which is very important for us, is

> the external peer review. . . we rely a great deal on their findings and that's one of the key things that the regulatory side of the house uses in their justification of the application of the tool. That's, in some respect, a lot cheaper and easier to do than all these model runs. . . the formal process here is very critical.

The formal process of peer review, far from a bureaucratic formality, reflects a scientific method that explicitly acknowledges the centrality of social relations and communication while staying close to the materiality of the world. CMAQ producers proudly talk about the model and the decisions it informs as "science-based" and their notions about what counts as improvement reflect this valorization of science as process. Rao told me that they make sure that (Rao, 2011):

> whenever we release a model, we document the superiority of this version in terms of the *processes* that we put in. In terms of model performance itself, how accurately the model simulates the pollutant concentrations that were observed, you may or may not see much difference. But we want to make sure that we're not going in the other direction, that the predictions get worse as you improve the science. That sometimes happens!

By processes, Rao is referring to the algorithms within the model—chemical reactions, first principles from physics—that structure the data, but the social processes involved in a care of the collective—communication among developers and users, the peer review process, prioritizing research questions—are equally important and structure the CMAQ model as a context that enables relays among different scientists, policy makers and models.

Focusing primarily on the processes and science in the model—the architecture of the numerical laboratory—is key for CMAQ's use in policy making contexts, but also helps make CMAQ a powerful research tool. CMAQ draws on complex skills and produces novel analytical capacity. If the model is robust, and predictions are off, it could be an indication that inputs, such as emissions inventories discussed above, need revision. In other cases the inputs may be relatively accurate and it is the "guts" of the model that call for revision. Rao told me that (Rao, 2011):

> we know what the real world has seen in terms of measured changes in air quality, so if our model doesn't simulate that measured change in air quality, then one of the inputs going into that model is probably not right.

> We can give our best estimate of emissions and then perturb those emissions estimates and see what kind of perturbation you need in order to match the observed change. . . But this assumes that our model is right, that the physics and chemistry are robust. Well that's not quite true. It's not perfect. The way you apply the model and learn from those exercises identifies some of the issues. . . the model applications drive future research.[116]

Rao and the CMAQ development and analysis team do not assume that the inputs *or* the processes in the model are correct; they are both continually questioned. Statistician George E.P. Box famously said "all models are wrong; the practical question is how wrong do they have to be to not be useful?" (Box & Draper, 1987, p. 74). Another question continuously asked by CMAQ producers is "*why* are models wrong?" Are the processes in need of improvement? Should more research in air chemistry be prioritized at the ORD? Are inputs off? Maybe the model is not so far off and the measurements it is being compared to are flawed? It is not simply that data from measurements or observations of the "natural" environment are out there and sufficient for ground-truthing the model. CMAQ producers point out that while modeling can be always critiqued for lacking absolute precision, absolute ground-truthing is also impossible; the map is not the territory, but the territory can't be known without maps. In the case of a recent study, by running CMAQ to match observed drops in ground level ozone due to regulations, it became clear that while large point-sources (smokestacks, etc.) are relatively well accounted for, emissions metrics from mobile sources remain highly uncertain and deserve revision. Since CMAQ modelers are aware that observations can be wrong, they do not compare modeling to some ideal, direct access to truth or reality. They recognize that all perception is mediated and that these mediations can be fruitfully compared, not just pitted against each other in zero-sum games.

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[116]CMAQ 4.6's peer review panel for states that (Aiyyer et al., 2007, p. 15):

> Periodic reviews are an excellent way to get input from a sub-set of the research community. But the CMAQ team at EPA is in a unique position to also identify present shortcomings of the modeling system, especially now that it is being run in forecasting mode. Communicating these shortcomings and the areas of greatest need for further research can focus the outside research communities efforts to better help in improving the model… AMD should help frame research questions from a CMAQ perspective.

Robin Dennis, who studies the deposition of pollutants in ecosystems and works to link ecologists with air quality mode producers, tells a story about how CMAQ can drive multiple scientific communities to re-evaluate their research and set priorities (Dennis, 2011):

> We ran into this with the nighttime conversion of NOx to nitric acid. The global modelers had this very large number for this conversion rate because that made their models look sensible against the data they had. We wanted that process in, for more completeness, but it made our answers come out high. So, looking at that result, we came to realize, based on additional field study and laboratory measurements, there were other influences that inhibited the conversation compared to what the global people thought was taking place. So we worked with people in NOAA who had a new instrument that was capable of measuring the key species involved under representative conditions in the real world, and indeed they found there were *other* aspects of the atmosphere that would reduce the conversion rate even further. . . and so it was a case of taking what knowledge we had, and it wasn't great, to address errors or missing processes in the model, and that helped spawn some questions to the measurement community that we posed, and they looked into obtaining better estimates of conversation rates for us. Now we're on more solid ground and have a better description of the process. . . part of your scientific credibility is completeness. You don't want to leave it out just because you don't *know*, so there's a judgment call about when it's understood well enough in the community to bring it in.

Having spent time connecting to disparate communities within and beyond the ORD, Dennis was able to coordinate among many different research entities with relative ease. New questions—a key trait of experimental systems—spawned in the modeling research process could be posed for the measurement community which could result in improved inputs for modeling. These examples, along with the debate above, suggest an active and interpretive role for modelers in dealing with data. The work of model evaluation involves "adaptive experimentation," rapidly adopting new hypotheses, control scenarios and problem definitions (Casagrande, Hope, Farley-Metzger, Cook, & al, 2007).

4.5 Conclusion: Modeling Future Epistemologies

Focusing on the scientific processes in the model, developing the collaborations that produce and evaluate this science and continual questioning of model inputs are three ways in which CMAQ developers care for the model, the collective and the data.

To extend one of this chapter's epigraphs, Kevin Teichman, at the 2011 CMAS conference, pointed out that (Teichman, 2011):

> When we regulate air quality, in the U.S. at least, the regulated industries are very concerned about what models we are using. . . therefore having a CMAQ model which is open for the public to see, for the public to contribute to—and in fact the public is not the public but the international [modeling] community—to make the best possible air quality model that we can, is a critically important way of making sure our environmental decisions are scientifically defensible. . . It's critical that we practice open communication in our modeling development, its evaluation and its application so that all can contribute to building scientific credibility

Teichman's figure of the public, the collective of air quality modelers distributed across the globe, is at the core of the modeling system's credibility. A system must be sustained in which all can contribute because the process is not simply positivistic, or geared towards possessing a single truth, but instead relies on collective, careful and honest engagement with the messy complexities of the real world.[117] The CMAQ community's care of the modeling system has made CMAQ both the go-to computational model for understanding future air quality scenarios and a sociotechnical model of the kinds of collectivities and tools that will be needed to address important informational challenges across multiple contemporary environmental sciences and policy decisions. CMAQ embodies a systems-based approach that enables the development of both the know-how (actionable knowledge) and the how-to-know (epistemological criteria and processes) necessary for tackling contemporary environmental problems.

Establishing Model's Credibility is an explicit research program within AMAD. Without credibility, the labor condensed in developing CMAQ would be largely wasted and opportunities would be missed for the science in the model to have effects in the world. Yet CMAQ developers are also careful not to over sell the modeling system. S.T. Rao says that "there's a tendency to do that, simply because computers have gotten faster

[117]In the case of CMAQ, given the complexity of the modeling system, full stakeholder participation does not necessarily mean that any U.S. citizen should be able to analyze the model. Expertise is highly valued, even as CMAQ developers recognize that no single form of expertise is up to the task of analysis, and that even the best possible collective critique will never result in a perfect model.

and the more stuff we put into the model the better the answer will be," but Rao thinks that more work needs to be done to show, in specific ways, how each new version is an improvement and what work remains to be done (Rao, 2011).

The development of the CMAQ modeling system is heavily marked by what Mike Fortun calls the "care of the data" (2010).[118] The CMAQ developers I spoke with are keenly aware that no technology will provide an unmediated vehicle for nature to "speak." The supplemental assessments Fortun discusses are necessary for the modeling system to run. It cannot, in fact, run at all without being coded and re-built for each use case. Guidance documents, an important part of the labor of helping users assemble configurations of the system, are some of the necessary supplements that make CMAQ usable. CMAQ gives structure to a wide-range of data, but not "by itself," and not somehow "objectively" separate from the structuring arenas in which it is used. Useful knowledge emerges out of a conversation among the modeling technologies, users, designers and the reality they seek to model.

Rao states that the model "really will try to replicate all the processes that are happening in the real world and that kind of modeling system we think is needed for understanding the interplay between climate change and air quality" (Rao, 2011). The production of useful modeling knowledge requires supplemental, subjective experimentation by its developers and users. While I have highlighted the social aspects of the CMAQ system in this chapter, this sociality is co-produced with modeling technologies and the materiality of the atmosphere. "Social construction" seems to be a poor signifier for CMAQ producers' articulations on their goals of approaching the reality of the atmosphere and their material-semiotic (Haraway, 1997) practices of

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[118]Fortun describes the interpretive, uncertain, subjective character of a biotech informatics program called STRUCTURE that clusters massive amounts of data into groups. Quoting from a description of STRUCTURE by its developers, Fortun writes that the program (Fortun, 2010, p. 13):

> can produce "anomalous outcomes," and requires supplemental "assessments" that involve "statistical difficulties" which are "not rigorous" and may lead to results that are "quite difficult" to "interpret." My emphasis on these terms is not intended to demolish STRUCTURE or its scientificity. Instead, I draw attention to these terms to acknowledge their status as necessary supplements to the STRUCTURE program, and to the program of science more generally. STRUCTURE and its supplements—interpretation, comparison, assessment—define or structure a data space, but are also defined or structured by the space in which these techniques of "schemes" are deployed.

building models that really do get closer to reality through their care of the collective (in the form of, among other things, the institutionalization of CMAS), the care of the data (especially the scientific processes in the model) and care of the model (as a context providing structure for the data). The very social structures within which CMAQ developers work (research and development that is immanent with the policy-making apparatus) demand ever-diminishing distance between the model and the reality (and futures) it seeks to understand. The modeling system should not be disparaged for its social components. And not just because they are *necessary* supplements to the structures given to data (a necessity that ideally would be somehow escaped in order to purge contaminating subjectivity and achieve a detached and transcendent objectivity) but because the forms of care I describe in this chapter (developing and sustaining collectivity, continual development and evaluation of the science, communicating closely with users) are essential, central and laudable aspects of the scientific method, as practiced by air quality modelers.

Creation of assemblages, and their comparison and assessment, are key supplemental (and yet central) aspects of the labor of situating CMAQ within a network of other models. Although the CMAQ model is the gold standard for regional scale air quality models, developers still argue that we need a variety of other models. When I asked how CMAQ "won" over all the other models, I was told that the models collaborate more than they compete. One developer told me that "if there's one truth, and we know what that truth is, that's fine, but [since we don't] it's good to have scientists developing scientific concepts independently, and then with multiple models we can better understand our degree of ignorance or our degree of confidence."[119] Having an ecology of models, with differences that make a difference, in/as different problem spaces, improves the accuracy of modeling overall. To this end, the Air Quality Modeling Evaluation International Initiative (AQMEII)—a group focused on regional air

[119]Rao's musings resonate strongly with Thomas Kuhn, who wrote that (Kuhn, 1996, pp. 147–8):

> if there were but one set of scientific problems, one world within which to work on them, and one set of standards for their solution, paradigm competition might be settled more or less routinely by some process like counting the number of problems solved by each. But, in fact, these conditions are never met completely.

quality model evaluation across the European and North American modeling communities—invests a great deal of time in assembling, experimenting with and comparing different assemblages of models.

The narrative element in the documentation process and the interpretive troubleshooting of the modeling system disrupts the mistaken belief that "qualitative researchers are in the business of interpreting stories and quantitative researchers are in the business of producing facts" (Boyd and Crawford 2011, 3–4). The acknowledgment of interpretive labor that I heard time and again from CMAQ producers contrasts sharply with the tendency Boyd and Crawford observe among computational scientists "to claim their work as the business of facts and not representation," reflective of an "arrogant undercurrent in many Big Data debates where all other forms of analysis can be sidelined by production lines of numbers, privileged as having a direct line to raw knowledge" (2011, 4–5). Geoffrey Bowker argues that "raw data is both an oxymoron and a bad idea; to the contrary, data should be cooked with care" (Bowker 2008, 184).

CMAQ developers can be seen as a recursive public; they are deeply concerned with caring for the sociotechnical conditions—namely the modeling system—that enable their community of practice to exist and grow. They embody the "care of the subject" called for by Schuurman and Pratt (2002) through the peer-review process, ongoing improvements to the model, curating contributions from the wider modeling community, actively participating in the EPA/NERL post-doc program and working closely with the regulatory modeling community to understand how models are applied and evaluated by these groups. Every one of these supplementary—yet core—activities requires recognition of the diversity of expertise within the communities of practice that make up the air quality modeling community, and a cultured ability to leverage this diversity in generative ways. CMAQ emerged out of a desire to draw together what Evelyn Fox Keller might call "explanatory pluralism" in order to better understand the dynamics of the atmosphere and air quality (Keller, 2002a).

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5. Concluding Contributions

5.1 Overview of the Arguments

There are many things I learned in the process of researching and writing this dissertation. The arguments that I want to highlight, because they are both important historically and clearly validated by the empirical material I have gathered, concern how the EMS producers I have engaged with conceive of communication or mediation and the audiences they seek to develop relays with. Through their practices and articulations, my interlocutors showed me how they and others in their communities of practice think about: the always mediated nature of perception and knowledge; heterogeneity among their own communities and the so-called public and how diversity can be made productive by practicing science communication as context production. They also showed me how they conceive of the value of recognizing political possibilities beyond federal regulations at multiple locations and scales. Following a discussion of my key findings and arguments, I briefly return to the research questions guiding this dissertation.

5.2 Mediating Perception and Knowledge

The designers and developers of the Atlas and CMAQ articulate a clear recognition of the always mediated nature of data and information; they suffer no illusions about perception without prosthetics or action separate from communication. Recognizing that nature or the environment or data cannot speak for themselves means taking responsibility for how prosthetics are crafted and the world-views that are pressed into them. In environmental *media* systems, different forms make a difference; the projects I discuss mediate, and are mediated by, information, institutional relationships, modes of knowledge production and public imaginations. "Media" recalls Marshall McLuhan's dictum that the medium is the message—or the massage—and signals connections with scholars of new media who write about communication in terms of spaces for interactivity and collaboration, which, of course, produce more than a displacement in the location of information (McLuhan & Lapham, 1994). EMSs can *circulate and create* new literacies, subjectivities, forms of collectivity, etc. The specific

architecture of media—as sculpted material-semiotic contexts—can have high stakes, shaping chances of living and dying, as in access for asthmatics to local ozone forecasts in sites like airnow.gov, or the temperature and pressure of a medium for culturing cells in a laboratory (Landecker, 2007). Certain media forms can be remarkably effective at culturing interdisciplinarity and grappling with contemporary environmental problems like land-use management and air quality regulations requires simulations, models and other technological prostheses that draw together a variety of expertise.

Media theorist Neil Postman summarizes Marshal McLuhan's theory of medium, perception and subjectivity (Postman, 1979, p. 39):

> The printing press, the computer, and television are not therefore simply machines which convey information. They are metaphors through which we conceptualize reality in one way or another. They will classify the world for us, sequence it, frame it, enlarge it, reduce it, argue a case for what it is like. Through these media metaphors, we do not see the world as it is. We see it as our coding systems are. Such is the power of the form of information.[120]

The Atlas and CMAQ do not simply convey or transmit information; their forms can have powerful effects on how users see the world. The Atlas "argues a case" for the environment as full of value, and not just for extraction. The Atlas aims to illuminate spaces where humans can *add* value to the environment by intelligently designing ecosystems in ways that maximize ecosystem services. Using CMAQ, or encountering knowledge produced with the modeling system, powerfully drives home a view of the atmosphere as incredibly complex, yet with futures that are partly knowable and modifiable. Engagement with EMSs, like engagement with teachers proficient at providing the conditions for critical thinking, can help produce new literacies and subjectivities. Carson's *Silent Spring* is widely cited as an example of media's ability to

[120]Postman's claims here are, I would argue, somewhat hyperbolic. We *do* see the world "as it is," to a degree, and not simply "as our coding systems are." Coding systems affect our perceptions, but content still matters. Coding systems are themselves shaped by our understanding of the materiality of the world "out there," as is made clear in the case of CMAQ, even as our interactions with this world are inherently mediated. In other words, media are themselves mediated by the material contexts in which they are deployed and developed. A key task of this dissertation has been to explore how EMS producers negotiate the interplay of context and content, how context and content are co-produced. There are unique challenges to designing and developing *environmental* media systems because they engage with the messy materiality of the world and the political and scientific complexities that come with decision making around this materiality.

catalyze new awareness, social movements, legal infrastructure, etc., and it was unique in its impact, but an ecology of well-designed EMSs could have similar effects (Carson, 2002). When McLuhan writes about the medium as the massage, he is evoking the materiality of media and gesturing towards their capacity to affect users, to subject them to sculpting (McLuhan & Fiore, 2005).

