CORNELL UNIVERSITY

THE INSTRUMENTED OCEAN:

HOW SENSORS, SATELLITES, AND SEAFLOOR-WALKING ROBOTS CHANGED WHAT IT MEANS TO STUDY THE SEA

A DISSERTATION

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DOCTOR OF PHILOSOPHY

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by

STEPHANIE BETH STEINHARDT

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ABSTRACT

The Instrumented Ocean:
How Sensors, Satellites and Seafloor-Walking Robots
Changed What It Means to Study the Sea

By Stephanie Beth Steinhardt

Doctor of Philosophy in Communication
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This dissertation is drawn from over 5 years of ethnographic inquiry into the U.S. Ocean Observatories Initiative through field observations and over 80 interviews. The work is contextualized via archival and historiographic resources from oceanographic institutions, professional societies and historians of ocean science. The dissertation fundamentally addresses the concomitant relationship between innovation (e.g. imagining, planning, constructing, operating) and degeneration (e.g. down-scaling, breakdown, failure, repair). In doing so it argues: (1) Technological solutionism is a widespread ideology that inflects oceanography and can be seen in the turn towards big data. (2) The dominance of technoutopian or tech solutionist imaginaries and narratives drives the character of the infrastructure and can obscure critical less shiny realities of ongoing maintenance and repair. (3) Funding bodies and program managers alike place emphasis on technological sustainability while sidelining issues of labor and human sustainability (overworking, turnover, harassment and grievance, career-building) that can undercut even the best laid infrastructure plans. (4) In these more tender moments of breakdown, hard lessons emerge that often reveal what technology alone cannot fix: problems of labor, inequality, marginality and violence. (5) By making visible narratives of care (for each other and for the environment) in understanding the OOI, I highlight critical power dynamics of building transformative infrastructure, including the gendered and marginalized labor in service of an infrastructure's development and futurism that does not get credited as time-on-task (e.g. mentorship and informal support networks, appealing to and amending grievance reporting, fallout from sexual violence, and accommodating peripheral stakeholders and agents like park services, fisheries, indigenous communities, industry manufacturers, etc.). My focus on care emerged from observing participants and is informed by feminist scholars such as bell hooks. I demonstrate that we must examine care in order to expand our understanding of the human and nonhuman actors that create knowledge about the ocean and, in turn, about the world.

BIOGRAPHICAL SKETCH

Stephanie B. Steinhardt is a Ph.D. candidate in the Department of Communication at Cornell University and an Assistant Professor in the Department of Media and Information at Michigan State University. She began her career as a backend developer writing the algorithms of infrastructure then became fascinated by the social and ethical consequences of technological development, particularly in building and maintaining large-scale long-term transformational infrastructures in the sciences. Her recent work contributes to and draws from an array of disciplines and sub-disciplines including communication and media studies, science and technology studies, infrastructure studies, feminist technoscience, gender and queer studies, labor studies, future studies and computer-supported cooperative work.

This manuscript is dedicated to my family, Dr. Joseph Steinhardt and Maeva Steinhardt.

In loving memory of Edward Gokhman.

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LIST OF ABBREVIATIONS

CDR	Conceptual Design Review
CI	Cyberinfrastructure
CND	Conceptual Network Design
COL	Consortium for Ocean Leadership
CORE	for Consortium Ocean Research and Education
CSN	Coastal Scale Nodes
D&I	Design and Implementation Workshop
DEOS	Dynamics of Earth and Ocean Systems
EPE	Education and Public Engagement
FDR	Final Design Review
FLIP	Floating Instrument Platform
FND	Final Network Design
GEOSS	Global Earth Observation System of Systems
GSN	Global Scale Nodes
IO	Implementing Organization
IOOS	Integrated Ocean Observing System
JOI	Joint Oceanographic Institutions
LSST	Large Synoptic Survey Telescope
MREFC	Major Research Equipment and Facilities Competition
NASA	National Aeronautics and Space Administration
NEES	Network for Earthquake Engineering Simulation
NEPTUNE	NorthEast Pacific Time-series Undersea Networked Experiments
NRC	National Research Council
NSB	National Science Board
NSF	National Science Foundation
OCE	NSF Division of Ocean Sciences
OOI	Ocean Observatories Initiative
ORION	Ocean Research Interactive Observatory Networks
OSU	Oregon State University
PEP	Project Execution Plan
PDR	Preliminary Design Review
PND	Preliminary Network Design
RFA	Request for Assistance
RSN	Regional Scale Nodes
RSVP	Rare Symmetry Violating Processes Project
SIO	Scripps Oceanographic Initiative
STAC	Science and Technical Advisory Committee
U.S.	United States
UNOLS	University-National Oceanographic Laboratory System
UW	University of Washington
WHOI	Woods Hole Oceanographic Institute
WOSE	World Ocean Surface Exploration

LIST OF FIGURES

0
INTRODUCTION

> Researcher's End Game
>
> When all is said and done
> And we are long since gone
> What will remain to be distributed
> Are the data we contributed
> With digital identifiers assigned
> And our names clearly defined
> Our work will be on-line
> Until the end-of-time.
> [(Wiebe, 2008) as published in (Lawson, 2012)]

On a Spring morning at a West coast oceanographic institute, in the middle of a dialog about the purposes of sustained oceanographic observation a participant leaned forward in his swivel chair and threw his arms up in the air:

> I dove to the seafloor in Alvin [submarine] many, many times! 4-5 hours a day became not enough! It was so exhausting because it took 2-3 days to recover... so it became clear that it was difficult to understand how these systems behave if you're only seeing them 4-5 times a year every other year… then working up the results, publishing the results, grant work for another dive… Then, we realized we didn't have to move around from place to place because [an observatory] was every place at once! (Participant quotation)

This participant identifies how the character of work aboard an oceanographic vessel differs dramatically from different forms of knowledge production in the ocean sciences. Whereas the collection of other types of data required days for a scientist to physically recover from the same location via submarine, this process consistently streamed a dataset from the ocean floor. While the latter might sound comparatively easy, I have heard participants describe real pain in their spines and lower backs from the physical effort of too many consecutive hours at a terminal. The transformation in what is considered valued data collection displaces and reorients the kinds of questions that can be asked of infrastructure and the environment both by ocean science and by social science.

To understand the significance of the data-driven observatory model in ocean science, consider this practice within the genealogy of oceanography as a discipline. In the early half of the 20th century, this field emerged as a type of exploration whose data looked like drawings and anecdotes and whose infrastructures largely rested on the sails of ships and the pencils and notebooks of men. The origins of oceanography were co-produced (Jasanoff, 2004) by the knowledges and inventions of explorers, mariners, whalers and fishermen. These were lives and livelihoods that paid attention to the currents, the winds, the fishes, the corals and the whales, people who relied on their imaginations for exploration and their vision for scientific analysis. At the start of oceanography, the ocean was unfathomable.

In contrast, today, fathoms are known. Oceanography is co-produced by complex charts and interactive representations, which are informed by the sensors and cameras that lie continuously on the seafloor, mapping the currents and fish migration patterns across multiple marine ecosystems. The oceanographic laboratory is an evolving assemblage of novel instruments and interdisciplinary people (Latour, 2005; Latour and Woolgar, 1979). Whereas oceanography was once inaccessible to those not among the explorers, modern technological and data-driven infrastructure development brings commercial and publicly-accessible products developed by industry powerhouses like Google to allow any person with access to view intricate detail of the world's coastal lines, down to the colors of its sands, and in some cases, under the waves and down to the seafloor. The infrastructures of modern oceanography are reliant not on a single explorer's crew and ship but rather on an established institution's financial backing and resources, often scaffolded by a large government body in service of particular broader impacts like understanding climate change, deep sea geologies for drilling, and weather prediction [cf. the large, interlocking systems of weather and climate research in (Edwards, 2010)]. In many ways, the romance of modern oceanography is no longer a vision of a passionate protagonist journeying to the sea aboard a customized vessel of his own heading toward a sunset as depicted in novels (e.g. Ahab in Herman Melville's *Moby Dick*, Peter Freuchen's personal depictions in the *Book of the Seven Seas*, Santiago in Ernest Hemingway's *Old Man and the Sea*) but instead it is in the captured footage of animals courting each other or protecting their young, as in a scene of the *Planet Earth* documentaries. Now, scientist explorers aren't the focus of the picture. Scientists do not necessarily even need to journey over or under the waves to see the ocean firsthand: in their stead, a technician or seafloor-walking robot often makes those journeys to extend or replace human eyes, ears, and sensing. The scientist explorer sits at a land-bound desk.

Amidst this new technological climate of ocean work stands the object of study for this dissertation: the US Ocean Observatories Initiative (OOI), the most intensive computational investment in the ocean sciences to date. Despite its unprecedented nature, the OOI exists as an extension of trends in the field, following an ever-increasing interest in time-series and observatory construction. This is neither an example of technological determinism nor is it an example of a spectacular phenomenon, as some descriptions may indicate. Instead, the narratives of the OOI that are found in this dissertation coevolved alongside 50 years of advancements of a long-term data-driven nature: the developments include both great successes (cf. Argo floats) and some initiatives that exist now in legacy (cf. TOGATAO, JGOFS). The OOI and its antecedents provide a provocative story of imagined futures that wholly redefine the character and capacity of our knowledge of life at sea and the development of infrastructure to ensure its coming -- a new paradigm that tightens the connective tissue between science, government and industry. In this new world, knot-tying and ship-steering are considered less important types of knowledge than building data-centric infrastructures for a long-term, distant, and ill-defined future. The cultural cache of seafaring has not been lost within the field, yet data- and technologically-driven expertise have gained substantive scientific value and resource allocation, dwarfing what was once seen as the heart of the field (cf. Edgerton, 2011). Indeed, the participants I interviewed shared a feeling that the need for data will not go away; they naturalized streaming data collection, as if the accretion of data from sensors is a valuable end in itself. This naturalizing is reminiscent of the phenomena of closure from the Social Construction of Technology (SCOT): in the ocean sciences, there are multiple ways to imagine how knowledge could be gleaned, yet the assumption that specific types of data collection are more valuable than others has transformed the field and created a prevailing sociotechnical imaginary (Jasanoff and Kim, 2009; 2015), one that will inevitably progress by continuing to develop tools for this technologically-innovative data-driven ilk.

In the decades that I discuss within this dissertation, data-driven architectures become a political imperative, echoing in many ways the lifestyles and rhetorics of Silicon Valley, where technological tools are described as revolutionary and traditional modes of performing work are called outmoded and where the imagined better future is shepherded in by technology (not social programs, cultural change, policies, etc.). This technological solutionism is built on the back of a presumed naturalness of interconnection, one that imagines that the more connected things are the better (Bollmer, 2016). With these many factors colliding and in new ways – the natural world, the built world, the human body, timescales, society, industry – how do the people inside the OOI make sense of it? How do we understand the social repercussions of an infrastructure at this large a scale? How do STS and infrastructure studies scholars make sense of it?

The OOI provides an interesting example for expanding a wide range of conversations in Communication and Science and Technology Studies. For example, it allows us to examine how technical apparatuses and practices fundamentally alter the types of knowledge that scientists can produce (Traweek, 1988, 2005). Furthermore, the example of the OOI demonstrates the centrality of narratives of futurity and fiction (found in media and in public rhetoric) in orienting the field, building upon (Raven, 2017; Raven and Elahi, 2015). Similarly, I examine how the adoption of new tools altered the practice of oceanography as well as the types of knowledge claims that "experts" in this area can make. For example, the short-term data collection of ship-based research is not as easily oriented toward questions of climate change and ecological processes like ocean acidification and urbanization that dominate the ocean sciences today. Lastly, the OOI's construction and operation is fundamentally driven by technical and systems credentials, which may dwarf important questions of human sustainability and labor that derail or even cause failure within the project, echoing formative STS work by (Vaughan, 1997; Star and Ruhleder, 1996; Latour & Porter, 1996) that demonstrate social construction has long established both tech and humans are critical with equal weight, that breakdown is generative, and that anticipation (with all of its affective components) drive collaborative projects.

Through the example of the OOI we see that the future is actually built through intimate, immediate acts and relationships and present-day practices that allow us to continue building support structures in the face of everyday fires, that there are hopeful, nerve-wracking anticipations that circumscribe our task lists and the way items get checked off. The project of this dissertation is to explore the many spectra unearthed by the practice of care: production and breakdown, hope and broken hope, blue sky and blueprint, sustainability and waste, insider and outsider, and so on.

The scientific practices that are reaffirmed by the OOI — and the worldview that those practices bolster — fundamentally reimagines the relationships among humans, the ocean, and the changing climate. This dissertation in many ways aims to surface work that is at once integral to carrying out a grand, culturally transformative vision of the ocean as data but, in keeping with other studies of infrastructures, also seeks to elucidate the work that is invisible to formalized power structures (concretized in plans, policies, and tenure) that provide credit, support, and authority. In my work, I have found that often the best laid plans and technical infrastructures can be derailed by interpersonal and seemingly extra-scientific issues, including combatting racism and sexism in the workplace, maintaining a positive working environment with reasonable expectations for labor and enough manpower to support stated goals, developing grievance reporting structures that do not force victims to report to superiors, negotiating across differing working cultures, or understanding the stakeholders who might exist at the margins of the system including tribal groups and natural resource industries. As STS scholars such as (Wacjman, 1991; Fricker, 2006; Barad, 1999) have shown us, science is not a rarefied practice that is removed from such social concerns; this dissertation continues the important work of illuminating the fundamentally social character of science in order to better understand the human lives made invisible that nonetheless construct knowledge about our oceans and climate. When my participant observers emphasize objectivity by drawing attention to the fact that sensors have replaced human eyes in data collection, they invoke the authority of objectivity (Daston and Galison, 2007). I will demonstrate how that objectivity was freighted by the tensions among different stakeholders.

The cases chosen within this study demonstrate the dynamic, temporally-oriented connection between infrastructure, human labor, and life. They help to show how investments in large-scale long-term infrastructure can wholly reimagine the worlds into which they are built: providing new structures of building credit, career and questions that were previously less attainable. In the chapters that follow, I narrate my ethnological observations of the OOI to show how infrastructure makes things visible and legible, how feminist technoscience is a productive lens for understanding the problems of labor and innovation that ring loudly within its lessons learned, and about tackling the thorny constructs of neoliberalism in science and the meritocracy. If sensors, apparatuses, humans, and government institutions are a part of oceanographic knowledge production, my observation also demonstrates that these labor and affective factors must also be recognized as an integral and tangible aspects of the practice of oceanography. Infrastructure, in other words, is political, economical, social, and consequential. Feminist scholar bell hooks (2000) asserts that conflict and care are concomitant and productive, that dissension is a part of love, and that hope is a part of failure. This attention to affect - care, love, dissent, and conflict - extends discussions of infrastructure from STS. When stakeholders set out to develop a new infrastructure, they negotiate and engage in a way that illuminates their assumptions. Oceanographers name what lives in the world as they hope to map it, and they decide who is represented in negotiations about what they will observe and how—with what tools. The development of OOI has renewed the way that scientists practice and define their work, redefines the roles that relate science to technology, society and industry, and supports (or constrains) different modes of creating new knowledge. While the OOI depends upon the cultural cache (and funding streams) of science, its futurism also invokes science fiction.

The resonances between the OOI's work and science fiction are not negligible, considering that much of the ocean itself is known through its fictions: through the literature of Arthur C. Clarke, Moby Dick, Robinson Crusoe, and Jules Verne, through the hyperbolic tales of Jacques Cousteau and other modern oceanographers, or through the films both fiction and nonfiction of James Cameron. As noted by historian of oceanography Rozwadowski (2008), much of the population lives in cities that border on oceans, and beach resorts are a particularly valuable commodity. Oceans are a space of connection, imagination, frontier, and adventure. Comparative literature scholar, Margaret Cohen, shows how the sea became a space for imagining modernity in the 18th and 19th centuries. Rachel Carson's The Sea Around Us (1951) is just one example of a text in which scholarship, literature, and the sea converge to demonstrate the driving aesthetic and identity-building that is done through adventure and empire on the sea. This dissertation is influenced by this confluence of reality and fiction, producing insights into the collective imaginative process of transforming from blue sky ideas to blueprints (Chapters 1 and 4), how even the most open and participatory of imaginations can fail to include (Chapter 5), and how we define and redefine our imagination of whose futures we are building (Chapter 6).

STS scholars have identified technological solutionism as a problematic but widespread ideology that promotes the misconception that technology drives history (Marx and Smith, 1994). Such outsized faith in technology is evidenced by the hope that self-driving cars will solve traffic problems, the precision of drones will end the senseless deaths of the military, Bitcoin will reshape poverty in the developing world, or Wikipedia will educate the Third World. This technological solutionism has inflected the practice of oceanography: scientists now collaborate with new cultures of systems-engineering business-minded people who use language like "be quicksilver" and "cultivate chance". While I recognized the adoption of these idioms, I should also note that my participants expressed unease with these relationships: one participant described being "confronted with" business people; another described "being forced to reckon with" these newly influential partners. Even in the pursuit of science, we see a spilling over of Silicon Valley mentalities, inequalities and meritocracies.

The most powerful companies in the world are tech companies and the possibility space that technologically-minded initiatives (in science or otherwise) strive to inhabit is largely colored by the futuristic visions laid out by these companies. These ideas about what constitutes a desirable future are being driven by corporate interests, which are couched as technological progress rather than technological profit (Jasanoff and Kim, 2009; 2015). This dissertation grapples with the pace of innovation and the construction of "the future." In the words of Leigh Star and Anselm Strauss, it asks, *cui bono?* Who benefits? Who is inconvenienced for that benefit? And how do we move these power dynamics "from background to topic" (Clarke and Star, 2007)? In my analysis, I conceive of productive imaginaries which envision infrastructures that uphold alternative social orders, not just rhetorically but in the lived experience of its interactions and productions. These narratives of innovation help to think of the lives and stories that are conspicuously absent from the OOI's conception of the world.

While dreamers and visionaries are an important part of the conversation, much is gained from looking at the less aspirational moments that define infrastructures, peering into less comfortable lessons learned and the often hard-pressed valuation that comes with unraveling. This dissertation describes the OOI's booms and busts, where the downscaling productively opens a moment to reconsider the ways in which we order and assess a space, where things do not necessarily reform into something recognizable as the system it once belonged, where metrics of success tend to be ill-defined. While often organization and resources are revalued after they are repaired (and thusly reoriented back into a recognizable system), the active form of breaking down I describe in the OOI encompasses that which does not again become disciplined and may fall out of view as waste or as a pure invisibility. Breaking down often discards as much as it recycles. This degenerative phenomena of breaking opens questions around the work of anticipation and constructing futures, even amidst adversity, of the invisibilities of human sustainability against the shine of technical sustainability, of the cost of caring or not caring particularly in times of turndown, and of the labor politics of big science where data is currency.

The example of the OOI shows us how infrastructures are built to take care of ourselves and our environment, and to extend our abilities to care. The kind of care I have seen in the OOI is often told is a re-enactment of contestation, a way of taking care of things that are about relations, of all the things and people around us. Those in the OOI recognize the structures that have not served the community thus far and create new structures of support that continue to be contested. The narratives found within this dissertation show in different forms how deeply care takes advantage of the care-givers, much as hope takes advantage of the hopeful, dreams take advantage of the dreamers. And, importantly, technology takes advantage of the technologists. What does the burden of care require the caretakers to do? It is at times backbreaking, betraying, and wrapped in violent social constructions that confine and coerce even the most beautiful, care-full, inclusive visions. The shared hopeful temporality of the future, the anticipation of technoscience ["anticipation work" as discussed by myself (Steinhardt & Jackson, 2015) and separately by (Adams et al. 2009; Clarke, 2016)] is full of dramas that maybe ubiquitously and deeply entwine hope with broken hope, always co-existing as both a drive and a death for something (Pfaffenberger, 1992). These narratives get obscured by the shiny dominance of the production-oriented future drive.

What follows in the next chapter is a description and history of the Ocean Observatories Initiative followed by a chapter concerning an infrastructural history of ocean science, demonstrating the central frame of infrastructure as a powerful mechanism for re-envisioning the world of ocean science: one that offers an alternative from commonplace tellings of its stories that encircle a heroic man, transformative device, new discovery, or large institution. The lens of infrastructure provides a vocabulary and set of sensitivities around human life, labor, the nature of collaboration and its ecologies: its natural, geopolitical and sociocultural flows. This chapter sets the stage for understanding the wave of history the Ocean Observatories Initiative has rolled in on, informed by previous understandings of infrastructure development and its possibility spaces.

Infrastructure studies has long recognized, if only in footnotes, the fictional, imaginative and fantastical elements of design and development as understudied and critical narratives. Following Chapter 3 that interrogates the methods that created and analyzed the data set that informs this dissertation, Chapter 4 is an exploration of the specifics of the OOI's journey from fantasy to reality, tracing back to the technical dreams found in science fiction of the ocean predating the field itself and threaded through the histories of Chapters 1 and 2. Through identifying the fictional signals found formally and informally in the OOI – across calls for participation, publicity, designs, interviews and field notes — what comes alive in the vision of the OOI is a hospitable hope for a future in which our oceans come into view as central to understanding the way the world works, opening society's collective imagination for the mysteries below the waves and encouraging anyone with interest to participate in making those discoveries. We see that a dream of technological utopia fuels the scientific field's fantastical fervor, opening questions about the power of hope and fantasy in our plans.

Chapter 5 acknowledges both the glossy and hard complexities of building transformative infrastructure. It is not solely within design that we will find the answers to the problems of innovation that face our newest constructions. Particularly when building infrastructure whose aim is in part to draw new participants into the field, we must look to the labor politics of big science and how individuals can build their lives into and around the infrastructure: toward the security of individuals, the viability to their communities, the sensing by their bodies and the practices and infrastructure that could allow everyone to live competently and sustainably each day. Chapter 5 begins to detangle the promise of the OOI infrastructure from the realities of ocean science by interrogating the disconnect between its technological solutions and cultural problems, identifying the holes between present and future: that this infrastructure was built with a rhetoric (and with administrative and technical structures to match) of openness, participation and democracy but that cultures of ocean science and ocean engineering are still grappling with its longstanding issues of diversity and labor that create barriers to participation for new demographics.

Collectively these chapters demonstrate how infrastructure is often built against the currents of cultural norms and political struggle, but is also built with resilience and hope. Detailed throughout this dissertation are the strikingly passionate and hard-working individuals who invest themselves in the OOI and the future it promises, who want to see answers to questions of climate change, ocean acidification, and urbanization through new big data resources about the ocean from sensors, satellites and instruments laid across the globe.

The final empirical chapter looks further into the "real world complexities" of building transformative infrastructure, to the failures or setbacks in the OOI that happen because of the unexpected or unanticipated hits from the peripheries of the infrastructure's plans: natural or man-made disaster, theft, failure to receive or abide by land or sea permits, disregard or dismissal of communities impacted by the infrastructure, or broader shifting political interests and laws. Through conceiving infrastructural vents, Chapter 6 looks to the challenges of infrastructure that are found at its margins, where living and nonliving things make their home in or make neighbors to the OOI community, positioning these margins as locations of great pressure and power, demonstrating that even the best laid plans mark territories that are continuously broken and reshaped, drawing attention beyond infrastructure to its margins and immediate exteriors and the critical breakdowns that happen there.

There exist remarkable ways in which infrastructures can be - or can be described in ways that are - absent of care (care-less or maybe care-free?). Care is almost a secret, and at times its reveal feels exploitative. Sometimes heartless technical acceleration is given more credence than the gruntwork of care, where any relating of this often evokes fundamentally patriarchal underpinnings and comments on meritocracy, authentic participation and authority. The OOI shows us that flaws are constitutive of normal life, that in future-building there is an ongoing ordering that tells us who will be viewed as exceptional and who benefits from exceptionalism, and, most importantly, who cares.

1
The OOI from Blue Sky to Blueprint:
Capturing and Classifying Nature Through Data-Driven Infrastructure

> I find the great thing in this world is not so much
> where we stand, as in what direction we are moving:
> To reach the port of heaven,
> we must sail sometimes with the wind
> and sometimes against it, - but we must sail,
> and not drift, nor lie at anchor."
> - Oliver Wendell Holmes, The Autocrat of the Breakfast Table
> [Introduction to ORION OOI Data & Implementation report (Daly et al., 2006)]

In the somewhat romanticized self-history of Earth sciences, renowned researchers were once adventurer-explorers, uncovering the mysteries of alien parts of the Earth with their research vessels, their tales joining a centuries-long quest to discover "what's out there." But such journeys of discovery have receded into the past. Even small expeditions have become too costly, and they are inadequate for answering the grand questions of climate and sustainability that dominate the fields of the earth sciences today. Now the environment is known in new ways: continuously present *in situ* sensor networks and projects known by their acronyms like the Long Term Ecological Research Network (LTER) or the National Ecological Observatory Network (NEON) have supplanted snapshots of insight gathered from expeditions. Advances in robotics, communications, and computational capacities have redefined a new era of experimental approaches to science. Commitments to comprehensive, sustained, long-term, time-series of data collected through the infrastructure of distributed scientific observatories have become the chief mode of approach to answering today's most pressing questions about the Earth.

This change is particularly prominent in the field of oceanography: whereas seafaring was once viewed as the backbone of scientific inquiry (including in countless romanticized media portrayals), more recent years have seen the valuing of data-driven infrastructures—a move away from Principal-Investigator-driven scientific explorations and toward collaborative, networked, and technologically-driven ways of knowing (cf. Bowker, 2000; Edwards, 2010; Waterton, 2005; Lehman, 2018). Amidst frequent concerns about the cost of ships' upkeep (Adler, 2015), much of the field's finances have recently been funneled into new observatories full of global sensor and satellite initiatives (Witze, 2013). In this mode of performing ocean science, technological tools are seen as revolutionary, while traditional modes of seafaring work are losing their scientific currency. In this context, the imagined future—a better future—will be shepherded in by data-centric technology, thus pushing the observatory to the forefront of oceanographic research.

This commitment to "observatory science" has created a technological boom in the ocean sciences that has curtailed research paradigms tied to ships' schedules. Instead, interactive mobile and moored sensors cover geographies of scientific interest to capture data through continuous, fortuitous, and deliberate instrumentation that is not reliant on research cruise schedules (cf. National Science Foundation, 2015). Agreements between and recommendations by the U.S. Commission on Ocean Policy, the National Science and Technology Council, the National Science Board, the Pew Oceans Commission, and the National Science Foundation's Geosciences Division, amongst other prominent earth science organizations in the U.S., have hardened such research-driven ocean observing into national policies. In doing so, observatory research priorities have become essential for our future use of and impact on the ocean, and have come to shape debates about the role and responsibility of humans on Earth.[1]

In April 2016—after 9 years of planning, approximately $400 million, and many adjustments (Witze, 2013; 2014; 2016)—these priorities manifested in a technologically and scientifically unprecedented project: the United States Ocean Observatories Initiative (OOI). The latest in a series of large-scale observing projects in the earth and environmental sciences, the OOI is an ambitious, transformative, global-scale data portal to the oceans, built to both generate data and cultivate new scientific interest in the seas. The OOI is informed by decades of dramatic change in scientific endeavors and by the trendiness of data-driven technologies. It is a bastion of this growing oceanographic paradigm, centrally concerned with engineering futures in and on the water. As one participant in my study observed:

> We were talking about new ways, transformative ways to go to sea. And that was the whole thing about ocean observatories. Different ways that scientists can go to sea besides the traditional method of going to sea by ship. There was a transformation in oceanography in the 1980s when satellites were launched, and that really increased our ability to go to sea. It gave us, you know, new pictures of what the global ocean looked like and it added to what we could do in the ocean. And it didn't replace ships but it certainly made what we do at sea on ships more effective. And so, this is, the OOI, is another step in that. There's been many, many steps in ocean observing and this OOI is one of them, like satellites are one of them... OOI is an important step. Again, it's increasing that

[1] Many national reports have debated the importance of observatories in the oceans (cf. National Research Council, 2000, 2003; National Science Foundation et al., 2000, 2001). The power of ocean observatories, particularly in answering questions of climate and ocean acidification, is discussed across many academic and popular contexts (cf. Broad, 2016; Consortium for Ocean Leadership, 2015; Ruhl, 2011; Henson et al., 2016). New national efforts at observatories also indicate the desire and need for additional ocean observatories (cf. U.S. House of Representatives Subcommittee on Research and Science Education, 2013), NOAA IOOOS, or DARPA’s latest call for intelligent floats (cf. Gieb, 2018).

> bandwidth that we can go to sea via the cables, via the other communication systems. And that interactive capability. It used to be that you could put moorings out. We could put moorings out for years, but you would put them out, moorings out, and recover them and hope that there was data. Now you have the ability, well you don't have them yet, but the vision is that you'll have this ability to interact at any point in time with those sensors or the AUVs. This is a big step in capability. (Participant quotation)

As the quote above suggests, the new computational turn in oceanography is deeply embedded in and dependent on infrastructure: satellites, cables that allow for greater bandwidth, constant interaction with sensors and AUVs, all indicative of the alchemy by which the ocean transforms into data. Proponents of these sorts of methods link oceanographic research to goals that extend beyond mere scientific exploration:

> The ability to grow food on land is directly tied to the ocean's motion. The ocean's health will determine whether the planet can feed humanity. The chasm between the haves and the have-nots has historically fomented political dissent, and in the future the divide could widen between wealthy nations and developing nations that can't feed their populations. Therefore, [John Delaney] reasons, studying the ocean could prevent the conflicts that can lead to terrorism. (Chan, 2004)

Proponents see the sea as an opportunity for understanding current life on the earth and the origins of life, for equalizing our knowledge of the Moon with our more recent knowledge of the Mid Ocean Ridge, for strengthening Naval security and surveillance of ocean-dwelling intruders,

According to such champions of the project, the OOI inaugurates an unprecedented undertaking in the ocean sciences, a future with unforeseen reach, extension, and human telepresence. In this vision, the stakes are high and far-reaching: oceanography will no longer simply increase understandings of the ocean, but, via the computing paradigm, will enable agricultural advancements and solutions to world hunger that will calm violent political dissent, among other contemporary problems. In other words, OOI enthusiasts imagine a future in which ocean science could occupy a more visible role for all humankind.

As these sentiments demonstrate, underlying the specifics of the OOI's technical and engineering plans is a vision, a set of priorities, and an imagination of what the future will hold for the worlds of ocean science. This vision, and the OOI specifically, are part of a broader international shift in the way that humans imagine the ocean and what it looks like to be part of it, to interact with it, and to understand it. It places ocean science at the center of debates around climate, life on Earth, big data's power to produce cultural and economic change, and the future of large-scale science.

This chapter offers a history and overview of the OOI's development. It provides context for my fieldwork and the major arguments of this dissertation regarding its data-driven cultures, where in the place of renowned heroic individuals there often exist nameless collectives with their technological vanguards, where the definitions of what it means to be an oceanographer and how we understand the natural world (and our role in it) are changing.

1.1 The Ocean Observatories Initiative Final Design

The Ocean Observatories Initiative (OOI) is a United States National Science Foundation (NSF) funded program, managed by the Consortium for Ocean Leadership (COL). It was approved through a cooperative agreement between the National Science Board and NSF in May 2009 and construction began on September 2, 2009. The OOI was designed to conduct 25-30 years of sustained distributed ocean measurements to examine climate variability, ocean circulation and ecosystem dynamics, air-sea exchange, seafloor processes, and plate-scale geodynamics. Its goal is nothing short of transformative access to the oceans, promising to provide earth, ocean, and atmospheric scientists with opportunities to capture diverse interconnected processes over timescales ranging from microseconds to decades. Such access offers the prospect of conducting comparative studies across regions and seasons, and developing complex models, charts, and maps from basin-scale to whole-Earth (Consortium of Ocean Leadership, 2013; Chave, 2003). Reports and participants alike note that an attempt at telepresent data collection of the seas, or engineering "an instrumented ocean," as one participant characterized it, would greatly increase the possibility of groundbreaking discoveries and extend both the geographic and temporal understanding of key ocean processes.

To this end, the OOI is a networked infrastructure of science-driven sensor systems that measure the physical, chemical, geological, and biological variables within the ocean and seafloor. It creates a permanent presence via global sensor networks throughout the ocean's water column (OOI, 2018). From its earliest documents, the OOI's primary science orientation concerns climate variability and physical processes like ocean circulation and acidification across coastal, open-ocean, and seafloor geographies and scales (Consortium for Ocean Leadership, 2011). The OOI was built upon 10 "guiding principles" created through a multi-year effort to gauge the broader interests of the ocean science community through workshops (see: Figure 6), symposia, advisory boards, and consultations with NSF officers and COL:

(1) continuous observations at high temporal resolution for decades;
(2) spatial measurements on scales ranging from millimeter to kilometers;

> (3) the ability to collect data during storms and other severe conditions;
> (4) two-way data transmission and remote instrument control;
> (5) power delivery to instruments between the sea surface and the seafloor;
> (6) standard instrument interfaces;
> (7) autonomous underwater vehicles (AUV) docks for data download and battery recharge;
> (8) access to facilities to deploy, maintain, and calibrate instruments;
> (9) an effective data management system that provides open access to all; and
> (10) an engaging and effective education and outreach program that increases ocean literacy. (ORION Program Office, 2013, p. 4)

The NSF's Division of Ocean Sciences established the Ocean Research Interactive Observatory Networks (ORION) program to bring these guiding principles to fruition. As such, ORION was responsible for planning the OOI's integrated observatory network, constructed with funds from the NSF Major Research Equipment and Facilities Construction (MREFC). Established in 1995, the MREFC was developed as an agency-wide account separate from the field-specific NSF directorates, an account that funds and manages large-scale, high cost engineering infrastructure like telescopes (LSST), earthquake simulators (NEES), and particle accelerators (RSVP). The MREFC is a Congressional response to the cost overruns of large projects, introducing accountability and auditability structures. MREFC dictates a tight political engagement of science with politics, as the White House, Congressional leaders and the NSF in concert designate the new line item in the presidential budget for a large project to be launched. MREFC defines a specific project management and governance structure upheld by Congressional review, the National Science Board and the Office of Management and Budget that carries new large-scale projects from planning through construction and early operation phases when their costs (often in the hundreds of millions or low billions) exceed or dwarf the budget capacities of typical NSF directorates. The MREFC regulates a specific project evolution through Preliminary, Conceptual and Final Design Reviews and its role in transitioning responsibility back to the NSF directorate through an approved Operations & Maintenance plan. OOI personnel and the NSF also oversee this work with assistance from both University-National Oceanographic Laboratory System (UNOLS) and the U.S. Navy. The OOI is managed and coordinated by the OOI Project Office at the non-profit Consortium for Ocean Leadership (COL) in Washington, D.C., which oversaw its construction and remained involved through the initial operations of the OOI network (Consortium for Ocean Leadership, 2013). In addition to its project oversight role, COL acts as a hub of research and education on Capitol Hill, facilitating oceanographic research projects, broader-scale policy, and technological development on behalf of the United States government (Consortium for Ocean Leadership, 2013).

Leadership at the construction level was provided by four major Implementing Organizations (IOs) and partners who guided the OOI, overseeing the physical and organizational building and development of the overall program, holding their teams and resources to the MREFC procedural constraints. These IOs were supervised by the Ocean Sciences Division and MREFC within the NSF, as well as the COL: (1) Woods Hole Oceanographic Institution (WHOI) and its partners at Oregon State University and Scripps Institution of Oceanography (SIO), responsible for coastal and global moorings and their autonomous vehicles; (2) nearby University of California, San Diego (UCSD), responsible for implementing the cyberinfrastructure; (3) University of Washington, responsible for cabled seafloor systems and moorings; and (4) Rutgers University, with its partners University of Maine and Raytheon Mission Operations and Services, responsible for the education and public engagement (EPE) software infrastructure, with an initial 3% of the overall budget (ORION Program Office, 2013). By spring 2016, Oregon State was no longer a subcontractor of WHOI, and the implementing organizations became: Woods Hole (responsible for the global arrays and the Pioneer Array); Oregon State (responsible for the Endurance Array); the University of Washington (responsible for all cabled assets, including those on the Endurance Array); and Rutgers University (responsible for education and public engagement, and data management (OOI, 2018). In 2015, Scripps and UCSD were removed entirely from the OOI roster and all cyberinfrastructure responsibilities were reassigned to Rutgers. Raytheon Mission Operations and Services provided consulting for carrying out these initiatives.

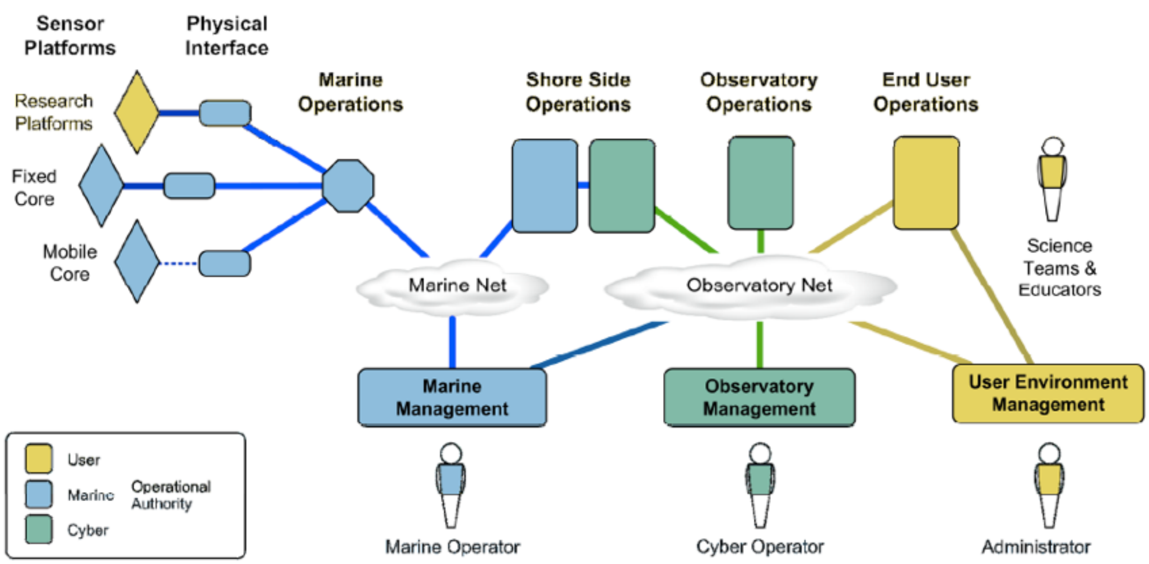

Figure 1.1. OOI Integrated Observatory Network Design. Different operational domains that together form the OOI Integrated Observatory through cyberinfrastructure, each maintained by the CI IO. The lines and clouds in Figure 1.1 represent communication networks and the nodes represent physical sites (Image credit: Consortium for Ocean Leadership).

The physical core of the OOI is separated into three dimensions: regional scale nodes, coastal nodes, and global scale nodes. As of spring 2018, these included 83 platforms carrying over 830 instruments, providing over 100,000 data products (OOI, 2018). Global nodes (all in the Western hemisphere, off the shores of both North and South America) operate at a distance from US shores through a set of buoys and moorings. Regional scale nodes are made up of sensors connected through telecommunications cables that are hard-wired to the seafloor. Coastal nodes contain hybridized instrumentation and communication channels, including moored buoys, cables, and autonomous instruments. These distinctions define a distributed set of instruments released into water or hard-wired onto the ocean floor, and linked through satellites and telecommunications cables (see: Figures 1.1 and 1.2). Junction boxes connected to this primary backbone on the seafloor support individual instruments or instrument clusters at varying distances from cables and moorings to both expand spatial reach and extend computational capacity. Additionally, the OOI houses data collected via mobile instrumentation—such as ROVs, AUVs, and gliders—to combine navigation and communications networks and further extend and connect the spatial coverage of the system (Daly et al., 2006).

The computational core of the OOI lies in its "cyberinfrastructure" (CI), which pulls raw data from each of the sensors and instruments, cleans and runs quality control on that data, and then publicly releases the calibrated data online, with the intention of maintaining real time or near-real time. Complementing this cyberinfrastructure is a series of Education and Public Engagement (EPE) tools, which transform the processed data into "forms more readily usable by students, educators, workforce participants, and decision-makers" (Consortium for Ocean Leadership, 2013, p. 5). In response to the MREFC Education User Requirements, the EPE was charged with developing web-based user tools that visualize the multiple data streams and merge with other non-OOI models that are "appropriate for cultural diversity, and social networking to enable collaborative workplaces" (see Figure 1.4) (ORION Program Office, 2013). According to the OOI's publicly available online Q&A, by 2016 the OOI Data Portal had 500 users from 180 different organizations around the world. In May 2016 alone, 900 GB of OOI data were downloaded with an average of 25 downloads per day (OOI, 2018).

1.2 Planning and Constructing the OOI

The OOI has two origin stories: one is a romantic narrative that draws on the historical norms of oceanography to celebrate one man's insight and genius; the other (see: Figures 6 and 7) tells a more collective story of creating large-scale observatories, involving a larger cast of characters engaged in frequently mundane, painstaking and sometimes frustrating work. Both bear important elements of truth.

As the story goes, the impetus for the first underwater observatory in the United States—what would become the Ocean Observatories Initiative (OOI)—began with a drawing on a bar napkin penned by a frustrated John Delaney of the University of Washington in 1990. Delaney, in conversation with a colleague, was venting his frustrations about the rising costs of seafaring and the serendipity required to capture events deemed most scientifically critical on the seafloor. He sketched instruments cabled all over the Juan de Fuca tectonic plate off the Pacific Northwest Coast, from fault line to coastline, capturing shifts in pressure, temperature, salinity, and acoustics (amongst others), and envisioned how this new instrumentation would diminish the centrality of serendipity in ocean research.

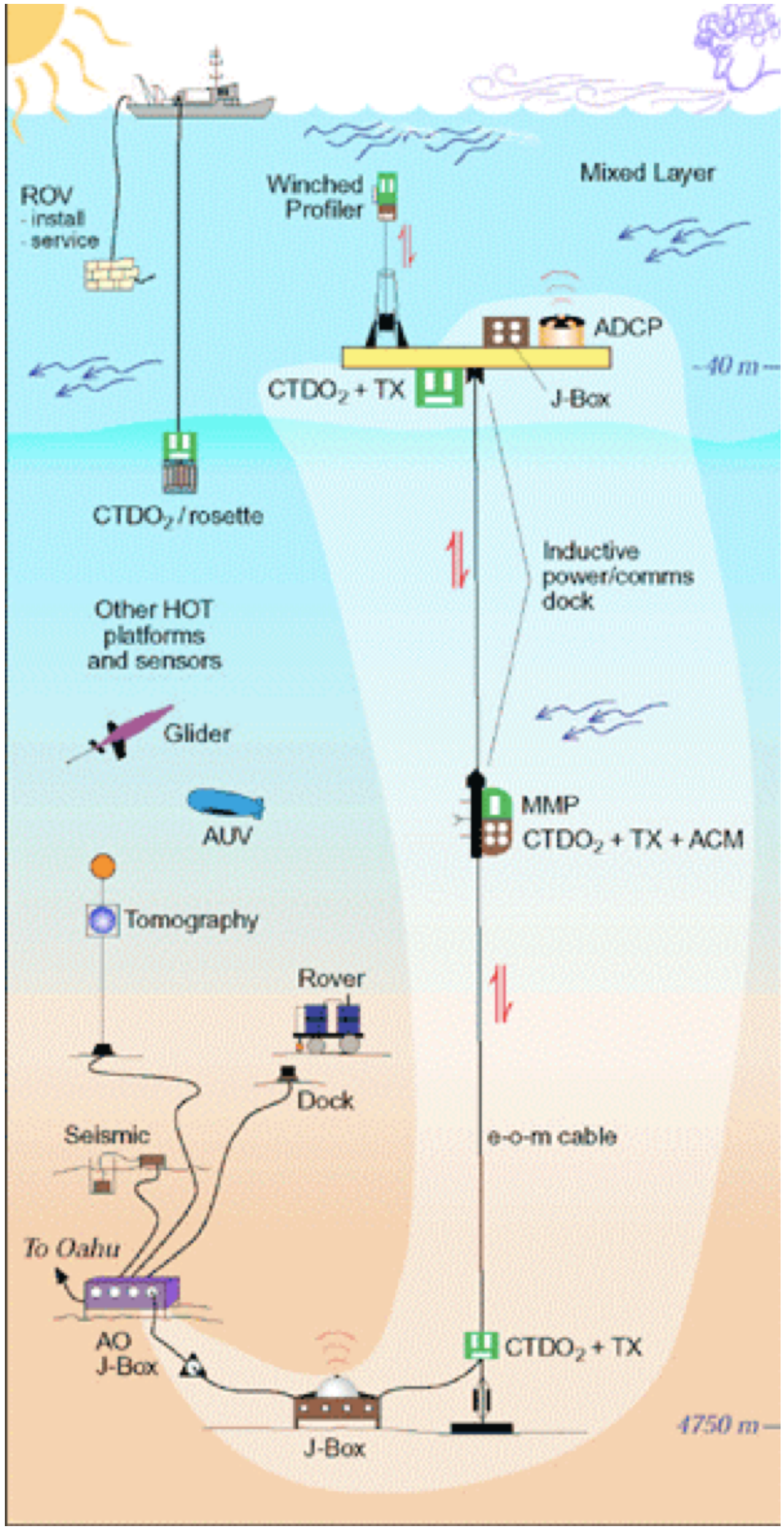

Figure 1.2. Illustration of cabled profilers and autonomous instruments. Rendering of the physical core of the OOI including extensions via junction boxes (Image credit: Consortium for Ocean Leadership).

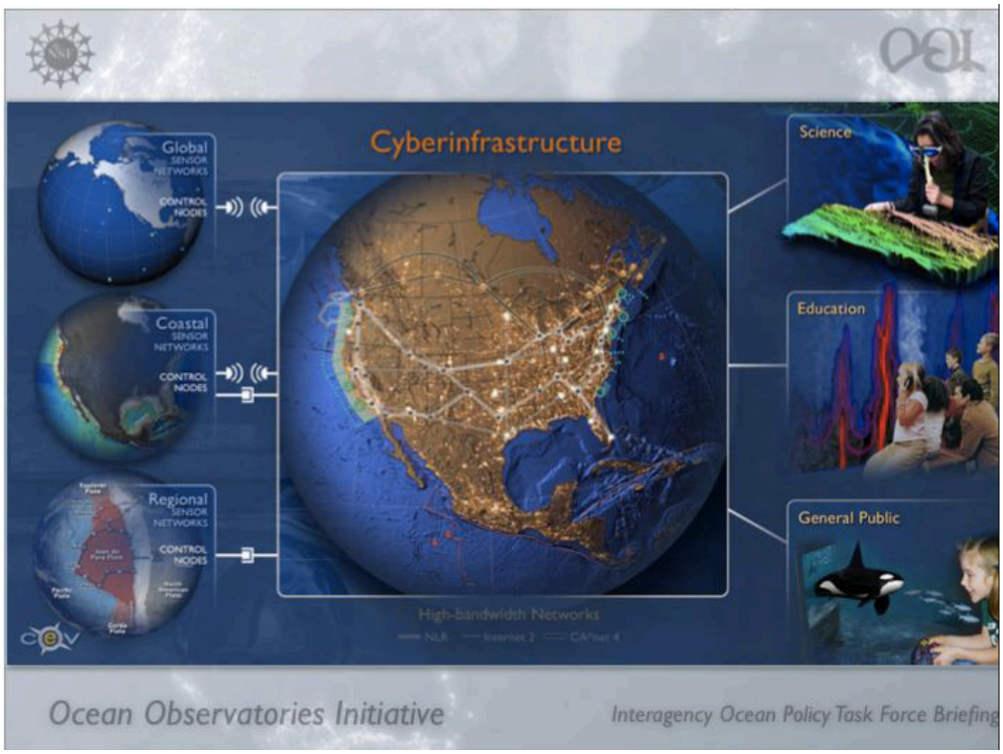

Figure 1.3. OOI Cyberinfrastructure. A representation of the OOI Cyberinfrastructure as a resource for scientists and the public, connecting the coastal, regional and global oceans with multiple institutions across the United States (Image credit: Killeen, 2009)

Figure 1.4. OOI Education and Public Engagement. A representation of the OOI's EPE, positioning the earth as accessible through a mobile device (Image credit: Killeen, 2009).

The major geographic locations of the OOI were selected to address six broad interests: (1) ocean-atmosphere exchange; (2) climate variability, ocean circulation, and ecosystems; (3) turbulent mixing and biophysical interactions; (4) coastal ocean dynamics and ecosystems; (5) fluid-rock interactions and the sub-seafloor biosphere; and (6) plate-scale, ocean geodynamics. The major arrays are housed in the Irminger Sea near Greenland and Iceland, in the southern ocean off the southern coast of Chile, in the Argentine Basin, on the West Coast over the Juan de Fuca Plate and on the East Coast off the shores of New Jersey (see Figure 1.5).

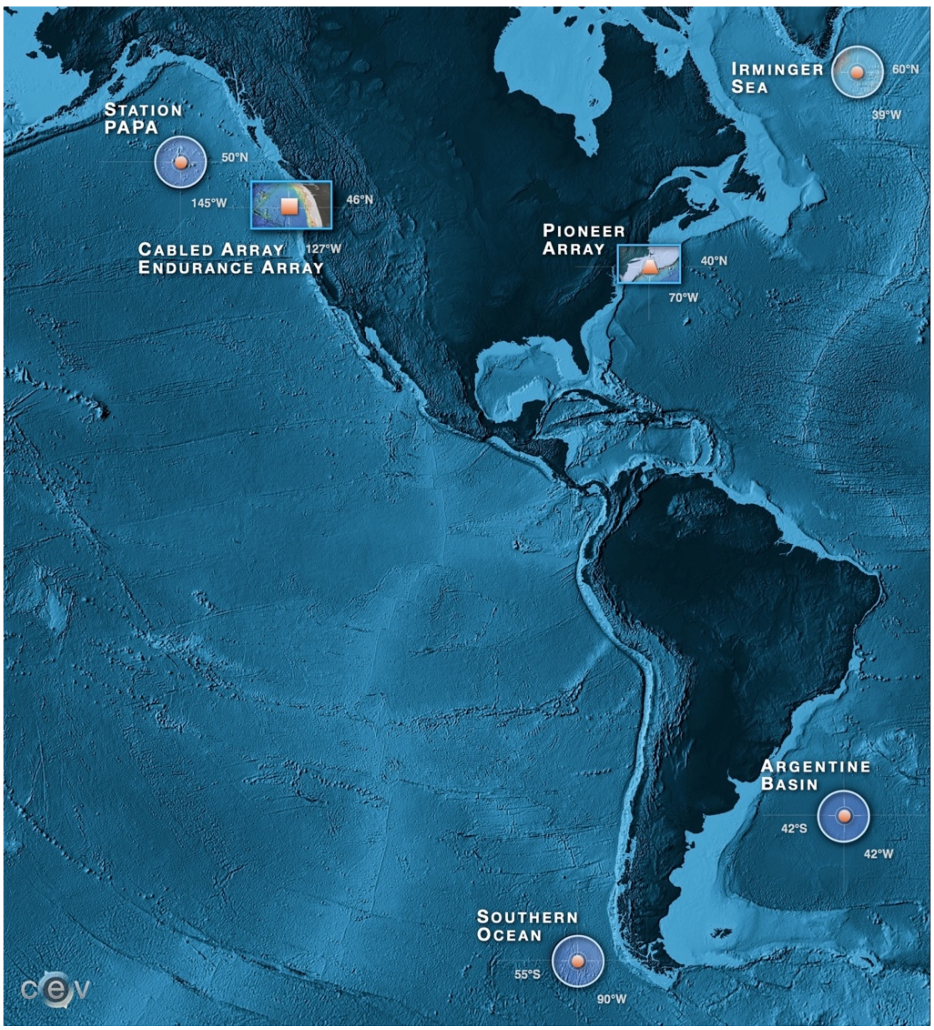

Figure 1.5. OOI Map. Map of the OOI's global and coastal arrays (Image credit: OOI Cabled Array & the Center for Environmental Visualization, University of Washington, 2018).

Decades later, what has become the OOI was not launched simply by one man and an impassioned scribble on a napkin, but by a multifaceted convergence of many policies, politics, and powerful actors--including John Delaney and his napkin. A more accurate history involves numerous intersections and potential starting points, a whole process of community consultation, reports, draft statements, tiger teams, requests for assistance, and the coalescence of national and international government, science, and industry players over decades. The OOI is a vision of diversity: of moments, of data, of questions, of answers, of instruments, of methodologies, and of people.

In the 1990s, major changes cleared the path for the OOI's development. First, there was the desire—a cultural shift among researchers toward interest in global time-series modeling, as explored in the following chapter. Second, funding options transitioned away from a decades-long reliance on the Navy. And third, the National Oceanic and Atmospheric Administration's (NOAA) long-term monitoring and observing initiatives began to fade. These changes created a context in which the NSF could implement an agenda for managing and financing Earth observatories generally, an area it viewed as ripe for a new large-scale endeavor.

The NSF began organizing workshops to assess the science and technology requirements of a national oceanographic observatory, with John Delaney and his team at the University of Washington at the helm, notably the Workshop for Scientific Uses of Undersea Cables in 1990 and Multidisciplinary Observatories of the Deep Sea Floor in 1995 (ORION Program Office, 2006; Yoder et al., 2006). The workshops were organized by a group consisting largely of physical oceanographers and ocean engineers from the major U.S. oceanographic research institutes with a collaborative presence from NSF officers, marine biologists, geophysicists, climatologists, and seismologists at multiple levels within the academy. These workshops were intended to identify the major players and possible collaborations, the sites of most vocalized interest to the community (amorphously defined), and develop more democratic practices for sourcing inputs and ideas that would inform the final design. Workshops were addressed by the community through publicly-available online-accessible comments (cf. Daly et al., 2006) which would be integrated into both casual and formal facets of the future system, reappearing in the later documentation.

As a result of these workshops, in 1997, some of the first proposals for a project recognizable as what would become the OOI quickly received funding to seed and support further planning efforts. In 1998, Delaney and his colleagues conducted a feasibility study that eventually became the Northeast Pacific Time-Series Undersea Networked Experiment (NEPTUNE) project. With oversight from the National Ocean Partition Program (NOPP), advisory recommendations from ONR and NSF, and jointly funded by the NSF and the University of Washington, "The Feasibility of the NEPTUNE Project" provided a map for a project that would cover the whole of the Juan de Fuca plate, the basis for what would become the OOI. The study employed traditional components as well as new technologies that participants described as imaginative and unfathomable at the time. By 1999, Canada's Institute for Pacific Ocean Science and Technology was invited by the U.S. to undertake a feasibility study of Canadian partnership with the U.S. NEPTUNE.

Meanwhile, a series of major advances in ocean engineering and climate interests in the 1990s fed the momentum created by these workshops. The International Ocean Network was founded in 1993, and by 1995, the first U.S. national committee was established with NSF funding, thus broadening the Dynamics of Earth and Ocean Systems (DEOS) committee. The enlarged committee was tasked with exploratory planning for an ocean observatory network. The first International Conference on Ocean Observing Systems was held in 1999 in San Rafael, France, and drew interest in fixed and mobile observing systems. Later that year, the international Global Eulerian Observatory (GEO) committee was formed (which later became OceanSITES) (OceanSITES, n.d.). Also in 1999, the Congressional Committee issued a House Report, the Marine Research and Related Environmental Research and Development Programs Authorization Act, which introduced guidelines for establishing NOAA and NSF as purveyors and recipients of responsibility and funding for ocean science research (U.S. Congress, 1999).

The boom of interest in time-series modeling persisted into the new millennium (cf. NSF Geosciences Beyond, 2000; Ocean Sciences at the New Millennium, 2001; Ocean.IT; National Oceanographic Partnership Program, 2010). The Oceans Act of 2000 went into effect on January 20, 2001, a coordinated, comprehensive, and long-range national policy for the responsible use and stewardship of ocean and coastal resources, to benefit the U.S. (U.S. Congress, 2000). The Act articulated that it would serve as the impetus for future scientific resources and funding to protect human life and property; fishery resources; protection of marine environment; enhancement of marine-related commerce; expansion of human knowledge about the role of the marine environment in global environmental change; enhancement of education, energy, and food security; and a close cooperation between government and the private sector. More broadly, the Act addressed the need for a concerted effort to preserve the U.S.'s role as a leader in ocean science research and ocean activities (106th Congress, law number 106-256). Establishing the NEPTUNE was a shepherd to that future.