5.3 Heterogeneity Among EMS Producers and Publics

Another key finding of this dissertation is deep recognition, within the communities of practice behind the Atlas and CMAQ, that there is a valuable heterogeneity of expertise among NERL scientists and their stakeholders. Diversity of expertise is seen as something deserving of support, accommodation, respect and care. A great deal of my interlocutors' labor, as scientists, is about developing relays among a diversity of approaches within the environmental sciences, policy and management communities. My interlocutors recognize that the community of experts within their communities of practice is itself so variegated that it can be a major, and important, challenge to develop spaces for communicating among themselves. In order to successfully address complex environmental problems, my interlocutors recognize that developing better modes of community and collectivity among scientists is at least as important as raising awareness and public understanding of science among lay populations.

Recognition of internal heterogeneity and increasing integration in EMSs can work to erode sharp dichotomies in science communication such as lay/expert and internal/external.[121] Internal communication among experts—who cannot necessarily be defined in advance—is a prerequisite for developing EMSs that various publics can use to develop better environmental understanding. In the case of CMAQ, developing robust processes for collective development and analysis of the model is key to the model's credibility and, in turn, modelers' ability to make claims with the model. CMAQ

[121]CMAQ producers' language sometimes slips in ways that reveal how dualisms between experts and the public are breaking down. "The public," for example, is corrected to mean the "international modeling community." When developers say "the model was made available for public use in 1998," they simply mean people outside of EPA could use it.

developers tend to exhibit impressive solicitude, in the sense Mike Fortun uses the term to describe "the overall goal of comprehending entire structures," in this case the structuring of data by CMAQ, the structuring of CMAQ within the broader contexts of air quality modeling, policy-making and the public imagination (Mike Fortun, 2010, p. 13). Rather than lump together experts or scientists on one side of the communicative divide and a homogeneous and de-skilled public on the other, producers of the Atlas and CMAQ are designing systems that account for heterogeneity in users' expertise, literacies, goals, potential courses of action, etc. Greater heterogeneity can mean more surface area, more nodes for plugging in relays.[122] The diversity of potential users (of projects like the Atlas) and uses (for CMAQ) speaks to how EMSs are increasingly impossible to characterize as designed for communication either within science *or* to the public. While my interlocutors sometimes speak of a generic public as one intended audience, more frequently they talk of designing their projects with specific types of scientists, journalists and policy makers in mind. CMAQ and Atlas producers understand that EMSs are taken up not only by users that are connected, but also who are situated in specific and multiple communities of practice, each marked by internal multiplicity.[123]

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[122]As Michael Fischer writes (1991, p. 530):

> anthropology should explore the fact that science is not a unitary enterprise. Instead, there exist a variety of cultures of science based on: the different cognitive strategies different fields use; the differently situated knowledge bases and social problems that science is involved in; and the lineages and social networks of mentor-student and research lab networks.

The scientists I spoke with share this task of exploring heterogeneity with the contemporary sciences of the environment. This shared task could be a site for collaborations that have been relatively unexplored in the EMSs I have investigated, namely between environmental scientists and STS scholars and anthropologists. I explore this potential connection in the Epilogue.

[123]This may seem a fairly obvious point, but science and risk communication scholarship, which can be layered into practice, is largely based on psychological research on individual behavior. As Kasperson and Kasperson write (2005, p. 26):

> the public consideration of risk characteristically occurs in a social group or community context, consisting of multiple sources and channels of information, peer groups, and an agenda of other ongoing social issues. Much more is known about the response to risk by members of the public as individuals than as members of social groups.

While Kasperson and Kasperson recommend the development of different communication "packages" for different audiences, it may be possible that EMSs, as synthesizing architectures, can be designed to provide contexts in which very different publics can assemble productively. In both the Atlas and CMAQ, different users have a limited but significant opportunity to configure the system to meet their needs.

5.4 Making Diversity Productive by Practicing Science Communication as Context Production

The aim of much of my interlocutors' work is to use EMSs to assemble diversity among their communities of practice and stakeholders, and make it productive. The Atlas and CMAQ are designed to help make diversity an asset, an essential task in the quest to tackle problems of "broad national significance." The practices of the EMS designers described in this dissertation are not easily or sufficiently described by widely circulating notions of science communication. It is common to hear popular articulations of science communication that evoke an image of specifically trained experts communicating to a lay and homogeneous public. This figure of science communication, resonating with the transmission model discussed above, focuses on *content delivery* to the public (in the form of popular science media, newspaper articles, science-focused TV shows and other forms of journalism) or to scientists with similar training and literacy as the authors (in the form of journal articles, produced by a single author/genius/hero/priest).[124] In this view, science communication has been seen as the last step (and almost outside) of the scientific project. Scholarship in STS complicates this view by showing how internal communication is key to the production of scientific knowledge and the circulation of credit (Latour & Woolgar, 1986). But little attention has been paid to recent innovations in the *form* of both external and internal communications in scientific arenas.

In order to describe the articulations and practices of my interlocutors, another model of (science) communication needed to be articulated. My ethnographic material suggests emergent conceptualizations and practices of communication *within* the sciences as creating connections among diverse elements by *producing contexts* for information circulation and collaboration. Contemporary scientists working in the environmental field are increasingly articulating and practicing science communication that takes the form of building mediated *systems* for the circulation and creation of environmental knowledge and literacy. In this emergent model and practice, the

[124]See Daston and Galison for an account of pre-1820 "genial depiction," in which the persona of objectivity is the genius, the practice is intervention, the image is metaphysical and the ontology universal (Daston & Galison, 2007, p. 17).

development of these systems (tools and spaces) is increasingly a legitimate goal within the communities of practice I researched.[125] The EMSs I analyze are interactive, exploratory, collaborative, actively shaping and experimental (in both form and content).

While they may not always see their task primarily as one of communication (especially CMAQ producers) all of my interlocutors articulate and enact a style of science/environmental communication that resonates with the tasks of context production and forging new relays. While content delivery is still an important goal, and traditional media for displaying and circulating research work well in some contexts, the EMS designer/scientists in this dissertation are focused on crafting contexts (tools, spaces and forms of collectivity) for sharing and re-combining information in new ways.

Ecologists who have spent decades focusing on content production (usually in the form of journal articles, for other ecologists) suddenly found themselves tasked with designing the Atlas as an interactive space with open-ended users and uses. The Atlas provides the layering and comparative powers of GIS—with added data layers and graphing capabilities—to a much wider audience than typically has had access.

The Atlas could also drive research in diverse fields because researchers may be motivated by the possibility of having their results proliferate through circulation in the Atlas or the Browser. EMS producers at the EPA are developing EMSs capable of disseminating information in a way that resonates with one of Gregory Bateson's definitions of information: a difference that makes a difference.[126] As Annie Neale put it, "I don't know anybody where that's not their main reason for working here. People want to see the right thing done" (Neale, 2009a). But a desire to have effects does not mean that objectivity is neglected or forgotten. Recognition of politics does not preclude science-based decision making. On the contrary, the stringent challenges to EPA-produced information and knowledge (attacks from industry, environmentalist groups,

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[125]See Bowker (2008) on the increasing value of (and rewards for) sharing data in developing databases.

[126]Gregory Bateson writes that (Bateson 2000, 457-459):

> A difference is a very peculiar and obscure concept. It is certainly not a thing or an event. This piece of paper is different than the wood of this lectern. There are many differences between them—of colour, texture, shape, etc. . . Of this infinitude, we select a very limited number which become information. In fact, what we mean by information—the elementary unit of information—is a difference which makes a difference.

etc.) drive many researchers at the ORD to develop careful modes of fact-checking and collective scrutiny, especially in the context of regulatory decisions.

Many of my interlocutors, in different ways, spoke about how *circulating* information, among groups with diverse backgrounds and expertise, is increasingly central to the *creation* of new knowledge.[127] *Communication*, sometimes dismissed, especially in activist circles, as "just talk" (see Figure 1 above) can be a powerful tool for making new *relays* (new intersections of people, knowledges, data sets, desires, models, etc.) which in turn can catalyze the *creation* of new understanding, ethical subjects, collective organization, discursive contexts and possibilities for change.[128] The Atlas was initially guided primarily by calls for better circulation of ecological knowledge and transparency in communication of research results to the public. But over the course of its development, Atlas designers have become excited about its potential as a research tool capable of speeding up and improving the creation of new ecological knowledge. Some of my interlocutors report that in the past, they were more likely to think of science communication as peripheral to, or after, the hard work of knowledge production.

Awareness of cultural differences among practitioners in the sciences has made the researchers I interviewed at NERL keenly aware of the need for producing contexts where differences among, say, air chemists, meteorologists and municipal decision-makers can become productive.[129] Air chemists and meteorologists can develop models

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[127]Especially as the environmental sciences are increasingly informated, it is difficult, or impossible, to separate out communication, circulation and production of scientific knowledge. Fundamental to a great deal of STS scholarship is the notion that developing scientific facts entails a great deal of communicative work, variously described as networking (Latour, 1998), articulating (Michael Fortun & Bernstein, 1998), heterogeneous engineering (Bijker & Law, 1994), etc. Re-packaging "old" knowledge, making connections, crafting communicative contexts and developing new literary and rhetorical technologies are some of the many strategies that can come to the fore when circulation is re-conceptualized as *creative*.

[128]Gilles Deleuze and Félix Guattari distinguish between making cartographies or maps and ready-made tracings (Deleuze & Guattari, 1996, pp. 12–15). The basic difference is that cartographies are creative; they do not simply aim to reproduce or describe a de facto state. "The orchid does not reproduce the tracing of the wasp," they write, "it forms a map with the wasp, in a rhizome. What distinguishes the map from the tracing is that it is entirely oriented toward an experimentation in contact with the real" (Deleuze & Guattari, 1996, p. 13).

[129]The Atlas and CMAQ are boundary objects, "those objects that both inhabit several communities of practice and satisfy the informational requirements of each of them. Boundary objects are thus both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust

that are pulled together in the context of the CMAQ modeling system, which in turn produces outputs that can feed into popular contexts like the Weather Channel forecasts and the Atlas, which could, in turn, be used by land-use managers to inform local strategies for reducing ground-level ozone and visualizing a host of side-benefits. The EMS producers I interviewed are designing systems that work by assembling, *inter alia*, public health researchers, physicists, ecologists, city planners, air chemists, meteorologists, non-profit environmentalist groups, etc. Continued de-centering the transmission model of communication could open the way to new research and communicative trajectories that take seriously the social dynamics of communicating about risk and the environment. The scientists I interviewed, in their work as communicators, are becoming *context providers*, a phrase Victoria Vesna, media theorist and art critic, uses to describe digital artists as creators of spaces for the production of meaning and culture, in opposition to the figure of digital artists as simply providing content for presumably static media (Lovejoy, Paul, & Vesna, 2011; Vesna, 2007).[130]

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enough to maintain a common identity across sites (Bowker & Star, 1999, p. 297).

[130] "In opposition" is not quite right. Vesna and colleagues write more in a chiasmic style about what I might call contentXcontext. In their introduction, they write (Lovejoy, Paul, & Vesna, 2011, p. 1):

> one of the main goals of this book [and my dissertation] is to provide context for an understanding of art [and science] that uses current technologies as a medium and to examine the multiple contexts that inform conditions of meaning in this medium. Using the term "context providers" as the title for a book, one cannot avoid invoking the term "content provider" and its connotations. . . this book aims to examine the relationship between the two, and the shifts in meaning that digital technologies may have brought about in understanding the interplay of content and context.

The term "content provider" suggests a role of filling set contexts or technologies with ideas, facts, concepts, meaning, etc. and resonates with the transmission model of communication. In contrast, the work of context production, and designing EMS, centers on developing new media, contexts, technologies, spaces and aesthetics.

Transmission Model	Context Production Model
Communication is outside or after the "real" work of knowledge production.	Communication is central to the process of knowledge production.
Last step in a linear process.	Located at every stage of the research process.
Unidirectional flow from experts to "the public."	Multidirectional flow and users—conceived as communities of practice marked by heterogeneous expertise and goals—may interact with or add to the system.
Image of a bullet or vehicle.	Image of a space with a shapeable architecture.
Simplifying complex phenomena.	Collective engagement with complexity.

Table 1: The "transmission" and "context production" models of science communication.

Table 1 provides a condensed snapshot of two modes of communicating science and environmental risk. Table 1 combines emic and etic perspectives and while the right column is heavily influenced by the practices of my interlocutors, I take most of the responsibility for these specific articulations. I am not making the case that that was then (on the left) and this is now (on the right) or that the left column sketches a naïve vision of the role of communication in science, and the right describes communication in science as it actually happens. Although my interlocutors do suggest that there has been a general shift in the conceptualization and practice of scientific communication towards the right column, aspects of the left column remain in play within many EMSs developed at the EPA and elsewhere.[131]

Internal and external communication, of course, are closely twinned, especially in the case of a science-for-policy organization like the ORD. Caring for collective

[131]Following Daston and Galison on objectivity and Fischer on culture, I conceive of contemporary understandings of communication as *layered*, with multiple, sometimes conflicting, models at play (Daston & Galison, 2007; Fischer, 2007). Tracing these legacies and emergent conceptions is part of my first research question situating EMSs in context and my second question on how EMS producers articulate the need for experimentation and innovation in environmental communication.

practices of evaluation and interdisciplinary circulation is increasingly seen as an essential prerequisite for producing the kinds of knowledge that can circulate effectively in wider spheres, especially regulatory domains. Data sharing and collaborating have been areas of significant growth in ecology in recent years. For many years ecology was marked by a somewhat counter-intuitive silo-ization. Researchers had their particular domains and did not stray far. The EPA, in part due to its national scale approach, played a role in fostering collaborative practice in ecology even before the Atlas. The EMAP program laid the foundation for metrics that could be used to compare across different spaces. When these metrics are brought together in the Atlas, along with a multitude of background maps on connectivity, water quality, and myriad ecosystem services, a juxtapositional logic comes into play. It becomes clear to ecologists that it is not just their objects (ecosystems, the environment) that are marked by heterogeneity and connectivity, but their own practices, systems of knowledge and the various communities of practice they see as their stakeholders. They move a step closer to an ecology of mind and begin to see the patterns that connect diverse forms of expertise.

In the case of CMAQ, the materiality of the atmosphere had a powerful role in catalyzing contexts of interdisciplinary that have made CMAQ a powerful tool in broader contexts of decision making. Like ecologists who had been working in a private niche, earlier air quality models focused on single pollutants and single pathways. The "one atmosphere reality" was not graspable. To create a model that could approach the complexity of the atmosphere required putting diverse experts, and the knowledge they produced, into conversation. While the Atlas is driven by calls to share information and results with the general public—even as specificity and heterogeneity within this public is recognized—CMAQ is primarily intended to be used by the air quality modeling community, primarily in regulatory decision making. This drives CMAQ producers to worry a great deal about developing credibility, while the Atlas producers are more concerned with putting information out for the public along with tools that could help users come to their own conclusions and make their own decisions about tentatively articulated linkages among ecosystems and human health and well-being.

Inspired in part by the ecologists I interviewed, I worked against the notion of the projects I analyzed as discrete entities, aiming to understand how different EMSs travel

and could be lashed together.[132] It may be the labor of scientists who work at the nexus of the Atlas and CMAQ that most clearly exemplifies some of the challenges and opportunities around developing EMSs. Researchers like Robin Dennis—the researcher introduced in Chapter Four who works at the interface of the Ecosystem Research Division (ERD) and the Atmospheric Modeling and Analysis Division (AMAD) and links acid deposition to ecosystem effects—have become keenly aware of how linking researchers, data, information and knowledge from different scientific domains at different scales demands recognition of EMS production as a sociotechnical process.

5.5 Recognizing Political Possibilities Beyond Federal Regulations: Working Scales, Swerving Subjectivities and Creating Collectivities

My interlocutors' close attention to the reading-effects and forms of collectivity that might be engendered by well-crafted communicative contexts open up new possibilities for political action. The developers of the Atlas and CMAQ recognize that scientists are part of the public, too, and that enabling political action on environmental issues does not always mean catering to regulators in Washington, D.C[133]. CMAQ is used in setting federal regulations on air quality, but it also helps different publics and policy makers understand local pollution on a day-to-day basis (on sites like airnow.gov) and mitigation practices (at state and municipal scales) such as National Ambient Air Quality Standards implementation plans.

The producers of the Atlas have spent a great deal of time and effort thinking about and reaching out to potential user groups in many different governmental agencies

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[132]Jacques Derrida, in "Signature Event Context," points out how iterability is central to writing (Derrida, 1988). Cascading effects, opening up new questions and literacies, are central to what EMSs are capable of producing. Derrida writes that (Derrida, 1988, p. 53):

> by virtue of its essential iterability, a written syntagma can always be detached from the chain in which it is inserted or given without causing it to lose all possibility of functioning, if not all possibility of 'communicating,' precisely. One can perhaps come to recognize other possibilities in it by inscribing it or *grafting* it onto other chains. No context can entirely enclose it. Nor any code, the code here being both the possibility and impossibility of writing, of its essential iterability (repetition/alterity).

[133]Referring to these CMAQ designers as a public differs from much scholarship on science communication which tends to exclude scientifically trained experts in constructions of the public, virtually defining the public by its lack of expertise.

and beyond. They do not take for granted that a public will be ready-made and eagerly awaiting their product. In advance of releasing the Atlas they work to account for the communities of practice that may become users, and they actively *construct* new user-bases for the Atlas.[134] The emergent user-base also shapes the Atlas in-process by providing feedback on presentations by the Atlas producers and asking for features (like enabling citizen science and sharing data). The Atlas producers realize that what seems intuitive to them may be unreadable by users lacking their training and world-view.