A series of international community workshops (see: Figure 6) and the U.S. National Research Council (NRC) studies, *Illuminating the Hidden Planet* (2000), and *Enabling Ocean Research in the 21st Century* (2003), catalyzed the National Science Board's (NSB) approval of the NEPTUNE as a Major Research Equipment and Facilities Construction (MREFC) project for inclusion in a future NSF budget. MREFC was a funding category within the NSF to support large-scale infrastructure investments that exceeded the annual programmatic budgets of individual NSF directorates and programs. This association with MREFC was fortuitous, as it would ultimately position the OOI as a major research facility with the ability to broaden its scope well beyond the NEPTUNE cabled system. A U.S.-based cabled test facility was opened in 2002 as the Monterey Bay Accelerated Research System (MARS) for the incoming global observatory that would require new testing at scale.

Heavily influencing the design and operation of the MREFC across scientific domains, the foundational infrastructure vision statement by the National Science Foundation, *Revolutionizing Science and Engineering Through Cyberinfrastructure* (Atkins et al., 2003), otherwise referred to as "the Atkins Report" for its primary author Daniel Atkins of the University of Michigan, is heralded as an essential document driving the future of modern US technical development in the sciences. Following generations of engineering thinking in the sciences [cf. (Black, 1989; Lax, 1982; National Science Foundation Blue Ribbon Panel on High Performance Computing, 1993)], the Atkins report embraces the exponential pace of computational technology and the NSF's commitment to producing, disseminating and preserving scientific and engineering knowledge for generations. The embrace of technology, according to this report, is not optional for most fields[2].

Through the MREFC the transformative vision of the OOI has transformed itself: starting from the glimmer in the eyes of the OOI champions in developing NEPTUNE and its predecessors GEOSECS, to the U.S. vision for climate change research tracing through the administrations starting with George Bush Sr. The OOI first became a real idea at the time climate change came into the rhetoric of a party platform, alongside global visions like the U.N. Framework on Climate Change. The next administrations' policies around climate and ocean research greatly impacted the funds that would make their way toward the OOI: Clinton and Byrd-Hagel, George W. Bush withdrawing from that pact, and then the Obama's stimulus package for climate change research alongside the American Clean Energy and Security Act.

By 2000, the main contours and wider motivations for what would become the OOI were in place. The NSF Geosciences Full Report stated:

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[2] However, this embrace also comes at a cost of uncertainty and risks located within the complexity of generational thinking. The report notes the dangers of cyberinfrastructure development and its possible negative results located in a "lack of understanding technological futures" or "lack of appreciation for social/cultural barriers."

> As the "information age" progresses, a vision emerges of an informed society that is empowered to maintain a healthy planet and develop strategies to respond to the continuing challenges posed by the Earth's physical and biological environments. In the future, detailed knowledge of the full range of interacting Earth processes will be essential for sustaining the health and prosperity of nations and individuals. Equally important will be the need for educational innovations to enable the populace to understand the complex and interwoven processes that support and affect their lives. The agenda for geosciences aims to develop the understanding society needs to maintain a healthy and habitable planet (National Science Foundation Advisory Committee for the Geosciences, 2000).

This report and others highlighted the need to resolve current social challenges, expressing, "We are profoundly aware that society has the ability to alter and/or exploit the planet's physical, chemical, biological, and geological environments on all scales—local, regional, and even global" (Geosciences Full Report, 2000). To the authors, technological interventions were necessary at each of these levels (local, regional, global) in order to glean new understandings and potentially solve these challenges—these interventions would be supported by human, temporal, capital, and material resources from the government and other powerful agencies. By linking the geosciences with a grander social discourse about humans' role on Earth, preliminary plans for a project like the OOI were substantiated as a scientific activity, one that served national interest. In light of climate concerns echoed in vision statements and policy, the questions asked of the ocean became broader and more humanistic, and tightly wound in the political and societal concerns of the time. And with funded participants, planning and community organization began in earnest over the following 8 years, defining and designing "the instrumented ocean."

The vision of the OOI at this time was still named NEPTUNE, and it was a joint project between the U.S. and Canada. The two nations prepared to install a cabled system from Vancouver Island to northern California, over the entirety of the Juan de Fuca tectonic plate, particularly at the fault lines where less predictable scientific episodes could be captured. Canadians participated in the planning of the U.S. NEPTUNE and submitted a complementary proposal for funding from the Canadian government in 2002. The proposal resulted in a $100 million award, and with the help of a very aggressive president, the University of Victoria began to construct NEPTUNE in 2003 (JOI/USSSP and NEPTUNE, 2003; OOI, 2018). They moved rapidly. By 2009, Canada had already completed the first regional scientific ocean seafloor cabled system, just as their U.S. counterparts were laying their first brick (Ocean Networks Canada, 2018).

By 2003, NEPTUNE was a separate and fully crystallized initiative in the U.S. on its way toward development.

Figure 1.7. OOI timeline. After the year 2000, timeline including major workshops and government reports up to the official launch of construction on September 2, 2009 (Image credit: Consortium for Ocean Leadership).

1.3 From the 2004 San Juan Workshop to the OOI Science Plan

Most participants and reports cite a 2004 Ocean Research Interactive Observatory Networks (ORION) workshop in San Juan, Puerto Rico, hosted by the National Science Foundation, as the origin of the OOI initiative as we know it today. The workshop was designed in part to codify and develop linkages between the U.S. Integrated Ocean Drilling Program (IODP)—a long-standing NSF initiative monitoring sub-seafloor dynamics through coordinated international efforts—and the OOI. The need for such a workshop became clear in conversations among individuals involved in one or both programs over the preceding year, recognizing the many ways in which coordination between the IODP and the OOI could help to advance both initiatives. Connecting the programs could also capitalize on the funding momentum being directed at both to develop new tools and techniques, excite scientific and public communities, and create unprecedented opportunities for profound, rapid progress toward resolving outstanding questions in Earth, Ocean, and Biological Science and related disciplines.

John Delaney, Deb Kelley from the University of Washington, Bob Weller from Woods Hole Oceanographic Institute and others who remain affiliated with the OOI led the 2004 ORION workshop, intending to gather together ocean scientists interested in building a continuous presence on the seafloor through a convergence of sensor technologies and satellite transmission. There were 1000 attendees: scientists, engineers, educators, program managers, representatives from eight countries, and one steering committee member from Canada. The University of Washington, in particular, the Applied Physics Laboratory, emerged during this time as a key player in the unprecedented development of the observatory, its affiliates participating in the workshop and occupying an increased authorial role in the official documentation of the initiative.

The first slide of the workshop's first session presenter read: "The rapid development of enabling technologies for time-series science offers the potential to revolutionize how ocean science will be conducted in the new millennium" (National Science Foundation, 2004). After outlining in broad strokes the potential technological infrastructure from mobile arrays full of instruments that would travel across the world's oceans to robust sensor networks laid across a tectonic plate's full fault line, the speaker then asked attendees to explore this prompt and develop science goals to fit the possibilities such a network would open up. The results of this imaginative exercise and the formalized report on the workshop captured the multifariousness of the program as well as its initial international collaborations (Daly, et al., 2006), explored later through connection to NEPTUNE Canada and the GEOSS and IOOS programs.

Multiple cultures of ocean scientists from around the world from multiple disciplines - atmosphere-ocean, seafloor tectonics, and microbial evolution - were assembled into workgroups of sub-disciplines to consider prospective challenges and outline possible resolutions (Daly, et al., 2006). A wish list of scientific interests in ocean engineering was refined into a report, "ORION Data & Implementation," that posed questions about how these imagined technologies would provide solutions to various problems and in what geographies. Hydrothermal vents and the Juan de Fuca plate were uncontested interests within the community, with a solidified working group and multiple dominant champions advocating for its inclusion. Participants noted that other possible infrastructural commitments were less solidified and more abstract, that some voices in the room were louder than others so their geographies and instruments were better represented in the later report[3]. Broader themes that emerged from the workshop were: physical processes and climate variability, biogeochemical cycles and marine ecosystems, Earth structure and geodynamics, fluid-rock interactions and sub-seafloor biosphere, ocean-atmosphere fluxes, marine meteorology and ocean hazards.

These themes indicated a number of possible technological interventions and geographies of interest: the East Coast North Atlantic basin, the Gulf Coast, the Labrador Sea, and the Gulf of Maine with mobile glider lines and arrays; Gulf of Alaska gliders and moorings; expanding the already established coastal Pioneer Array; an itinerant pioneer array that could travel the globe with associated mobile platforms as a "traveling road show" (Daly, et al., 2006) observatory; Scotian shelf sediment collection and measurements concerning animal and human contributions to the ecosystem; the Juan de Fuca plate cabled assets; expand the global RIDGE site and the southern and western Pacific sites, including remotely interactive buoys and global wave instruments for sound detection; FLIP platform on the MOMAR/RIDGE location; CORK sub-seafloor sites; SAB coastal observatories or one in the equatorial Atlantic. This acronym-filled wish list contains some of what would eventually come to be the OOI, with the Gulf of Mexico and the FLIP platform as notable exceptions to the OOI's final design.

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[3] In later chapters, I will explore some of the silences not present in fictional and nonfictional imaginaries of the OOI.

Concurrently, funded in late 2004, the $3.9 million Laboratory for the Ocean Observatory Knowledge Integration Grid (LOOKING) developed early versions of software, hardware and network services to allow researchers, educators and students to access and to analyze ocean and atmospheric data in real time (Boyle, 2016). The LOOKING prototype experiment laid important groundwork for the OOI. The prototyping concept became its own NSF proposal as an early collaborative effort between the UW, UCSD and Oregon State University whose co-PIs would serve as co-PIs of implementing organizations within the OOI (UC San Diego Jacobs School of Engineering, 2017).

As the ORION proceeded after the 2004 workshop and the scope of the whole program grew, significant coordinated efforts emerged to gauge and listen to the communities that would benefit from these instrumental advancements. Through this repositioning and expanding of the project, the NSF decided "NEPTUNE" was too closely related to John Delaney and the University of Washington and the Canadian network, and that if it was to become a national facility, it should not carry that identifying name. While the Canadian counterparts cashed in on the near-decade of name recognition within the fields of ocean science, the U.S. made significant efforts to distance the project, renaming the West Coast cabled array as the "Regional Scale Nodes" in the new Ocean Observatories Initiative (OOI). This important change signaled a new identity for the project: the establishment of the OOI as a solely U.S. endeavor, moving into more diverse geographies, more collective thinking and away from the international tone it had taken in prior visions.

The U.S. OOI's plan also subsumed and rebranded the expansive goals of the NEPTUNE observatory, with the idea to reproduce them across the globe with multiple fixed and floating observatory locations, as well as a cyberinfrastructure code base to pull data from distributed instruments and unite them online. In the NEPTUNE reports that were revised into the OOI (Ocean Networks Canada, 2018; Daly, et al., 2006), the new observatory promised sustained, continuous, real-time observations across conditions and geographies from data collection at multiple time scales and spatialities, access to underwater maintenance and repair vehicles, and support for developing, testing, and calibrating new instrumentation with both data management and outreach resources. Howe et al. describe this transition:

> Innovations offered by regional observatories such as NEPTUNE will give users the ability to enter, sense, and interact with the total ocean-Earth environment. Via the Internet and other innovative media, students and the general public will be offered unparalleled opportunities to interact with scientists and their data in settings that will range from aquariums, museums, science centers, and schools to living rooms and libraries anywhere on the globe. NEPTUNE's real-time video and data streams and the products derived from them open a wide range of possibilities for education and outreach… There will be possibilities to capitalize on the appeal of "charismatic megafauna" such as humpback and killer whales, and on the broad interest in migratory fish stocks such as salmon. The public's interest in hazardous earthquakes and volcanic eruptions is considerable and the potential for linking these more dramatic geologic events to hydrogeologic and biologic activity will certainly have a broad appeal. Fluid-flux processes often have short-term periodicities that lend themselves well to real-time displays. (Howe et al., 2003)

The rebranding of NEPTUNE as the OOI became an opportunity to draw new understanding of the globe as well as new interest from a broad range of social, political, scientific and public spheres.

The ORION Project Office, in cooperation with NSF's Division of Ocean Sciences, issued a Request for Assistance (RFA) in January 2005 to acquire detailed conceptual proposals for experiments from interested investigators of the future OOI. These proposals would define the nature and cost of the principal OOI infrastructure needed to support the highest priority science of the ocean research community (OOI, 2018). The office received a total of 48 proposals from 549 individually named proponents, representing 137 institutions, agencies and industries in 35 states (Consortium for Ocean Leadership, 2013; Daly, et al., 2006). A peer-review panel comprised of scientists with no connection to any RFA proposal was convened in September 2005 to evaluate the proposals and provide prioritization based on the importance and uniqueness of the proposed research, adequacy of the experimental plans, readiness of the experimental designs and proposed technologies, and innovative use of the OOI concept (OOI, 2018; Daly, et al., 2006). A series of new workshops and panels synthesized the results of this RFA, asking about the values and priorities of the community. For example, the 2006 Design and Implementation Workshop contained the prompt: "So, how do we decide, for example, whether to build infrastructure to study phytoplankton ecology or the structure of the core-mantle boundary? Or, to study cross-shelf biochemical fluxes off the east or west coasts of the U.S.? We need criteria that don't pit disciplines against each other, and we start by applying those criteria to the detailed science plans provided by the RFA, under the guidance of the RFA Review Panel." (ORION Program Office, 2006). The workshops culminated in the determination of 3 major arenas of exploration (regional, coastal, and global) with designated chairs that would manifest these more inchoate workshop wish lists and the formalized requests for assistance (RFAs) into a fiscally responsible reality (e.g. Figure 1.8).

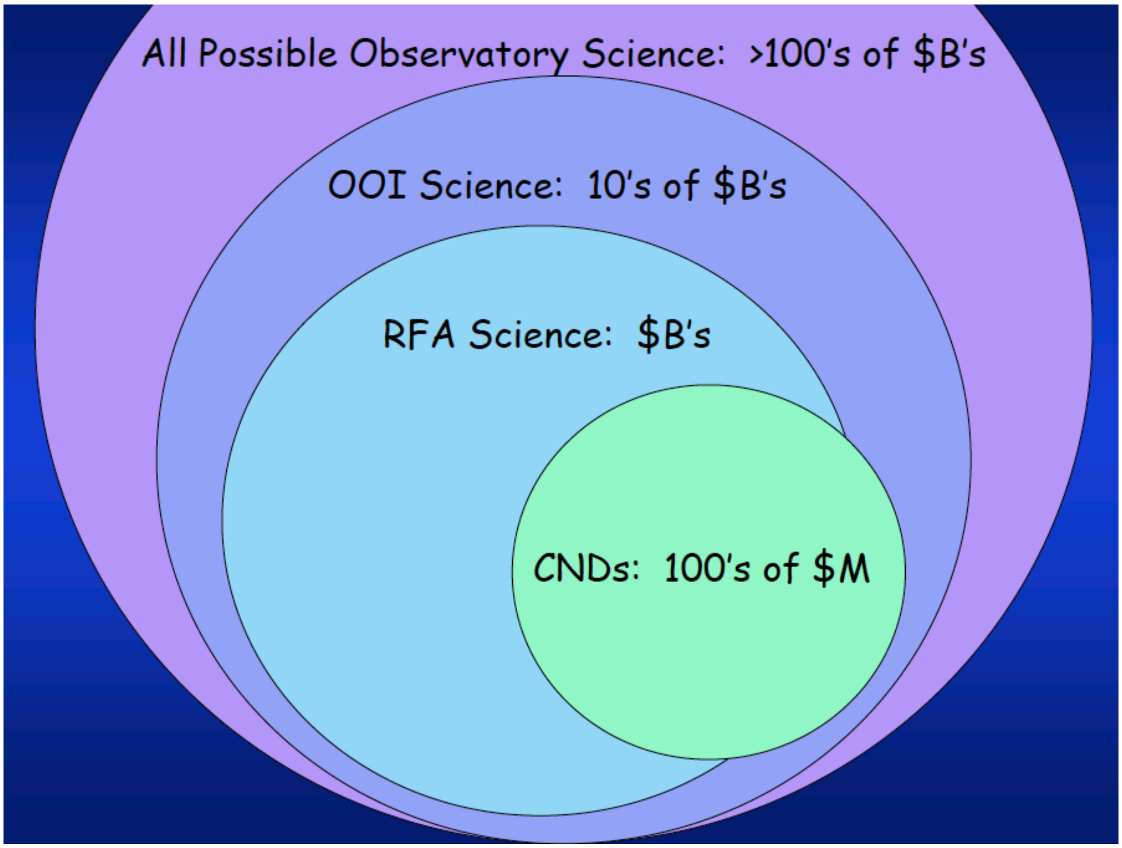

Figure 1.8. Representation of financial cost of all requested instruments. This visualization of the ORION STAC chairs' responsibility to determine which instrumentations could be included in the final design was projected below the title "Fiscal Constraints Are Formidable (no, Horrific)". Each circle represents the amount of funding that would have been needed to fulfill all of the RFAs received for the expanded NEPTUNE project (Image credit: ORION Program Office, 2006).

The RFAs amassed a range of possible instruments, too many to build with the available budget. Later in 2005, the OOI held another workshop in Salt Lake City, UT, where participants further refined the OOI's scope by organizing the RFAs and community reports. They selected three general areas, following regional, coastal, and global categorizations: an un-cabled Endurance Array on the West Coast, a Pioneer Array on the East Coast, and cabled arrays. The latter concentrated the discussion around RFA-proposed sites in the South Atlantic Bight, Gulf of Maine, and Oahu, Hawaii (Daly, et al., 2006). While reports and participants alike reported interest in the Gulf of Maine, what was suggested in these designs was a moveable platform, whose first station would be off the coast of New Jersey, where community support could alter the array's geography in the coming years of operations.

As a further step toward establishing detailed engineering specifications for the OOI, the ORION Project Office tasked its advisory committees—the Science and Technical Advisory Committee (STAC), the Engineering Committee, and the Sensors-Technology Committee—with producing draft Conceptual Network Designs (CNDs) for the three components of the OOI (coastal, regional, and global) (Daly, et al., 2006). STAC sub-committees led these efforts. The CND drafts provided a description of the required infrastructure for numerous specific science initiatives. After considering anticipated costs of management, cyberinfrastructure, education and outreach, surveying, permitting, contingency reserves, and other factors, the STAC sub-committees were directed to plan for $40 million, $90 million, and $300 million funding levels for the OOI's coastal, regional and global components, respectively. The draft CNDs also supplied options for the oceanographic community to debate at the upcoming ORION Design & Implementation (D&I) Workshop (Daly, et al., 2006), which extended an open invitation to the ocean research community (Daly, et al., 2006).

In tandem, by 2004, the NSF Division of Ocean Sciences (NSF OCE) established the OOI Project Office to coordinate OOI planning. The office was a joint enterprise between two independent but complementary groups: Consortium for Ocean Research and Education (CORE) and Joint Oceanographic Institutions (JOI), located on two floors of the same building in Washington, D.C. The Program Office eventually transitioned into the Consortium for Ocean Leadership (COL) in 2007, a 501(c)(3) limited liability corporation. The newly minted Consortium for Ocean Leadership was to shape the future of ocean science and education by managing community-wide programs (like the OOI), coordinating and facilitating federal agencies with similar agendas, and influencing ocean policy throughout the country.

The OOI Science Plan was finalized in 2005, an amalgam of previous workshop reports, particularly the San Juan workshop, and the U.S. Commission on Ocean Policy 2004 report (U.S. Commission on Ocean Policy, 2004). The report rhetoric emphasized the increasing importance of ocean observing for public health, homeland security, severe weather such as tsunami and climate forecasting, and fisheries and maritime management. The major science drivers of the OOI, according to its 2005 Science Plan, were: climate variability, ocean food webs, and biogeochemical cycles; coastal ocean dynamics and ecosystems; global and plate-scale geodynamics; fluid-rock interactions and the sub-seafloor biosphere; and turbulent mixing and biophysical interactions. The OOI was built to enhance knowledge of the ocean's interrelated systems, which is vital for increased understanding of their effects on biodiversity, ocean and coastal ecosystems, ecosystem health, and climate change. In addition to these scientific needs, the formalized Science Plan details the OOI's national and political interests:

> 1. We must maintain the leadership role of the United States in ocean and environmental observing systems. Other nations (Japan, Europe, Canada) have made, or are planning to make, major investments in ocean observing systems in the next few years. If the U.S. research community does not have access to these

> same tools, it will not be able to pursue the most exciting and important questions in marine science.
>
> 2. The President's Commission on Ocean Policy has clearly identified many areas in which the oceans are in crisis, and it is essential that we act now to begin to address these issues. Improved understanding of all of these issues—the impact of pollution on coastal systems, managing the ocean's living resources, improving earthquake and tsunami hazard assessment, and others—will benefit from the new knowledge of ocean processes and observing technology that the OOI will develop. (ORION Executive Steering Committee, 2005, p. 6-7)

The Science Plan, the RFAs and associated review results from COL, the OOI Project Office, and external advisory committees developed an initial Conceptual Network Design (CND) for the OOI, which then served as the focus of community discussion at the ORION Design & Implementation of the OOI Workshop in March 2006. It was led by Alexandria Isern, director of Geosciences at NSF, and attended by nearly 300 members of the ocean research community. The workshop reviewed the draft CND, solicited comments and recommendations about the design, and provided opportunities for collaborative groups, potential projects, and future infrastructural commitments to develop.

After the March 2006 workshop, the project moved rapidly, following tracks and milestones established as part of the MREFC review process. In July 2006, the NSF assembled a Science Panel to provide a merit review determining whether the CND would provide the ocean research community with infrastructure capable of addressing the high-priority science questions motivating the OOI (Isern, 2006). The panel endorsed the OOI as a worthy investment that, when implemented, would advance understandings of the Earth and the oceans (ORION Program Office, 2013). In August 2006, the NSF convened a Conceptual Design Review (CDR) to assess the Project's technical feasibility and budget, Management Plan, including Master Schedules and Milestones, and Education and Outreach plans. The CDR panel affirmed that the OOI, as proposed, would transform oceanographic research in the coming decades.

Between 2006 and 2007, Isern moved on to another role in NSF and was replaced by Shelby Walker. Walker ushered the OOI through the Preliminary Design Review (2007) and Conceptual Design Review (2008). On December 4, 2007, the same date that the Preliminary Design Review was submitted, Robert Gagosian was appointed Chair of COL. In what one participant described as "hitting the ground running" (participant quotation), Gagosian followed the MREFC pipeline, turning the Preliminary Design into the Conceptual Design and then into the Final Design Review to be presented to the National Science Board (NSB), the advisory board for all NSF.

1.4 American Recoveries and Reinvestments Act and the Launch of the OOI

The Final Design was approved in the context of changing presidencies and rising political concerns around climate and urbanization of the time. Construction for the OOI launched on the back of the Obama Stimulus Package—an investment in US climate change research infrastructure with a grand total approximating $1.8 billion over its tenure (111^{th} Congress, Report 111-16). In the wake of worldwide financial collapse, President Barack Obama announced the American Recoveries and Reinvestments Act (ARRA, or "Stimulus Package") in February of 2009, which sought worthy and "shovel-ready" projects that could help stabilize and jump start the faltering economy through federal investment. The OOI's image was reoriented to demonstrate how it would produce jobs, address societal problems due to climate change (see:

Figure 1.9), contain well-researched risk and fallback measures, and affirm that mission-driven science via observatories was a safe large investment for the U.S. One participant articulated the increased emphasis on climate as follows:

> It was certainly climate-oriented but [with] the transition from Bush to Obama it was clear that it had to be more climate-oriented. The Argentine basin and a second line of moorings off Washington State were added to make it look more climate-like and some of Delaney's cables were cut by about one third. For that, climate was important. But if you go to someone like NOAA and the climate observation division, trying to sustain a program in the face of political realities in this country, it is much better to say that these observations serve everybody, from weather to safety and life at sea, to sea level rise, or how do you deal with inundation with things like Sandy all the way to the climate problem. (Participant quotation)

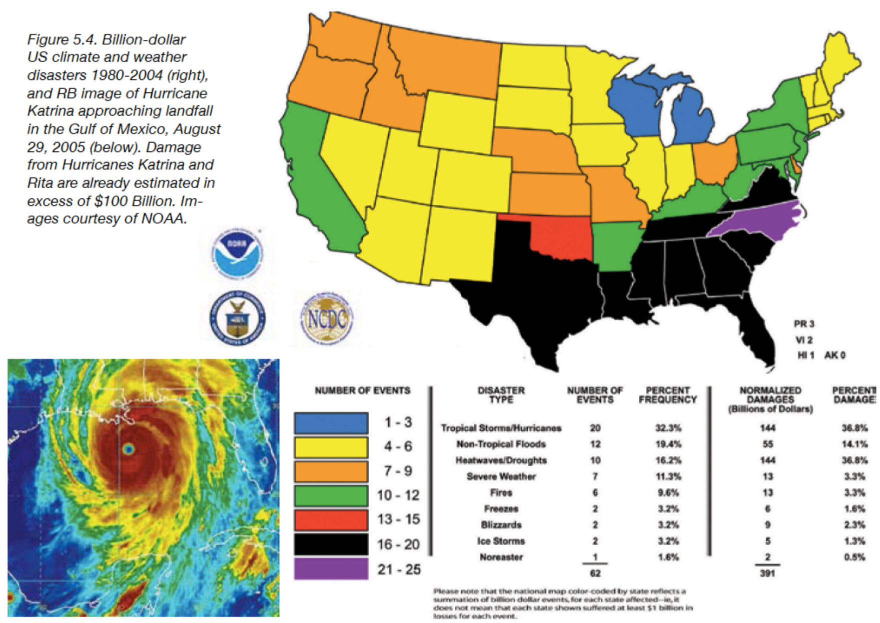

Figure 1.9. Climate and weather prediction and prevention in early OOI planning documentation (Image credit: Daly et al., 2006).

This demonstrated a political imperative for time-series modeling and observatories and the minimization of exploratory ship-based studies in fulfillment of the pressing questions.

The rebranding attempt paid off; on May 14, 2009, the federal government announced the funding of the OOI, which broke ground that same year under the supervision of Tim Cowles at the Consortium for Ocean Leadership. The project received funds from the Stimulus Package in a joint agreement between the NSF and the COL as a major contribution to the broader national and international agenda of the Integrated Ocean Observing System (IOOS) and the Global Earth Observation System of Systems (GEOSS) (OOI, 2018). The Stimulus Package sent approximately $3 billion to the NSF, with $1 billion dedicated to OOI facilities. In its first year, $105.9 of the $254m for large facility projects was directed to the OOI. Another $16 million arrived through the Stimulus funds in September 2009, before OOI affiliates were defined and roles and obligations distributed.

Although this injection of funds rapidly accelerated the OOI's construction timeline, "all of the people weren't at the line when the gun went off" (participant quotation): as a result, the stories of the OOI that follow in this dissertation are both about groundbreaking phenomena and about the phenomena of breaking. Through both trials and triumphs, by April 2016, construction was complete and the revolutionary experiment had begun.

1.5 Conclusion

The OOI proved to be transformative even before it launched. From the start, it provided new organizational and technological capacities, new skillsets and paths for research opportunities and education, and lessons for future endeavors in the ocean sciences and beyond. As it moved into construction, the OOI began to change the field, geographically repositioning prominent scholars and technicians, and reorienting relationships between industry partners and the academy, as well as relations of oceanographers to local governments and national parks, police and local law enforcement, both recreational and industrial fishing communities, and indigenous populations along the coasts.

The scale up from PI-driven science to large-scale long-term and distributed science was not without tension. The years of ideation and planning provided many lessons in designing a more collective view of the field while managing a democratic process. In this more collective and democratic endeavor, program managers and champions grappled with its manifold and multiple interested (and at times competing!) parties, balancing the diversity of people and disciplines represented, taming who is loudest and amplifying those who may have been harder to hear, against the flows of engagement and participation that were contingent on weather and episodic oceanic events and tenure schedules (cf. Steinhardt and Jackson, 2014). Almost two decades of workshop reports - from the 1990s and 2000s that led to the crystallization of the OOI in 2009 - reveal the significant efforts to identify who the community might be, to reach that community, and to attract thoughtful critical feedback and assistance from that community. Affiliates of the OOI had to contend with both their many dissidents and those who felt burned when their proposals did not appear within the pages of the Final Network Design. The transition from planning and into construction revealed a significant tension in balancing the research-driven perspective of scientists with the culture and requirement of project management integral to the MREFC.