While Atlas producers spend a great deal of time weaving in a multitude of data layers produced at the EPA and by other ecological experts, they also recognize the potential for users to work in the space of the Atlas with their own data. But institutional habits (one might even say paranoia) are just one factor making this difficult to actualize. The labor Atlas producers have invested in thinking through work-arounds, such as hosting user-provided data on a separate server or including meta-data about data provenance, will likely be useful for many future projects that grapple with similar challenges in attempting to link government- and citizen-produced data

The EMS designers I interviewed are keenly aware of potential uses of their systems, but also can imagine how they will likely engender surprises in process: new questions, research priorities, and reading-effects that could transform users' engagement with their environments. The scales or arenas in which EMSs will be used cannot always be known in advance. The Atlas is designed to be a problem-solving space, but the problems are not entirely predictable; in the context of the Atlas, users can work with myriad goals and challenges. As in the application of CMAQ driving new questions, the diverse uses that the Atlas will be put through are likely to drive the evolution of the medium and the kinds of research it is capable of facilitating.

Unanticipated effects can also be engendered through re-mediation. Much work on environmental and science media focuses on the mass media or journalism. My interlocutors, by and large, do not write newspaper articles or produce television segments, but they do sometimes enable these more traditional media to be produced

[134] As Stengers and Pignarre state in the epigraph of the Epilogue below, "every connection is a creation, a 'putting into' relation, an event creative of the plane that it will inhabit" (Stengers & Pignarre, 2011, p. 69).

with more easily and with higher quality.[135] CMAQ is re-mediated not only when its outputs are taken up in the Weather Channel's air quality forecasts or sites like airnow.gov; it is also plugged directly into the Atlas and countless models in ecology and elsewhere.[136] The CMAQ modeling system itself can be considered to operate through re-mediation internally, as it is made up of a suite of models that actively shape information as it travels from one component to the next.

EMS producers at the EPA are primarily trained in ecology, chemistry, physics and the environmental sciences, not media or communications theory. They tend to have approaches to communication that are highly pragmatic, but not purely instrumentalist. Despite the challenges, they are passionate about designing EMSs because they recognize their potential for making new connections among people, forms of knowledge, repositories of data and courses of action. They aim for these new connections to help solve particular problems, but also recognize the potential for EMSs to change the habits and world-views of their users, including scientists who may be focused on environmental problems, but have a fairly narrow view. The Atlas—with its layering of disparate data sets and its ability to help envision unintended consequences or "side-benefits"—and CMAQ—which enables users to go beyond the limits of single pollutant, single pathway atmospheric analysis—could help users gain an ecological and future-oriented perspective, ask new ethical questions or connect to or develop new

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[135]Bill Pease, founder of the popular "pollution information site" Scorecard, told me about how Scorecard surprised him by turning up countless times in journalistic articles, even though it was designed almost entirely with community activist groups in mind. The Scorecard example illustrates that "although a large array of participation techniques exists, current knowledge does not allow for successful prediction as to which are likely to be effective under what conditions" (Kasperson & Kasperson, 2005, p. 26). Collecting material from outside my primary field sites helped me contribute suggestions in interviews with the producers of the Atlas and CMAQ. Bill Pease's insights on the surprising degree to which scorecard.org was used by journalists, for example, were included in my formal feedback on the Eco-Health Relation Browser, described in Chapter Three.

[136]Aside from uptake in mass media, the Atlas and CMAQ, and EMSs more generally, can be better understood in terms of new media frameworks. Developing EMSs involves context production. Innovation in new media, similarly, often comes down to creating new forms, or spaces, and not just new content. The Atlas and CMAQ both feature many of the celebrated aspects of new media, such as the 14 "messages of new media" listed in Robert K. Logan's *Understanding New Media: Extending Marshall McLuhan*: Two-way communication, ease of access to and dissemination of information, continuous learning, alignment and integration, the creation of community, portability, convergence, interoperability, aggregation of content, variety, choice and the long tail, reintegration of the consumer and the producer, remix culture and the transition from products to services (Logan, 2010). These affordances resonate strongly with the right column in Table 1.

forms of collective organization (as in CMAS).

The design of the Atlas is informed by its producers' serious engagement with its potential reading-effects, the ways in which it could affect how users grapple with data sets, sustainability challenges and their own conceptions of how humans and the non-human environment relate. The Atlas designers may not have primarily been motivated by creating new subjectivities—the goals they articulate tend to be more instrumental and focus on enabling better environmental management decisions—but they are aware of the potential for working (or playing) in the space of the Atlas to engender new ways of conceiving of the surrounding environment, and humanity's place within it. Communication, from this point of view, does not leave the participants unchanged, except with more information. Engagement with communicative spaces does not leave the participants' system of frames untouched, simply adding more data.[137] New relays can have myriad effects. EMSs can be spaces for creating new relations and new connections. EMSs can help people think in new ways, perhaps more like ecologists, perhaps like modelers.[138] EMS designers, somewhat unconsciously perhaps, as ecologists and modelers, embed their world-views and thought styles into the EMSs they create, in both form and content.

From literacy, or mind-shifts, that can result in a more ecological view across space and time, it is a short step to recognizing the potential for EMSs to create social connections. In addition to the CMAQ model itself—or as a pre-requisite, or effect—a

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[137]To think of frames not as static, but as actively mediating—and mediated—views of the world, Paul Edwards instructs us to "think of 'frame' as a verb, not a noun; think of aiming a movie camera and choosing your focus, where you center the scene, and what you leave out of it" (Edwards, 2010, p. xiv).

[138]Ecological thinking helps make unintended consequences or effects of one's decisions visible and goes beyond thinking of elements in isolation. Model thinking, at least in the case of my interlocutors working on CMAQ, involves a continual evolution and evaluation of the prosthetics used to understand the environment and possible futures. In the introductory lecture for Model Thinking, a free online course, professor of complex systems, political science and economics Scott Page argues that (Page, 2012):

> In order to be an intelligent citizen of the world, I think you have to understand modeling. . . models are everywhere. And so in order to just be involved in the conversation it's important these days that you can use and understand models. . . they make us clearer, better thinkers. . . models let us take data, sort of structure it into information and turn that information into knowledge. . . eventually maybe even some wisdom. . . models help us make better decisions and to strategize better.. we use models to design things like institutions and policies.

collective (CMAS) was institutionalized. The diverse array of CMAQ users that make up CMAS can be seen as a recursive public to the extent that they are a community constituted in relation to a medium (CMAQ) and the group's *raison d'être* is to do the collaborative work of continually, collectively improving the model, as well as the social work of maintaining the community itself (annual conferences, frequent face to face meetings, training the next generation, a highly active list-serve, etc.). The EMS designers I interviewed often spoke about the labor of accounting for, and sometimes working to create, the contexts in which EMSs may be used and the new forms and collectivity they could, in turn, help assemble.

5.6 Returning to the Research Questions

5.6.1 Context: The Underlying Matrix

This dissertation has explored the contexts in which EMSs are designed and operate. EMS producers are always enabled and constrained by the various systems in which they work, such as the modes of collectivity in which they are assembled and used, even as they push the edges of these systems with different kinds of experiments.[139] In naming this dissertation, built on scholarship on environmental information systems, I retain the word *systems* to maintain close attention to how EMSs are embedded in broader systems, or contexts, even as they sometimes re-work these contexts from within, or provide users with new contexts.[140] Many different forces

[139] Marshall McLuhan argued that to understand the effects of technologies, it is essential to analyze figure (medium) and ground (context) together. Medium and context, figure and ground, can only be intelligible in light of each other. McLuhan studied media in their historical context, including the genealogy of technologies and media practices that preceded them. Legacy systems (and media) influence the contemporary context even as the present environment is giving rise to emergent sociotechnical systems and subjectivities.

[140] As George Lakoff argues in the *Journal of Environmental Communication*, "since frames come in systems, a single word typically activates not only its defining frame, but also much of the system its defining frame is in" (Lakoff, 2010, p. 72). Lakoff contends that, without the creation of new frames, and attention to values, the content of individual communications can have little effect. But Lakoff sometimes gives the impression that frames can be created and circulated quite intentionally and instrumentally. Butler warns about a risk with frames (and any mark): "frames are subject to an iterable structure—they can only circulate by virtue of their reproducibility, and that very reproducibility introduces a structural risk for the identity of the frame itself" (Butler, 2010, p. 24). The risky identity of frames can make the task of framing difficult, but can also open up possibilities for shifting

(institutional, technological, political, economic, legal, historical, ecological) shape and could be shaped by the EMSs I analyze in this dissertation. This section summarizes how I see some of these forces at play in the contexts of the Atlas and CMAQ. In process, I re-visit a number of descriptive, empirical findings from this research on the contemporary state of environmental science communication.

The Atlas and CMAQ are not simply developed and used *in* a given context (with fixed rules of evidence, a pre-determined audience or set of stakeholders, static goals, etc.); they can be understood *as* contexts in which the broader contexts in which they are created, used and evaluated can be questioned and re-configured.[141] The Atlas, for example, will be used in decision-making contexts that are highly conditioned by economic structures and habits that place profit above all and enact sharp lines between terms such as nature/culture, environment/economy, animal/human. In the context of the Atlas, users are given a systemic perspective and encouraged to push against short-term economic gain as the only deciding factor and a tendency to make land-use decisions in a fragmented fashion. The Atlas, in the process of its production, also links agencies and other organizations in new ways, perhaps opening up new possibilities for collaboration in future decision making and research.

In the context of NERL, creating and sustaining interdisciplinarity remains a major challenge. This challenge is becoming increasingly salient as the EPA moves to tackle broad questions of national significance. Real-world problems necessitate innovations in communication and collaboration among differently trained scientists because they do not fit neatly within disciplines. The "one atmosphere, one model" approach of CMAQ exemplifies the drive to synthesize the state-of-the-science in many areas of expertise. CMAQ developers speak about how the modeling group has "carved out" a space for interdisciplinary work in the overall context of a bureaucratic institution that, despite its intentions, will only gradually bridge long-standing institutional and

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discourse because frames are never stuck or monophonic.

[141]Derrida writes that the sign "can break with every given context, engendering an infinity of new contexts in a manner which is absolutely illimitable. This does not imply that the mark is valid outside of a context, but on the contrary that there are only contexts without any center or absolute anchoring" (Derrida, 1988, p. 12). Also see Deleuze and Guattari on minor literatures, a concept they invented largely to describe how literature, even in a "major" language, can provide new contexts in which new questions can be asked and new thoughts thought (Deleuze & Guattari, 1986).

disciplinary boundaries.

While research at the EPA has always included some communication across disciplinary boundaries, and has from the beginning been guided by a mandate to protect human and ecosystem health, my interlocutors speak about how, ten years ago, researchers were much more likely to have their own highly focused science projects. Many of my interlocutors at the EPA describe an emergent institutional focus on greater interdisciplinarity and public relevance. These two tightly coupled goals have driven the ORD to increase efforts at enabling collaboration and communication among differently trained scientists and publics. In addition to the Atlas and CMAQ projects, the emergent focus on synthesis, collaboration and resilience is embodied in recent organizational shifts towards a matrix management structure.

Official and explicit acknowledgement of the importance of communicating science *to the public* is common at NERL and the EPA (EPA, 1983, 2011a, 2011b). Researchers working on the Atlas say that due to its high priority as an instance of making ORD research accessible to the public, it is unlikely to be in much danger of being cut, even as they frequently described funding at the EPA as bleak and a serious hindrance to the development of the science necessary to address pressing environmental issues. The high priority of projects like the Atlas is reflective of the EPA's recent rhetoric of transparency and the public relevance of research.

A key factor shaping environmental communication is the institutional reward structure in which science media are produced. Many of my interlocutors report that there is more credit given in recent years for work that would fit with what I call the context production model of communication. For many of the designers of the Atlas, trained primarily as ecologists, day-to-day labor has shifted from on the ground fieldwork research to include the work of media design, learning and advancing the informating and networking of ecology. Fieldwork, for Annie Neale, the director of the Atlas, now involves a great deal of travel to assemble the necessary stakeholders and data sets that make the Atlas possible. My description in Chapter Three of Neale's work on developing better connectivity is indicative of a general trend at the EPA towards

fostering integration among different scientists, tools and EMSs.[142] The Atlas will simultaneously amplify connectivity among, on the one hand, different kinds of environmental scientists and, on the other, a diverse range of stakeholders that bring their own questions, goals and practices to the medium. The Atlas also draws together tools and technologies in new configurations.

Technological advances have contributed to the increasing centrality of communication and visualization in the production of scientific knowledge. Peter Fox, a researcher on semantic web technologies, Professor of Earth and Environmental Sciences and collaborator on *The Asthma Files*, writes in a special issue of *Science* on open data (Fox and Hendler, 2011, p. 705):

> unfortunately, visualization too often becomes an end product of scientific analysis, rather than an exploration tool that scientists can use throughout the research life cycle. However, new database technologies, coupled with emerging Web-based technologies, may hold the key to lowering the cost of visualization generation and allow it to become a more integral part of the scientific process.[143]

Fox's comments about the usefulness of seeing visualization as central to the process of science, and not just an end-point, along with the articulations and practices of many of my interlocutors, point to an increasing tendency for scientists to take account of, and active interest in, the more social, communicative, mediated aspects of science. Visualizing data in ways that are usable by different communities is becoming a key mode of scientific communication; visualization can also muddle the distinction between circulating and creating new insights, making science—as both process and content—more accessible to wider publics while making data easier for researchers to work with.

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[142]Landy et al. argue that *integration* is a key process that deserves nourishing at the EPA, though developing rewards, behavioral change and recruitment patterns (Landy et al., 1994, p. 15):

> integration is partly a matter of structure: the crafting of occasions and relationships so that relevant specialities come together to raise questions and to respond to each other's concerns. Structure alone, however, is insufficient. Integration also involves behavior and hence a concern for recruitment and reward patterns that foster the preferred behavior. An agency needs to attract people who have the capacity and desire to work with and learn from those with other points of view. Patterns of promotion must reflect these integrative commitments.

[143]Guattari writes of "the technological evolution of the media and its possible use for non-capitalist goals, in particular through a reduction in costs and through miniaturization" (Guattari, 2005, p. 62). He sees this as one of the factors for tempering "media fatalism" behind a "seeming impossibility" of escaping the current unparalleled level of media-related alienation.

Technological advances—such as GIS tools moving to web-based platforms, advances in computing power and Web 2.0 interactivity—provide new opportunities that my interlocutors are quick to take advantage of. Yet, as CMAQ producers point out, the demand is always growing alongside computational capacity, and technological factors are spoken about as limiting and constraining, as well as enabling and a driving force behind advancements in the modeling system. Stakeholders at the EPA and beyond simultaneously demand finer spatial resolutions and attention to global processes. Every fragment of computational capacity is being used. The scarcity of computing power has led to new collaborations, such as CMAQ developers partnering with the Department of Energy to use their supercomputers and the global modeling community collectively deciding about how best to coordinate global efforts (in the venue of AQMEII). Atlas producers, similarly, pointed out that pooling resources is especially important given limited resources and budget constraints. Technological advances have played an important role in the proliferation of many environmentally focused websites and tools, but these individual projects can be relatively disconnected and fragmented. Looking beyond the technology "itself" helps the Atlas and CMAQ producers stay close to questions of how best to develop the sociotechnical *systems* needed for effective environmental media projects. Accounting for sociality also keeps these producers attuned to the broader political-economic context they work within. The contemporary political climate around environmental issues in the United States is extremely charged and highly polarized. Influential conservative think tanks, such as the American Enterprise Institute, described above in Chapter Four, have recently ramped up attacks on the sciences of the environment and the legitimacy of the EPA.

George Lakoff argues that conservatives have largely won the battle over public perceptions of the costs of environmentalism by developing long-term strategies and framing tactics that give them the upper hand. They are able to cut social programs by activating a frame of lacking. When progressives talk about limiting our consumption in a finite world, the frame of lacking can unintentionally be activated, supporting policies such as cuts in social programs.[144] For Judith Butler, frames are "ways of selectively

[144]Lakoff writes that (Lakoff, 2010, p. 74):

carving up experience" (Butler, 2010, p. 26). The Atlas could be experienced as a map of lack (showing how many services have been degraded over recent decades), or a map of abundance (making visible services provided by ecosystems and the built environment that are often overlooked). Annie Neale hopes the Atlas will show how smart land-use decisions could maximize the potential of remaining ecosystems services and how conservation measures can preserve the goods that underlie such services. A section with use-cases could highlight some of the best outcomes of engagement with the Atlas, showcasing stories such as Neale's on water filtration by planting on farmers' adjacent land instead of investing in an expensive technological fix. Use-cases could show how ecological insights can help in developing synergistic solutions. Protecting the environment, of course, is not necessarily a net drain on the economy.

Economic factors have a huge effect on environmental action. Invoking the costs associated with mitigating pollution and transitioning to cleaner technologies is a key strategy conservatives use to rationalize attacks on environmental regulation. When talking about the need for robust science, CMAQ developers repeatedly invoked the cost of regulations. EPA laws limiting pollution, slowing resource extraction or taxing gasoline are portrayed as job killers that hit the "middle class" hard. A zero-sum game with the environment vs. the economy is precisely the kind of thinking that the Atlas, and the ecosystems services paradigm, could work against. In contrast with recent focus at the EPA on "balancing" ecological and economic concerns (as in the rhetoric behind press-releases for the Atlas) and making economic impacts a guiding principle (as heard in recent commentary by administrator Lisa Jackson), the EPA has a history of framing itself as an independent agency that acts as an environmental advocate.