By the last decades of the 20th century, it had become clear to multiple actors in ocean science that traditional methods of knowledge production were insufficient to address late-twentieth- and early-twenty-first-century oceanographers' big questions. Their questions were scientific and also resonated at a broad scale with more humanistic concerns, including the urgent matter of climate change, how the ocean relates to food shortages and terrorism, and what oceanography can do to ameliorate other social problems. There are various design choices for addressing those questions (cabled versus un-cabled networks, for example), but what is interesting about the OOI is the consensus that this type of research must involve data analytics. The social actors surrounding it, thus, reframed the problem as a data problem, and that reframing has impacted the field of oceanography in tangible and enduring ways that, as this dissertation will show, prioritize technological sustainability over human sustainability.

While the promising dream is not without critique and its story is not without peril, the effort of the OOI inaugurates an unprecedented undertaking in the world of ocean science in terms of its intended reach and hopeful extensions, and to many participants has served as a cry against the fickle political whims around climate change and the tightening scientific budgets that exist in the US today. The OOI grew as both a scientific and political imperative, hardened into a line item of a presidential budget and a commitment by the scientists who will give and sustain its life. The press release for the OOI announces,

> 'This award represents the fulfillment of over a decade of planning and hard work by hundreds of ocean scientists, and also reflects the commitment of the National Science Foundation to new approaches for documenting ocean processes. Those of us within the OOI project team are excited to play a role in implementing this unique suite of observing assets – knowing that we're

> building an infrastructure that will transform ocean sciences,' said Ocean Leadership Vice President and OOI Program Director Tim Cowles. (ORION Program Office, 2009)

According to one participant within the COL, “There are going to be people who aren't interested in moving in this direction but NSF is interested in this and 85% of ocean sciences funding comes from the NSF so basic research is going to change form” (participant quotation). The OOI is being viewed by NSF as a model for something novel and unique with potential application to other programs, transformational to other big science endeavors.

The start of OOI mobilized hundreds, and redesigned or fully constructed new buildings on and offshore for the people and technologies of the future. But inside the Matryoshka doll (Eastern European nesting doll) of formal documents and plans, institutional settings and policies, is another story. The OOI is full of fictions, not found directly in these formalized components but rather in the ways these forms, workshops, and policies are discussed, debated, contested, and championed. The power of ethnography throughout this dissertation has been in unearthing narratives about the OOI that no Science Plan, Work Breakdown Structure, or Workshop Report could tell. A world that benefits from instrumenting the ocean, a technological utopia of the seas, cannot be mobilized by just one man on a napkin, but through many players' efforts and an expansive cultural orientation of oceanography, tracing back to the fields' roots in Arthur C. Clarke and Jules Verne. In moving from blue sky to blueprint, the OOI increasingly codifies and reasserts this form of utopia. The following chapter develops a historical account that led to the development of the OOI by tracing the fields' dominant infrastructures and then begins to untangle these fictions and their foils in the chapters that follow.

2
An Infrastructural History of Modern Ocean Science

> You row forward looking back, and telling this history is part of helping people navigate toward the future.
> (Solnit, 2016, p. XXVI)

Intrepid, adventurous, exploratory, mystical, fantastical, imaginative, alien: these are just some of the words that tend to lead histories and tellings of oceanographic tales. The oceans are a space full of fiction and imagination, an expanse that boosts our understanding of the world and of ourselves through contraptions, doo-hickeys and thingamabobs alongside highly-engineered high tech "machines of desire." In my years observing oceanographers at sea and in their laboratories, I have witnessed first-hand the ingenuity of performing oceanographic work and how strongly cultural, political and technical flows influence the trajectory, resources, promises and hopes of the field. The following chapter attempts to provide context to this co-construction of science and society, to develop an understanding of who and what supports and has been supported by the infrastructures of modern oceanography and to assert the productivity of a relational infrastructural lens on the understanding of oceanography on a whole and of the Ocean Observatories Initiative (OOI), which serves as the focus of the remaining dissertation.

From the earliest conceptions of oceanographic research, there is a strong tie between available ocean infrastructure and the goals of ocean research broadly, often built around a research vessel and the availability of monetary support for research efforts. The earliest recognizable forms of oceanography often were fronted by a single man, often of an affluent background venturing on personal funds or private investment in a ship with a small crew to demystify the world and bring pieces of it back to civilization through drawings and expressive texts [think, Aristotle's earliest explorations of the ocean counting and identifying fish and marine mammals (Deacon, 1971; Rozwadowski, 1996) Charles Darwin's HMS Beagle (U.S. Commission on Ocean Policy, 2004), or the HMS Challenger of 1872 often noted as the birth of modern oceanography]. The history of life on the sea comes out of this adventurous age of empire and exploration, with a heavy emphasis on knowledge that would impact fisheries. The knowledge of winds and reefs, depths and waves, were integral knowledges of the early ocean sciences.

This era was largely undocumented and only carried on in myths and legends, yet much of the culture of this early work has greatly informed impressions of the field even to this day: intellectual and adventurous individuals of high stature adventuring out from coastlines on rafts and small vessels to make sense of the world and captivate the public as the mysteries of the sea unfold. From its very origins of Benjamin Franklin, Juan Ponce de Leon or James Cook, we see a labor and class story about who gets recorded in the history of oceanography, who can witness phenomena, what it means to produce systematic knowledge, and, indeed, what that knowledge should do.

A more recent telling of the history of oceanography, over a century later, sees a significant shift in this narrative and in its dominant infrastructures: ships and their crews fall out of the stories of oceanography and over time are replaced with computerized time-series models using sensors, seafloor-walking robots and satellites.

While central concerns of early oceanographic work were once about the coasts, the waves, and the surface, over time the fields' core interests have moved deeper and as far away from the coasts as possible. Early historical works place significant value on the character of seafaring research and the importance of natural context, the romance of the ocean and the embodied and material investment in the sea that lies at the heart of what it means to be an oceanographer. However, what we see in more recent histories is a removal of the human as a producer of knowledge, the actor who is exploring the ocean, and instead a shift to the human as a recipient of good things from the grand explorative data collection of high tech machines. The heroics of oceanography (Oreskes, 1996) has shifted from the emotive sensorial experiences detailed by adventurers into the sensorial abilities of instruments and data collection machines: from warm bodies to warm hardware, from a concern for the tireless work of the ocean scientist and their bandwidth for scientific data collection for weeks on end in a research vessel to a concern for the work of a technology by its telecommunication bandwidth and its voltage capacity for months of remote data collection.

The construction of the history in this chapter is informed by the sensibilities of infrastructure studies (cf. Edwards, et al., 2009). Rather than a focus on individual technologies and artifacts, this chapter looks to the grounds under which action and artifacts exist: the underlying systems of organizational and material structure, relationships and interrelations, the heterogeneity and differing levels of structure and substrates, the responsibility, empowerment and dispossessed. Infrastructure by definition connects things and in doing so determines what should and should not be related, what can be easily accessible and what it does not consider itself responsible for. Rather than simply the inner-workings of a particular technology and its materials and algorithms, infrastructure studies allows for tracking where the money and materials go, and provides exploration into the complex technical, administrative, political and social underpinnings that inform and crystallize into technological worlds. In this way, infrastructure studies is less interested in the internal of a technology such as the oceanographic CTD instrument but rather the larger geopolitcial and social relations that leads to questions about the dominant values of ocean science in that moment, of the desires for simplicity and reliability that underlie the proliferation of the CTD aboard the standard medium-sized vessels largely funded by the government, whose chief scientists were taught research practice through The Oceans (Sverdrup, 1942). This perspective allows for focus on the non-technological elements of systems development and into the production of ethics and more political domains. In this chapter and throughout this dissertation, the lens of infrastructure allows for a range of commitments, categorizations and threads, where in some of the moments described here the interiors can be exteriors and vice-versa.

Infrastructure studies explore the ways of working that come with technological innovation, including new forms of data collection and information processing, storage, and reuse. This field of work stresses the constructivist and interconnected ecologies of technologies, human relationships and practice. Rather than a focus on narrow visions of a system, infrastructure studies blurs the lines outside of what a formalized structure might delineate as a single infrastructure. In this way, infrastructure includes brick and mortar structures like buildings, laboratories, roads and cables but also the human organization, standards, protocols and policies that give shape to everyday interaction and connect different groups (Bowker, 1994). Infrastructure and its maintenance are often in the background or entirely invisible (Star, 1999), but many scholars in the tradition of science and technology studies have offered methods for surfacing systemic structures in moments of breakdown (Star, 1999), scaling (Ribes, 2014), or via infrastructural inversion (Bowker, 1994; Bowker & Star, 2000). These studies show us the complex work of sustaining systems and the often invisible and powerful narratives that connect the ethical, social, political and technological dimensions of infrastructure. This chapter will draw from infrastructure studies to (1) emphasize work practice and material culture as critical aspects of understanding large-scale infrastructure for the long-term, and (2) assert the importance of a feminist perspective for the analysis of infrastructure to break from traditional affordance-centric design implications.

Recent decades have seen a move away from traditional embodied modes of engaging with the sea and into new technologically-bound skillsets: from knot-making and breaking, hand-drawing and navigating into the modern worlds of model-making and code-breaking, CAD drawing and GPS navigation. The projects of the later half of the 20th century are less focused on a single individual explorer and increasingly involve interdisciplinary teams with acronym-ed names that anonymize the actors within the groups. These actors come from multiple disciplinary backgrounds to develop the technologies dropped in the ocean and to analyze the data from those technologies. With these acronyms comes a decreasing emphasis on a person or powerful institution and more emphasis on global-scale findings, international organizations, whole ecologies, environment and climate. As the dominant concerns of US political forces move from wartime to climate, as do the dominant infrastructures that dictate (through funding, resources and expertise) the possible forms of performing oceanographic work. At the turn of 2000, oceanography finds itself less reliant on the structures of power and interests of the Navy, and less reliant on seafaring forms of work more broadly, and instead the field is animated by an increased connection of research to the technology industry and the fishing industry. Through its recent history, oceanography has been faced with something participants and historians of ocean science alike call an "identity crisis", where new forms of interacting with the ocean through sensing infrastructures rise in prominence, accompanied by new practices, new funding mechanisms, new data regimes and new definitions of who calls themselves an oceanographer (and gets funded to be an oceanographer).

Markers of human difference like gender, class and race have in the past been deeply (and problematically) tied to the labor of ocean science (cf. Helmriech, 2009; Lehman, 2018). Identity, ideology and ethics are wrapped deeply into the practice of ocean science: what values are held in regard and what skills are seen as outmoded or regressive. In the modern day, there exist new answers to the question of who does oceanography and how do they do it. The history of ocean science holds an amoeba-like structure, the field tends to lean in to the national needs of both war and peace times, adapting goals to a new set of funders, new organizational regimes, and new perspectives on the role of the ocean in the earth and the human to the ocean.

While many of the technical histories of big science may reflect some of these concerns, the present infrastructural history of ocean science is meant to distinguish itself through its concern with understanding continuities in scientific practice that may capture the important threads that have been thwarted by the dominating histories of ocean science based on spectacular events like war and discovery. It's not just a story of material stuff and it's not just a story of great men. There are great organizations, relationships (and shifting relationships) between public and private support for science. Writing history in this way emphasizes the collectively held nature of infrastructure, in some ways dissolving the previous mastheads that represented oceanographic work and instead pointing to some networks in which responsibility, care and aspirations are crystallized and normalized. This infrastructural turn is an attempt to shift focus away from the movers and the shakers and instead into the larger systemic structures that give way to discovery and to the heart of what makes infrastructures: the often thankless grunt work and laborers who enable much of what is at the root of discovery. In this way, infrastructural history is also centrally concerned with unearthing dialogs of invisible work and invisible labor, and with representation, who was present to do the decision-making and who was considered a stakeholder. Institutions are important sites and anchors of moving forward and have a formative influence on how work happens.

With each technological advancement, new infrastructures of support of ocean research acted as a link that was once less visible and able to be analyzed. Many of the recent oceanographic collaborations transcend boundaries between institutions, state, countries, shores, basins and waves. None more illustrative of this coalescence is the recent (as of Spring 2016) obstacle plaguing American life on the sea concerning the tightened seafaring resources, deterioration or death of many major oceancraft and the responsibility for maintenance and construction of seafaring vessels (ships, icebreakers, submarines, aircraft). The debate concerns the imperative for improving upon the

American fleet for human presence out in the sea: this imperative is not only to build new ships, but also to maintain and refurbish older ships and their devices for deploying instruments or carrying weaponry. The debate over the expansion of the American fleet is often found in mainstream media outlets and social media under the hashtags #platformsmatter and #presencematters (Adler, 2015). The debate serves to emphasize the longstanding lynchpin of engineering and design in ocean work but also importantly highlights the multimodal histories that enmesh in the oceans: this debate resounds across circles of Navy yards and public shipyards, shipbuilders and breakers, disaster relief and telecommunications industry technicians, sailors and labor activists, policymakers and politicians. It draws out big questions about who funds oceanography and for what purposes, and, notably, who gets funded by those oceanographic grants (read as: who is identified as an oceanographer through formal means). This debate highlights the critical nature of infrastructure in defining the possibility space of work on the oceans, pointing to a need for centering changes in major infrastructure development in our understanding of oceanography. The philosophical stakes of this reorientation of history around infrastructures is high, as what is crystallized within our histories can be negotiated as parts of our present and futures, whereas the invisibilities of previous accounts likely remain invisibilities.

As US governmental and militaristic interests move to accommodate the realities of climate change and terrorism in the present day, threads set forth from the innovations of postwar computing are synthesizing with new advancements in distributed technologies and big data. In recent decades, downward trends in fleet use correlate with downward trends in vessel construction and maintenance, with upward trends in innovative technological development at a large scale. In this way, innovation becomes as much about historical and institutional innovation as it is about technological innovation [a paradigm echoed throughout other histories of big science (de Solla Price, 1963; Galison, 1997; Vermeulen, 2013)]. Big science's institutional context demands the attention of historians and ocean science's extensive documentation points to a space ripe for especially productive research that traces the technological and infrastructural history of the field. This chapter acts as a crude starting point in developing that understanding.

2.1 From Individualism to Nationalism

Oceanography is often cited as having two distinct periods, along different axes: its exploratory age of discovery which speaks to geography and its more recent history rooted in geophysics and climate concerns (Green, 1993; Helmreich, 2009; Edwards, 2010). For decades ocean science research looked just this way: Charles Darwin and the HMS Beagle, Sir Charles Wyville Thomson, and later the HMS Challenger. It wasn't until the 18th century in Britain that Captain James Cook established a more expansive understanding of the world's oceans through charts and documenting new marine life and mammals on his journey. By the mid-1800s, Lieutenant Matthew F. Maury founded the Naval Depot of Charts and published the "The Physical Geography of the Sea" including atmosphere, currents, depths, winds, climates and storms. Maury's work marked a repositioning of ocean research toward quantitative studies that over time would increasingly rely on technological advancement for observations and measurements, placing emphasis on funds coming from state grants and philanthropic or entrepreneurial venues (WHOI, n.d.). Beginning in the late 18th century and early 19th century, oceanography saw the first shift away from the formative descriptive work of drawings and comprehensive writings like those of Charles Darwin on the HMS Beagle or Edward Forbes in his systematic study of marine life around British Isles and Mediterranean and Aegean Seas (U.S. Commission on Ocean Policy, 2003).

It was at this time that the broader public became captivated with the sea, as seen in the high acclaim of Jules Verne's science fiction novel 20,000 Leagues Under the Sea, published in 1871 (which continues to be regarded as one of the most significant science fiction novels of all time). Shortly thereafter, in the U.S., Alexander Agassiz - marine scientist, Harvard University professor, and son of famous naturalist Louis Agassiz - led private expeditions of deep sea biology for big question studies on 1882 Albatross (Mills, 2009). It was using this vessel that he drew attention to the center of the sea and was afforded the resources to develop one of the world's most famous and profitable mines, opening huge funds for new opportunities for American scientists to explore long-term collection of data about the water column. As we will come to know, oceanographic research, particularly in its earliest forms, was largely built around dynasties of both families and mentorships who defined, for large swaths of time, the possibility space for how we may interface with the sea. The Albatross and the Agassiz family may be at the center of one of oceanography's first major infrastructures.

By 1903, Scripps Institute of Oceanography (SIO) was founded at the University of California San Diego by a wealthy newspaper publishing family for whom the institution is named and, William E. Ritter, one of Agassiz's students (Inman, 2003).

Simultaneously at an international scale, institutions and laboratories dedicated to understanding the ocean began to emerge, like Station Biologique de Roscoff in France (Rozwadowski, 1999). The history of Scripps is rich (and well-documented), formed on the backs of philanthropists like Ellen Browing Scripps and zoologists like William E. Ritter whose personal ships were the sole vessels in operation at any one time for the facility for many decades: by Scripps (family), Browing and Agassiz. Therefore research of this era was largely confined to the programs of study of those in control of the ships and to interested parties already affiliated with Scripps as an institution. In 1871, the U.S. Commission on Fish and Fisheries opened a collection station on the East Coast at Woods Hole, MA, and by 1888, Hyatt, a student of Agassiz, formed the Marine Biological Laboratory in Woods Hole. Later emerged the first permanent marine laboratory, Woods Hole Oceanographic Institute (WHOI) in 1930, funded by the Rockefeller Foundation (WHOI, 2018).

During wartime of the early part of the 20th century, there were few people performing oceanographic work and those that were performing this work were often met with significant frustrations and practical problems in the inhospitable environment on the sea (Hamblin, 2008). This frustration motivated the design of new research equipment to automate the work, like reconfiguring the rim of a winch, an engineering advancement that was then fed back jointly to the scientific realm and into the larger militaristic system (Mukerji, 1990). Wartime quickly shepherded in a new oceanographic-industrial revolution which was less concerned with its charismatic artist explorers and instead brought technology, particularly echo-sounding technologies, into the fore. It was during this time that the first mapping of the Atlantic sea floor came to be, with the German Meteor Expedition (Howe, 2012; Mukerji, 1990; Sverdrup & Kudela, 2013). The growth of Scripps on the West coast of the U.S. boomed as esteemed oceanographer, Harald Sverdrup, took the helm as director of the institution (Raitt and Moulton, 1967). During his tenure at SIO, Sverdrup occupied a unique vantage point in which many of the most prestigious research initiatives in oceanography were housed by his institution. Capitalizing and chronicling this vantage point, Sverdrup wrote a book cataloguing the known work of oceanography to date, The Oceans: Their Physics, Chemistry and General Biology (1942), which not only defined the research of the time and further elevated the repute of Scripps but has served as the basis for oceanographic curricula across all related fields since its development (Knaus, 2003).

These major public institutions were isolating but also found themselves at the frontline of changing the culture of diversity in science: at once being a field of elite riches - geographically, socioeconomically and topically confined - and also acting as a home to women and minority scholars that would build bridges for more inclusion in the future. However, as is the case across scientific fields not confined to oceanography, those minorities who did manage access and participation were not faced with equal footing. Notably, between 1927 and 1936, Roger Arliner Young became the first black woman to earn a Ph.D. in zoology and to conduct research at the prestigious Marine Biological Laboratory at Woods Hole (Warren, 1999) shepherded in by her mentor Ernest Everett Just, a pioneering black marine biologist who gained a national reputation for his work with invertebrate eggs and embryos. Just began working at MBL in 1909 and passed away at Station Biologique in 1941. After his passing, Young was limited to teaching positions without access to research facilities and support without the oversight of Just. Even to this day, Young's treatment in histories of oceanography is often quite superficial, and most even brief mentions of her life include the discrediting speculation that she and Just were romantically involved (Diaz et al., 2013). Often these positions wouldn't have successors from diverse backgrounds and it really wouldn't be until the next century, in the early-2000s that this culture of exclusion would shift radically and oceanography would begin to name its many "firsts": obtaining research high impact funding, winning prestigious ocean science awards, leading institutions that set research agendas, occupying a percentage of the graduate enrollment, holding leading roles upon research vessels, being elected to grant panels.

During World War I, oceanography rose into the collective consciousness for its importance in feeding our fondness for seafood, for the ease at which we can travel freely by wind and steam, and for the advantage of military action taken by sea. The military saw ocean science as strategically important, which shifted the configurations of science into a tighter coupling between government and science, a less autonomous world in which money was used to keep scientists on a particular topic. Bigelow of WHOI saw this military work as "plumbing" yet a necessary evil, which led to contractual work at Woods Hole that was conducted with full disregard for its moral and political significance in favor of "interesting problems" (Burstyn, 1980). There became a rift in what was considered "engineering work" (applied oceanography) vs. "real science" (the exploratory work at sea). The decade saw significant private developments in equipment to locate icebergs (catapulted by the Titanic sinking) by scientists such as Reginald Fessenden, which brought Naval attention to echo-sounding equipment and submarines to profile the deep sea basins for submarine detection. By the 1930s and World War II, government support of research was central to the operation of oceanographic science where vessels and echo-sounding instrumentation were critical investments needed to map and locate activity on the seafloor, with the ability to leverage this information to both detect and hide submarines from acoustic sensors (Oreskes, 2003).

The depression following World War I affected practical government science such as fisheries research, so oceanographic research which was considered very expensive at the time, slowed down dramatically until preparation began for World War II (Schlee, 1973; Rozwadowski, 1996). The period during World War II and into the Cold War marks the tools and practices of ocean science as rooted in stories of militaristic infrastructure and monumental discovery: from deep sea submersibles and submarines such as Alvin discovering Titanic and the monumental “Lost City” within mid-Atlantic hydrothermal vents, to the atomic fallout facilities off of Bikini Island that provided basis for international policy change for its diagnosis of the radioactive effects on organisms and land and its movement through waves (Howe, 2012; Rainger, 2004). This period also marks a disruption to the growing international community of ocean researchers. The midcentury discovery of the ocean’s depths set precedent for resources that continue today (Rozwadowski, 2008b). Underwater listening for Soviet submarines opened funding for the next unprecedented expenditure in seafloor vehicles and camouflage, and along with this money came new motivations for performing oceanographic work, sharing its values with Navy patrons (Oreskes, 2003).

The US political desire to monitor and map the deep sea provided both justification for substantial expenditures for deep-oceanographic research, and motivation for oceanographers to build expensive experimental technologies and use them in creative ways. The coinciding coupling between government and entrepreneurial interest for scientific progress spanned well into the twentieth century, particularly after World War II. During this time, ocean weather stations were affixed permanently to ships to support early trans-Atlantic and trans-Pacific aircraft service, collecting both oceanographic and meteorological time-series data as they traversed the oceans (Oreskes, 2003). Once the US entered into the Cold War in the late 1940s, ocean science became a lynchpin for understanding the environments through which humans and machines could travel and communicate (Mukerji, 1990). With this, ocean acoustics became a backbone of Cold War defense (Mukerji, 1990) and longer term data-driven time-series models began to thrive (Howe, 2013). Echo sounders, or fathometers, a device invented around this time, took prominence in the infrastructure of oceanographic inquiry: these instruments determine depth in water by sending out sound waves and measuring how long the waves take to reach the seafloor and return to the surface.

During the war, oceanography gained attention for developing radar to find enemy ships and planes. In fact, knowledge about the oceans became so highly valued that Sverdrup's The Oceans was classified by the federal government for its powerful content: the knowledge of ocean currents helped transport troops and supplies quickly and conserve limited fuel and knowledge of the weather, waves, and tides was used to determine the best time for beach landings like those on D-Day. As time passed, physical and chemical properties of water were used to develop improved sonar and other technologies to find and destroy enemy submarines and protect our own (Mills, 1989).

In the aftermath of war, oceanographers returned to their laboratories and ships with new instruments and a new outlook. Given the preciousness of oceanographic work during wartime, the U.S. decided that science should not be left to the private sector. In an attempt to establish a clear move to the scientific forefront, Vannevar Bush's *Science: The Endless Frontier* (1945b) and more popular essay, "As We May Think" (1945a), established a framework for science policy thinking and practice that would carry wartime research threads forward from the Office of Naval Research (ONR) into a National Science Foundation (NSF). This move was a particularly difficult negotiation, as the government had well-articulated to that point its desires for particular kinds of scientific outputs that are often pragmatic and of military interest, and its interest to date in sharing ideas was minimal at best (yet is a critical component of performing scientific work to move fields and ideas forward). Major funding for oceanography now came from the Office of Naval Research and the National Science Foundation, as well as Atomic Energy Commission on the West Coast at sites of atomic testing (van Keuren, 2000). The US Division of War Research during WWII had become more of less an acoustics lab and was combined with the US Navy Radio & Sound Laboratory (later the US Navy Electronics Laboratory) on Point Loma, where the Marine Physical Laboratory (MPL) would soon be constructed. MPL was the first Navy-supported external physical laboratory of scientific research. Out of wartime through funding by ONR, scientific questions came into focus through the crosshairs of national security and military pertinence brought certain subjects into clear sight while others remained on the edges of the scientific field of view (Hamblin, 2008; Oreskes, 2003). Wartime acted as a vast machine (h/t Edwards, 2010) and the great question for Vannevar Bush. As explored by Edwards (2010), Mukerji (1990) and others, the looming questions of the period immediately postwar became: can oceanography go back to doing publicly-funded science? What is the new governance structure of the ocean sciences? What happens with the machineries created during the war, including the skilled people who have been trained? The answer was found through the NSF, which promised a new trajectory for the doing of science outside of wartime's militaristic interests (van Keuren, 2000).

2.2 From Global War to Global Warming

Historians of science, Naomi Oreskes (2000; 2001; 2003) and Atsushi Akera (2008) map the relationship of military to the artifacts and practices of ocean science in postwar US research, illuminating the normative assumptions built into new infrastructures about the style, legitimacy, and craft of scientific practice. The global changes in the field defined the requirements that members must retain, how educational contexts are developed and what challenges are worthwhile pursuits. At this time, the public social currency of seaside holidays, yachts and marine natural history's big blue whale exhibits drew masses of new people to oceanography, captivated by popular culture's romantic desire to experience work at sea and live like a maritime novel (Rozwadowski, 2012). The character of life and the kinds of questions asked of the sea involved practices, motivations, and equipment in many ways informed by the possibility space set out in popular culture's dialogs about the promise of the oceans.

These relationships and anticipations define the tools and measurements of scientific legitimacy for oceanography, opening material practices by sea and in the laboratory as a moment to draw attention to the ordering and long-term effects of institutional policies and infrastructural ties on the life of science.

In particular, the major infrastructures of wartime brought with them a reliance on telecommunications cables and an increased desire to collect long-term data. This era is arguably the first glimpse of what is to come with the rise of the observatory and the later Ocean Observatories Initiative. These projects firmly established the use of telecommunications cables for oceanographic research use and initiated a culture of data and long-term collection that would reorient the field for years to come. By the 1950s, long-term and large-scale data collection became an unavoidable trend, punctuated by the Coast and Geodetic Surveys which began a seismic sea wave (tsunami) warning system. The military had been using cabled hydrophone and long sonar range systems since the 1950s (e.g., Project Caesar, the Sound Surveillance System or SOSUS, and Project Artemis) (Howe, 2012).

A noticeable trend in oceanography emerged that valued depth: deep sea submersibles, submarines, seafloor cables and instruments that could survive extreme conditions became well-funded pursuits in the sciences and thusly infrastructures of support were developed around these endeavors. In 1963, for example, the US Navy nuclear submarine Thresher sunk unexpectedly arousing a military concern that led to increased development of deep-sea technology. In a very public and hallmark event in the world of oceanography, Trieste located Thresher on the seafloor. In the late 1950s, the US

Navy controversially bought Trieste, designed by Auguste Picard and his son Jacques Picard, another oceanographic family dynasty who were affiliated with Scripps. In 1960, Trieste, manned by Jacques Picard dove to the deepest site in the ocean, the Mariana Trench, thought to be the closest humans had come to the center of the earth (Howe, 2012; Conway, 2006). However, Trieste was a large vessel whose upgrade was sorely desired by the Navy and academia. In 1964, Alvin, the human-occupied deep sea submersible went into service at Woods Hole Oceanographic Institute, jointly owned by the Navy. Originally proposed in 1958 as the “Seapup” by Harold “Bud” Froelich, Alvin launched as one of the world’s first deep ocean submersibles, and would continue to be upgraded and overhauled over the course of the next 50 years and to this day remains as a stronghold of ocean observation infrastructure.

By the late 50s, the International Geophysical Year (IGY) program was launched, mobilizing 67 nations to collaborate in exploring the sea floor, and leading to the building of special seafloor vessels. While the work of this era was no longer of military concern, the coupling set forth during wartime between external military interests and oceanographic inquiry was still not only well felt but was written formally into the infrastructures that supported oceanographic work, particularly those in pursuit of the IGY. As Naomi Oreskes writes of this time,

> Oceanographers chose to work on subjects that interested them, but these interests were bred in a context in which some lines of inquiry were amply funded and brought persistent rewards - material, emotional, and intellectual - and some did not. Not surprisingly, fields that were well nourished, flourished, while those that were not, did not. Moreover, as scientists trained students, the interests of the next generation remained weighted towards issues originally driven by Cold War concerns, even after military funding had decreased or ceased, and even after the political context that inspired them had changed

> (Kaiser, 2002). Military concerns were naturalized, and the extrinsically motivated became the intrinsically interesting. The 'next most important' scientific question is always conditioned by what was answered last. (Oreskes, 2003)

Scripps, maintaining its stronghold on the pace of oceanographic life, launched an atmospheric carbon dioxide monitoring program for the IGY. These measurements led to the first evidence of CO2 buildup, identified as a major factor in global warming. This discovery foregrounded decades of interest in the political nature of the oceans, indicating that global warming is a problem of the seas and seeing a new trend in academic trajectory from scientist to later career public policymaker (which led to many who would become involved in OOI in their late careers, explored later in the dissertation). The infrastructure of IGY and its satellite projects like the Coast and Geodetic Survey not only define the geographies of humans that reorient around novel infrastructures at institutions like Scripps but the geographies of scientific inquiry that follow the currents of technological prowess, where California's coast now became a magnet of scientific inquiry (Shor, 2003).

The emphasis of the IGY on the cross-governmental interdisciplinary work within the Indian Ocean led to a major reorganization of government agencies in 1957 to accommodate the shifting interests of its field: in particular, the Environmental Sciences Services Administration (ESSA) formed by consolidating the Coast and Geodetic Survey and the Weather Bureau. This bureaucratic shift opened gateways (aka: new funding streams) for satellite technologies and long-term data-driven efforts to rise to prominence that paved the way for the next decades of data-intensive research to come. Scripps participated fully in the Navy-funded postwar expansion, with several ocean-going vessels, contributing significantly to the new global view of the ocean emerging in the postwar years and to the growing interest in marine geology to tackle new questions about traversing the seas.

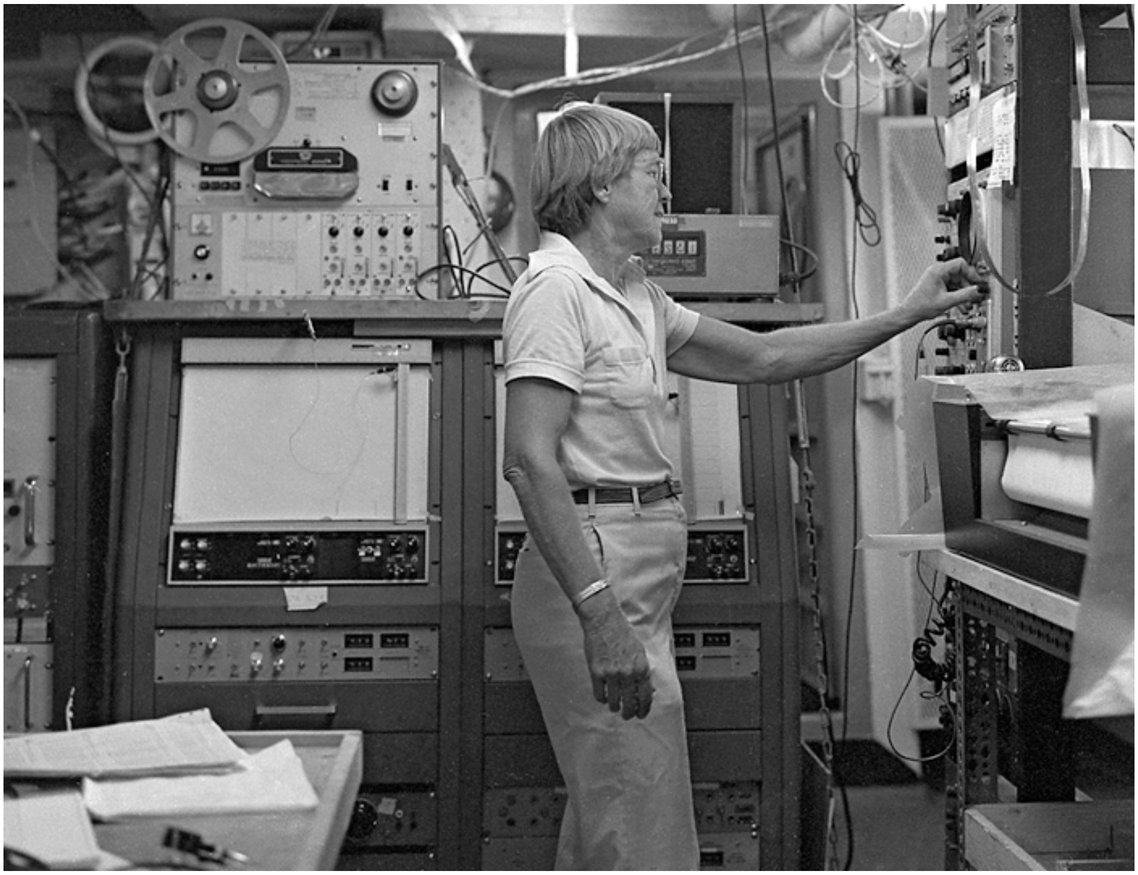

Figure 2.1. Elizabeth "Betty" Bunce was one of the first female oceanographers. Bunce is remembered as having a punching bag on research cruises (Image: Woods Hole Oceanographic Institution Archives).

The increased attention to oceanography via the IGY brought an increased amount of participation in the field, which drew in both new demographics and specializations. At this time, in 1959, the first female oceanographer was allowed to sail on a United States oceanographic expedition. In 1960, reporting on this experience, Betty Bunce became the first woman to present a paper in marine geophysics at the International Union of Geology and Geophysics in Finland (Orcutt and Cetinic, 2014; Bonatti and Crane,

2012) (see Figure 2.1). To this point women involved in oceanography had not been to sea and had not in person presented their work: though, major revolutions to the field had been catalyzed by women like Marie Tharp, a geologist and cartographer who, with colleagues, created the first map of the ocean floor that supported the theory of continental drift and mid-ocean ridges (Barton, 2002). Adding to the many female firsts Bunce would become, she served as the first woman appointed to Department Chair at WHOI, and serving as Acting Chair of the Geology and Geophysics Department a number of times later in the 1970s and 1980s. In 1965, Betty Bunce became the first woman to dive in Alvin (Lavole and Hutchinson, 2005). In 1974, Betty Bunce would serve as the first woman chosen as a chief scientist on a deep-sea drilling cruise aboard Glomar Challenger and became the first woman scientist to go to sea routinely. Supporting much of this work was ANGUS, a camera-carrying tow sled of arguably the most famous living oceanographer, Robert Ballard, that was used for remotely operated investigation of deep-sea sites. In part driven by this interest by Bunce and her colleagues, the 1960s and 70s, the Indian Ocean became a prominent location of focus for ocean sciences after the IGY for its appealing connection to both the drilling industry and scientific communities. The Chain expeditions, some headed by Bunce, conducted significant site surveys for future scientific drilling. Bunce went on to hold the position of chief scientist aboard WHOI's R/V Bear. Bunce infamously worked out with a punching bag aboard her ships.

This legend of Betty Bunce's punching bag follows suit with the perception of ship work as machismo at its core (and thusly the one woman involved was even more macho than the rest): masked by stench matched only by its intrinsic filthy language, operating by the rhythms of lifting heavy things with calloused hands to and fro or via the trance-like repetition of heaving machinery by rope and winch (a heavyweight pulley); the explosives and knive and the tall tales of dangerous life-threatening heroism that accompany most of the known expeditions (Kahari, 1990). Sleeping and bathroom conditions aboard ships were designed minimally to maximize room for the work to be done: often described as 'confined', 'unsanitary' and 'miserable'. Many accounts of early oceanographic cruises even note the hardness of mattresses and the bruising coming not from manual labor but from rough waters during "sleep" (Orcutt and Cetinic, 2014). The masculinity of the ship's configuration paled in comparison to its culture of machismo which was often formalized into strict policies concerning women with a vast range of constraints (later in my interviews these were often referred to as "excuses") diminishing women's ability to participate: if a woman was to be on board, acceptable sleeping and bathroom conditions must be met (i.e: cruise plans would not factor in cleaning living areas and therefore women were not allowed on board); restrictions or reference to "dangers" for those with physical inabilities to perform labor-intensive work aboard the ship (i.e. females who are generally less strong could not be exposed to the perils); explicit restriction of gender based on potential sexual predatory dangers or distractions (i.e. men would want to sleep with women and this could cloud their judgment both in seafaring work and in interpersonal boundary work). It was not for another decade that more women were allowed to take part in oceanographic cruises, yet each was made well aware of the long tradition of "superstitions" that women bring "bad luck" aboard ships (Holmes, 2014).

By the late 1960s, oceanography was squarely within boom times: many universities began offering marine science degrees at all levels, shepherding in a new generation of research scientists and naval fleet. The US was scientifically, culturally and politically prepared for a revolution in oceanographic participation. At this time an explosion of fiction concerning both space and the ocean captivated the general public. Space scientists at this time speculated that Europa, a moon of Jupiter, may possess a warm ocean beneath thin sheets of ice, possibly containing microbes like those found around hydrothermal vents on earth. Recognition of the increasing importance of the oceans to humanity led in the USA to the Stratton Commission report “Our Nation and the Sea” and the founding of Sea Grant (Farrington, 2001).

To accommodate the fast growth of the field and its reliance on ship-based resources, the U.S. University National Oceanographic Laboratories (UNOLS) fleet was launched in the 1960s to develop a nation-wide scheduling system and set of operating standards to avoid mission and platform obsolescence in the ebbs and flows of ship’s lives. Part of UNOLS’ contribution to the field is its ability to bridge the interests of the Navy and science, now in terms of militaristic preparation rather than offensive as in wartime. In fact this infrastructure of support held a very specific role, and Navy ship acquisition in the latter half of the 20th century did not include specifications and procurements from the scientific community (National Research Council, 2000 Sapolsky, 1990). From this came needs for new laboratories, new deck spaces and new accommodations for instrumentation on and off the research vessels. Physical oceanography during the 60s, 70s, and 80s was colored by the Navy's interests in blue-water oceanography: acoustical and optical oceanography were developed as remote-sensing tools because the Navy was interested in studying things that affected sound and light in the ocean, their ears and eyes for communicating and detecting the enemy. These remained single-serving expeditions, dropping an instrument into the water and retrieving it after some time, then repeating this processes every few months over the course of a year or two (Mills, 1989).

In 1968 two historic precedents were set that would alter the course of oceanographic work for decades to come: (1) the Deep Sea Drilling Program was the first to sample Earth's crust beneath the sea (aboard the Glomar Challenger) and (2) computers went aboard ships for the first time. As the interests of industry in the Deep Sea Drilling Program tightened the relationship of academia to for-profit institutions in oil and gas, the relationship between the military and university research began to deteriorate during the Vietnam War of the late 1960s. The shrinking research budgets of wartime drew new scrutiny over the ONR's support of scientific ventures. ONR began tightening its purse strings to more exploratory work in order to focus on practical outputs that aid in defense: a fissure that is still felt in modern day oceanographic work. However, the seafloor spreading at the heart of the Deep Sea Drilling Program became environmentally attractive to studying the ocean's role in global warming and weather production, as well as for oil and gas industry in the development of new probing mechanisms (Bascom, 1961, 1990; WHOI, n.d.).

The expense of tying up ships to take turns at occupying efforts for oceanographic and meteorological time-series was too staggering for any country to support. Capital and lifecycle costs of seafaring research were dependent on shipyard labor and the cost of raw materials such as steel, and rising fuel prices and crew salaries contributed to high overall operation costs of the fleet (NOAA, n.d.). Oceanographers searched for a more permanent and less costly solution for ocean observing that would not be not reliant on ships. This marked a critical moment in establishing a fault line within the field between traditional forms of seafaring work and the work of computational method not requiring presence at sea. This turn generated a newfound interest in moorings and buoys, which were just recently being developed as viable and workable technologies. Deep diving submersibles and submarines brought in a new large size and scale as well as increased complexity. Much like the replacement of sail by steam after the Civil War lessened general interest in studying winds, underwater research was then reoriented toward initiatives building ROVs, AUVs, GPS and satellites. At this time the vernacular of oceanography became centrally concerned with distinguishing between HOV (human-operated vehicle) and ROV (remotely operated vehicle) (Pierre-Yves, 2013). In addition to scuba diving, rebreathers, fast computers, remotely-operated vehicles (ROVs), deep sea submersibles, reinforced diving suits, and satellites, other technologies were also being developed. In this development came a closer connection between the intellectual and the social in oceanographic worlds: resources, trade, commerce, and national security all factored into each new development for surveying the sea. As oceanographers were looking at other ways to keep sustained ocean observing going, people started to campaign for investment into the new mooring and buoy technologies that could support sustained observatories.

George Sutton, at the University of Hawaii, and colleagues deployed a cabled ocean-bottom seismic station off Point Arena, California, while John Delaney and his colleagues at the University of Washington in the Northern part of the Pacific Ocean proposed establishing long-term ocean bottom observatory/laboratory systems based on cables (Howe, 2012). These developments were catalysts for the new character of oceanography: as a pursuit of broader social concern and not an exploratory endeavor, as rooted in understanding grand challenge questions about the earth and not more romantic notions of adventure and exploration, as a recognition that the ocean is a very political player in a global narrative.

Hawaii took on a special importance during this period as a premiere location of engineered or "hard-wired" science, serving as the site of what some consider the first observatory. Largely in an effort to understand volcanoes, earthquakes and ocean seismology, the Hawaii Undersea Geo-Observatory (HUGO) on Loihi submarine volcano included a general-purpose node attached to a telecommunications cable laid to the island of Hawaii; this was the first prototype of what we now consider to be a "cabled ocean observatory" (Howe, 2012). The director of the Hawaii Institute for Geophysics at the University of Hawaii Manoa, Charles "Chuck" Helsley and Rhett Butler (oceanographer, likely named after Clark Gable's character in Gone with the Wind) focused on a new initiative later in the early 1980s called the Incorporated Research Institutions for Seismology (IRIS) toward creating a single international and long-standing catalog of the oceans. Building off Hawaii's newfound attention from the 1970s, the National Science Foundation supported IRIS's vision and has replicated many of the tenets of its mission within future investments even to this day. Coinciding with the renewed interest in seafaring, Betty Bunce's expertise in crustal structure, marine seismology, reflection and refraction, and underwater acoustics associated with seafloor studies brought her to the foreground of the field.

The instrumentation boom of this era contained multiple paradigm-shifting technological innovations and a resurgence of interest in seafaring activities (Mills, 1989; Sverdrup and Kudela, 2013; Rozwadowski, 2016). Following this, the 1970s were deemed the International Decade of Ocean Exploration (IDOE), punctuated by a survey of seabed minerals which eventually led to large-scale data collection to understand earth's surface at a global scale via satellites to capture currents, eddies, algae production, sea level changes, waves, thermal properties, and air-sea interactions (U.S. Commissions on Ocean Policy, 2004). The IDOE shepherded in a huge expansion of graduate programs in fields of ocean science, and eventually led to the Joint Oceanographic Institutions (JOI), which served as a government body to create a unified front across the growing institutions that support oceanographic work and to further promote the expansion of enrollment in the fields. At University of Rhode Island, Dean John Knauss began graduating Master's and doctoral students at a rapid rate, which encouraged others within JOI to recreate his educational paradigm to keep up with the new pace of growth (Farrington, 2001). This translated to generations of students following Knauss' curriculum which emphasized talking across the many disparate disciplines that do work on the oceans. Knauss encouraged collaborations and cross-disciplinary conversation where "all branches of oceanography, i.e. physical, chemical, biological and geological, are seen as closely fitting parts of a single science" and sparked a controversy in the field of "breadth vs depth" that continues today (Farrington, 2001). Solidifying his agenda-setting role, in 1970, Knauss served on the

Stratton Committee to create the National Oceanic and Atmospheric Administration (NOAA), nested in the US Department of Commerce, focused on stewardship of the environment and understanding weather and ocean conditions. From its start, NOAA's funding has been clearly in service of global community-building around forecasting, prevention and advising "for the betterment of society, economy and environment" (NOAA, n.d.).

Often touted by participants as the earliest predecessor to the OOI, one of the earliest and largest NOAA investments, the Geochemical Ocean Sections Study (GEOSECS), spun up during this time, introducing oceanographic stations worldwide that captured samples in addition to shipboard collection and, introduced shipboard computers with a dedicated "electronics engineer" to each cruise for real-time data processing. These initiatives defined a distinctive turn from the private, Navy-funded, single-PI traditions of ocean science toward satellite and big data-driven research, launching decades of long-term satellite-centric and interagency infrastructural projects funded by the National Science Foundation, NASA, NOAA and the Environmental Sciences Services Administration. Through each series of increasingly complex and distributed infrastructure builds, the experience of science changed significantly with each new configuration of government, agencies, universities, and national and international programs in setting common priorities, sharing program results and developing standards for research ahead.

This began the current of change in oceanography. The emphasis on time series modeling meant sustained and continuous observation from moored (cabled) instruments to document and study climate and ecosystem variability over daily if not decadal time spans. This continuous presence catapulted a mode of ocean observing that hinged on telecommunications cables and the work of AT&T, less ad hoc or single-serving deployment of instruments and therefore a greater interest in materials science and processes of decay on plastics, metals and batteries. The funding bodies who supported time series models were interested not in exploratory work that described the seas, but in predictive models that could contribute to the knowledge of weather systems and disaster prevention (Howe, 2012). The spatial footprint of this model of oceanographic work is large, not only in the cables and instruments it deploys but in the autonomous vehicles and docking stations necessary to provide power and maintenance to the instruments. Design and cost complexities plagued this period of oceanographic engineering and many harsh lessons were learned about the repair cycle that mends the chaotic and destructive nature of the ocean and its ramifications on human-made instrumentation placed within it. These docks were no longer named for their publicly famous investors, like Emma Browning at Scripps, but instead were named for their industry investments like the AT&T Makaha Shore station of ALOHA, which would be built in the next decade (Shor, 2003).

Amidst the midcentury boom of data riches from remote sensing and satellite data, one of the most influential oceanographers of all time, known for groundbreaking theory of global circulation in ocean currents, Henry Stommel, once wrote of ocean observation and the possible new contexts of scientific investigation, and of the regressive character of traditional seafaring work:

> When I emphasize the imperfection of observing techniques perhaps I should say that I wrote this chapter during a succession of midnight-to-dawn watches during an attempt to survey the Somali current near Socotra in the heart of the Southwest monsoon. It is rather quixotic to try to get the measure of so large a phenomenon armed only with a 12-knot vessel and some reversing thermometers. Clearly some important phenomena slip through the observational net, and nothing makes one more convinced of the inadequacy of present day observing techniques than the tedious experience of garnering a slender harvest of thermometer readings and water samples from a rather unpleasant little ship at sea. A few good and determined engineers could revolutionize this backwards field. (Stommel, 1966)

Satellites and deep sea submersibles began to see the ocean more regularly than human eyes. Submersibles were considered high cost, largely sized, and logistically complex and necessitated particular kinds of ships to haul them, particular crews to run those ships and particular interdisciplinary teams with particular skills in both collaboration and engineering to maintain and repair the technologies over time. These submersibles fully overtook work that had once been accomplished by scuba-diving, which was seen as limited in depth, with a short duration that couldn't possibly alleviate the temporal concerns growing in the field. It was in this moment that portability became less of a desired trait of oceanographic instrumentation, in favor of more cumbersome machines which could reach greater depths and longer durations (Howe, 2012). In biological oceanography, this marked a time when the scale of studies increased significantly while the objects of study became minuscule and multiple (Helmreich, 2009). The 1970s shepherded in the arrival of satellites, deep-ocean drilling, data processing, and ecosystem modeling. Through these new mechanisms for probing the earth, the world has been brought into sharper focus and with it has come a new era of oceanography, with bounds of new scientists to explore its riches.

While maturing into what looked more like a field, oceanography in the 1970s still did not have a clear career track: hiring, promotions, salary, tenure, equity, etc, were largely ad hoc in their assignment. In those days, research was mostly PI-driven, so each person had their own grant and there weren't collaborative groups: an investigator would write a proposal and then invite friends to work on that problem. Often connection to an institution came out of a desire to work on similar problems, species or locations: for example, if one was interested in crustacean symbiosis in the 1970s they would simply move to Woods Hole and begin campaigning to use resources from their lobster study of a similar nature.

During this time, the Office of Naval Research (ONR) picked young investigators and "took care of them" (participant quotation) during their early career, particularly those who were working at prestigious institutes like Scripps and Woods Hole. Often funded oceanographic work was at least supplemented by ONR, in fact, most vehicles were still supplied by the Navy. At this time ONR shouldered the weight of public interest in expanding to the Arctic and the development of remotely operated vehicles. For example, Emory Christoph from National Geographic had the first remotely-operated vehicle in the Arctic, and Charles Greene of Cornell University operated the second. These studies and the fiscal landscape of oceanography at the time, hinging on the grant work of ONR, established oceanography as a scientific field reliant on the “soft money” of governmental agencies.

Oceanography since the early-mid 1970s had its own internal large projects that were largely out of the research community through funding within NSF or ONR.

Participants reported that during this time, oceanographers often would gravitate toward one of the major institutions of the time like Scripps, WHOI, Oregon State or University of Washington as Ph.D. students, postdocs or early research scientists then would be plugged into a part of a bigger project like GEOSECS, designing big sediment trap moorings or as a marine technician. From there, often ocean scientists moved to other big programs, on cruises for programs like RIDGE in the geosciences (where they first discovered the hot springs in the Galapagos in ’77) or the WOSE (World Ocean Surface Exploration) project. A critical turn in oceanography occurred when John Corlis and Robert Ballard discovered deep sea vents in 1977 aboard WHOI’s DSV Alvin (Kahari, 1990; WHOI, n.d.).

In 1977, when hydrothermal vents were discovered in the manned submersible Alvin of the Mid-Ocean Ridge by the WHOI Deep Submergence Group including famed oceanographer, Robert Ballard, researchers began to flock toward understanding organic compounds in sea water, sediments and oil and how they change in the depth of the water columns as a result of microorganisms (showing microorganisms - more than phytoplankton, as was previously thought to be the only living component - was an important part of the ecosystem of the ocean and water content) (Kahari, 1990). These same markers were used by many oceanographers to trace atmospheric sources (fatty acids, alcohols from plants) and the transport of continental material into the Pacific-CEREX Exchange Project from ’79-89, bridging the world of Woods Hole with that of international groups of inorganic chemists and meteorologists, in the North and South trades and into the North and South Indies, China, West Indies and into the Central North Pacific (Kunzig, 2000). Following the success of this first Alvin dive, Ballard founded the Woods Hole Deep Submergence Laboratory with this group, where he spent 30 years as the figurehead and as a strong magnet for experts in manned submersibles. With this, the previous bounds of oceanography were broken and an era of interdisciplinarity, international collaboration and long-term studies was shepherded in (WHOI, 2018).

2.3 Oceanography's New Data Society

The major dialogs about the ocean at this time emphasized the importance of the classic Gulf of Maine research studies by Bigelow in the late 1800s, and pointed toward the incapacity of a field campaign to truly capture the big questions of oceanography like the growing field-wide interest climate change and hydrothermal vents. As field campaigns grew in length (some average campaigns up to 50 days), as did work to accommodate the fleet: many ships were in their midlife and needing to outfit or refit to sustain those long stays out in sea. Many existing ships of the U.S. fleet of the 1970s were cut in half then extended so they could stay out for long campaigns. For example, the research ship Knorr was a full 50-75 feet shorter before it was sent out as part of the WOSE (WHOI, 2018). It was at this point of physical instability that scientists became vocal about a need for reorienting their research practice and available ocean infrastructure toward collecting 40-50 year data sets, encouraging the next generation of large-scale, long-term and synthetic analysis by machines rather than the exploratory, individual and mobile data collection via cruises of the past.

The very birth of oceanography in the early part of the 20th century involved staples still found in today's ocean engineering landscape, including underwater telecommunications cables, whose integration into the purview of scientific inquiry has only increased over time. While the early studies unearthed current and fish migration patterns to understand where and how to lay cables, by the end of the Cold War oceanographers were employing those cables for scientific re-use, collecting, analyzing and modeling data about the sea floor at unprecedented rates (Howe, 2012). The wave of technological innovation of the 1980s and the 1990s, which carries forward into the present day (2018), presents a move even further away from the paradigm of the single investigator going to sea to examine a specific research problem. Recent decades see the rise of large multidisciplinary scientific teams that also include involvement of fisheries and industry using mobile platforms, fixed observations and remote sensing. Not only does this organization bring the telecom industry deeply into the negotiations of how oceanographic research can be performed, but the new era of big data and modeling the oceans has obviated the field's classic need for research vessels, or at least has deterred attention away to a degree where funds have been syphoned for technological development and maintenance over vessel construction and repair, both in the U.S. and more broadly.

Catapulted by the IDOE in the 1970s, the United States joined the International Council for the Exploration of the Sea (ICES) working internationally and collaboratively to create a database useful to scientists, policymakers and industry for identify unifying problems across fisheries, ocean research and the marine environment. It was during this time that scientists realized measurements using different time scales (minutes, hours, days) could not be easily compared, highlighting the problematic nature of variation and the variability of nature. Satellite imagery and data-gathering of the

Coastal Zone Scanner (1978-1986) and later SeaWIFS (1997-2010) brought in new interest that crossed the bounds of disciplines where even nutrient chemistry became part of the global concern about climate change (Mills, 1989). Volcanism and mid-ocean ridges were a new child in the portfolio of research around the late 1980s, but by 1990 it became clear that the time-series models were a good thing:

> The shift toward climate studies are things you can't really study with a field campaign. You really need long-term 40-50-year data sets (more than a research cruise in the Gulf of Maine). Approaching a topic more synthetically, synthesizing disparate data sets to answer the questions I wanted to answer. [It was a] very expensive, very slow process of collecting data - not only expensive but increasing in expense because of less ships now, not refitted or replaced and instead retired. And high fuel costs make it expensive. We've gone without an ice-breaker for a long time! We rent from Russia or Switzerland! The problem is that sometimes ships just aren't available… (Participant quotation)

By the early 1980s, physical oceanographers began to rise to prominence as potential keys to the secrets of climate change. Since the 1970s, the ocean sciences graduate education community has grown larger and more diverse, expanding well beyond Farrington’s (2001) description of a dozen or so programs offering graduate degrees in the four subdisciplines of oceanography (physical, biological, chemical, and geological) and ocean engineering as well as several excellent degree programs devoted to marine biology and biological oceanography. However, the industrial growth of the 1970s as a result of the IDOE (described in the previous chapter) left the field unclear of its identity.

What it meant to collect “climate quality” data came into view, and the relationship of physical oceanography to the telecommunications industry - and the cables laid but left unused by the industry - became a point of concern for the community. In the 1980s, a growing chorus of researchers became interested in measurements at the seafloor from re-used cables. However, the signals from these reused cables was very small, and the ability of the sensors was not necessarily up to the task of producing climate quality data.

The obsolescence and retirement of the first-generation fiber-optic telecommunication cables, installed in the 1980s and 1990s, provided a valuable resource for ocean science. The relatively large amount of power and data transmission bandwidth that they provided made it possible to continuously power instruments and obtain real-time high rate geophysical data from distant ocean observatories using cable infrastructure that still had decades of useful life. This resource takes advantage of instrumentation and technology developed by the telecommunications, cable, connector, and ROV (remotely operated vehicle) industries to evolve from existing stand-alone instrument systems into permanent observatories for relatively low cost. Testing using the existing cables prior to the installation of the observatory demonstrated that the communications system could operate error-free over ocean basin distances.