Beyond setting the conditions under which ORD scientists can speak, EPA

> what is needed is a constant effort to build up the background frames needed to understand the crisis, while building up neural circuitry to inhibit the wrong frames. . . yet, the communications teams for environmental non-governmental organizations, the U.S. Environmental Protection Agency, the think tanks, and U.S. Congress have something to say by next week—or tomorrow! They need words and slogans now! And so they see framing as a short-term messaging issue.

How could future EMSs take account of a context in which staccato articulations, or aphoristic slogans, are called for, even as they transform the context, making more room for longer term strategies and frame-building?

communication policies can also limit the affordances of EMSs. Atlas producers face serious challenges as they attempt to design the avenues for citizen science called for by many of their stakeholders. There is great concern that citizen-produced data, which has not been vetted, might be confused with EPA data. But this kind of concern is far from unique to the EPA, and there are many examples that could be drawn from to work-around these challenges and create a space where well-curated data could be mixed and matched while maintaining the meta-data and distinctions in the processes that created the data (Mclaren, 2012). Marking how data has been collected and interpreted and making uncertainties explicit are already key design logics of the Atlas. With the help of the Atlas's contextualizing affordances, the value of citizen-generated data, relative to other data sets, could be interpreted differently by different users. There will always be difficulties with data provenance, but developing the meta-data procedures to make differences apparent and navigable could show that the EPA is capable of publicly acknowledging and working through these difficulties.

The perception of the world as in ecological crisis has led to some of my interlocutors shifting their ideas about certain strategies and frames, such as sustainability and ecosystems services. Laura Jackson speaks about how, despite sympathizing with many of the critiques of the eco services paradigm, she feels compelled to endorse it because "we're at a point where we're in crisis. . . we just need to switch tactics. . . I feel like this is the last ditch argument for conservation" (Laura Jackson, 2011a). Motivated by rapidly acting threats to biodiversity and a feeling that previous paradigms simply are not working, Jackson is experimenting with a kind of strategic anthropocentrism in her design of the Urban Atlas and the Eco-Health Relationship Browser. Jackson's negotiation of these tensions is an example of a broader trend at NERL to develop systems that respond to politically and scientifically complex problems.

5.6.2 Substantive Logics, Design Logics and Imaginaries

Researchers at the EPA feel the need—perhaps increasingly so—to develop relays with various publics in order for their research to make a difference in land-use management, policy making and modes of conceptualizing the nature of the

environment. Traditional modes of circulating environmental information, largely reflective of the transmission model of communication, are simply not up to the tasks of raising public awareness, enabling interdisciplinary collaboration, developing sound science or tackling problems of national significance. My interlocutors recognize that science communication focused on producing articles for closed-access journals that can be difficult to access by the public is increasingly outdated. With projects like the Eco-Health Relationship Browser, they are making environmental data and information from disparate fields much more accessible and usable. The Atlas draws data sets together to inform decision-making in a way that, compared to written articles interpreting results from a particular point of view, can be taken up for many more purposes by a variety of users. Results that are published in scientific journals, such as advances in photochemistry, can also find their way into the algorithms of the CMAQ model where they are combined with the state-of-the-science in other fields.

My interlocutors, as public servants at the EPA, have an explicit mandate to protect the environment and human health. Yet they also seek to maintain an aura of objectivity and do not want to be perceived as activists driven by "politics." CMAQ developers' articulations and practices around credibility help to illuminate, and catalyze, emergent epistemological mutations. The CMAQ community has shifted away from failed experiments in quantitative benchmarking to focus their development and evaluation efforts on close scrutiny of the networked science in the model. The Eco-Health Relationship browser contains a mix of qualitative and quantitative claims and relies on a kind of informated objectivity. Layering related claims can add up to robust evidence. In both CMAQ and the Browser, the collective wisdom of peer-review, based on assembling situated and partial perspectives, is valued over an image of truth as full and final. To return to a refrain from Lawrence Reiter, a phrase that has come to mind countless times since our fist conversation in 2009, the goal is reaching *requisite precision*. Perfect precision is recognized as impossible, and decisions about what counts as requisite are highly, and inescapably, political. Given the contested nature of modeling, CMAQ developers pay great attention to caring for the (scientific processes in) model *and* the collective that produces and evaluates it. They are driven by the need to produce a sociotechnical system that can withstand well-financed critique. CMAQ

developers are guided by a sense that we need improvements in literacies around modeling, development of modeling systems that meet ever-changing demands from policy makers and new forms of collective decision-making about research priorities and what should count as sound science.

The assemblage of EMSs capable of fostering new forms of environmental and scientific literacy will require the development of new design imaginaries. My interlocutors articulate and practice a number of design techniques and styles that were rare, or non-existent, at the EPA just a decade ago. Many of the design logics articulated and practiced by my interlocutors resonate with the language of new media (Manovich, 2002).

Both the Atlas and CMAQ place high value on interactivity. The Atlas presents pre-defined quantitative assessments of eco services so that values can be compared across space and time, but also allows users to modify this index to accommodate their particular concerns. Unlike a scientific article, which tends to have very focused goals, chosen by the author, the Atlas allows readers to bring their own questions and aims. CMAQ requires users to interact with the system in a profound way; they must essentially re-assemble the system for every use case.

My interlocutors, of course, do not use the language of communicationXcreation, but they are designing systems that exemplify this concept. Goldstein (2011, 299) points out that the ORD "has two major responsibilities with regard to EPA's needs: (1) the performance of pertinent scientific and technical research and (2) the translation of their own work and the work of the scientific community for use by EPA regulators and its stakeholders." The Atlas, CMAQ and this dissertation are largely motivated by the need for improving the latter, especially by creating new contexts enabling translation and interaction. But the two goals are not mutually exclusive and the Atlas and CMAQ are exemplary cases where improving translation and circulation for stakeholders beyond the ORD could also enable better scientific research within ORD.

When I asked Neale if the Atlas, with its ability to circulate, visualize and synthesize data, could be a research tool that could help in the creation of *new* knowledge, she replied the Atlas would go a long way to making data much more accessible and usable by researchers, especially those focused on making connections

among ecosystem health and human health. Neale says that it can take months to compile data for a research project and the Atlas will radically cut down on the time it takes to gather data. With the clip and ship function, users can highlight the area of concern and download all the geospatial data for that space.

Neale's description of the Atlas as a container for diverse data sets and the state-of-the-science in various fields resonates strongly with CMAQ developers' articulations of the model as a numerical laboratory. Both the Atlas and CMAQ draw together and circulate diverse data, create a context for better collaboration and decision-making. Synthesis *within* these two projects draws on and produces connections *across* projects. The Atlas, for example, will serve CMAQ output data to account for air pollution as a driver (or detractor) of ecosystem services. CMAQ is far from a user-friendly interface for people outside the air quality modeling community or without programming experience and its inclusion in the much more intuitive Atlas interface will make its outputs far more accessible.

The communicative practices of NERL scientists like Robin Dennis clearly illustrate how the labor of EMS creation cannot easily be parsed into "social" and "technical" aspects. Designing and developing EMSs requires working through differences in paradigms and, Dennis explains, requires a great deal of communication and coordination among different types of scientists, as well as different tools. Leveraging the heterogeneity of expertise at the ORD, Dennis helps build relays among watershed people and CMAQ people, the outputs of one model and the inputs of another. This communication is essential for the creation of usable knowledge on how pollutants in the atmosphere interact with the Earth's surface under various land-use conditions. Modularity and affordances for relaying were built into CMAQ from the start;[145] Dennis and his colleagues are drawing models together to create an ecology of EMSs that helps to understand ecologies of pollutants, landscapes and meteorological phenomena.

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[145]As core CMAQ developers Byun and Schere write, "CMAQ is not a monolithic model;" rather it is a "modeling system that allows users to build customized chemical transport models for air quality problems" and a "key design choice" is allowing "integration of multiple emission processing models, meteorological models, chemistry transport models, and analyses of inputs and outputs" (Byun & Schere, 2006, p. 7).

5.6.3 Cultural Critique

Through their design of EMSs, and their collective practices, my interlocutors articulate a number of critiques of standard conceptions and practices around the key themes of this dissertation: communication, literacy and collectivity. They also critique economic schema that ignore the value of the natural world, policies that see humans as separate from our environment, the Enlightenment view of separate individuals that are self-sufficient and a construction of nature as a separate-something to be dominated. But my interlocutors also provide more generative insights. Their values are embedded in the EMSs they produce and reflected in the collective processes of production. The Atlas enables better visualization of the interconnectedness that is at the foundation of an ecological world-view. A kind of humility, based on recognition of the complexity of the atmosphere, and the inability of any single individual or discipline to grapple with this complexity, underlies the development of the CMAQ modeling system's peer review practices. Rather than seeing these more social aspects as contaminating otherwise pure scientific content, the Atlas and CMAQ show how robust sociality can actually produce better science. In the environmental (regulatory) context, appeals to truth and sound science are necessary in the development of policies that work.

My interlocutors' articulations and practices challenge traditional notions of what communication is and can do. Their work circulates in contexts that are themselves re-produced through this circulation. The differences between a transmission model of communication and one that focuses on context production can have significant effects when they are embedded in EMS design. In the cases of the Atlas and CMAQ, linking data requires linking experts. The EPA EJ 2014 document states that (EPA, 2011a, p. 114):

> the hallmark of the integrated proposed transdisciplinary approach is "systems thinking," which seeks to understand the complex interactions between social, natural, and built environmental systems, conditions and policies that impact human health and well-being.

I use a broad definition of EMS—including people, practices, online spaces, technologies—as sociotechnical systems, whereas "environmental information systems" tends to emphasize the technological aspects of the system. Defining EMS in this way is

reflective of the labor of my interlocutors, which this dissertation shows is simultaneously social and technical.

The articulations of producers of the Atlas and CMAQ provide opportunities for rethinking what counts as good scientific practice, science communication and communication writ large. The material I gathered for this dissertation is especially rich because my interlocutors grapple with my research questions as well. They are highly reflexive about the contexts they work within, their motivations, their design choices and their critiques of traditional practices in science communication. Future research could use this material as a jumping off point to further explore questions shared by STS scholars, a variety of decision makers and my reflexive and articulate interlocutors.

6. Epilogue

6.1 Overview

> *It would also mean not affirming that "everything is connected" but knowing that every connection is a creation, a "putting into" relation, an event creative of the plane that it will inhabit.*
>
> - Isabelle Stengers and Phillipe Pignarre, *Capitalist Sorcery: Breaking the Spell*, (2011, p. 69)

Every connection is a creation; this short phrase forges a relay with my contention, articulated at the beginning of this dissertation, that widely circulating calls for going "beyond talk" should be supplemented with the task of going beyond models of communication that separate talk from action, communication from creation.

To address the environmental challenges of the future, we will need EMSs that draw on and produce explanatory pluralism (Keller 2002, 300) but also epistemological, communicative, strategic, tactical, affective and aesthetic pluralism. EMSs never exist in isolation; like the linkages that make up the CMAQ modeling system, we need an ecology of EMSs that, as an assemblage, enhances our ability to tackle a plurality of intersecting environmental problems. There are lessons to be learned from many naturecultures, such as the permaculture principle of designing a system where each element has outputs and inputs that connect with many other elements. Synthesizing the tools and knowledges that already exist (work performed by both the Atlas and CMAQ) and developing better overviews of what has already been accomplished, so lacunae become visible, remain key tasks.

Based on my readings of EMS producers' practices and articulations, the following pages offer modest suggestions to invest resources and build capacity to better: account for the mediation of perception; understand heterogeneity among scientific communities of practice and the so-called lay public; make differences within communities of practice productive by fostering science communication as context production; broaden notions about where political action happens (including the development of epistemological literacies); look beyond technical fixes to account for necessary cultural shifts and re-conceptualize environmental communication to provoke

different perspectives and not simply transmit more of the same. I then revisit some of the stakes involved in EMS production and conclude with a call to develop relays between environmental scientists and scholars in STS and other social science and humanities disciplines.

6.2 Prescriptions

6.2.1 Improve Prosthetics for Mediating Understanding of the Environment

We—as a society, government and advocates of various stripes—should give up the notions of perception without prosthetics and raw data. We can only know the environment through partial, situated, mediated lenses, so rather than disparage our lenses for their imperfections, we should draw together a pluralism of perspectives and examine their strengths and weaknesses in different contexts, as well as their potential layering. We should pay close attention to the potential of EMSs to catalyze (and reflect) the assemblage of new forms of objectivity or notions of good science. The explicit attention to mediation and interpretation exemplified by the Atlas and CMAQ producers I spoke with, for example, departs from the epistemological ideal of mechanical objectivity, which aims for the capture of nature with as little human intervention as possible (Daston & Galison, 2007). My interlocutors' articulations and practices tend to resonate closely with informated objectivity (see footnote four above). When evaluating scientific knowledge, we should take into account the processes of its production and communication should be considered to be essential in the scientific process, not outside or after the fact. EMS producers are experimentalists and cultural producers that should be listened to as we attempt to imagine new conceptions, practices and political discourses around scientific communication, visualization, objectivity and literacy. Helping to draw attention to, and develop, new discourses of legitimation for the environmental sciences is a key political contribution of this dissertation.

In order to improve the systems with which we mediate our understanding of the environment, my interlocutors engage regularly with many of the important and under-analyzed ethical and political tasks brought up by Geoff Bowker in *Memory Practices in the Sciences,* such as paying close attention to standards and classification systems that are folded into models and simulations (a key aspect of producing and evaluating

CMAQ) and developing institutional structures that can take full advantage of emergent possibilities for collaboration and sharing data, information and knowledge (Bowker, 2008). Bowker contends that (Bowker, 2008, p. 127):

> The central issues for science and technology in the context of the new knowledge economy are the development of flexible, stable data standards; the generation of protocols (both social, in the form of international agreements about data exchange, and technical, in the sense of metadata standards) for data sharing; and the restructuring of scientific careers so that building large-scale scientific infrastructures is as attractive a route as performing high-profile theoretical work.

The work being done by the designers and developers of both the Atlas and CMAQ resonates strongly with many of Bowker's concerns. The environmental media they produce are embedded in and are catalyzing new systems: institutional and social (in the form of modes of collectivity, public transparency of peer review, value of the labor of EMS production), technological (synthesizing ecologies of tools and knowledge, making connections among platforms, providing new points of view at different spatial and temporal scales) and cultural (enabling shifts in ecological literacies and ontologies).

6.2.2 Foster Greater Understanding of Heterogeneity

Scientists should be encouraged—with educational and institutional initiatives, as well as exposure to EMSs like the Atlas and CMAQ—to learn about heterogeneity among their communities of practice and the so-called lay public. Seminars or workshops at NERL could focus on unpacking the term "community," frequently used in initiatives such as Barzyk's Tools for Community-Based Cumulative Risk Assessment (Barzyk, 2011). Recognition of a diversity of expertise, goals, etc. potentially increases connectivity and potential relays. Problematizing the scientist/public dichotomy further could help make NERL research more relevant and effective. Departing from standard models of risk communication and scientific literacy, I argue that cases of uncertain science demand *new kinds* of literacy and, therefore, new approaches to the question of why and how science should be communicated to different communities or publics (including scientists). While much scholarship on the public understanding of science

focuses on *what* people know (measured with surveys or multiple-choice tests), we also need to account for the effects of *how* publics think about knowledge.[146] Instrumental content delivery is one role that EMSs play, but, perhaps more importantly in many cases, these systems can sometimes allow the user to interactively re-assemble content (perhaps adding their own) in order to see/be/ask something new. The EMSs I analyze, reflecting and catalyzing emergent modes of work and knowledge production in the environmental sciences, are made possible through the assemblage of diverse experts and institutions and, in turn, are heavily cross-linked with, or incorporated into, other systems.

6.2.3 Make Differences within Communities of Practice Productive by Fostering Science Communication as Context Production

In addition to recognizing difference within communities of practice, it is essential to create spaces for *making difference productive*. Attention should be paid to how drawing together different perspectives, goals and forms of expertise can generate new *knowledge* (through interdisciplinary collaboration or educational initiatives), *subjectivities* (through trying on the lens of an other, as in using the Atlas designed by ecologists or working with the CMAQ model) and *collectivities* (as an explicit outcome of EMS production and use, not just a preexisting precondition for its assemblage). We should invest more resources— including funding, education, job creation and credit— in science communication as *context production*. Context production, in the sense practiced by Atlas and CMAQ producers is an emergent form of work that deserves greater credentialing and support. We need to go beyond the transmission model of communication because a) complex objects and challenges demand it, b) single contexts (EMSs) that accommodate and draw together diverse expertise and multidirectional

[146]In his visit to Mike Fortun's (Minor Literatures in) Science Studies class (May 14, 2010), Rich Doyle, Professor of English and scholar of scientific rhetoric, talked about (and poked fun at) a conception of information as quantitative objects, encapsulated in bits and shared with audiences in a process that requires no transformation by the sender or receiver in order to attain shared comprehension. This conception of information underlies what I would call a weak version of literacy, one that is measured solely by the quantity of knowledge acquired and does not touch on meta questions (so dear to STS) of how knowledge is produced, valued and circulated.

communication foster interdisciplinary collaboration better than fragmented packages tailored for different communities of practice.

6.2.4 Broaden Notions about Where Political Action Happens

We should look beyond the federal policy-making process when identifying pressure points for change in environmental practices. The Atlas producers' work suggests the value of providing informational resources for municipal decision-makers, NGOs focused on conservation, land-use planners at a variety of scales, etc. CMAQ shows how EMSs can be taken up around the world in different regulatory contexts and be used to model the global environment. When building relays, environmentalists should not only identify potential collaborators (with different forms of expertise); they should also consider a pluralism of scales and effects.

How can EMSs be designed to provide the conditions of possibility for usefulness to an array of users? How could EMSs catalyze the formation of new kinds of users, new forms of collectivity and new techniques for participation? What would it take to create an ecology of EMSs that actually *worked* to create a radically better social, ecological, cultural environment?[147] Would the machine run more efficiently if attention was diverted from needless redundancies to the weakest links? What could scientific and environmental literacy become in the digital age? The EMSs described in this dissertation play an important role in decision-making at the federal level, but they could also have myriad reading-effects, including the catalysis of the kind of epistemological literacies that are at the foundation of an education in STS. EMS designers and developers should take this potential for reading-effects seriously. EMSs, at their best, can provide tools for developing environmental literacy that attends to knowledge accumulation *and* the skills required to navigate complexity and uncertainty. Literacy should go beyond "learning the facts" by developing understanding of the practices by which information is produced, stabilized and circulated. The Atlas, for example, will

[147] As a former NERL director put it: "we have lots of star players, but we're not yet winning any championships." George Lakoff argues for the development of an institutionalized environmental communication system with the long-term goals of creating framing systems so that progressive environmental articulations can be heard (Lakoff, 2010).

provide both a) an interface that allows users to stack different data layers and see relationships among, for example, the amount of green space around a residential area and an index of health and well-being in that community and b) information on the limitations of the data provided in the Atlas and instructions on how to drill down to the original sources, identifying the producers of the data and their institutional and financial affiliations. This could bolster epistemological literacy in Atlas users. If the public becomes accustomed to investigating where claims are coming from and giving more credence to claims (and models) that have been through thorough peer-review, they might be less likely to be duped by publications like *Bad Science*, the tobacco industry-funded handbook that contained claims like "undue regulation costs a family of four $1,800 per year," yet "contained no primary sources or annotations. Nearly all the quotes were assertions presented as facts" (Oreskes & Conway, 2010, p. 145)

Helping users to negotiate floods of data and develop acumen for recognizing the relative strength of varying scientific claims is especially important in new media contexts. New media can accomplish a kind of flattening of hierarchies that is sometimes applauded for democratizing information, but also presents novel challenges. As Lovejoy, Paul and Vesna write (Lovejoy et al., 2011, p. 3):

> digital culture is based on the absence of structures that are common in the offline world, which is saturated with hierarchies that do not make much sense online… the immediacy of transition that is made possible by hyperlinks erases the perception that we have moved between blocks of information that—in the offline world—would be pages and shelves, or even cities and counties apart. The order of the elements is no longer a reliable indicator of hierarchies. The spatial distance dividing the center from the margin or text from context is subordinated to the temporality of the link.

The disintegration of hierarchies can seem a welcome development for those who seek to challenge the hegemony of state science. But, as Chapter Three on the Atlas shows, opportunities for citizen science may sometimes actually depend on developing meta-data markers that keep distinctions on the surface. The EPA is unlikely to allow citizen-scientists to publicly share and display their data alongside official EPA data unless data provenance is clearly marked. More generally, indicators of credibility are essential in an

informational ecology marked by corporate greenwashing and excessive data in need of curating.

6.2.5 Look Beyond Technical Fixes

Arguments that technical fixes will emerge for problems like peak oil and climate change circulate widely, but environmental challenges demand socio-technical solutions. Firstly, there is no technology separate from society or social processes. Green technologies will only emerge rapidly and with high quality if their development is prioritized through political and social decision-making. Complex environmental problems require a plurality of solutions working together; not all are primarily technological. To successfully address daunting environmental challenges, we also need cultural shifts.

The reading-effects of EMSs could operate at the level of ontology. Engagement with EMSs could encourage a more ecological mode of seeing, thinking and acting. Teaching and learning are not about the transfer of information, but worldviews. Likewise Antonio López, writes that **"**after half a century of media theory, we should be well beyond a 'content'-only approach to communication**"** (López 2010, 99). In *Steps to an Ecology of Mind,* Gregory Bateson describes the challenges of developing a view of the world based on immanence instead of transcendence. He writes (pp. 462-463), perhaps somewhat hyperbolically, that if you have a transcendent relation to nature

> *and you have an advanced technology*, your likelihood of survival will be that of a snowball in hell. . . the most important task today, perhaps, is to think in the new way. . . the step to. . . making habitual [an immanent] way of thinking. . . is not an easy one, [but] there are experiences and disciplines which may help me to imagine what it would be like to have this habit of correct thought.

EMSs should work to "make habitual" the "correct way of thinking" in which "the perceiver and the thing perceived become strangely united in a single entity."[148] Bateson

[148]But I do not want to romanticize total immanence between subject and the world. Baudrillard (1988) writes that (Baudrillard, 1988, p. 27):

> The schizophrenic is not, as generally claimed, characterized by his loss of touch with reality, but by the absolute proximity to and total instantaneousness with things, this

was a true radical, in the sense of striving to make sense of the roots of things. In "The Roots of Ecological Crisis," he argued for a shift from *ad hoc* approaches to environmental problems to addressing the unintended consequences of technological advance, population increase and "conventional (but wrong) ideas about the nature of man and his relation to the environment" (Bateson, 2000, p. 496). He argued that focusing on conventional attitudes toward the environment was the only possible entry point to reverse a self-reinforcing process that could lead to the logical *reductio ad absurdum* of our old positions destroying us.

Cultural shifts in how we know and inhabit the environment are especially important in light of communicational theories that go beyond the transmission model, which Boholm argues can entail a lack of attention to matters of context (Boholm, 2009). Transformations in the contexts in which environmental communication is interpreted, which include cultures of literacy and sensibility, feed back into further shifts in literacy and sensibility. EMSs are technological prostheses that enable the spread of thought styles, such as ecological and model thinking (Fleck, 1981). Ecologists like John Kineman and popular environmentalist writers like Francis Moore Lappe converge on the belief that **w**ithout transcending the paradigm of mechanistic thought**,** framing strategies alone will not produce the deep change necessary to tackle the matrix of contemporary environmental problems (Kineman, 2011; Kineman & Kumar, 2007; Lappe, 2011). Since the notion of 'pure' information is fictive, and the mind-set and context in which EMSs are used inevitably affects the outcome (as in the powerful influence of set and setting on the experience of psychoactive substances), shifts towards an ecology of mind will feed back and affect how the double-binds and affordances of different EMSs play out, their effects and affects in the world.

6.2.6 Reconceptualize (Environmental) Communication and Develop Provocative EMSs

More poly-vocal and provocative communicative strategies should be developed in the environmental arena. In "Signature Event Context" (1988), Jacques Derrida asks,

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overexposure to the transparency of the world. Stripped of a stage and crossed over without the least obstacle, the schizophrenic cannot produce the limits of his very being.

"is it certain. . . that the word *communication* corresponds to a concept that is unique, univocal, rigorously controllable, and transmittable: in a word, communicable?" (Derrida, 1988, p. 1). The same might be asked about the words *environment* and *nature*. Conceptualizing nature as univocal may tempt us to stick with communicative forms that transmit, as simply as possible, the single voice. Conversely, subscription to a kind of multi-naturalism may more accurately describe the pluralism in concepts as excessive as the environment or nature. De-centering the priority of control or intention—whether in regards to communication or the environment—could open up more collaborative possibilities. Giving up the notion of fully controllable communication and environments does not mean ignoring the hard work of attempting to account for unpredictable effects of articulation or working to shape nature as more livable; on the contrary, if we take account of how communication and environments can escape the trajectories we plan for them, and learn from experiments along the way, we may be more likely to successfully engage in the labor of crafting resilience and resonance.

Derrida carefully dismantles what he calls "classical" conceptions of language, communication and writing as vehicles for the transportation of meaning, extending the presence of the author with various inscription technologies. Instead, he insists on (Derrida, 1988, p. 12):

> the possibility of disengagement and citational graft which belongs to the structure of every mark, spoken or written, and which constitutes every mark in writing before and outside of every horizon of semio-linguistic communication. . . every sign. . . can be *cited* . . . in so doing it can break with every given context, engendering an infinity of new contexts in a manner which is absolutely interminable.

While it is central to Derrida's argument that *every* mark is iterable, different marks can iterate differently, in/as different forceful contexts. The ability to *create* new contexts (and subjectivities, collectivities, desires and new signs in turn), through citation and iteration, is a key attribute of the EMSs—as experimental systems—I map in this dissertation. The extent to which EMSs travel and are re-mediated in other forms and contexts can be a mark of their experimental nature and degree of success.[149] CMAQ, for

[149]Could a classical conception of writing underlie some of the EPA's policies on communication, in which

example, can only work by citing a multitude of other models and then becomes useful to policy makers through its re-mediation via visualization software.

In part in order to see articulations from my interlocutors at NERL in a new light, I spoke with a number of artists working at the nexus of art and biology in the course of this research. While their practices are quite different from the producers of the Atlas and CMAQ in some ways, their approach to thinking through communication resonates with the model of communication as context production. They viewed artistic practice as creation, or *provocation*; they compose new contexts that create opportunities for exploring ethical subjectivities, critical questions and models of collectivity. I found that referring to their work as an example of "communication" could be heard as degrading of their practice, or just missing the point. When I first mentioned wanting to explore bio-art projects as instances of environmental or scientific communication, media- and bio-artist Kathy High cautioned that artists in general, and perhaps especially bio-artists, wouldn't generally use the word communication to describe what they're going for. Perhaps, I thought, this dis-ease with the term communication could be productive. How could we mutate our notion of communication to better accommodate the goal and process of bio-art and tactical media projects? High told me that she thinks artists—when being considered in collaboration with science—are often asked to become the communicators, decorators, illustrators or visualizers. While incredibly important and useful, High prefers to focus on the potential for art to provoke discussion around the sciences, not just translate the results of the scientific process. Like the Atlas and CMAQ, interaction with bio-art can provoke new questions, drive new inquiry and shift perceptions. High speaks to how many artists working with scientists and scientific

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the Office of Environmental Information appears to aim for rigorous control of both the articulations of ORD scientists and the contexts in which their communications appear? How could recognition of the radical iterability of communications inform EPA communication policies, especially attempts to make science relevant, seeking citations in policy, public action and perception? How else could the EPA and others improve the cite-ability and iterability of their work? How might EPA policies change with the recognition that "the possibility of the negative (in this case, of infelicities) is in fact a structural possibility, that failure is an essential risk of the operations under consideration" (Derrida, 1988, p. 15). Instead of excluding that "essential risk" as "as accidental, exterior, one which teaches us nothing about the linguistic phenomenon being considered… in the name of a kind of ideal regulation" (Derrida, 1988, p. 15), the EPA could experiment with systems that are more comfortable with, or even welcome, the structural possibility of being taken up in multiple ways.

practices do not want to be seen as communicators if communication is seen as something that happens after the real labor of science, or outside of it.

I can relate to High's concerns in my own attempts to develop collaborative practices with so-called "hard" scientists in *The Asthma Files*, which is developing into a digital assemblage of many different perspectives on asthma and environmental health. We do not want to simply translate scientific findings into easier language, for consumption by the public. We do not want to simply transmit information. Instead, we mobilize collage tactics and juxtapositional logics, taking things that might not ordinarily appear next to each other, in a multitude of discrete asthma files, in order to provoke questions that our audiences might not have otherwise come up with.

One of the key arguments that cuts across my research sites is that communication and circulation of information is actually central to the scientific process itself. In art as in science, when an experimental system is successfully produced, communication gets crossed with creation: creation of new knowledges, tools, subjectivities and careful collaborations. EMS designers at NERL should take account of how the systems they design could provoke new questions and discussion within their communities of practice and beyond.

6.3 Re-Visiting The Stakes and Starting New Conversations

The shifting and layered modes of scientific communication I document and analyze (communication as transmission and context production, vehicle and space, one-directional bullet aimed at the public and interactive tools usable by surprising audiences with unexpected modes of distribution) exist in an environmental communication landscape characterized by a great deal of worrying (for good reason) about poor scientific communication on complex environmental conditions like climate change. Tea-party logics, short-sighted thinking and rhetoric bemoaning the "interference" of the EPA need to be countered. As corporations intensify efforts at greenwashing and discrediting work linking the environment and health effects by picking apart webbed knowledge (or informated objectivity, assembled from exposure science, toxicology, modeling, etc.), we need better narratives for how EMSs could *work* to develop compelling (and actionable, even though imperfect) evidence in the face of uncertainty

and complexity. STS is well positioned to go beyond critique and contribute to the composition of new questions, discourses on legitimacy and accounts of how the EPA could engage in political, ethical and economic debates.

Judith Warner's article "Fact Free Science," in the *New York Times*, describes the refusal of political functionaries to recognize anthropogenic climate change and argues that science studies is partly to blame (Warner, 2011). Similar critiques are emerging from within STS. In "Why Has Critique Run Out of Steam?: From Matters of Fact to Matters of Concern," Bruno Latour rants that (Latour, 2004):

> entire Ph.D. programs are still running to make sure that good American kids are learning the hard way that facts are made up, that there is no such thing as natural, unmediated, unbiased access to truth, that we are always the prisoner of language, that we always speak from one standpoint, and so on, while dangerous extremists are using the very same argument of social construction to destroy hard-won evidence that could save our lives.

While Warner and Latour's blanket (mis)treatments of contemporary science studies are less than charitable, this dissertation shares their frustration with much "debunking" STS scholarship and seeks to contribute to a growing body of work in STS that goes beyond some of the limits of social constructionism.[150]

Poststructuralist scholarship is sometimes painted by detractors as part of a (perhaps unintentional) project to destroy scientific authority. In *Good Science: The Pursuit of Truth and the Evolution of Reality,* Timothy McGettigan spends the entire forward disparaging the so-called postmodernists for their anything goes attitude towards truth, unfortunately re-producing simplistic and unproductive accounts of the so-called science wars.[151] Rather than fall into the reductive and worn out rhetoric of the

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[150]I am inspired by writers such as Elizabeth Wilson (who draws on readings of Darwin and the materiality of "neural geographies" to re-invigorate feminist science studies), Elizabeth Grosz (who re-images nature as active, creative, vibrant and immanent with culture) and the materialist/realist ethnographies of Stuart McLean and Todd Ochoa (Wilson, 1998; Grosz, 2011; McLean, 2009; McLean, 2011; Ochoa, 2010).

[151]See Schurman and Pratt on debates over GIS in which accusations of "positivism" were thrown around, but with very little substance or agreement on what this term means (Schuurman & Pratt, 2002). They reviewed a host of feminist critiques of GIS in which abstract and general critique was rarely generative of new insights or practices. Accounts of scientists (or "postmodernists") as "reductive" (or "relativist") it turns out, tend to be themselves quite reductive. Tomes disparaging scientists for their lack of reflexivity can lack reflexivity. My descriptions of the Atlas have aimed to embody the "care of

so-called science wars, hurling offenses—Positivist asshole! Postmodern freak!—back and forth when both sides can share many of the same goals, my interlocutors should be understood as highly reflexive about the limits of their practice and inventive in articulating the value of their work, crafting narratives that do not require appeal to grand narratives or enlightenment notions of progress. Given the scale of unprecedented environmental threats like climate change, we should continue to develop understanding on how people respond when the world in which they operate is outrunning their training (Fischer 2004, 9).[152] The work of the CMAQ group and the Atlas producers suggests that, often, they experiment. They develop skills that were not on the job description. For Rheinberger, "experimental systems. . . must be capable of differential reproduction in order to behave as a. . . 'generator of surprises.' 'Differential reproduction' refers to the allowance, if not the necessity, of shifts and displacements within the investigative process" (1998, 288). When EMSs become experimental systems, at their best, they generate answers, shape new questions and catalyze both inquiry and literacy.

This dissertation weaves articulations from my interlocutors to help sketch new narratives for the legitimation of science (or at least bring attention to the sketches they're in the process of creating). Jean-François Lyotard, philosopher and literary theorist, argued that the sciences often have excluded narrative (and, by proxy, I would add, visualization, communication, the care of the data, etc.) in their articulations of how science works and instead relied on meta-narratives, or grand narratives, such as enlightenment notions of progress through history, the knowability of everything by science and the possibility of absolute freedom (Lyotard, 1984). Evelyn Fox Keller, a

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the subject" called for by Schuurman and Pratt by including close readings of the technology itself and, instead of chastising GIS for reducing the complexity of the world (a critical move that would be, *ironically*, reductive of the complexity of GIS, and the myriad contexts in which it can be used) describing how framing choices in GIS enable some things to be seen, while occluding others. I use the term ironically here in Isabelle Stengers' (2009) sense of the term, which she opposes to "humor," the former tending towards a detached form of critique, while the latter signifies an immanent engagement with the subject at hand, and a stance of Nietzschean affirmation (Nietzsche, 1974).