In just this way, in the late 1980s the observatory model rose to prominence, accompanied by a tight relationship between telecommunications companies, notably AT&T and local cable companies, and necessitating the use of cable ships, like Charles L. Brown (Howe, 2012). In early May 1989, the University of Tokyo, Joint Oceanographic Institution (JOI), the National Science Foundation (NSF), the Office of Naval Research (ONR), and the National Oceanic and Atmospheric Administration (NOAA), held a meeting at Incorporated Research Institutions for Seismology (IRIS) to discuss ownership models for the cable transfers. It was the consensus of the group that IRIS would accept ownership of the AT&T share of the cable on behalf of the U.S. scientific community. Major considerations involved the cable and associated spare cable and repeaters, nominal technical advisory support, benefit of disposal costs (charges only for incremental costs over retirement costs), an invitation to join the International Cable Protection Committee, and temporary housing of spare stock after retirement) (Howe, 2012). This was also a period of time in close collaboration with Japan. The Japanese Ministry of Education eventually provided the funding for instrumenting and deploying the GEO-TOC (Geophysical and Oceanographical Trans Ocean Cable) system in 1997.

2.4 From the Age of Exploration to the Age of the Acronym

The interest in volcanism and mid-ocean ridges of the 1970s were a new child in the portfolio of research, yet by 1990 it became clear that the time-series models were a "good thing" (participant quotation) and "a necessary thing" (participant quotation). It is during this era that participants in the present ethnographic study were able to comment on their experiences developing, employing and eulogizing large-scale scientific efforts of the 1990s and 2000s that led to (and specifically led these participants themselves to) the Ocean Observatories Initiative of the modern day. As the past moments of infrastructural development reflected the political climate and agendas of Navy and government, as does the rise of the observatory, upon which oceanographers worldwide and the NSF began planting seeds for what would become the U.S. Ocean Observatories Initiative. As explored later in this dissertation, modern computing makes it possible to connect the processes on terrestrial earth with the fears of climate change that bubbled up in the 1970s and drew a new broad attention to our waters. From decade to decade, the way that we view our role in the oceans and our planet has changed. In many ways, what we begin to see is that the monsters of the sea that once piqued the curiosities of early explorers to adventure through its waves are now found simply by looking down into the reflection of ourselves on the water.

It was only in the 1990s that "we (the field of ocean science) got sort of cocky about" (participant quotation) developing instrumentations for the ocean floor and began campaigning for more global instrumentation of the ocean. Participants described that when the array in the tropical Pacific, the Tower Array of the mid-90s was erected, the community first began more cohesively coming together to think about and problematize global problems. It was said of ocean work of the 1990s, “Earth studies require governments, agencies, universities, and national and international programs to agree to set common priorities and share program results" (participant quotation). Inside this wave that expanded the scope and depth of ocean data collection was the development of the Argo float, which would become critical ocean infrastructure for the next decades. Argo floats were developed by Robert Ballard in 1981, a remotely controlled sled carrying video cameras that can photograph in almost complete darkness. The Argo floats and later the OOI expanded the ways in which ocean scientists conceived of the possibilities for studying the ocean along new temporal and material dimensions:

> It (Argo floats) goes back about 15-20 years and has the same roots as OOI. It was the transition to start thinking about the ocean globally and I mean there were a few programs, global surface structures and things and I think the new technologies of the Argo floats and such... and it wasn't until the mid 90s that we

> could start keeping things out there for more than a year at a time. The technology evolved to make it possible. (Participant quotation)

By 1990 efforts were well underway to use the retired telecommunications (TPC-1) cable. This culminated in the Japanese GEO-TOC and VENUS observatories. In parallel, the Hawaii Undersea Geo-Observatory (HUGO) was built and installed in 1997 on Loihi Seamount, an active volcano just south of the island of Hawaii (HUGO, 2016). With its own cable, it was the first to depend on submersibles or remotely operated vehicles to connect the sensors on the seafloor, and to provide general purpose user ports delivering high power and bandwidth using fiber optics. These efforts lead to the Hawaii-2 Observatory (H2O) halfway between Hawaii and California that was installed in 2001 and operated for 4 years (WHOI, 2018). Installation of the ALOHA Cabled Observatory (ACO), just north of Oahu, was begun in 2007, and was completed in 2011; it is the deepest operating cabled ocean observatory.

In the 1990s VENUS incorporated a junction box with underwater-malleable connectors. A wide array of instrumentation included broadband seismic, magnetic, oceanographic, and geodetic sensors. The VENUS system collected about one and half months of useful data before failing due to a connector fault (Howe, 2012). In the 1990s and early 2000s, many OOI participants were involved in VENUS or with the US side of negotiations for expanding a cabled observatory across the Juan de Fuca Plate over American waters. Many participants worked also on drilling projects in the Atlantic, but some noted their eventual distaste for spending 8 months on a ship, missing Thanksgiving, Christmas and New Year’s Eve for many consecutive years." You probably heard that going to sea is like being in jail except for the added risk of drowning? Some of that is true!" (Participant quotation).

What occurs over the course of the next few decades (leading up to the development of the OOI) is a deepened coupling between academia, government and industry where technical standards become public goods and commodities. A new necessity arises to advocate for one's form of science to compete in the tightening fiscal climate of ocean research. What this necessitates is an urgency for advocating for the components of high tech 21st century development that are less recognizable as measures of innovation and success in the field (like human sustainability, traditional forms of seafaring work, more ad hoc instrument building, code and process documentation). As the decades would pass, oceanography, as would other scientific fields amidst a shifting orientation of the operation and scrutiny of science more broadly, would be met with an almost hostile or indifferent financial climate.

> The world of oceanography is changing whether the OOI exists or not. It's still going to change. And many pieces are out there helping that change. And there's the whole Integrated Ocean Observing Systems in the US and that part of the change in oceanography. And that's contributing to the global ocean observing system which is contributing to the global EARTH observing system. And so treating the earth as system is really the big change. And the many ways to observe that system. you have to observe it from those observations you build understanding and then from that understanding you build the ability to predict, the ability to predict the future. And if you can predict the future you can make decisions about the future. And so that's the step. And the OOI is one piece in that huge endeavor. And so that's what I tell my students… This is very important for their lifetime because a lot of these changes will happen in their professional careers. You know lot of the predictions for climate change they talk about what it's going to be like in 2050. I tell my students that in 2050 you'll be my age! You'll be at the leadership level in your careers! And this is climate change! You're going to live by 2050 the population of the globe is going to increase by 2 billion people. So we're going to go from 7 to 9 billion. Those extra 2 billion people are already in the countries that are less developed and

> being added to those countries and as it is there is not enough water, there is not enough food, there is not enough energy to go around. (Participant quotation)

What is striking is that despite this sure-footed rhetoric of change, some of the problems that plagued oceanography at its very start still remain more than a century later (Mills, 1989). Work continues to be frequently limited by insufficient funds and furthermore pressed to be justified with relation to broader public interests such as the fishing industry, oil and gas industry or climate change. As the years pass, the economic costs of climate change present themselves as serious damages associated with inaction on climate and a pressure is placed on oceanography to find answers to these deficits. We see major foundations like the Rockefeller brothers and other highly responsible groups who take their fiduciary responsibilities very seriously, who have said the time has come to divest from fossil fuels and into research that can provide answers for alternatives.

As a result, scuba diving, re-breathers, fast computers, remotely-operated vehicles (ROVs), deep sea submersibles, reinforced diving suits, satellites, and other technologies have been developed to capture the wildness of the sea in quantifiable form. And, in addition to far-reaching shipboard spatial surveys and maps of marine characteristics conducted by early oceanographers that revealed many secrets of the world oceans, time series measurements have become required to explore the variations of the ocean at a single location. Repeated shipboard observations at particular sites provide access to such variations; but the temporal sampling is limited by the duration capabilities of the ship and crew. Not to mention, the ocean changes between lowerings of instruments, fluctuating with large amounts of energy at high frequencies, and such shipboard measurements are easily aliased. To cope with the sampling requirements, engineers package sensors (e.g., temperature, pressure, acoustic, seismic) into pressure-resistant cases along with batteries and tape recorders.

Many participants involved in the OOI held the position that despite current technical mysteries of how to sustain instruments in the sea over long periods of time, the field needs time series models within the blue water oceans, where understanding dynamical processes requires long-time series to quantify underlying statistics. Typically for an observatory, five to ten years are needed from initial planning to fruition; this takes dedication (and a degree of stubbornness!) to persevere through all the obstacles and challenges, many of which are non-technical. Further, a long-term plan is necessary for the operations and maintenance of an observatory. One participant estimates there are over 150 people maintaining time-series sites that can now share their data and have made those data interoperable. In France there is an assembly center that is hosting data, helping to collect it and pushing it out to the public because "open access and interoperability are something we can strive for" (participant quotation). “It is just sort of seen as a way into the future" (participant quotation). Every year the deans and directors of oceanographic institutions internationally meet under POGO (Partnership of the Global Oceans) and develop mission statements around these sorts of ventures, which become "Action Groups”, for example, of the data buoy cooperation panel. Now interested in global climate change, emplacement of geophysical and geochemical observatories on the ocean floor, deep structure of continental margins and oceanic crust, the world of oceanography moved from expedition to a process of hypothesis-testing, and a sense of exploration moved into the background. This shift changes the way we imagine the ocean and what it looks like to be a part of it, to interact with it and to understand it.

Cabled observatories began to occupy increasing attention of funding bodies and scholars alike, such as the ALOHA or NEPTUNE Cabled Observatories, which provide remote interactive instrument control, continuous real-time data streams and large amounts of electric power (Howe, 2012). Cabled and autonomous technologies are complementary in that the cable systems can provide the power and communications interface to subsurface autonomous fixed and mobile platforms using docking stations and acoustic communications, without the routine use of ships, thus significantly increasing the spatial footprint and the overall observing system efficiency.

> Instead of looking at a snapshot from a month cruise, you get information about changes that have never been seen before - it will change the models and the way we look at our oceans. (Participant quotation)

Funders of the field became interested in cabled systems that would extend terrestrial infrastructure to the sea floor. The questions became: how can we distribute power in a communication capability throughout the whole ocean? The answer increasingly seemed to be: through cabled systems on the sea floor, moorings in the water column, filled in by autonomous instruments and vehicles that can recharge batteries. And so the vision of the OOI came to be.

2.5 Conclusion

This chapter provides context to the Ocean Observatories Initiative which serves at the basis for the subsequent chapters of this dissertation, where there exist not only multiple futures the infrastructure may inhabit but also the multiple pasts: the multitudes of worlds which study the sea each have distinct and separate trajectories that coalesce into the next era of ocean science in the rise of the observatory and interdisciplinary collaborative ocean work.

Mirroring the call of Helen Rozwadowski (2004) and Philip Sternberg and Kimberley Peters (2015) to think of history vertically and better integrate our oceans into our stories of human life, this chapter aims to think of the present experience of oceanographic life by integrating the history of experiences on the ocean. Remembering and forgetting has long been part of the characterization of "infrastructure": this chapter intends to unearth the legacies of US ocean science that preceded the current moment in oceanographic infrastructure development and look to lessons: documenting and acknowledging the ebbs and flows of innovation to understand the present and the future.

Oceanography is considered a "young" science: most discoveries of oceanography can largely be condensed into the last 50 years. While research on the ocean can be traced back for centuries to Aristotle, oceanography as a formalized discipline is considered one of the newest fields of science more broadly and, as such, has a small number of participants in comparison to other fields. In its short tenure, what it means to be an oceanographer has radically changed (or expanded, depending on who you talk to).

Oceanography as a cohesive field is highly contested (Rozwadowski, 2008a), as those who would be colloquially assigned the role of "oceanographer" often do not term themselves as such: instead they may be marine engineers, geologists, marine biologists, hydrologists, climatologists or seismologists whose interest (whether long-term or temporary) is in the oceans. On the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) website under a link titled "What do Oceanographers Do?", the answer is:

> Just as there are many specialties within the medical field, there are many disciplines within oceanography. (NOAA, 2017)

With as many disciplines that claim the oceans as their home, there comes a range of funding bodies such as the Navy, Coast Guard, fisheries and ocean researchers, who at times are working in parallel and at times working collaboratively, weaving into and out of separate but fundamentally integrated histories. Potentially in response to the amorphous definition of oceanography, histories of oceanography often are written from a more myopic perspective: following a great man (e.g. Robert Ballard, Jacques Cousteau), a great institution (e.g. Scripps, WHOI) or a great place (e.g. Antarctica, the Mid Atlantic Ridge). Therefore, a coherent history of oceanography is quite complex to delineate and requires a uniting of multiple discrete timelines. Few and far between, rich treatments of oceanography's history dive deeply into a single sub-field such as the beautifully detailed work of marine biology by Eric Mills or physical oceanography by Helen Rozwadowski.

Raising this complexity, science's interest in the ocean also follows a multimodal trajectory: its history is rich with major shifts in reaction to world events and new political climates that reorient the labor force and often manifest in new technological interventions, new locations of interest and new groups of experts who are able to investigate those locations through those technologies. For example, there exists a rich, fascinating history of icebreakers in the US that illuminate this mobile force of available infrastructure amidst shifting sociopolitical climates. For example, in the late 1800s the nation's acquisition of Alaska resulted in the US Coast Guard's commitment to safety at sea in northern regions, regions that required new icebreakers to journey through those currents. Researchers who once did not have the financial or human resources to commission Oden, the Swedish icebreaker (which later, in the 1990s, famously reached the North Pole) suddenly became able to explore the geologically important territory north of Washington State (Spielhagen, 2012). Or, decades later, in 2014, the increased interest in climate research and the potential of oil beneath the Arctic placed pressure on the U.S. to replace a 1960s icebreaker that was in need of major repair. The result was RV Sikuliaq, owned by the National Science Foundation and supported by a crew of over 20 marines and technicians with new winches that could bear the latest large-sized instruments being towed aboard ships for collecting deep water or air-sea interactions (Witze, 2014). The capabilities of modern oceanography integrally concern its major infrastructures, hinged largely around the backing of a major government institution (e.g. Coast Guard, Navy, NSF).

The infrastructural history of this chapter is characterized by four major concerns: (1) identifying and following shifting dominant practices and key infrastructural elements over time; (2) signaling the increased coupling of government, industry and science; (3) indicating the significance of temporalities in defining the future(s) of ocean work as well as shaping the materiality and everyday character of work. By telling the history of the ocean sciences through its dominant infrastructures, we see clearly (4) a reorientation of the labor politics in the scientific workforce within the move toward "big science." Often overlooked by the shiny histories of great men, great institutions and great discoveries that dominate archives and anecdotes alike, this infrastructural history of oceanography highlights how major technological shifts coincide with new realities of human labor and new materialities of ocean science, with an emerging and diminishing importance of particular temporalities (like climate, disaster, or publishing deadlines). Through an engagement with literatures around the rise of big science and science policy in postwar American contexts, this chapter points to a conspicuous absence in historical narratives around breakdowns, ends and failures.

Through the traversal of the infrastructural history of the ocean sciences, we see that the availability of major infrastructures that support research of the oceans heavily dictates the character of work and life on the seas. The norms, conventions, practices and policies provide us a sedimentation of important priorities and relations of the funding and managerial mechanisms which seed new infrastructures. The development of an infrastructural history was to follow as closely as possible the politics and practices:

> There are many ways to recount the history of the sciences, and to ground the politics of the future on them. What I am proposing puts the emphasis on the event, the risk, the proliferation of practices. (Stengers, 2000: 114)

As the field grows in both its participation and in its scope through the 1970s and into the 1980s, a broad range of people, institutions and sectors became involved in the operation of research. More recent decades see a soulful romanticism not for the sea itself as in previous incarnations of ocean science but for the immortality of data about the sea. The earliest forms of oceanography were not concerned with instruments but with men, and the more recent forms are not concerned with instruments but with data. Rather, knot-tying and ship-steering is sidelined for building data-centric infrastructures for generations to come. This long-term future is so distant that it isn't clear what kinds of science will be undertaken, yet there is a feeling that at its most fundamental level the need for data will not go away. As de Solla Price (1963) describes, field-wide changes "from little to big" are often measured, not drastic, yet each change demands shifts in manpower, literature, expenditure and organization. Through the narratives of this chapter is a reorientation from the locus of the ship to the satellite; from the Albatross to SeaWIFS. In recent decades, data-driven architectures become a political imperative, echoing in many ways the lifestyles and rhetorics of Silicon Valley, where technological tools are revolutionary and traditional modes of performing work are outmoded.

This newfound perspective on the relationship of humans to the sea brings about a particular scrutiny of how humans should interact with the sea from both within and outside the scientific realm. The unprecedented expenditures of big science initiatives in oceanography are met with comparable public scrutiny. Public evaluation of government spending on the large-scale invokes a new journalistic performance of research, or what Weinberg (1961) termed "the spectacular of science" or what Lezaun & Soneryd (2007) deem "the new centrality of the public." In this way, the big science of observatories and time series enters the realm of public debate: it cannot survive in isolation from the nonscientific spheres of society (Nowotny, 2008). Results from large-scale projects intended for academic journals, broadly speaking, are now re-purposed for the popular press and congressional hearings, expanding to far more publics than the typically esoteric nature of smaller scientific endeavors. While oceanography began as an insular practice by the end of the Cold War we see a rise of “socially robust knowledge," in which external checks and balances are inserted into the research lifecycle, integrated fully into the institutions and infrastructures that hold up this work, and along with it the presence and permeation of research councils like the Stratton Committee are forged into the configuration and operation of research facilities (Nowotny, 2008). This phenomenon has given rise to a tighter coupling between congressional bodies and the operation of science, and a particular emphasis on the role of consortia and advisory boards in the new knowledge economy, in part to manage the public perception of government spending. Unlike the exploratory model that mirrors the fantastical voyages of Jacques Cousteau, this more integrated configuration of scientific evaluation depends on the attachment of social and political significance to scientific projects for justification and intellectual content (Nowotny, 2008), particularly present in the declaration of the International Decade of Ocean Exploration (IDOE). Much of these important shifting relations have been left untouched by recent ocean scholarship, particularly absent in modern histories that catalog that last twenty years of oceanographic research and its very recent turn toward big science (notable exceptions include Bruce Howe, Helen Rozwadowski, Eric Mills).

What we learn from following from large shifts in infrastructure in the ocean sciences is that new systemic structures will leave a blueprint for practices carrying forward into the field, like the changes in the field that are already felt by OOI explored later in this dissertation. The oscillation and integration between computation and ships in oceanography brings about a notion of anticipation and performativity: as we design infrastructures for the future exploration of the seas we are laying the pathway for enacting subsequent research and defining a legitimacy of certain computational scientific endeavors over those operating at a smaller scale. Grounded in the shared material culture which shapes social life on the sea, communication scholar and historian of technology, Chandra Mukerji (1990) offers a provocative depiction of the relationship between the sociopolitical climate and funding bodies in the lived experience, practices and opportunity space of oceanography, a provocation which is explored throughout the expanse of this dissertation. Mukerji's perspective serves as a backdrop to the present chapter: not only do the technological underpinnings of oceanographic research (e.g. prevalence and desirability of submarines, icebreakers, ships, satellites, sensors, etc.) form the backbone of formalized governance and organization that supports and constrains oceanographic work, but they also shape the character of work and the life of those who perform that work.

In establishing the feminist perspective in studies of infrastructure, Star and Ruhleder (1996) raise considerations for the dynamic, temporally-oriented connection between infrastructure, human labor and life. As changes over time in systemic structures like technology or plans become formalized, the meaning of those changes will be unique to each individual and will highlight power relations in the adoption and resistance to new forms. As trends move toward larger and more open initiatives in the world of oceanography, these orientations play with the ability to generate new scientific knowledge without the constraint of physical location; many participants noted there is still unequal representation of strong institutions (including their scientists and staff) with superior financial status as well as unequal opportunities for connectedness to cutting edge technologies and other reputable scientists within the development of new infrastructures. Under this lens, we might think about where Amy Bower's story lies inside the tellings of oceanography, who has performed years of research at sea despite blindness. In this way, infrastructure studies open a dialog about the distributions of wealth, race and gender in life on ships to date, which will be further exacerbated by struggles for gaining status in the competition for funding in the ebbs and flows of fiscal health for oceanography. Infrastructure studies also provides a series of considerations for thinking of infrastructures as "growing" rather than "being built" (Edwards, 2010), which lends itself in particular to understanding the nurturing and maintenance inherent in institutions and projects that lean in to the national needs of both war and peace times, the sorts of infrastructures and transitions that pepper this present chapter, and adapting goals to a new set of funders, new organizational regimes, and new perspectives on the role of the ocean in the earth.

The complex bridging between intellectual and social factors influences the geographical, topical and methodological sites of ocean work as resources, trade, commerce, and national security shift with the political climate. Key efforts in increasingly large-scale ocean infrastructures have been crucial to the outcome of war and industry in the United States since the earliest documented marine research. Through histories of ocean science there is a clear influence of political climate on the possibility space, form and function of research practice with a clear gap in our understanding of modern environments for performing work without a map that relates those narratives to the retrospective determination of their success or failure.

As explored further in the following chapter, the ocean cannot be investigated without the mediation of technologies, built through the imaginations and cultural conceptions of the space (Helmreich, 2009, 2011; Rozwadowski, 2004; Goodwin, 1995). The promise of time-series sensor technologies to instrument the ocean is a new embodiment of oceanographic work, a physically drier 'new order of intimate sensing' than experienced on the deck of a ship (Helmreich, 2009). In the pages that follow and in the histories of its autonomous, satellite and remote technologies, oceanographers see the potential for the emancipatory power of data and instruments, where being an oceanographer no longer means adhering to the constrained nature of being at sea, but rather allows an almost cyborgian extension of humans of all types into the expanse below the waves. This new liberating technological expansion generates a new temporality of change, a historical development caught up in the realizing of the future:

> One result of this heady lineage is that it is difficult to separate an analysis of infrastructures from this sedimented history and our belief that, by promoting circulation, infrastructures bring about change, and through change they enact progress, and through progress we gain freedom. (Larkin, 2013)

Despite this promissory power, participants at times describe the observatory in ways that evoke an exploitation of the body in favor of only the mind, where these data-driven initiatives greatly diminish and constrain the ability to act physically and to be physically present. In juxtaposition to this, there exists a beautiful rhetoric of this bodilessness of this research, where data-intensive science could open new worlds of research that might not differentiate between male and female bodies in the way that traditional forms of ship-based work has in the past (cf. Lehman, 2018). While women were confronted with many barriers to entry on ships and particularly submarines even into the last decade, participants noted the shifting tides of inequality and the potential for open data and infrastructure to support discovery without the physical and social barriers of race, strength, or more subtle forms of sexism that once deterred engagement (also found in initiatives like NSF ADVANCE, Oceanography Magazine's Women in Oceanography edition, or in the archiving of female bodies in womeninoceanography.org). Much like that of Donna Haraway's Cyborg Manifesto (1991), these participants are building their vision where all genders have the capacity to assert power through the ocean's coming big data resources.

This high-tech world of deep sea ocean exploration that began in the 1980s and continues today is similar to space: it is flashy and otherworldly, exciting and provocative. Our futures of seafloor-walking robots and new lifeforms of the ocean capture the imagination of children and adults alike, permeate our artistic fictions (in film, and in television) and capture our most integral scientific budgets and policies. In some sense, these visions are built into the very fabric of what it means to be American (e.g. aquariums, Jaws, Titanic). However, what lies underneath the fictions and grand discoveries are complex human stories, spanning further than the ways we have advanced our computational capacities and beyond how neoliberalism has seeped into the operation of science. Instead what appears most significant are the personal experiences of science and what development means for the future of science in a concrete and pragmatic way.

Following the methods chapter which divides the predominantly archival and historical work of the present and previous chapters with the remaining ethnographic chapters, Chapter 4 identifies the longstanding scholarly interest in the fictions of infrastructure and connects them to the fantastical fervor of the seas. In doing so, it demonstrates the power of considering infrastructure with fiction to draw attention to new pieces of the OOI narrative, to their dangers as well as their opportunities, and demonstrate the thick and enmeshed stories that connect and drive scientific visions. The chapters that conclude this dissertation pay mind to the things that foil the technological utopias found in these fictions of the sea, opening new questions about how to responsibly care for ourselves and our environment.

3
Methods

This chapter follows the methodological journey through the multiple scales and concerns of the Ocean Observatories Initiative (OOI), detailing some of the tools, perspectives and decisions that led to the ethnographic data set that informed this dissertation. This chapter candidly reveals how this dissertation was produced, its major challenges and attempts at developing an ecological analysis that shines a light on the invisible, political, future-oriented work of the OOI. This dissertation is greatly influenced by the formative work of Leigh Star, Geoffrey Bowker and others in its attention to boring things (Star, 1999; Bowker & Star, 2000; Star & Bowker, 2006; Strauss, 1978): significant time was spent investigating and discussing with participants their organizational charts, engineering change requests, master schedules, and calls for procurement. These documents and everyday interactions with them reveal the imbrication of social order and infrastructure, how things become fashioned by infrastructure, the mechanisms that create lasting standards and hold them, that indicate roles and responsibilities and the ways in which these designations are and are not followed closely.

In Fall of 2012, I sat in the office of Dr. Steve Jackson deliberating next steps in our joint research venture when he asked, “Have you heard of the Ocean Observatories Initiative?” I had not. The initiative is funded by the same mechanism - the National Science Foundation (NSF) Major Research Facilities and Equipment Competition (MREFC) - as other large-scale aconym-ed projects in the earth sciences Dr. Jackson investigated for many years prior, investigations that drew me toward the present collaboration: Long-Term Ecological Research (LTER) Network, National Ecology Observatories Network (NEON), and the WATer and Environmental Research Systems (WATERS). As we chatted, I opened oceanobservatories.org in a browser (see Figure 3.1). The unfamiliar shapes and colors of ocean engineering found in the photographs of the site's banner floating above the black-and-white text of its newsfeed detailing the significant injection of funds it received from the Obama Stimulus Package drew my immediate attention. So it began. I signed myself up for a university-wide oceanography list-serv and enrolled in Cornell University's most popular undergraduate course, EAS 1540 Introductory Oceanography, taught by the inimitable Dr. Bruce Monger. Five years later, through years of the Ocean Observatory Initiative (OOI)'s construction and into its live operation, I have not yet taken my eyes away.

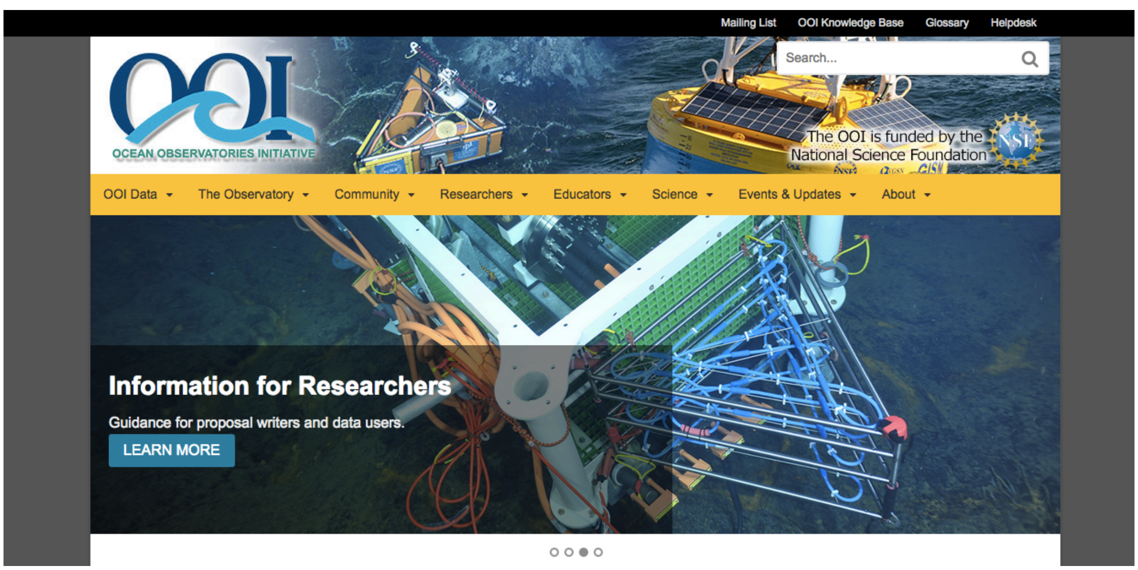

Figure 3.1. Landing page of the Ocean Observatories Initiative website. Retrieved from oceanobservatories.org (Image credit: Consortium for Ocean Leadership).

The initial moment of intrigue was at first driven coarsely by the question of: "Why haven't I heard of the Ocean Observatory Initiative?" and led to weeks systematically consuming and cataloguing policy documents concerning cyberinfrastructure and climate change in the US, specifically through the NSF and the American Recoveries Act budgets and mission statements, as well as publications and press releases concerning the development of the OOI. I began by creating two spreadsheets: one spreadsheet for any and all documentation of the OOI and its related policies, which had a corresponding location on my local filesystem on my personal computer. The other document contained a list of the OOI's affiliates, their roles and whether those roles had changed over time, their institutional affiliations, contact information, and what documents they had authored. Through the triangulation of these two documents, I sought out the major players in this endeavor: what are their histories? What institutions and professional societies are they affiliated with and where do they publish? What presentations of theirs are available on Youtube and Vimeo? Where do they get written about and interviewed? As I traversed the breadcrumb trail of the OOI available to me via public and academic online network access, the complex history, the passionate-yet-fraught present and the promising-yet-uncertain future of the OOI was immediately revealed to me.

Before embarking on my first day of ethnography of this infrastructure, the OOI emerged as a site that would be best understood through multiple avenues and scales of inquiry: firstly, through its broader sociopolitical embeddedness, necessitating an understanding of policy, governance and national budgets. The story of the OOI from afar seemed to be powerfully tied to the political story of presidents and their platforms, particularly to the politicization of climate change and scientific thinking in general, and to energy consumption and environmental policy reform. Infrastructure scholars show us the quite invisible nature and the complex layers around tech use – we simply use electric grids, water, telecomm systems, train lines, city streets but we largely do not think of the broader sociopolitical spheres and ethics concerning their construction, their materialities, temporalities, development policies. To understand the agenda of this infrastructure development in the ocean sciences, I placed an importance on capturing how to be a part of it, what high level aims might look like, what conversations are being had and heard in policymaking arenas that dole budgets, and in what ways do the affiliates of the OOI seek political and politically-driven public support. My mentor, Steve Jackson, has said, "to study an infrastructure without studying its policies is like watching half the court of a tennis match." In this way, from its start, this research has paid a special interest to policies, politics and governance structures and their evolution over time.

Secondly, even at a distance it was clear that fictions, imaginations, and more personalized visions or goals of those within the initiative are critical to understanding the OOI's enactment and the way it is built. The videos and talks, the media invoked in writing and in motivating the case for the OOI, and the imagery of the OOI were all ripe with science fiction and fantastical speculation, motivated by long-term future world-building. Not only does the broader vision of the OOI ring similar to a science fiction in its coarse descriptions (or its colloquial name of "the instrumented ocean") but its affiliates also express their participation in oceanography in artful ways. Throughout my ethnography I came to learn many of the oceanographers who contribute to its building are also photographers, artists, poets and musicians who create more than scientific instruments, at times this creative process is extracurricular to the practice of science and at times pointedly part and parcel of their scientific practice and knowledge dissemination. The imaginations and fictions about the OOI and its future are found in the ways its affiliates discuss the future world around the OOI and in the work toward accomplishing and building the infrastructure as well as in the art they create and circulate to me and their colleagues. These are practices, dialogs and concerns generally absent or sanitized for formalized policy and funding spheres but are importantly driving how the OOI came to be and continues to operate, for answering why individuals will dedicate their lives and careers to this new endeavor and how these fictions find themselves in the structures of OOI practice, policy and structure. Therefore, much of this dissertation is concerned with fictions and futurisms, the storytelling and the characters who inhabit those stories.

The continued driving purpose of this ethnographic inquiry has been to identify some of the major challenges of designing transformative infrastructure and to develop a greater understanding of the impact of infrastructural development on labor and life for the oceanographic research community around the OOI. This understanding began by asking: what common (but maybe overlooked) human-centered narratives arise in the planning and construction of a large-scale scientific investment? What is the meaning of big science for the ocean science community around the OOI? How can we develop forward-thinking theoretical frames that capture the social and cultural consequences of OOI's big data and big science? What are the expectations across scales (laboratories, OOI, Ocean Leadership, Congress)? How do actors plan for long-term sustainability of both technical and human resources around the OOI? These insights fold into the driving research question for the present dissertation:

> How does transformative infrastructure get carried from blue sky to blueprint and beyond?

This dissertation may well ask more questions than it answers, where the continued collection of ethnographic and archival data generated increased intrigue and more nuanced holes in my understanding of the operation and situatedness of the OOI. The broad-scale moment of technological progress in America – in popular press and the broader zeitgeist, far beyond the confines of the OOI and the territories it touches, found in my disciplinary and personal everyday interactions with the world – turns a particularly critical eye toward modern digital systems: forcing a scrutiny, cautiousness and studiousness about the standards and ethical principles that are designed sometimes naively into our modern technological environments. As an analyst in this climate, I have performed the work of this dissertation attuned to questions that might look more like an agenda of social justice:

> What is being built and who is it being built for?
> Who decides what to build and who does the building?
> Who benefits and who is inconvenienced for that benefit?

As such, the work of this dissertation places an importance on a diversity of voices both in the typical sense of inclusivity and representation along demographic lines but also by engaging in one conversation both those employed to build the OOI and those at the top who make employment decisions, thinking toward the disconnects and commonalities of their imagined futures. Throughout my time with the OOI, it has been my experience that there exist few people who inhabit a space concerned with both policy and with the weeds of development: developers have called their project managers "illiterate" about the technology they are building and project managers have called their developers "profoundly unaware of the politics." This dissertation concerns the issues facing infrastructure design that are not wholly encapsulated in one bug fix, SCRUM meeting or a talk on Capitol Hill. Throughout my field work I began to recognize a profound need for understanding sociotechnical systems through the eyes of diverse actors by the repeated stories of broken components of infrastructure – where components don't deliver or fail – which largely arose in moments where cultures on the ground didn't match their development protocols handed down by administration, particularly in reporting success and failure to the government and funding bodies. This dynamic demonstrated a productive conversation to be had between ethnography and the policy that sets the agendas for those large-scale engineering projects. This produced an additional line of questioning that connects on-the-ground action with broader governance and reporting questions: why do they make these decisions? How are the metrics of success determined and communicated upward? How can we design better pipelines that work with the multidisciplinary complexity of the projects we are funding?

Performing ethnographic inquiry into this politicized infrastructure required multiple predominant challenges. The present chapter is organized into three sections, addressing those challenges. The first discusses the research methods and the concomitant relationship between historical work and ethnographic method that provided understanding of the OOI as a situated field site yet left as many questions as it answered. Next, I describe access and my relationship with participants, participant check, the productivity of ethnography and the vocalized desire for social science, as well as the difficult line between friendship and formality that ran through much of my fieldwork. Lastly, I discuss navigating with and around my participants in times that were less easy for them to reveal, in breakdown, failure and heavy turnover. I conclude this chapter with a reflection on my status and abilities to engage in the field after becoming a mother while still in the field. This chapter is a journey through my experiences immersing myself into the world of oceanography, gaining (or not) access to ship-based and labor-intensive work, becoming what multiple participants would call "a therapist" inside a very large infrastructure where it is difficult to discuss or be proactive about grievances, curbing my own emotional attachment to particular participants who were charismatic or simply in better communication, and attempting to do a service to both my participants and to the research while grappling with the realities of what a dissertation can do.

3.1 An Ethnography of Ocean Infrastructure

The work that informed this dissertation was largely conducted under NSF CAREER #0847175 and NSF EAGER #1258927. The human subjects certifications for this work were IRB-approved at the University of Michigan and Cornell University under Dr. Steve Jackson and myself. Data collection for this dissertation began on November 6, 2012, and is organized into three major categories of data: (1) observational, (2) interview and (3) archival and historical.

3.1.A Ethnographic Observational Data

The first (1) category of data contains ethnographic observational field notes, video and audio recordings, photographs and drawings taken intermittently through the course of field work from November 2012 until October 2016. A typical round of field work consisted of one week or more spent at one of the 5 implementing organizations of the OOI (Scripps Oceanographic Institute, Oregon State University, University of Washington, Woods Hole Oceanographic Institute and Rutgers University), repeated a 2-3 times a year between 2012 and 2016. Field visits took multiple forms: a few weeks spent at an institution, on a nature preserve or at sea; an overnight or a few days spent in a city hosting a conference or seminar, or; a single-day outing to a local institution deploying, producing or testing an instrument to be included in the OOI. Observations were conducted on ships, docks, workshops and warehouses – often beginning with a personal tour of the facility led by a single individual, documented by handwritten notes and photographs, with particular attention paid to the people, manufacturers, responsible parties, documents and policies invoked during the tour. Observational notes and images often focused on small interactions with tools, with particular attention to hands and whose can work or whose hands are emptied (see: Appendix: Hands). The majority of ethnographic observation was drawn from laboratory meetings, conferences or seminars, and most substantively during small and initiative-wide meetings often held in a university room around a single table with multiple participants virtually attending by conference call.

Observational data was largely collected through handwritten field notes into a series of Moleskine notebooks using generically-available mechanical pencils and pens. Notes taken at the time of observation were largely written in pencil, with annotations and later additions including questions or speculation drawn using colored pencils or pens. Photos, audio and video during fieldwork were largely collected using a Samsung Galaxy SIII camera, video recorder and voice recorder set to airplane mode. All digital data (audio and video, photographs, transcriptions) was uploaded to a personal hard drive and shared amongst the research team via a password-protected online Box repository housed by the University of Michigan, at the administration of PI Dr. Steve Jackson and research assistant Sarah Barbrow.

Prior to engagement in observation, a 1-page research description and IRB-approved consent form was sent to all members of a research team with an option to opt-out of the data set. The few opt-out cases largely did not interfere with data collection. The option, in fact, was only selected by affiliates who I did not encounter naturally through observation (whether this was intentional obfuscation or not, I may never know).

I occupied the role of participant-observer during laboratory or facility tours and when attending deployments and ship-based work, offering my help in achieving tasks when useful or potentially interesting to engage. These kinds of participant engagements included mostly small tasks: checklists and bookkeeping, relocating cameras, organizing equipment, grabbing supplies while on deck, or scraping living organisms off of instruments newly pulled from the water. My role in performing these tasks ranged from necessary to novelty: at times I was asked to participate in activities that were purely to gain experience rather than fulfill a team's need. I maintained a form of recording on my person at all times during all observation, whether a mobile phone or physical notebook, and used this to document field notes amidst and immediately following activities.

Following engagement, all observation participants received a thank you email where they were reminded that if I am to detail any experiences of theirs in public outputs that they will be contacted. Participants who had not yet been interviewed received an invitation for an in-person or remote individual meeting. All participants were invited to engage with my research moving forward. I collected a list of participants interested in the outputs of my work and sent an email (BCC) of all publications and talks related to the work these participants informed. Additional detail of the process of participation check for this project and on maintaining relationships with participants is detailed below under "On Social Science and Hard Science."

3.1.B Interview Data

The second (2) category of data is drawn from 77 recorded semi-structured interviews and 83 consenting participants, some of whom chose to answer questions via email or keep their discussion entirely off-the-record. Interviews were conducted between February 2013 and June 2017. The average length of recorded interviews is 57.30 minutes. This measurement does not include interview sessions or portions of sessions that were taken off the record or interviews that were not audio recorded. This data set includes 62 recorded in-person interviews (with some sessions that continued virtually after the initial meeting) and 15 recorded remote interviews. 23 participants were interviewed multiple times. Interviews were primarily conducted in-person and recorded using an Olympus WOW XT offline digital recording device or a Samsung Galaxy SIII phone set to airplane mode.

After a verbal consent (systematically performed at the start of each interview even if written consent was already obtained) and an introduction to myself and research space, interviews began with the same approach: “[Participant name], thank you for agreeing to this interview. You are currently [participant’s position] in the OOI. Can you tell me what you do?” The next questions sought to understand the participant’s journey to that position, whether they have held other positions within the OOI and how each came to be an oceanographer and the particular kind of oceanographer they are today. This first series of questions were used to ascertain the why and how of participation in the OOI, above what can be gleaned from a CV, to understand the kinds of science aims that might lead one to become a part of the OOI, and to generate both a biography and a history of the initiative. These questions led me to understand the major institutions, collaborating groups and kinds of scientific questions of the participants.

The second series of questions concerned the work of building the OOI:

> What was the vision of the OOI and have you seen it change over time?
> What do you see as some of the grand questions that might be solved through the OOI? What do you see as the purpose of the OOI?
> What are the OOI's biggest tensions? What have been some of your personal biggest hurdles in developing the OOI?
> What do you see as the OOI's greatest strengths and successes?

The answers to these questions provided understanding of the current challenges, current successes and lessons learned in the planning and construction of the project as well as the role of each participant when problems arise and need solving. The answer to these questions also provided an understanding of the imaginations of the participants in what the OOI could do and what gets in the way of those visions.

The following question concluded all first-time interviews (yet generally occupied a substantive portion of the interview time):

> I now understand how you got to the position you are in, what that role is and how it fits into your larger story, but I'd like to hear some specifics of what that role really means in practice: can you walk me through your day yesterday?

The answer to this question derived critical understanding of the labor, affect and first-order concerns of those within the OOI, what participants were "supposed to do" versus what fires they had to fight in the day, what documents and people each participant interacted with, what policies were being contested, what meetings were being held ad hoc and what meetings were planned. The answer to this question significantly aided in my understanding of observations where formalized documentation was present. For example, much work involved filling in a form to check or complete a field of a Work Breakdown Structure, Engineering Change Request or Call for Participation (CFP) for instrument procurements. I would observe a participant testing different battery packs for gliders, for instance, and then better understand why those specific configurations, products and encasings were selected through the requirements written in for battery packs in a CFP.

Most interviews were transcribed by myself. 8 were sent to a professional transcription service. All transcriptions were added to an online repository shared with the research team. Post-processing for each interview included one memo including a reflection on the interview with relevant themes and literatures, potential future directions and open questions to ask of myself or of the interview participant in the future. As field work progressed, text would be added memos if future contact, contextualization, information or questions relevant to the interview would arise.

3.1.C Historiographic and Archival Data

The third (3) category contains archival and historical materials collected through communication with oceanographic professional societies, ocean science historians and major oceanographic institutions and was appended with documentation and references provided to me by participants throughout the duration of the study. Historical and archival data served to construct the story of big data as a longstanding interest and problem in the ocean sciences, blossoming in the last 20 years and leading to the upstart of the OOI. Collection was centered on large-scale, time-series, climate concerns, and long-term research in the ocean sciences to identify the major institutions, funding bodies, disciplines and initiatives who have taken up the task of big data in the ocean sciences in the past, how they have changed over time and how (if at all) dominant research aims have changed over time.

Historiographic and archival data were collected in both material and digital forms. All physical materials (archival or not) for the dissertation work are stored in a key-locked cabinet in my personal office, which requires key entry. Digital materials are stored on my personal local machine with a backup repository on SpiderOak, an encrypted cloud storage tool. The content of these resources spans multiple forms: statistical data from professional societies concerning labor statistics around hiring, tenure and degrees received; histories of institutions, individuals and individual initiatives; formative publications that have been noted within the planning documents of the OOI or that have been delivered to me by or recommended to me by participants in the ethnographic portion of the study. Memos were developed around archival materials and analyzed alongside ethnographic observation and interview data. The storage and analysis of memos are discussed further in the following section.

The recording of oceanography to date has centered largely around a single institution, great man or great discovery. This data was used to triangulate between oral accounts of participants and documentary record where available, but the documentary record was significantly more formal and bureaucratic than the interests of this dissertation. Through discussion with ocean historians and administrators of professional societies, I attempted to ascertain whether there were holes in my understanding that were actually inaccessible or if they are just holes in my own knowledge. Much of the more pragmatist interests of this dissertation were difficult to uncover without deeper exploration into autobiographies that detail practices, motivations and lived experience. In this way, the archives were not always set up for what I was searching for them to do. Therefore, this historical exploration opened more questions than it answered, as many details of the non-dominant practices and invisible work remain unrecorded and missing from historical accounts.

3.1.D Grounded Theory Approach

Data was collected and analyzed by a grounded theory approach (Glaser & Strauss, 1967). Qualitative data was collected from interviews, field observations and archival materials and then open-coded (Charmaz, 2005) using Nvivo qualitative coding software as well as hand-coded via multiple documents saved under passwordprotection on the collaborative note-taking software Evernote and shared with Dr. Steve Jackson. Evernote was accessed through its multiple available interfaces: web, mobile and desktop app. Themes found across multiple data sources and codes were expanded upon via broader thematic memos that contained descriptions, quotations from the data as well as reflections, interpretations, relevant literature and additional questions or future directions. Synthesis and analysis work was largely completed within memos, which operated at multiple scales (note: the following list is organized from temporally shortest to longest):

- individual interviews, isolated activities; individual documents;
- full-day reflections and themes;
- full-site visit reflections and themes;
- comparative-site visit reflections and themes;
- full-project reflections and overarching themes;

The critical thematic codes that appear within this dissertation include: futurism, labor, temporality, care, and breakdown. Beneath these broader-level coding categories exist multiple codes that identify subtleties of the phenomena. For example, “breakdown” is an aggregate of “decline as generative”, “decline as resistance,” “contingency”, “valuation”, “stabilizing”, “aftercare” and “delinking and relinking.” Many moments fell into multiple categories, for example, the code “aftercare” often indicated a crossing of “care” and “breakdown”, and the code “multitemporality” was found within “breakdown” as well as all of the other coding categories. This cross-cutting informed the broader framing and orientation of the dissertation, where, often implicitly, much of the theorizing and narrative of this dissertation concerns a grappling with the multitemporalities at play in the development of the OOI.

Memos across scales were then organized within categorical folders intended to collect outputs for publication or chapter-building. Folder names include: Anticipation Work; CSCW as Science Policy; Disrupt, Dismantle & Decline; Labor & Temporality; Networked Science; Rhythm & Plans. These output folders housed relevant ethnographic memos, historical materials, annotated bibliographies or notes on relevant literature and public debates, timelines and conceptual maps, associated meeting notes (containing insights from the dissertation committee members, but also colleagues at Cornell University and elsewhere, named within the Acknowledgments) and rough sketches that link empirical materials to potential theoretical contributions. In this way, codes were given richness through memos joined with the materials of categorical folders, then transformed into the theories that served as the basis of each chapter in this dissertation.

Grounded theory (Strauss, 1978; Corbin and Strauss, 1990; Charmaz, 2005) provided the methodological backbone to critically and deeply investigate the practices of building the large-scale long-term infrastructure and its consequences. Grounded theory, pragmatism and their joint attention to practice made answering the questions of this dissertation possible. The constructivist, pragmatist approach employed for this data collection and analysis opened a door into what the affiliates of the OOI do to create the futures they desire, and how the future is constructed by all of these facets collectively, what is routine and what is habitual, what is or might become standards and norms. Attention to practices opened productive questions about what gets solidified into future work, what the future might look like and how actors navigate towards it, asking: how do practices in the present reflect a desire for particular outcomes in the future? Through investigation of the OOI, it was clear that practices both stabilize and destabilize other practices, highlighting important flows of action and resistance. Following the preceding two points, practices provided an entryway into longer time scales than we can usually engage in our studies of HCI design work by indicating traditions, norms, and orientations toward long-term usage into the future. By documenting practices, this dissertation attempted to articulate both the conscious and unconscious, tacit and explicit work, and point to who and what is necessary to perform work, reflecting local, regional and global conditions. Practices connected the complex contexts in which they are occurring by operating within, around or halting to the constraints and supports of the environment. In this way, the attention to practices created a gateway connecting the individual bodies I observed to larger social, political and economic bodies, integral to the core questions of this dissertation.

Through grounded theory's attention to lived experience and practice, it was possible to identify ways in which larger spheres uniquely shape the lives and continuing livelihoods of those affiliated with the OOI and to develop compelling narratives that tell a more nuanced story of building one of the world's most ambitious oceanographic research facilities to date. In the increasingly complex environments by which we use and build technology, ethnography presented itself as a powerful tool for surfacing what does not get easily captured: the in-depth nuances and tensions in that which is underlying or muted, those things often completely unknown to participants themselves, and the things that are driving, contentious or damaging about the system. Meaning, a survey or interview of scientists or policymakers about their practices would have failed to capture many of the things that external observation told, that participants did not see in themselves in order to report through interviews alone. Through this extensive ethnographic and archival data set, I have come to learn that typically for an observatory, five to ten years are needed from initial planning to fruition and that this undertaking takes dedication (and a degree of stubbornness!) to persevere through all the obstacles and challenges, many of which are not technical.

3.2 PARTICIPATION AND ACCESS

3.2.A On Social Science and Hard Science

Through the initial foray into the public face of the OOI (described in the introduction to the present chapter), the visible major champions and named affiliates of the OOI were identified and then contacted through a cold-call email that included a rough one-page description of the grant with aims of this oceanographic portion of the work, as well as an unsigned IRB consent form, and an invitation to an introductory interview. Administration for interview and observation participation was largely documented in a growing word document listing all contacts, their status as accepting or rejecting of the offer to interview, and information about their consent and corresponding file locations. This document was populated quickly with interested participants, a very small minority returned silence or rejection. Following the initial cast for participants, participants were collected via snowball approach and through author lists on the continued publication of OOI materials throughout the duration of data collection for this study between 2012 and 2016.

I found myself accepted quite warmly into the world of the OOI. While negotiating for space at sea proved significantly more difficult than on land (more on this in the following section), participants were largely forthcoming, enthusiastic and open to the possibilities of the ethnography that built this dissertation. The dominant enthusiasm for social science from the participants of this study was striking, a consistent dynamic that held through my years of investment in the OOI. Multiple participants offered an unsolicited expression of desire for social science within their spheres of work. Many of OOI's project scientists and project managers, in particular, were interested in adding anthropologists and sociologists to their work in order to gain more holistic understanding of their operations and investments, to document the transformative work being undertaken, to collect lessons learned that rarely get communicated across projects. Some participants even shared their grants which asked to fund a social scientist that did not get funded. Many participants noted the difficulty (if not impossibility) to get a social scientist funded on their project, often remarking that their efforts at transformation will be lost to time with no one documenting their work. Participants assert a growing need and importance of a social scientist's expertise in hard science spheres particularly at this scale, and particularly scholars who think at scales above usability and user experience, above the level of specific technologies or interfaces. Participants celebrated the social scientists that do find themselves inside oceanography projects, who are largely inside these UX or UI spheres, while also recognizing the range of productive work that could be done to understand sociotechnical issues at a broader scale than the interface design.

Participants often lamented that no one had a broad picture of what was actually happening within the OOI – indicating a disconnect between the productivity of individuals at the implementing organizations and the governing bodies in Congress or the Consortium of Ocean Leadership who oversaw the everyday work of the OOI. Often the power of social science was invoked to point to specific disconnects between policymakers, designers and scientists that could be more easily filled by an outsider who is none of those things: an ethnographer. Participants asserted that no one understood the cultural effects of building infrastructure and how it affected the field and science policy more broadly, for example, as the OOI has set in motion new funding structures, technology standards and data practices. It was often remarked that the adoption or rejection of large investments felt cloaked in mystery, that narratives (collected via social science methodologies) might help to understand what works and doesn't, to pinpoint the stresses of OOI's decision-making in its continued Operations and Maintenance. My role in this way was seen as a documentarian, a present-day historian or something like a well-wishing journalist.

3.2.B On Land and on Sea

A particularly evocative nuance of oceanography was found in the markedly disparate experiences of participants on land and at sea. In interviews, rich detail was drawn from walking through participants' daily activities, a first-hand look at those activities revealed important and unarticulated collaborative work, directions and motivations. From this introductory interview question, it became readily apparent that the pace of life on land is distinctly different from that aboard a ship (cf. Steinhardt & Jackson, 2014). This was signified often in even small quotations inside interviews and

observations, like when one participant expressed frustration with a policymaker who came to govern the OOI from a different discipline: “by the by, weather windows are not real to folks who have never been to sea” (participant quotation). Some participants had been land-based for months, if not years, while others were regularly shuffling in and out of the preparation and post-production of continuous cruise-based work, testing and deploying instruments and collecting research data. When asked about conflicts of time, interview responses were often skewed toward more indoor rhythms unless the interview was conducted on a ship or in the immediate aftermath of a cruise.
There exists a distinctly different material culture on a ship versus on land, and a distinctly different hierarchical organization within faculty and integrating the crew, which couldn't be captured while land-based at the research institutes and warehouses. The commingling of land-based and ship-based observations provided a significantly more nuanced perspective about the dominant concerns of the participants, and particularly around the concerns and politics of available resources, whether they be the ships themselves and their maintenance, relationships with manufacturers, or access to instruments or tools on the ship.

Many participants have a very affective and romantic attachment to their time at sea. Often seafaring work provoked a complex commingling of emotion and priorities, difficult to understand or capture through conversation alone. To really understand the plight of the oceanographers, and their relationship to and distinctions from the technicians and policymakers, it was critical to observe their seafaring work, what is viewed as being at the heart of an ocean scientist and of the differences of culture between their collaborators across spaces. This juxtaposition of ship-based and land-based work was intended to bridge dialogs; identify the variations of actors, tools, policies, practices and major players; and to gather an understanding of both the idiosyncrasies and norms of large-scale computational oceanographic work across its multiple contexts.

As an analyst, the two spaces of oceanography presented challenges. For example, the novelty of the ship did not wear down throughout the course of field work, a dynamic which at times led my eyes away from important threads I would later wish to capture. I would describe in detail, photograph extensively and capture videos of a ship's voyage into a sunset and its technicians and crew yielding technologies across decks, yet never learn the ship's name, the crew's composition, or the rich biographies of those who did not have "OOI" in their titles. I wouldn't ask the ship captain about his previous cruise and what cruise will come next, or what he needed to do to prepare for the new scientists and technicians on board. I wouldn't ask where his funding came from or where he resides, making invisible to my data set an integral biography inside the OOI of actors who are not co-located with the OOI affiliates for whom that question would be redundant. In this way, UNOLS and academic research cruise crews are largely peripheral to this data set, despite their centrality to the construction and operation of the OOI.

3.2.C On Formality and Friendship

Most expressions that I might artfully construct to describe the OOI's dream would do a disservice compared to the beautiful words my participants have readily deployed themselves. This chapter is followed by more than 100 pages that act as a complicated tribute to my participants, a passionate group who have allowed me to observe them for 5 years and whose emails still enter my inbox regularly. To be let into their world has been invigorating and motivating, provided me many new beautiful turns of phrase and objects of consideration, and supplied lessons that are at once sociotechnical and about living more generally. On my first day on the job as an ethnographer of the OOI, I drove to a Perkin's Pancake House in central New Jersey to meet one of its affiliates who happened to be traveling near the town where I was raised. Holding my professionalism while also acknowledging the intimate feelings of being inside in my grandmother's favorite restaurant, he said to me,

> Life is fortuitous. Always make a decision that opens opportunities, never closes them. (Participant quotation)

This quotation and its situatedness ring as emblematic of my experience with the OOI: the unique entwining of intimacy and professionalism my participants have opened to me is at times breathtakingly existential and driving, an entwining that is found across experiences on land at a familiar restaurant or in a deep conversation inside my messy, smelly berth upon a ship. The project of this dissertation is in some ways an attempt to honor my participants as people who walk this line, a group who accept responsibility for the future, who commit to seeing a transformative vision for the future through, who work hard even against difficult conditions, and who can relish in the introspection that being the subject of an ethnography can provoke during difficult moments. Understanding the OOI necessitates an exploration of a series of spectra between personal and professional, friend and research subject, human and myth, utopia and dystopia, progress and breakdown, immediacy and futurism, dreams and realities -

multiplicities that ring loudly through the narratives and theories found in the present and subsequent chapters. In short, to tell the story of the OOI without its dreams and intimacies alongside its formalisms would be a poor reflection of the world that I have observed.

This ethnography was performed with an orientation like a film critic, as a fan and lover of oceanography and ocean engineering. After six years of investment into the world of the OOI, I now consider some of my participants my friends, my mentors, some have become my collaborators and my informants outside of the expanse of work detailed in this dissertation. Participants invited me into their homes, to their nights out, to their f-cursing anxiety-ridden coffee break catharsis, to their mostly-silent downtime between events in front of a television, to speak at their labs and in their workshops, or to walk on a nice day. Categorization of what is and is not research became a key point of internal struggle throughout this field work: theoretical frameworks are profoundly consequential and much work of this dissertation involved finding and defining clear boundaries and borders between research and not.