[152]Fischer writes that "we live (again) in an era in which there is a pervasive claim, or native model, asserted by practitioners in many contemporary arenas of life (law, the sciences, political economy, computer technologies, etc.) that traditional concepts and ways of doing things no longer work, that life is outrunning the pedagogies in which we were trained" (M. Fischer, 2004, p. 9). Three arenas, relevant to this dissertation, in which Fischer sees this dynamic as especially clear are: expanding information-data-bank-networked infrastructures, environmental or ecological changes and the legal, economic, psychological and social institutional innovations that these overlapping arenas require.

biologist, philosopher and historian of science writes that Thomas Kuhn's classic work "provided a welcome alternative to the view maintained by scientists themselves, and until then unchallenged by most historians: the view that science is autonomous and absolutely progressive—approximating ever more closely a full and accurate description of reality 'as it is'" (Keller, 1996, p. 5). Contemporary physics, which has thrived on the hegemony of grand narratives, may actually be chipping away at that very hegemony by putting into question the nature of reality as objectivist and knowable. Keller, writes about how a myopic focus on the gene as "the holy grail" fueled much work in genetics and, ironically, has resulted in a partial unraveling of a narrow focus on the gene (Keller, 2002b). In *Disrupting Science,* Kelly Moore documents how many scientists act reflexively to change scientific practice in light of societal demands (Moore, 2008). Similar moments of science de- and re-constructing itself are highlighted in this dissertation as sites where emergent ontologies and epistemologies may be coming into view. CMAQ developers, for example, are candid about the porous walls of the modeling community, speak of how regulatory needs are directly connected to decisions about model development and describe how models are never "true," though some are useful; this is all while maintaining—and for good reason—pride over how the model is continually improving, through diverse collective effort, and becoming better at approximating the complexity of the atmosphere.

Michael Fischer contends that (Fischer, 2004):

> the aim of the next generation and its children [after Horkheimer, Adorno and the multicultural movements of the '80s and '90s] should be to find new narratives to live by, new modes of critique that can help establish ethical signposts and queries for an age of more complex institutions, cultural diversity, and reconfigured modalities of agency.

The EMS designers' articulations and practices discussed throughout this dissertation could inform new narratives for legitimizing the sciences of the environment.

The production of new contexts for articulating environmental problems and solutions is an important intervention given the "subalternity of environmental health problems," as discussed by Kim Fortun and Mike Fortun in *The Asthma Files* (Kim Fortun & Fortun, n.d.-b):

> Environmental health problems are notoriously difficult to understand, legislate, litigate and care for. In part, this is because of entrenched and powerful vested interests. But it is also because environmental health problems are very complex biologically, very technically complex to account for, and very conceptually complex to analyze. We've designed *The Asthma Files* to present the many different ways scientists try to capture environmental exposure and their effects. All are fraught by partiality, and most are markedly non-hegemonic in their logics. We can thus understand environmental health problems as subaltern phenomena, unable to speak, so to speak, in ways that can be heard within dominant institutions.

The complexities of environmental health call for developing EMSs that can link partial and situated ways of understanding in order to create an assemblage capable of making powerful articulations within dominant discourses, even as these articulations might be capable of re-shaping those discourses a bit.

New media technologies, like those that make the Atlas possible, could catalyze scientific legitimacy and literacy by helping the public feel a sense of involvement with knowledge production through hands-on experience. Online mapping seems to be a particularly promising medium for broadening the production of and access to information and knowledge about the environment. Mapping is, on the one hand, a long-established medium for guiding action and documenting knowledge (Turnbull, 2000). But the recent combination of GIS technology with Web 2.0 interactivity has resulted in new possibilities. Combined with new ways of mediating databases that make them *usable* (and not just accessible) by different publics, the mapping interfaces of projects like the Atlas can provide up-to-the-minute information customized for a user's specific locale. In the case of the Atlas, new modes of collectivity could extend to include contributions (and not just use-as-consumption) by the so-called lay public and people with expertise outside of ecology.[153]

At a 2011 AQMEII meeting—where representatives from the European and North American atmospheric modeling communities came together to exchange information on practices and make decisions about collaborative evaluation of air quality models—I

[153]The EPA itself has recently referred to "lay experts": "ORD plans to evaluate existing tools developed by ORD scientists with respect to appropriateness and ease of use for lay experts in communities" (EPA, 2011a, p. 116).

realized that the decision-making processes within the CMAQ community closely resembled the consensus process I've observed at the General Assemblies (GAs) of the Occupy movement in Chapel Hill, NC, Albany, NY, New York City and Montreal, Canada.[154] While there are, of course, ways in which power operates within CMAS in unequal ways, there does seem to be a strong culture of direct democracy and transparency, both within the CMAQ development and analysis community and the ORD more broadly. The CMAQ community, like Occupy, is marked by close attention to, and experiments with, collective process. While the concerns of Occupiers in each city were unique, the processes I observed were remarkably similar in each space, and repeat worldwide. In addition to CMAQ developers' own focus on process, it is partly this ability for processes to travel among contexts, perhaps with some modification, that has drawn my attention to process in the CMAQ story. A focus on process in *The Asthma Files* is driven by a desire to create a context for collaborative digital humanities scholarship that could travel to any number of different topics.

While it is not entirely clear to me how decisions were made about who to include in the AQMEEI meeting—I was permitted to attend by special invitation from S.T. Rao—all the decisions I witnessed were made by consensus and only after thoroughly attempting to hear concerns from everyone in attendance.[155] Collective decision-making processes that draw on the "potential intelligence of democracy" (Lindblom, Charles &

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[154]Donna Haraway sees hope in the "consensus conference" model of technology assessment pioneered in Denmark and now being widely adopted in Europe. "The Danes have pioneered a practice of establishing panels of ordinary citizens, selected from pools of people who indicate an interest, but not professional expertise or a commercial or other organized stake" in areas of science and technology that are under debate (Haraway, 1997, p. 95). These citizen panels "hear testimony, cross-examine experts, read briefings, deliberate among themselves, and issue reports to a national press conference" (Haraway, 1997, pp. 95-6).

[155]Robin Dennis explains how decisions about where to focus energy in CMAQ development also take into account what other parts of ORD understand to be important priorities. "I go out and talk with the eco people," he said (Dennis, 2011):

> to find out where are the problem areas and what can we do to make our communication regarding the role of atmospheric deposition and transfer of deposition information, smoother, better, more accurate, and get at issues they're running into when they're trying to apply their models. From that we try to set some priorities, but then we have group discussion to identify what the big ticket items are, and then we get together with the CMAQ development team and say ok which ones can we do, where do we have to have some coordination with, for example, the emissions or the meteorological people.

Edward J. Woodhouse, 1993) are central to the making of good modeling and good science in the CMAQ community.

CMAQ often involves a future-oriented approach, posing questions like what will the effects be of a given regulation in 10, 20, 50 years? How will climate change affect asthma in 50 years (Knowlton et al., 2004)? CMAQ embodies Hans-Jörg Rheinberger's description of an experimental system, or what Francois Jacob called a "machine for making the future"(Rheinberger, 1997). Bold claims about the future make CMAQ users vulnerable to certain critiques, but these future-oriented claims are essential if we are to successfully address future environmental challenges such as climate change and peak oil. One NERL interlocutor suggested that, ideally, their goal was to produce the knowledge that would be useful ten years down the line.

What might a more future-oriented STS look like? How could STS of the future help address environmental challenges? One step to an STS of the future might be to examine agenda-setting, prioritizing the development of ethnographic knowledge that could prove useful in addressing the problems of the future. Unfortunately, we are generally quite poor at anticipating future trends, or even accounting for the novelty of contemporary challenges. Responses to disasters (especially legislative responses) are frequently based on previous disasters. The problem is that disasters are singular events. Acknowledgment of uncertainty and the uniqueness of each environmental problem could produce greater humility, which in turn could drive support for research on identifying and reducing the most worrisome uncertainties.[156]

STS could also engage the future by improving our ability to ethnographically investigate how various cultures are making sense of speculative knowledge claims. "Our goal," S.T. Rao told me, "is to really replicate what is happening in the real world, through some simplified conceptual models" (Rao, 2011). Replicating the processes in the "real world" atmosphere is the primary substantive logic driving developments such

[156]Goldstein concludes his "eclectic review" of ORD's complex history by calling for greater humility, preparedness and flexibility (Goldstein, 2011, p. 308):

> Ten years from now there will be major issues that virtually no one now predicts. The implication is that our track record of shortsightedness must be taken into account in our planning. To respond to the unexpected we need a vibrant ORD with state-of-the-art expertise capable of anticipating or rapidly reacting to new environmental threats and at the forefront of innovative approaches toward a sustainable environment.

as the integrated meteorology and chemistry interactions in the recent release of CMAQ 5.0. I must admit that my STS-trained mind, which has—productively—been steeped in social constructionism, is more comfortable when CMAQ developers talk about uncertainty. I wince a bit when I hear talk of the reality of the atmosphere and aspirations to approach a 1:1 representation of the real world. But I welcome this discomfort and hope that it could help me move beyond social construction to what might be called a modified realist epistemology. This would incorporate lessons learned from decades of social constructionist scholarship on the sciences—clearly the social is a key part of CMAQ's development and analysis—but would also take seriously CMAQ developers' claims about reality and materiality.[157] Haraway is an invaluable guide in this endeavor. "So, I think my problem and 'our' problem," she writes (Haraway, 1988, p. 585):

> is how to have *simultaneously* an account of radical historical contingency for all knowledge claims and knowing subjects, a critical practice for recognizing our own 'semiotic technologies' for making meanings, *and* a no-nonsense commitment to faithful accounts of a 'real' world, one that can be partially shared and friendly to Earth-wide projects of finite freedom, adequate material abundance, modest meaning in suffering, and limited happiness.

We need a future STS that traces how truth, evidence and knowledge, even if impartial, highly mediated, conditional, etc. are necessary for addressing complex environmental problems. Pickering's account of the "mangle of practice" is useful for developing a model of science that allows for new kinds of objectivity while avoiding radical and cynical relativism; in the mangle, the "real world" presents "resistance" which requires response and "accommodation" by scientists (Pickering, 1995; Pickering & Guzik, 2008). Haraway helps us see that (Haraway, 1993, p. 589):

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[157]Hans-Jörg Rheinberger writes that (Rheinberger, 1997, p. 108):

> The process of modeling is one of shuttling back and forth between different spaces of representation. Scientific objects come into existence by comparing, displacing, marginalizing, hybridizing, and grafting different representations with, from, against, and upon each other. It might be argued that this view amounts to standard conventionalism, if not relativism or even anarchism. I disagree. I would like to strongly assert the claim that it is not conventions by which scientists agree, for whatever reasons, that something is such and such. It is *convenience* in the etymological sense of the word: being drawn together in space and time, in a concurrent and recurrent gesture of involvement and involution.

> relativism is the perfect mirror twin of totalization in the ideologies of objectivity; both deny the stakes in location, embodiment, and partial perspective; both make it impossible to see well. Relativism and totalization are both "god-tricks" promising vision from everywhere and nowhere equally and fully, common myths in rhetorics surrounding science.

Nadine Schurmann and Geraldine Pratt's call for a care of the subject is motivated by a desire to go beyond critiques of GIS that demean scientists for being positivists, even when there is little agreement on what it means, exactly, to "be a positivist." The science wars were marked by a great deal of polarization and lacked a politics of friendship. Schurmann and Pratt argue for a form of critique that tackles enframing assumptions while remaining invested in the subject. "To be constructive, critique must care for the subject. A feminist critique of GIS engages more directly with GIS practices, and need not reproduce the antagonistic dualisms that have characterized debates about GIS and technology to date" (291).

Erich Schienke suggests that reading the work of scientists as "experimentalists," rather than reductionists or positivists, can open up a new set of ethical questions, ethical questions that are being asked everyday by CMAQ developers and analysts (Schienke, 2003). The CMAS community experiments not only with the science and the model, but with innovative forms of collectivity, decision-making processes and dissemination. A CMAQ developer told me:

> we have to *cultivate* [a tradition of collaboration and openness to this kind of iterative feedback]. . . when we build models, it's not one field, we bring together chemists, meteorologists, mathematicians, engineers, statisticians, computer scientists, etc. . . when we're working with multidisciplinlary problems, we have no choice but to bring that team together.

An experimental approach to ethics, as opposed to a more staid ethics of following pre-determined scientific procedure, or doing science by numbers, calls for attending to questions such as: Why inquire or risk in one direction and not another? What is at stake in the production of any knowledge? Why generate one epistemic strategy instead of another? These are questions that can be studied ethnographically in order to better understand the contexts within which EMS producers work and their motivations and logics.

I would argue that as we consider the futures of Anthropology and STS, it may be useful to look to arXiv.org, CMAQ and other projects for examples of how we might, as a community, adapt more open modes of dissemination and peer review. And as we make collective decisions about the future of academic publishing, perhaps moving from proprietary models to open-source platforms, we might benefit from a close examination of CMAQ developers, the Occupy Wall St. Movement and other collectives experimenting with democratic processes of decision-making and models of knowledge production. This is a particularly rich moment in the history of STS. The scientists I interviewed are thinking deeply about the questions that I brought to the table. The material discussed here could prove to provide a rich space for experimenting with a politics of friendship between environmental scientists, STS scholars and other social scientist and humanities scholars.

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8. Appendix 1: Timeline

This timeline—and this dissertation at large—is inspired in part by the concept of informated objectivity and the layering logic of Geographic Information Systems. The key realms that are assembled here are 1) developments in conceptions of the environment, 2) environmental legislation, 3) institutional development, especially at the EPA, 4) environmental media and information technology, particularly as it relates to the Atlas and CMAQ. Sources include *Great Events From History II: Ecology and the Environment Series* (Magill, 1995), *The Environmental Protection Agency: Asking the Wrong Questions: From Nixon to Clinton* (Landy et al. 1994), Daewon Byun and Ken Schere's history of air quality models (Byun & Schere, 2006), the GIS TiMELiNE developed at the Centre for Advanced Spatial Analysis (GiSTiMELine Team, 2000) and the EPA Milestones Timeline (EPA, 2012c).

1766 – Sweden passed the Freedom of the Press Act, also known as the Principle of Publicity, which provided public access to government documents and foreshadowed the U.S. Freedom of Information Act and post-Bhopal right-to-know legislation.

1845-62 – Alexander von Humboldt, considered by many to be the father of ecology, published *Kosmos*, a five-volume treatise that aimed to create a compendium on the environment. *Kosmos* contained an atlas that was taken up in Britain as *The Physical Atlas of Natural Phenomena*. Humbolt's approach attempted to account for the "unity of nature" within the diversity of elements that made up ecosystems. Humboldt analyzed patterns that affected where a given species of plant would grow. This required drawing on biology, meteorology, geology and other disciplines. Humboldt sought to illuminate patterns that connect across diverse natural processes and scientific disciplines. As can be seen in both the Atlas and CMAQ, understanding the material complexity of the natural environment (ecosystems and the atmosphere) requires developing complex interdisciplinary collaborations and tools. Humbolt's focus on the "unity of nature" resonates with CMAQ's "one atmosphere" approach, the ecological thinking embedded in the Atlas and the systems-thinking and cybernetics of Gregory Bateson and his

contemporaries. “Humboldtian science” was largely quantitative and relied on collecting huge swaths of data; thus the era of “big data” is not as new a phenomenon as it is sometimes framed. Despite a focus on connections among natural elements, Humboldt, steeped in romanticism, sometimes enacted a sharp division between human beings and the rest of the environment, culture and nature. Humboldt’s discourse has been criticized for describing the “new world”—especially Latin America—in ways that left people out of the frame.

1866 – Ernst Haeckel, known as the “Pope of Monism,” and a proponent of Darwin in Germany, coined the term “oekologie,” drawing from the Greek root *oikos*, meaning household, house or family.

1875 – Eduard Suess, an Austrian geologist, coined the term “biosphere” to refer to all living beings and their relationships on Earth, including their interaction with the lithosphere, hydrosphere and atmosphere.

1877 – Karl Möbius, a pioneer in the field of ecology, coined the term “biocoenosis” to describe interactions among communities of diverse living beings. To this day, the term is used in community ecology, a field that focuses on interactions among species on many spatial and temporal scales, although Anglophone ecologists tend to speak instead of ecosystems.

1895 – Eugen Warming, a Danish botanist and founding figure of ecology as a scientific discipline, published a widely circulated textbook on plant ecology that took seriously the interactions among abiotic factors (flooding, drought, climate, fire, air quality, etc.) and the assembly of biotic communities. This text was a key step in expanding beyond Darwin’s focus on competition as the key selective force.

1905 – The first influential American ecology book, by Frederic Clements, was published.

1922 – Pierre Teilhard de Chardin according to some, first coined the term "noosphere" to refer to the "sphere of human thought." Chardin wrote, "this amounts to imagining, in one way or another, above the animal biosphere a human sphere, a sphere of reflection, of conscious invention, of conscious souls (the noosphere, if you will)" (Chardin, 1966, p. 63).

1926 – Jan Christian Smuts first used the term "holism" in his book *Holism and Evolution.*

1935 – Arthur Tansley, a British ecologist, devised the term "ecosystem" to describe the field of interactions among the biocoenosis (biotic elements) and the environment in which they live.

1936 – C.H. Bosanquet and J.L. Pearson published "The Spread of Smoke and Gases from Chimneys," which contained one of the earliest air pollutant plume dispersion equations.

1948 – First water pollution control act in the U.S.

1948 – Smog in Donora, PA, caused twenty deaths and hundreds of illnesses over the course of five days.

1952 – Smog in London killed thousands over the course of four days.

1955 – The Air Pollution Control Act was passed. This was the first piece of federal legislation to address air pollution on a national level and granted $5 million annually for five years to the Public Health Service for research.

1957 – Formation of the Advanced Research Projects Agency (ARPA) within the U.S. Department of Defense (DOD)

1960 – Amendments to the Air Pollution Control Act extended research funding for four more years.

1962 – Publication of *Silent Spring* by Rachel Carson, an environmentalist and marine biologist. The book described environmental effects of toxic chemicals in pesticides and catalyzed public concern.

1962 – Amendments to the Air Pollution Control Act called for the U.S. Surgeon General to conduct research on the health effects of motor vehicle exhaust.

1963 – First Clean Air Act (CAA) required the development and enforcement of regulations to control air pollution on a national level. The CAA granted $95 million over three years to state and local agencies for research and control programs. On the national level, the CAA established a new research and regulatory program in the U.S. Public Health Service. "In its first 20 years, the Clean Air Act prevented more than 200,000 premature deaths by significantly reducing the presence of lead, sulfur dioxide and other harmful pollutants in the air" (EPA, 2012c). The CAA was the first major environmental law in the U.S. to include a provision for citizen suits against people or organizations (including the federal government) for being in violation of emissions standards.

1964 – The RAND Corporation, an eminent cold war think tank, conceptualized the Internet as a communication network without central authority, in order to be safe from a nuclear attack.

1965 – Amendments to the CAA, collected under the "Motor Vehicle Air Pollution Control Act," established standards for automobile emissions and makes transboundary air pollution a focus.

1966 – President Lyndon B. Johnson enacts the U.S. Freedom of Information (FoIA) Act, allowing for the full or partial disclosure of previously unreleased information and

documents controlled by the U.S. government.

1967 – Research program for the CAA expanded under the Air Quality Act, which developed national emissions standards for stationary sources (instead of dealing with different industries separately) and created Air Quality Control Regions (AQCRs) to organize monitoring efforts. Individual states were now held responsible for non-attainment areas.

1969 – Esri (producer of ArcGIS, the platform that the Atlas is built on) was founded by Jack and Laura Dangermond as "a small research group focused on land-use planning. The company's early mission was to organize and analyze geographic information to help land planners and land resource managers make well-informed environmental decisions" (Esri, 2012).

1969 – The Advanced Research Projects Agency Network (ARPANET) formed, initially with four nodes of supercomputers.

1969 – The Group Against Smog and Pollution (GASP), a non-profit citizens' group, formed in Pittsburgh, PA, to fight air pollution and educate the public and government officials.

1969 – The Canadian-based environmentalist organization Greenpeace formed.

1970s – The Urban Airshed Model, developed by Systems Applications International (SAI), and the Caltech Air Quality Model are two early urban-scale photochemical grid models developed in the seventies.

1970s – The chemist James Lovelock and microbiologist Lynn Margulis co-develop the Gaia hypothesis, proposing that the organisms and the inorganic material comprising the Earth are closely integrated in a single system that self-regulates and maintains the conditions for life on the planet.

1970 – First Earth Day organized by environmentalists and government officials.

1970 – U.S. Environmental Protection Agency (EPA) established by President Nixon to protect human health and the environment by writing and enforcing regulations based on laws passed by Congress. Nixon's "Reorganization Plan No. 3" consolidated the roles of many arms of different federal agencies and created the EPA as a centralized, independent agency. As the first EPA administrator, William Ruckelshaus (Landy et al. 1994, 35-36):

> decided to give first priority to enforcement. Other directions were certainly possible, even attractive. The woeful state of environmental science and pollution control technology provided a strong rationale for devoting the lion's share of agency resources to research and development… during its first sixty days, EPA brought five times as many enforcement actions as the agencies it inherited had brought during any similar period… the early commitment to enforcement led to a shortchanging of other functions, such as research and development and planning. As a result, EPA has had to struggle to develop the scientific capability that would render its work technically credible" (35-36).

1970 – Clean Air Act amendments expanded the federal mandate for the EPA to set national air quality, auto emission and anti-pollution standards. The National Ambient Air Quality Standards (NAAQS), developed in these amendments, fall under authority of the CAA and contain primary standards (designed to protect human health) and secondary standards which protect public welfare from air pollution, including protection against visibility impairment and damage to buildings, animals, crops, vegetation. In the case of ground level ozone, secondary standards largely focus on damage to crops.

1970s – Aerial photography, according to ecologist and Atlas producer Megan Mehaffe, became available for landscape ecology

1973 – Production began of the catalytic converter, a technology that resulted largely from the 1970 CAA amendments. This technology, a vehicle emissions control device,

disproved automobile industry claims that the CAA's calls for reductions in motor vehicle emissions would be impossible.

1976 – Congress passed the Toxic Substances Control Act (TSCA) which gave the EPA the authority to control toxic chemicals. In contrast with the Registration, Evaluation and Authorization of Chemicals (REACH) legislation in the European Union, TSCA grandfathered in most existing chemicals.

1976 – Jimmy Carter was elected president and brought in Douglas M. Costle as EPA administrator. Landy et al. write that (1994, 41-2):

> To justify such expenditures at a time of slow economic growth seemed to require a more compelling goal than ecological purity. Preventing disease, especially cancer, offered just such a justification. Although most of EPA's regulations were based on health considerations, in the public's mind the agency's mission was more involved with protecting nature. Costle became determined to convince the public that EPA was first and foremost a public health agency, not a guardian of birds and bunnies… it was the largest of the regulatory agencies concerned with environmental health and the only one that combined a significant research effort with its regulatory duties. . . [Costle] redefined the central mission of the agency: protection of public health replaced the maintenance of ecological balance as EPA's central objective.

Costle also made enhancing the EPA's scientific credibility a key objective. Landy et al. write (1994, 50-51):

> At the time neither EPA's own laboratories nor its grant-supported research were held in particularly high regard. Scientists had come from a variety of agencies when EPA was created, and not all of these scientific units were first rate. In addition, external awards were often made without competitive bidding or peer review to a few favorite investigators. Costle wanted to convince both scientists and the general public that EPA could itself undertake, and use, good scientific work, and he wanted to involve leading scientists in the agency's decision making.

1977 – Amendments to CAA aimed to prevent damage to statospheric ozone. These amendments set more "realistic" goals after the ambitious CAA of 1970. Attainment deadlines were extended to at least 1982 in all areas and to 1987 for the worst areas and

automobile manufacturers were given more time to meet mobile source requirements. On the other hand, Congress tightened requirements for stationary sources and required areas to apply "reasonably available control technology" to existing hydrocarbon sources. After these amendments, there would be no significant developments in air quality legislation for over a decade.

1977 – The artists Kit Galloway and Sherrie Rabinowitz, in conjunction with the National Aeronautics and Space Administration (NASA) and the Educational Television Center (Menlo Park, California) developed a dance performance among performers on the Atlantic and Pacific Coasts of the United States. Lovejoy et al. write that (2011, 2):

> The performance included the first satellite feedback dance, a three-location, live-feed composite performance accompanied by flutist Paul Horn playing his time echo. These artists were very consciously striving to create context to expose others to the wonders of connectivity. Of course, this had all been anticipated by earlier generations of artists—the Dadaists, the Futurists, and even the Surrealists. Indeed, many performative and interactive contemporary works can be traced back to conceptualist work.

1978 – Lead plants and non-essential aerosol uses of CFCs were banned in the U.S. CFCs are still common in much of the world.

1978 – The Love Canal neighborhood in Niagara Falls, NY, was evacuated after an investigation by the local newspaper, the Niagara Falls Gazette, revealed that the site had been used to bury over 21,000 tons of toxic waste by Hooker Chemical (now Occidental Petroleum Corporation). Clear information was hard to come by and residents found themselves in a flurry of conflicting accounts over toxicity and potential health effects.

1979 – Partial nuclear meltdown at the Three Mile Island power plant in Pennsylvania. Officials of the utility and the Nuclear Regulatory Commission were criticized for poor transfer of risk information to nearby publics. This event helped to shed light on environmental risks and the need for better risk communication.

1979 – At a briefing outlining the EPA's 1979 budget plan, administrator Costle announced that EPA had become a public health agency and mentions "health" six more times in his brief talk (Landy et al. 1994, 42). To expand research on human health effects, the 1979 budget reduced both funding and personnel for research on ecological effects of pollution.

1980s – Building on lessons learned in the development of urban-scale photochemical grid models, the 80s saw the emergence of a number of modeling systems geared towards regional air quality issues, such as the Regional Oxidant Model (ROM) for regional ozone study and the Sulfur Transport and Emissions Model (STEM) for regional acid deposition. The need to go beyond focusing on a single pollutant in any given model is one of the key forces behind the emergence of CMAQ a decade later.

1980 – Congress passed the Acid Deposition Act which established an 18-year assessment and research program under the direction of the National Acidic Precipitation Assessment Program (NAPAP).

1981 – First Esri International User Conference, with 16 attendees, was held. Today, there are more than 14,000 attendees.

1982 – Esri releases ARC/INFO, the first commercial GIS software. It combined computer display of geographic features, such as points, lines and polygons, with a database management system for assigning attributes to these features.

1983 – "Fishbowl" Policy: Administrator Ruckelshaus commits the EPA to communicating as openly as possible, sending out a guidance letter to all employees, asking them to "keep the public in the loop on decision making and making more specific rules, like publicizing key officers' meeting calendars" (EPA, 1983). Administrator schedules are still posted on the EPA web site.

1983 – The National Research Council released its *Risk Assessment in the Federal*

Government report, known as the "Red Book," a key report that has guided the EPA's framework for risk assessment and management.

1984 – A massive leak of methyl isocyanate from a Union Carbide plant in Bhopal, India, caused thousands of deaths and brought attention to the dangers of toxics. The chemical industry claimed that a similar disaster could not happen in the U.S., "but it could no longer be argued that hazardous chemical production was a closed system. Chemicals clearly leaked out, both routinely and catastrophically" (Kim. Fortun, 2001, p. 57).

1985 – The EPA admitted to "inadequate communication of risk to concerned individuals and public officials during the handling of the ethylene dibromide (EDB) controversy and has since enlisted science writers for a new programme to improve the agency's handling of risk communication" (Kasperson & Kasperson, 2005, p. 20)

1986 – In the wake of Bhopal, President Reagan signs the Emergency Planning and Community Right-to-Know Act. Congress declared that the public has a right to know when toxic chemicals are released into the air, land and water.

1986 – Esri releases PC ACR/INFO, GIS mapping software, "in response to the proliferation of IBM PCs" (Esri, 2012).

1987 – 68 areas in the United States did not attain the 0.12 ppm ozone standard. Don Clay, Former Assistant Administrator of the EPA's Office of Air and Radiation, reported that the effort to reach attainment failed because, in part (Clay, 1989, p. 91):

> the tools we use for predicting ozone formation and needed emissions reductions needed improvement and still do. Current empirical models are an improvement on proportional rollback, but further refinement is still needed. We would like to make greater use of photochemical grid modeling, including regional transport modeling, but these models are still expensive and take a long time to set up and run. . . we still have a lot of work to do on emissions inventories. Calculating needed percent reductions does not do you much good without a good idea of what is actually being emitted.

1989 – Edwin L. Meyer, Jr., from the Office of Air Quality Planning and Standards (OAQPS) at the EPA presented on "The Use of Ozone Modeling in the Design of Control Strategies," at the third US-Dutch International Symposium hosted by the EPA in the Netherlands. At this time two urban scale photochemical models were approved for use in U.S. regulatory applications: the Urban Airshed Model (UAM) and the Empirical Kinetics Modeling Approach (EKMA). EKMA was the most widely used model for designing control strategies due to its relative ease of use and inexpensiveness. At this time, EKMA was evaluated by comparing to observed ozone concentrations. If predicted and observed daily maxima agreed within plus or minus 30%, its performance was considered to be sufficiently accurate. Control strategies would then be developed by estimating percent reactive organics reduction needed to reduce daily maximum ozone to 0.12 ppm on the five days having the highest observations at the monitor with the highest measurement during the base period (generally three years). Chapter Four examines a shift from such a quantitative approach to evaluating the model against measurements to one that evaluates the whole model and its processes through peer review. The latter strategy resulted in less ad-hoc tuning of the model to meet observations in ways that can throw the modeling system off.

1990 – After a long lull, major amendments to the Clean Air Act increased enforcement authority and added provisions for acid rain and toxic air pollution. These amendments also established a national permits program for stationary sources. Title VI, on stratospheric ozone protection, established new regulations on chemicals such as chlorofluorocarbons (CFCs) that harm the statospheric ozone layer. Title 42 USC S7403, on "Research, Investigation, Training, and Other Activities," called for the (U.S. Congress, n.d.):

> development of improved methods and technologies for sampling, measurement, monitoring, analysis, and modeling to increase understanding of the sources of ozone precursors, ozone formation, ozone transport, regional influences on urban ozone, regional ozone trends, and interactions of ozone with other pollutants

In a subsection on ecosystem research, the law calls for the "development of improved

atmospheric dispersion models and monitoring systems and networks for evaluating and quantifying exposure to and effects of multiple environmental stresses associated with air pollution" (ibid.). The 1990 CAA amendments were an explicit driver of CMAQ (Byun & Schere, 2006).

1990 – Congress passed the Pollution Prevention Act, which mandated the founding of the Office of Pollution Prevention within the EPA and required facilities to report data to the EPA on waste management and source reduction activities. The Toxic Release Inventory (TRI) assembles this data and informs publics about pollutants released from specific facilities in their communities.

1990 – Congress passed the National Environmental Education Act which directed the EPA to support environmental education programs and to encourage students to pursue careers related to the environment and sustainability.

1990 – Fred Singer creates his Science and Environment Policy Project to "promote 'sound science' in environmental policy" (Oreskes & Conway, 2010, p. 143).

1990 – The Regional Acid Deposition Model (RADM), an open-source model produced by the National Acidic Precipitation Assessment Program (NAPAP), reaches its second phase, and achieves a level of development that allowed it to become the base on which CMAQ would be built in the following years. The RADM provided more succinct marriage among meteorological and air quality models than earlier systems.

1992 – The United Nations Conference on Environment and Development in Rio de Janeiro led to the Rio Declaration which contains "principle 10," focused on the need for citizen participation in environmental issues and access to information on the environment held by public authorities. The U.S. joins other nations in endorsing a global plan of action for sustainable development.

1992 – Meteorologists and modelers, led by the Atmospheric Modeling Division (AMD)

of NERL, began work on the Modles-3 Community Multiscale Air Quality (CMAQ) modeling system. Most of the initial researchers on the AMD CMAQ Science Team were on detail from the Air Resources Laboratory of the National Oceanic and Atmospheric Administration (NOAA). A key motivating factor for the development of CMAQ was the limitations of earlier models that addressed individual pollutant issues such as urban ozone, regional acid deposition, particulates, nitrogen and toxic problems separately. CMAQ developers also saw a need for considering multiple temporal and spatial scales within a single modeling system. Three primary components make up the CMAQ system: meteorology, emissions and a chemical transport model. Interface processors link these components and CMAQ maintains the flexibility to swap in other emissions modeling systems and meteorological models.

1994 – Federal Communications Commission (FCC) Telecommunications Act continues trend towards consolidation of U.S. media ownership and control.

1995 – In order to better monitor land-use, the EPA signed an agreement to share remote-sensing data from satellites with three other federal agencies.

1996 – President Clinton signed the Electronic Freedom of Information Act Amendments.

1998 – Scorecard.org, the popular "pollution information site," was made public.

1998 – The EPA launches MyEnvironment, a website with an interface similar to scorecard.org, allowing the user to get data by zip code. MyEnvironment provides local information on air and water toxicity.

1998 –CMAQ first made available, free of charge, for use by air quality regulators, policy makers, industry and scientists, to address multiscale, multi-pollutant air quality concerns. This initial release of CMAQ was accompanied by a User Manual on the software system. The initial version of CMAQ was somewhat limited by computing

power and could not, at first, run an annual simulation of air quality.

1998 – The UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, also known as the Aarhus Convention, is signed by 35 countries from Europe and Central Asia and goes into effect three years later. The U.S. is not one of the signatories.

1999 – Esri launches GIS Day in coordination with the National Geographic Society.

1999 – Byun and Ching, scientists at NERL's AMD release "Science Algorithms of the EPA Models-3 Community Multiscale Air Quality (CMAQ) Modeling System," the "science document" behind CMAQ.

2001 – The second version of the National Land Cover Dataset (NLCD) was released. The NLCD, which draws on satellite imagery and refined classification methods, provides land cover data on a national scale. The NLCD, created by a group of federal agencies, is one of the primary inputs for the Atlas.

2001 – First Annual CMAS Conference

2001 – U.S. Attorney General John Ashcroft issues the "Ashcroft Memorandum" on FoIA declaring that the Department of Justice would defend agencies' decisions to withhold documents "unless they lack a sound legal basis." This memo shifted the burden of proof to those requesting information, reversing the Reno Memo's establishment of a "presumption" in favor of disclosure. Ashcroft's memo's language of "sound legal basis" resonates with the development of the concept of "sound science" within the Tobacco industry; both work to discredit claims that are not deemed "sound."

2001 – September 11th attacks on New York City and Washington, D.C. Camile Freanny, a former CNN producer that had focused on environmental and scientific issues, recounts that these attacks, in conjunction with the Iraq War, changed the focus of

reporting significantly. “We became the technology experts of war… all of a sudden everything was about the war and if you could not justify your work, you had a hard time getting your stories on the air” (Daley, 2010).

2001 – President George W. Bush signs the Uniting and Strengthening America by Providing Appropriate Tools Required to Intercept and Obstruct Terrorism Act, commonly known as the Patriot Act. One of the effects of this act was the weakening of right-to-know legislation around sites that could be considered targets of terrorism.

2001 – On November 1, Bush issued Executive Order 13233 to limit the Freedom of Information Act by restricting access to the records of former U.S. presidents.

2002 – A U.S. delegation to a UN conference announced it will not join the negotiations of a working group to improve public access to information about sources of pollution, amending the Aarhus convention. U.S. delegates stated that they believed the text of the resolution did not adequately address chemical-specific information.

2002 – First Annual Models-3 User’s Workshop. The theme was “One Atmosphere, One Community, One Modeling System,” and special emphasis was given to bridging the gaps among Models-3 and other models and among the regulatory and research communities.

2003 – CMAS moved to UNC-Chapel Hill.

2003 – First CMAS Quarterly newsletter is circulated. Published four times a year, the newsletter aims to keep the CMAS community aware of upcoming events, trainings and new model applications.

2005 – United Nations Millennium Ecosystem Assessment (MEA), a four year study involving more than 1,300 scientists around the world, popularized the ecosystem services paradigm and formalized definitions. The MEA grouped eco services into

provisioning, regulating, supporting and cultural categories. The assessment measured 24 ecosystem services and reported that only four have shown improvement over the last 50 years, fifteen are in serious decline and five are in an overall stable state.

2007 – 30 EPA employees shared the Nobel Peace Prize for work with the IPCC on Climate Change

2007 – Ric Linthurst came in as the EPA ORD's National Program Director (NPD) for ecology and announced that the eco services paradigm would be a key strategy for getting the message across about the importance of ecosystems for human health and well-being. Linthurst and his associates decided that the ecology research program at the ORD, according to Atlas director Annie Neale (Neale, 2010c):

> was going to re-make its story and focus its research efforts into ecosystems services. . . the idea was that at that point in the Research Program's history, there were many people doing good research, but those research projects were not connected and did not tell a cohesive story. At the time, it was difficult to tell a good story about what the eco program was doing. This upsurge in the emphasis on eco services was a prudent move on the part of the NPD, really relevant to the time, that focused everybody.

2007 – The peer review panel reviewing CMAQ 4.6 finds that (Aiyyer et al., 2007, p. 1):

> the CMAQ modeling program continues to lead the state-of-the-science. The overall breadth of the model development and research conducted by the CMAQ Modeling Program is unmatched by any other group worldwide. Model developers have done an outstanding job of incorporating new mechanisms, algorithms and data as they become available in the scientific literature, with appropriate consideration undertaken before incorporation and of developing new approaches when warranted.

2008 – New primary and secondary NAAQS for ozone set by the Bush Administration. Despite calls from the EPA's Clean Air Scientific Advisory Committee (CASAC) to set the standard at a level between 60 and 70 parts per billion (ppb), the administration set the standard at 75 ppb. Even this lower standard was never enacted. The outdated

standard of 84 ppb, enacted by the Clinton administration in 1997, remained the law. Three years later the EPA would again determine that these standards were too loose, and again the administration in power would reject its ruling.

2008 – CNN laid off its entire science and technology staff (Daley, 2010).

2008 – Associated Press reports that the Union of Concerned Scientists found that 60% of the 1,586 EPA scientists surveyed experienced incidents of political interference and pressure in their work in the past five years (Associated Press, 2008). About 40% of scientists who have worked at the EPA for more than ten years reported that interference had increased in the last five years. Francesca Grifo, director of the Union of Concerned Scientists' Scientific Integrity Program claimed that "the investigation shows researchers are generally continuing to do their work, but their scientific findings are tossed aside when it comes time to write regulations" and Rep. Henry Waxman wrote in a letter to EPA Administrator Stephen Johnson that the survey suggests "a pattern of ignoring and manipulating science." Johnson was criticized by environmentalist groups for delaying regulations around climate change, mercury pollution and smog.

2009 – In President Obama's Inaugural Address, he promised to "restore science to its rightful place" (2009). On April 27, Obama announced the President's Council of Advisors on Science and Technology (PCAST) which makes policy recommendations "in the many areas where understanding of science, technology, and innovation is key to strengthening our economy and forming policy that works for the American people" (U.S. Office of Science and Technology Policy, 2010).

2009 – The Reinvestment and Recovery Act, also known as the Stimulus Plan, provided $7 billion for EPA projects and programs.

2009 – EPA and its state partners began to monitor outdoor air near schools for more extensive air quality analysis. Schools located near large industries and in urban areas received extra attention. But indoor air quality testing is still rare.

2009 – At the direction of President Obama, Attorney General Eric Holder slid FoIA practices back towards the Reno Memo, shifting the burden of proof once again to those seeking to withhold information. Obama's memorandum was written at a time when there was a great deal of chatter indicating an emergent discourse on federal information practices described as open, transparent, accountable, responsive, etc. President Obama stated that (Obama, 2009a):

> The presumption of disclosure also means that agencies should take affirmative steps to make information public. They should not wait for specific requests from the public. All agencies should use modern technology to inform citizens about what is known and done by their Government… I also direct the Director of the Office of Management and Budget to update guidance to the agencies to increase and improve information dissemination to the public, including through the use of new technologies.

2010 – ArcGIS Online was launched "as a comprehensive mapping resource, providing web mapping and GIS to anyone with a browser" (Esri, 2012).

2011 – EPA calculated that if the ozone standard were modified to 65 ppb, "as many as 7,200 deaths, 11,000 emergency room visits and 38,000 acute cases of asthma would be avoided each year" (Broder, 2011b). CMAQ was used in characterizing ozone exposures to vegetation on a national scale, especially in the western U.S. where rural monitoring is sparser, in order to rule for new secondary standards.

2011 – The ozone rule from the EPA became, as John Broder reports in the *New York Times*, "a symbol of what opponents called a 'regulatory jihad' and brought out a swarm of industry lobbyists and Republicans in Congress who identified it as one of their top targets" (Broder 2011).

2011 – In September, President Obama rejected the EPA's proposal to tighten the NAAQS for Ozone. Cass Sunstein, who leads the Office of Management and Budget (OMB), which reviews all major federal regulations, wrote in a letter to Administrator

Jackson that the OMB recognizes that (Cass R. Sunstein, 2011):

> the relevant provisions of the Clean Air Act forbid EPA to consider costs in deciding on the stringency of national ambient air quality standards, both primary and secondary. Nonetheless, we believe that the draft final rule warrants your reconsideration. . . more generally, the President has directed me to continue to work closely with all executive agencies and departments to implement Executive Order 13563 and to minimize regulatory costs and burdens, particularly in this economically challenging time.

In a press release, Obama stated (Obama, 2011)):

> I have continued to underscore the importance of reducing regulatory burdens and regulatory uncertainty, particularly as our economy continues to recover. With that in mind, and after careful consideration, I have requested that Administrator Jackson withdraw the draft Ozone National Ambient Air Quality Standards at this time.

John Broder writes that the White House announcement "came barely an hour after another weak jobs report from the Labor Department and in the midst of an intensifying political debate over the impact of federal regulations on job creation that is already a major focus of the campaign" (Broder, 2011a). Bill McKibben called Obama's decision "flabbergasting."

2011 – EPA began regulating greenhouse gases (GHGs) under the Clean Air Act (CAA). Both mobile and stationary sources fall under these new regulations.

2011 – CMAS trainers offered CMAQ training in Seoul, Korea, to government and university groups around East Asia.

2011 – At the request of the EPA, the National Research Council (NRC) convened a committee under the Science and Technology for Sustainability Program to provide an operational framework for integrating sustainability as a key driver within the regulatory responsibilities of the EPA. A report, *Sustainability and the U.S. EPA*, was modeled, at the request of the ORD's Assistant Administrator Paul Anastas, on the 1983 "Red Book" on risk (National Research Council 2011). The report recognized that "the growing identification of sustainability as both a process and a goal to ensure long-term human

well-being" is in part driven by the fact that "sophisticated tools [such as the Atlas and CMAQ] are increasingly available to address cross-cutting, complex, and challenging issues that go beyond the current approach" (ibid., 2). The report recommended the development of a "sustainability toolbox" that would include "a suite of tools for use in the Sustainability Assessment and Management Approach. Collectively, the suite of tools should have the ability to analyze present and future consequences of alternative decision options on the full range of social, environmental, and economic indicators" (ibid., 4). The Atlas and CMAQ are shining examples of these kinds of tools and the suggestion for a toolbox suggests the important task of developing better indexing and distribution of the many tools developed by the EPA. The report also resonates with the ecosystems services approach, recognizing that it is not a matter of a zero-sum game of trade-offs between "the environment" and "the economy": "the potential economic value of sustainability to the United States is recognized to not merely decrease environmental risks but also to optimize the social and economic benefits of environmental protection" (ibid., 2).

2011 – PCAST releases a report on July 22 titled "Sustaining Environmental Capital: Protecting Society and the Economy," which calls for the Federal Government to (U.S. Office of Science and Technology Policy, 2011, p. 1):

> launch a series of efforts to assess thoroughly the condition of U.S. ecosystems and the social and economic value of the services those ecosystems provide… The report also recommends that the Nation apply modern informatics technologies to the vast stories of biodiversity data already collected by various Federal agencies in order to increase the usefulness of those data for decision- and policy-making.

Annie Neale states that the report is "so incredibly relevant to what we are doing with the Atlas and highlights the importance of ecosystem services" (Neale, 2010b).

2012 – CMAQ 5.0 is released.

2012 – The EPA and the U.S. Department of Commerce announced a joint effort to boost U.S. jobs and environmental technology exports. The Environmental Technologies

Export Initiative builds on President Obama's National Export Initiative, which aims to double U.S. exports by 2015 and will include a "comprehensive web based portal" which will be hosted at export.gov (EPA, 2012a)

2012 – The EPA reported that "the annual economic cost of asthma, including direct medical costs from hospital stays and indirect costs such as lost school and work days, amount to approximately $56 billion" (EPA, 2012d). A press release on Asthma Awareness Month in May encouraged readers to be "air aware" by checking the Air Quality Index with a mobile app, but no mention is made of the need for greater awareness of the science of the air, indoor air quality, differences in air quality among spaces, or the reasons that outdoor air continues to cause asthma (ibid.).

2012 – EPA Administrator Lisa Jackson referred to "the mission to strengthen the American economy" as "the defining mission of our time in office" (Lisa Jackson, 2012).

2013 – The year that Obama claimed Administrator Jackson will—if he is still in office—have an opportunity to revisit the Clean Air Act standard for ozone (Broder, 2011b).

9. Appendix 2: Methodological Reflections and Description of Interviews and Fieldwork

This dissertation employs multi-sited ethnographic research methods (Coleman, 2009; Falzon, 2009; Marcus, 2009) to produce thick ethnographic descriptions of how differently situated EMS producers understand the forces affecting their work. At times, as with *The Asthma Files*, fieldwork required prolonged engagement with the technologies and techniques of media production around environmental issues. Ginsburg et al. argue that, "refiguring the ethnography of media necessitates a further expansion by taking into consideration the physical and sensory properties of the technologies themselves and examining the materiality of communication across cultures" (Ginsburg, Abu-Lughod, & Larkin, 2002, p. 19). But other field sites, like the Atlas, did not necessitate extensive training (in GIS in this case) in order to develop a rich understanding of the producers' imaginaries, and even offer frequent suggestions that were received with enthusiasm, and may ultimately influence the design of the project.[158]

I conducted five interviews with Annie Neale, the director of the Atlas project (three on my own and two during research at NERL with collaborators, along with informal correspondence over three years) and two interviews with Laura Jackson, who directs the Urban Atlas and the Eco-Health Relationship Browser and focuses on linking environmental indicators with human health and well-being. Other interlocutors working on the Atlas include Megan Mehaffey, William Kepner, Robin Dennis and James Wickham. I arranged for Neale to present a webinar on the Atlas to the Spring 2011 Asthma Politics seminar at RPI. We recorded a discussion which I transcribed and provided for Neale along with a formal report on the Atlas which included a description along with edited text written by Asthma Politics students. I also provided formal "expert feedback" on the Eco-Health Relation Browser.

I helped prepare for and conduct two interviews with Tim Barzyk, who has developed a strong birds' eye view of EMSs at the EPA. Bill Pease, an original founder

[158]I did complete a two day intensive course in essential skills in GIS as part of a summer fellowship in digital humanities at the University of Southern California and produced maps (described below) in collaboration with my colleague Nick Shapiro at the University of Oxford.

of scorecard.org, was also interviewed during Asthma Politics and provided insight into how EMSs can travel in surprising ways.

During the NERL interviews I helped prepare for and conduct interviews with user/producers of CMAQ including S.T. Rao, Rohit Mathur, John Pleim, Timothy Watkins, Robin Dennis and Ken Schere. I attended the 10th Annual CMAS conference in Fall of 2011, including the AQMEII and U.S./U.K. meetings by special invitation thanks to S.T. Rao. I am grateful for the insights that dozens of CMAQ developers shared with me in between sessions and over meals, especially Adel Hanna, the Director and Outreach Coordinator of CMAS, and Christian Hogreffe, one of the authors on the article linking future climate change scenarios with potential health effects discussed in Chapter Four. During a research trip in Houston, I helped prepare for and conduct interviews with Barry Lefer and Winnie Hamilton (who use CMAQ in health-effects research) that expanded my understanding of the range of CMAQ applications and the politics of credibility around the modeling system.

For *The Asthma Files*, I worked as a Graduate Research Assistant for two summers, helped prepare for and teach two undergraduate classes and a graduate seminar, participated in dozens of planning meetings and went on six research trips relevant to the Asthma Files (NERL twice for a total of 34 interviews, Houston as an "asthmatic space," an EPA Air Quality Conference in North Carolina, an Asthma conference in Washington D.C. and the Columbia Children's Health Center in New York City). Along with Ali Kenner, I also conducted an interview with hilosopher of science and *Asthma Files* collaborator Dan Price. My Research questions for this dissertation also fed into and drew from shared (ethnographic) questions in the project, especially for "communicating asthma" section and the substantive and design logics.

I participated as a fellow in a Digital Humanities Summer Institute at USC in which my collaborator Nick Shapiro and I developed an online platform tracking the diaspora of FEMA trailers around the U.S. after Hurricane Katrina in New Orleans. We used ArcGIS to produce maps that track the re-sale of over 100,000 trailers with high levels of formaldehyde that were originally deployed by the U.S. Federal Emergency Management Agency. This project aims to go beyond anthropology of media to produce new media within anthropology (beyond the traditional focus on journal articles, books

and, more recently, ethnographic film). These attempts to develop creative modes of proliferation have been inspired in part by two seminars on Fieldwork as Art taught by ethnomusicologist and dance professor Tomie Hahn.

Inspired in part by trends among my interlocutors towards sharing data, I have put the video and/or audio from a number of these interviews online, sometimes with supplemental contextualizing material. Key to this effort was the development of IRB protocols and an informed consent form that gave my interlocutors a variety of options based on how public they were comfortable with the interviews being. My interlocutors could check boxes to give permission for audio, video, having quoted excerpts used in written publications, parts of the video or audio posted on websites and allowing recordings to be made "available to students, artists, journalists and others interested in the material for their own projects."

My interlocutors and I share the challenge of developing criteria for analysis of EMSs and the knowledge they can help produce. In order to develop these criteria, which are especially necessary in a context marked by contention and an explosion of new media, I draw inspiration from a number of sources. Many of my field sites taught me the value of presenting preliminary "score cards" for comparison across projects, geographies, temporalities, etc. Tim Barzyk, a researcher at NERL, assessed over 70 EPA-produced web-based GIS and database tools based on ease of use, relevance of information, output type (e.g., maps or lists), information needed to interpret results and comprehensiveness (e.g., breadth and depth of information) (Barzyk, 2010). Geoff Bowker stresses the importance of metadata, especially when attempting to link different data sets (Bowker, 2008). The Center for Digital Humanities at the University of Nebraska, Lincoln, offers guidelines for evaluating digital humanities work, including "compatibility between design, content, and medium. . . technical innovation and sophistication. . . involvement of experts in design and implementation. . . collaboration with or connections to related digital research projects at other institutions," etc. (Center for Digital Research in the Humanities, n.d.). Edward Tufte writes about "beautiful evidence," stressing the value of clean aesthetic design and of "honest" representation (Tufte, 2006).

While using the above evaluation criteria alone would be duplicative, mixing these and other criteria (especially from my interlocutors), and developing new design logics along the way, helped me to analyze and evaluate the environmental communication practices and projects I observed in the course of this research. Cultural shifts that may be encouraged or produced by recent EMSs may be their greatest impact, but they are notoriously difficult to evaluate. We need better modes of accounting for cultural effects, perhaps by focusing on the users of EMSs. But due to the ethnographic nature of this project focused on EMS designers, I focused on drawing out my interlocutors' conceptions of their audiences and imaginations for some of the less tangible potential effects of their work, such as the potential to usher in new environmental subjectivities, world-views and collective modes of evaluating scientific knowledge.[159]

[159]Here I found it useful to be in conversation with Félix Guattari who, in *The Three Ecologies*, extends the concept of ecology to encompass human subjectivity and social relations as well as environmental concerns (Guattari, 2005).