"Stephanie, yu good wid dat?" closed my first email invitation to meet an affiliate of the OOI in person. I was. So, in Spring 2013, I traveled from Ithaca, New York, to Boston, Massachusetts, for the AAAS conference in which a number of OOI affiliates would be holding multiple panels and a workshop as well as performing individual talks throughout the week. As I walked up to the agreed-upon meeting place, the second floor restaurant inside the Marriott Copley Place conference hotel, an oceanographer recognized me and ran over with a hug, having never met in person before and having had only spoken for 20 minutes prior to this moment. With his arm still around my shoulders, he led me quickly and warmly into a large circle of ocean scientists, some of whom had particularly recognizable names, who also without hesitation mirrored this hug in their introductions. I was met with a jolly mix of laughs, disbelief and relief: "You are too fashionable to hang around us! Look at us schlubs!" "I can't believe you want to do this! For years!?" "Finally someone notices! We are changing the world here!" As I introduced myself and described the research I planned to develop, I collected many business cards, on the back of the cards I would handwrite others' contact information or schedules for the remainder of the conference in order to organize additional observation and interviews during my visit. It crossed my mind that this may be a manipulation, that I am about to write about these people and they want to be looked upon fondly, and it worked: I liked these people in spite of their disregard for personal space and professional boundaries. I was immediately in their court.

My assimilation period, learning what is required to be a member in this world, felt rapid, if not immediate. Prior to my engagement in the field, I had studied the initiative and its people, had began reading - with an almost obsessive tenacity – about modern oceanography and climate research going back to the origins of oceanography as a field. When I entered into my first conversation with an oceanographer, I already had a sense of the dominant people, institutions, tools and vocabularies and I was forthcoming about my desire to learn and outsider-ness, inviting participants to teach me more about their culture and concerns.

With these tools of words in hand, I fell quickly into a very friendly report with many of the participants of this study. I have likened the culture of many ocean scientists to a world I inhabited in my youth working at a surf and skate shop at the Jersey Shore. It was immediately recognizable as not “my culture” but one I am comfortable inside, a masculine patriarchal dominance that is also infused with strong appreciation for community, counterculture, spirituality, art, music and solitude. It is a space where Characters find themselves a comfortable home, where discipline looks distinctly different from those in other professional spaces, where the politics and poetics of nature are dominant conversations over the politics or poetics of any other kind of space.

I at once quickly belonged and was a conspicuous presence: participants warmly welcomed me and appeared comfortable with my presence but also reminded me often of their ambient awareness of my presence. I did not “blend in” in this way, and I rarely occupied the role of a fly on the wall. Participants would often say things particularly for my ears even if the content was directed toward others, breaking the third wall, describing their work or their tasks in ways that would be comprehendable to me as a new onlooker. The presence of an ethnographer will always impact what is being done there and how those observed are relating to eachother. The ethnographer has to be sensitive to how they are perceived and treated, what they have access to and to what they have seen. Part of this project of reflection and reflexivity has been documenting these moments in which I know I am an obvious ethnographer, attempting to understand who I am to my participants and what my role might be, how that identity effects their actions and disclosures. At times this involved explicitly checking in with my participants about my presence.

My role as ethnographer looked distinctly different across groups and circumstances. I developed written rules that I held for myself across different circumstances, how I would record information and when I would consider myself (1) learning, (2) collecting data, (3) networking or (4) socializing. For example, I did not meet any participants in my office, nor in locations that I suggested, nor allowed any participants to pick me up from my temporary places of residence during field work: part of this distinction was an orientation that I would be entering their world if I was engaging in data collection. Unless held in a formal capacity hosted by an institution and not by an individual, if alcohol was present, I did not count this as collecting data – this precluded some very interesting stories from being invoked in this dissertation, admittedly. If I attended a workshop for my own edification, even if OOI affiliates were present, I did not include this as data collection. Participants often asked explicitly to be taken off the record or expressed a desire for confidence (despite allowing the story to be recorded), which I did not break and would catalog in my memos or field notes differently than if it were on-the-record. At conferences and in public spaces, I inhabited a mode of confidentiality not unlike a psychiatrist: I would alert my participants ahead of the event that I would be present and I would allow them to approach me, never approaching them first. In these cases, I would not act as if I knew them previously unless their approach indicated a familiar orientation. In other circumstances in which family members or friends in an informal capacity were present with participants, I did not include their stories unless I provided them consent and formally included them as study participants (a situation that only presented itself twice throughout the years of fieldwork). Any information learned in this way was documented differently than if it were part of the research process, similar to moments that were off-the-record. If important information or new questions were revealed inside these informal, intoxicated or confidential exchanges, I initiated separate exchanges in order to learn more, find answers and collect on-the-record data.

Participants are most interesting when they are comfortable and their most emotional, most passionate, exposing their obsessions and their weirdness. Yet, the most "boring" (and easy-to-overlook!) of interactions reveal the critical substrates that underlie those more recognizably interesting moments: those mundanities that reveal what is intrinsic, standard, commonplace, routine and habitual. I used writing, memoing and qualitative coding to aid in my personal attachments to moments in the field and to particular people whose stories resonated with me most, to the Characters that arose and occupied my attention moreso than the quiet members of the teams, to the breathtaking scenes burned into my memories moreso than the beige meeting rooms and hallways. Following Lucy Suchman's (2007) accountable cuts, I was very attuned to the territory I defined within this dissertation as a story, not naturalized from the world. It is borne from my perspective and is also my responsibility. For example, I have not detailed a particularly fascinating audit that occurred in the center of my field work: this was not forgotten but was left out with intention in the storytelling of the present theories and constructs. After years in the field with the OOI, it was difficult to cut important moments from the theorizing encapsulated in this dissertation, to think beyond my omniscience as an author and observer.

One way in which this reflexivity about the limitations of my omniscience manifested was in gender and race assignment of my participants: I did not identify characteristics to my participants unless they explicitly called out these labels for themselves. Early in the research I was struck that my questions were not gendered or leading toward gendered answers (cf. interview data above) yet in many of my first introductory interviews, women explicitly identified their gender and the hardships and inequalities faced in the world of oceanography, positioning those cultural critiques against the infrastructure being built. When a person discusses their abuse, my impulse is to hug her and tell her that too many of us have these stories and that I wish work like mine would help to move the bar, though in reality I'm not sure how to make this work have that kind of impact because the problem is so complex. Physical affection from a stranger can in the moment feel comforting but upon reflection often is frightening: who is this person? Is this person taking advantage of me? Did I open up too much? What are they going to do with my stories? I have heard one ethnographer describe their job to make participants fall in love with them and then break their hearts at the end: I find this deeply disturbing. The work here aims to build something with my participants. Participants lead me to the spaces I could be most helpful through their stories, their emotional work, their practices. Betraying their trust is not a necessity and, moreover, I feel it important to return their honesty with honesty. As part of this process, I perform a participant check on every publication, letting into the research process those who I have quoted, whose stories I tell, and those who have expressed generic interest in knowing exactly what I am doing with their stories.

3.2.D On Breaking Down While Building Up

My presence amongst the OOI has felt like circling the outer edge of a campfire, half in the dark and half in the light: the closer I move to its fire, the more I begin to feel its warmth and also see the ways in which it burns. Many participants used the phrase “burning” to describe some aspects of the infrastructure as it was being built, many pieces of the infrastructure broke, failed or fell out of favor as more pressing concerns took priority. Much of the everyday interactions that I observed were workarounds in reactions to bottlenecks in policy, behind-schedule cyberinfrastructure development, slow administrative pipelines, and in the less manageable realm of third party instrument procurements.

This project is an attempt, as Deleuze might say, to see things from the middle to not look down upon my participants with sympathy or up to them with awe, to not approach their politics from the left or from the right. This an attempt to follow Rosi Braidotti's (2017) anti-negative dialectic of feminism: looking at things as in-the-process-of-becoming, "it is not a question of either/or but a question of and/and." The OOI has both been built up and broken down as it was being built: pieces and people within the project fell out of favor as it was being constructed. The narrative of the OOI is anything but linear.

Dewey canonically claimed that behavior is reflected on in times of crisis: the OOI demonstrated that actors are engaged in thoughtful, reflective and reflexive practices in building the infrastructure and the future of their careers, that things break down even as they are built up. Does OOI reflect a constant state of crisis? Does actively engaging in long-term "sustainability" look a lot like actively fixing a continuously breaking thing? Collapse, decline, decay, breaking, repairing, fixing: these are active words that are given concreteness in practices and the scenes I observed.

Many of the stories of this dissertation concern breakdown, but OOI is not broken. In witnessing participants navigate this Janus of breaking and building, there have been moments in which different individuals claimed in different accounts that the same technology is working, was on its way to success and was irreparably broken. These were often discussions of the same components, sometimes on the same exact day, where it was difficult to ascertain where the truth lies. These moments revealed metrics of success, sometimes articulated within formalized documents, but also revealed personal commitments to, responsibilities for and attachments to particular parts of the infrastructure and its longevity.

Over the course of six years, there were a few prominent events in which the OOI received significant blows from upper-level administration and government that impacted the present ethnography. Two events in particular fundamentally reoriented the organization of the data collection that informed this dissertation: the first, an audit from the Consortium of Ocean Leadership and the NSF on the cyberinfrastructure group at Scripps and, later, a report from the National Academies in which the US government was advised to diminish the capacity of the OOI in specific ways. After these events, participants were markedly more tight-lipped, delivering to me more boilerplate words than they had previously, individuals appeared significantly more busy, harder to pin down for interviews and observation and were less available by phone or email. Participants, in fact, explicitly questioned whether I would give them bad press, seemingly more aware of my departmental affiliation of Communication and its links to journalism. With only speculation and no causality, I can note that key informants changed after both of these events in surprising ways, where access and communication were less available to me.

Lastly, in performing this field work around the OOI, I have become something-like enamored with infrastructure's death and dying, finding myself invested in narratives across disciplines concerning the design and decline of systems, structures and materials. What I did not expect was the death of a parent that I would encounter while midway through developing the concepts of dissertation chapter on breakdown and how it would change my thinking. There are many ways in which things declined, degraded, ended, where each degenerative moment was different from the next, and reactions to these circumstances varied across the individuals responsible and affected by their demise. Individuals mourn in many different ways, some need a period of retrospection and introspection and require a forensic investigation before continuing on, to build accountability and lessons-learned; while others forge forward onto the next project (or sub-project) with the appearance of ease if not detachment from the lost direction. Wherever a participant landed in this spectrum between forward and backward thinking or stasis, there were many tears mixed with charged programmatic discussions of values and futures, frustrations were aired and complacencies were attacked. These were moments in which participants, and myself, recognized what and who we care about, and what and who we want to bring into the next chapter.

3.3 Conclusion

As I moved through the space of the OOI, every action felt very much like a political act by both analyst and actor: every selection of what to pay attention to, what felt important to reveal and keep close, who I would speak with and how I would speak with them (cf. Suchman, 2002). Just as important as policy and governance are the ways in which we discipline our bodies to be sensitive to the forming, reforming and resisting. This ethical turn, according to Barbrook (2007), calls for more attention to art, film, religion and news media and the ways that analysts require a cultivated, patient sensory attentiveness to how humans act both in the normal and countercultural action for their survival and flourishing. The chronology of this dissertation follows an unfolding of my understanding of my own self in a context full of unprecedented personal and international events.

My impulse for this work has been to write as nakedly and confessionally as possible, each first draft opened with sentences that start with "I" and traveled through my experiences, detailing how these experiences led to theories of sociotechnical work with broader applicability (these sentences were then largely removed for final drafts). I have approached this work with a heavy sense of reflexivity, acknowledging the ways in which I see or interpret something as potentially different from how others may see or interpret that same thing. Striking a balance between my own reflexivity, path of understanding, and an analytical tone has been most challenging in this endeavor. To grapple with the OOI, I needed to break from writing in prose and began writing in poetry or building things, mirroring how my participants make sense of their own worlds, bridging my artistic self with my academic self in surprising ways. The emotional and sensorial texture of ethnographic work and analysis led itself to many participants revealing their artistic outputs that aid in their reflection and communication of their experiences at sea: photography, painting, poetry, and many songs played on acoustic guitar. In turn, I found as I became deeper entrenched in this world, my personal artistic practice began to blend with the worlds I was observing (cf. Binding Wires Twining Ropes, DIS/COMFORT, On Hospitality and Hope). I found myself recording the sounds of the docks and the night-time creaks when laying in complete darkness in my berth on a ship, and revisiting these sounds as I read through my field journal and transcripts. Often as I wrote I found myself asking: what does this sound like (literally) and what do these stories sound like (figuratively)?

My field work is also separated in two parts by my own biography's chapters. The "I" that I place in the narrative for myself has changed, seeing and hearing different things in the ambient noises and in the words of my participants. I attribute much of this change to becoming a mother midway through my field work in 2014. Parenthood produced a new body and mind, one which was more cautious of the field sites I would inhabit and one that was received more cautiously by participants who had once opened the doors to their ship's decks for me years prior. I became more connected to some participants who learned of this transformative moment, who sent well wishes, photos of their own children and requested photos of mine. Confessing this part of my biography also came at a cost, some of which I am likely not even yet aware of. I have learned through this work that the world of oceanography, as with all STEM fields and industries, can be particularly unkind to women and to mothers, though I have not been the recipient of anything directly unkind.

Within this manuscript I attempt to make a case for context, particularly historical context and how we leave threads that lead us into future contexts we imagine we will inhabit. The importance of context in this dissertation is no exception. In many ways, I wish that I kept a better log of the national and international-scale political events occurring during the ideation, data collection and writing phases of this project. I wrote this dissertation amongst a flurry of heartbreaking tragedies to which I often found myself crying into my computer for how we as a society favor technology over humans; how writing a dissertation seems a trivial effort when friends and loved ones are dying and watching their friends and loved ones die; how spirituality and religion can lead us to both cherishing the multitudes in this world around us and fearing it; how the demographics of my sizable participant pool are skewed in ways that give me goosebumps; or how ideals of masculinity are powerful constructs to which I and my participants are not immune. Detangling the current moment from what I was observing in the field was not possible, as the shifting presidencies and uprising of feminist dialogs into the general public were very well felt both interior and exterior to my field work. I long ago learned that politics is found everywhere, but it has been even more present in the recent years in which this field work was performed and documented. In its methodology, this dissertation amplifies the feminist assertion that the personal is political and even goes so far as to say that science is both personal and political. I have learned from my participants that we give our bodies and our minds and attempt to hold ourselves to higher standards than the generations before us but I often have found myself unsure of what to do with my body and my mind in the face of these tragedies when my face is staring at this computer screen attempting to grapple with this dissertation. I find myself constantly distracted, heartbroken and angry with nothing but my words to fight with.

In my very first draft of this chapter I wrote:

> In this one day, I am tacking back and forth between this manuscript and a Twitter feed that reads of endless information and reactions to the terrorism by ISIS in Bangladesh, Philando Castille and Alton Sterling's police brutality killings, and Chelsea Manning's attempted suicide in prison. Michael Brown in Ferguson, Eric Gardner, HB2, ISIS, missing airplanes, the Orlando club… This writing is amidst news of the Brexit decision and ensuing panic, a self-driving Tesla crashing into an old-fashioned tractor-trailer and an article called "How Soylent and Oculus Could Fix the Prison System" that was somehow taken seriously enough to be written about in multiple venues.

Almost two years since this was written, I am now publishing this methods chapter. I have dropped social media since November 2016. My digital practices operate largely outside of the mainstream: I use a Linux machine and open source software as often as possible. Years ago I stopped using Google search engine (including Google Scholar) and instead only Duck Duck Go and the university library repositories. I also switched primarily to a Tor browser or Firefox with multiple extensions for privacy protection or use a VPN. These measures often break sites, stop content from being served or prohibit access altogether. This dissertation was written largely in Scrivener and through LibreOffice, organizing tasks through KanBanFlow and pomodoro timers. These choices of what and who can benefit from my data and practice were intentional and reflect a commitment to the politics of the personal in performing the work of this dissertation.

Field work within the OOI has forced a recognizing my own privilege but also my own naivety around my demographic set. Engaging in this site over the issues that follow in the pages after this chapter has been both deeply fun and humbling, has forced me into an array of introspections about my own positionality, to confront the way that I experience the world and my comforts within this one - in which I present as a slightly left-of-the-dial friendly heteronormative middle class white educated scholar amongst a community in which those attributes also ring true for most individuals in my participant pool. Through observing, through art, through critical frameworks I have attempted to detangle my own identity while detangling the complexities of building scientific futures through the OOI, envisioning myself as the scientific crew, as the engineers, or as the budget personnel.

I join a growing body of scholars like Silvia Lindtner, Lilly Nguyen, Marisa Cohn, Paul Dourish, Lilly Irani and Six Silberman who argue that design is a problem of infrastructure and assert the importance of analyses of power and labor in design work. This attention to human experience and relations is reflected both in my scholarly contributions and in the way I interact with collaborators, participants and the field itself: I pay close attention to collectivity, workers, practice and representation. This represents a turn away from the "design savior" and a turn toward a more feminist and relational understanding of technology and infrastructure.

This dissertation acts as a form of refusal and as an alternative, acknowledging the multiple forms of resistance and multiple possibilities for alternatives, for thinking of its multiple pasts and possible futures. This dissertation about oceanography, technology and futurism has a citation list that is mostly non-male despite that these topics are most dominantly covered through a male academic perspective. While appealing to gender concerns, this work lacks or even further marginalizes global perspectives. I'm interested in understanding what has dropped out of the conversation. Why emphasize data over humans? Who isn't served by this infrastructure and what might that mean for the field more broadly (particularly in hard financial times)? What can I learn from seeing the politics of the personal in participants and taking it seriously myself?

4
Dreaming This World into Existence: Infrastructure Fictions of the Instrumented Ocean

> I recommend... that the student of science do some literary research, so as to become familiar with the stylistic tricks employed by scientists. By drawing on these two sources (fiction and science) the social scientist will soon realize that there is in fact only one large literary genre: that of science fiction (the best part of which is not written by science fiction writers). (Latour, 1981)

> It matters what matters we use to think other matters with; it matters what stories we tell to tell other stories with; it matters what knots knot knots, what thoughts think thoughts, what ties tie ties. It matters what stories make worlds, what worlds make stories. (Haraway, 2016)

This chapter explores the work that shared (and sometimes discrepant) fictions play in shaping and sustaining the imagination, but also practice and organization, of emerging scientific infrastructures. First, this chapter asserts and extends the argument for examining fiction in relationship to infrastructure and design following formative work by (Dourish and Bell, 2011; Haraway, 2016; Raven, 2013; Rozwadowski, 2004) and demonstrates that, in oceanography, as in many other spheres, the world is apprehended, negotiated and organized through fictions. Through the exploration of two dominant fictions that circulate through the worlds of the OOI, this chapter documents and analyzes how fiction informs the development of large-scale, long-term infrastructure in multiple registers, whether as referent grounded in the genre of science fiction as orienting themes in project documentation, and further, they developed scientific fictions of their own through narratives of the future and generational thinking. The chapter concludes by reflecting on the work of fiction in defining the cultures of scientific projects, orienting and justifying broad-scale choices and directions (for example, whether to invest in people or technology), and how the structure of fictions –

their sense of actors and protagonists, their points of conflict and resolution, and their idealized trajectories – shapes decision and practical action, including around the allocation of time, money and resources.

Fictions as deployed in this chapter are creative narratives that may both represent and help to call into being the worlds they describe. In shaping and ordering imagination they are central to the maintenance and construction of meaning and coherence in the world (thus contributing to what Jerome Bruner describes as the "narrative construction of reality" (1991). Fictions have authors or (re)tellers, who decide what will exist in their narratives: protagonists, antagonists, plot twists, resolutions, the scene, the time, the tone, the cast. Fictions also have audiences – people who are meant to (or choose to) *hear* these fictions, in service of some perhaps dimly understood effect. Far from free-floating narratives, fictions are told and heard by social actors engaged in distinct worldly projects, and build off the resources around them, in world and imagination (including other fictions). While drawing on and contributing to larger-scale imaginaries (including in their sociotechnical forms) (Jasanoff and Kim, 2009; 2015), fictions are also specific and discrete – particular stories told by and about particular people and things, in particular times and places. Fictions are also a key carrier and modality of visions, and form one of the specific and concrete ways in which social and technical visions get packaged, spread, and sometimes contested. As such, fictions have direct and formative links to social and material practice – including in more rarefied worlds of science that we have sometimes (but wrongly) presumed to be fiction-free, or at very least fiction-lite. For all these reasons, fictions *matter* – in the double sense of producing real material effects (fictions give birth to things), and in the sense of being consequential for the direction and practice of large-scale infrastructure projects in the sciences (as indeed in many other spheres). Indeed, in early-stage science infrastructure projects, as in emerging fields of technoscience more generally (Haran and King, 2013; Jasanoff and Kim, 2015), fictions may be the most real and powerful thing we have.

4.1 Infrastructure Fictions

The above epigraph from Bruno Latour's "Insiders and Outsiders in the Sociology of Science" summarizes a theme in the scholarly literature on infrastructure: the importance of fiction. This section details the scholarly literature in which fiction intersects with infrastructure, and situates this study's arguments about the OOI and oceanography in relation to this existing literature. In both fiction and scientific practice, creating future worlds requires imagining something different, becoming sensitized to particular problems as storytellers and sensitizing an audience to particular aspects of life (ones that new interventions might support), thinking about how things are now, and assigning future responsibilities. Creating infrastructure entails linking the past, present, and future through an imaginative practice, and is crucial to the practice and comprehension of modernity itself (Edwards, et al., 2009). Understanding infrastructure's long-term futures therefore demands grappling with complex technological and political pasts—factors that have led to the current moment and will extend beyond it. The complex and dynamic relationship between infrastructure and the social worlds they support and uphold (and vice versa) is therefore caught up in the fictional elements of designing for long-term and fundamental futures.

As renowned science fiction author and futurist Bruce Sterling and science fiction author and sociologist Paul Graham Raven assert in “Design Fiction: Infrastructural Fiction” (2013), the contemporary moment is ripe for thinking about what infrastructure means: what it does, who does it, with what materials, at what timescales, at what cost, through which governance and organizational structures, via what funding mechanisms, and to what political ends. For Sterling (2013) and Raven (2013), fiction can assist in answering such questions because it straddles two worlds: the artistic worlds of imagination and science fiction that can hold a god’s-eye view over its characters and ecologies; and the real worlds of practical, sure-footed engineering work that can be blind to complexities it did not anticipate:

> For artists, writers, designers and theorists and thinkers, however, infrastructure fiction is best described as a call for you to radically change the way you understand the role of technology in your lives, to look afresh at the relationships between the things you do and the systems that make it possible to do them… But write about people, too, because they’re most reliably invisible part of any infrastructural system: not just the people who use it, but the people who maintain and operate it, the people who protest against it, the people who blow it up or steal bits of it, even the people who live among its ruins. Write about the relationship that people have with the bridge, and that the bridge has with the people. Remember that neither makes sense in the absence of the other. (Raven, 2013)

In addition, there is great importance in developing narratives that name things, concepts, qualities for engaging social factors, and culture in pushing scientific agendas.

Scholars of sociotechnical systems have long affirmed the generativity of science fiction, in particular, for illuminating important understanding of infrastructure: a connection found in pointed titles like “Science Friction” (Edwards, 2011) and in the prominent tropes mobilized in STS scholarship: Donna Haraway’s cthulu (2016), monsters (1991b), and cyborgs (1991a); Bruno Latour’s Aramis (1996); Laura Watts’s dragons (Watts et al., 2014); and and Geeta Patel’s (2000) ghosts. These scholars, as well as others like Naomi Oreskes and Eric Conway (2014) and Six Silberman (2015), often tell their stories through explicit references to science fiction tropes and metaphors, at times venturing into science fiction as a modality of scholarly writing itself. Feminist scholars have periodically evoked science fiction in an effort to “imagine things otherwise” (e.g., Haraway, 1991); Ursula Le Guin in particular has found strong footing within radical feminist technoscience for scholars who are, as Raven quotes futurist Anab Jain, grappling “with the weirdness of our times” (2013). Such cultural production of science fiction is powerful in envisioning futures, serving as mechanisms for thinking through and with the resources available, and informing how policies and plans are made (Strathern, 1992).

Scientific actors themselves employ and mobilize fictions in the development of infrastructure, through reference to science fiction as a genre as well as developing narratives about science that are written in literary construction. *Infrastructure fiction*, as developed by (Raven, 2013), is a productive mechanism that acknowledges these narrative tropes in the design of technological worlds, one that applies a literary critique over narratives of futurity in infrastructure development, identifying how actors draw their futures and what kinds of utopias those futures aim to inhabit (Raven, 2015b; cf. James, 2003). With infrastructure fiction "the latter is almost always winking at the audience, while the former tries to pass for realism, and thus falls into fiction's equivalent of the uncanny valley." Underlying and motivating the present chapter, infrastructure fiction offers a productive lens in which to move away from any technocratic understandings of infrastructure development and use, and instead provides agency and authority to the individuals behind the infrastructure and to the kinds of problems they are looking to solve, people they are looking to support and to the worlds they are working to build.

Narratives of utopia, fantasy, and possibly fetish that resonate in the tellings of infrastructure fiction found later in this chapter provide critical lessons for infrastructure scholars and science planners. Fiction can transform into fantasizing that sometimes produces wholly new worlds in which to exist. These worlds may fetishize the technologies that this world "rode in on" or reproduce familiar worlds that actors want to see succeed, either again or for the first time. The desire inherent in technological solutionism or technoutopianism can disseminate like a snake oil cure-all, unable to attend to the complexities of the social, political, and natural realms that play roles in the fundamental need for infrastructure in the first place (Edwards, 2003; Larkin, 2013).

Taken together, these works warn of the perils of "technofetishism" or "technoutopianism." That is, there are certain downfalls to using fiction to unearth narratives of futurism that get hardened through infrastructure development. Considering such concerns is necessary for the important project of centering humans and complex social problems in infrastructure—something that is often lacking in understandings of infrastructure development. People tend to worry much more about the airplane than about the crew on the ground or in the air, indicating a knee-jerk (and often misguided) attention to hardware above humans (Edwards, 2003). While STS as an academic field has long acknowledged the co-construction of science, technology and society, the lived experience of developing the OOI tells that there is a moral order in which technical problems must be solved, whereas human problems—particularly those concerning marginalized social groups—are simply accepted as inescapable, normal features of the work. A growing body of scholarship around the anthropocene has especially illuminated the ways in which nature pushes back on human endeavors, arguing that technological and engineering advancements that focus solely on design (and design fictions) are not enough.

As numerous scholars have observed, this issue of technocentricity is central to the development of new and emergent infrastructures in the sciences where actors often (and problematically) disregard or misrecognize the social underpinnings and sociopolitical consequences of building systems (Haraway, 1991; Jasanoff and Kim, 2009). Conceiving of infrastructure through the fictions of its actors is generative for drawing in social components where technology may appear most prominent. This chapter extends a body of scholarship that attends to the affective, ideological and future-oriented imaginations of technoscientific work – as explored under the language of "sociotechnical imaginaries" by Sheila Jasanoff and Sang-Hyun Kim (2009), “technoscientific imaginaries” by George Marcus (1995) and the “imaginative anticipatory discourse” by Lisa Messeri and Janet Vertesi (2015). Following the prescription of Raven, it asserts the need and value of fictions in uncovering the underlying assumptions and motivations for technological development, and the value of a “close read” (as in literary theory) in locating expectations and assumptions, sometimes problematic ones, around for whom and what the future is being built.

Building on these literatures, this chapter makes 3 basic arguments. First, infrastructure fiction is foundational to infrastructural development, particularly in navigating away from technocentric understandings of the world. Second, the technoskepticism of infrastructure studies highlights the perils inherent in the technoutopian underpinnings of the OOI’s collective fictions. Third, OOI affiliates’ infrastructure fictions construct particular actors, arcs, and identities that define the purpose and meaning of OOI work.

The following section describes the artful and fantastical rhetoric that informed the OOI’s development, arguing that those building the OOI conceived of it as a technological utopia. It demonstrates the power of considering infrastructure with fiction to draw attention to new pieces of the OOI narrative, to their dangers as well as their opportunities, and demonstrate the thick and enmeshed stories that connect and drive scientific visions. It then delineates how those within the OOI attempted to build this technoutopia, explaining the broader ecology and climate surrounding its development and then detailing the specifics of its plans. What emerges is a bridge between fictions of infrastructure development and its materialized forms.

4.2 A Technological Utopia of the Oceans

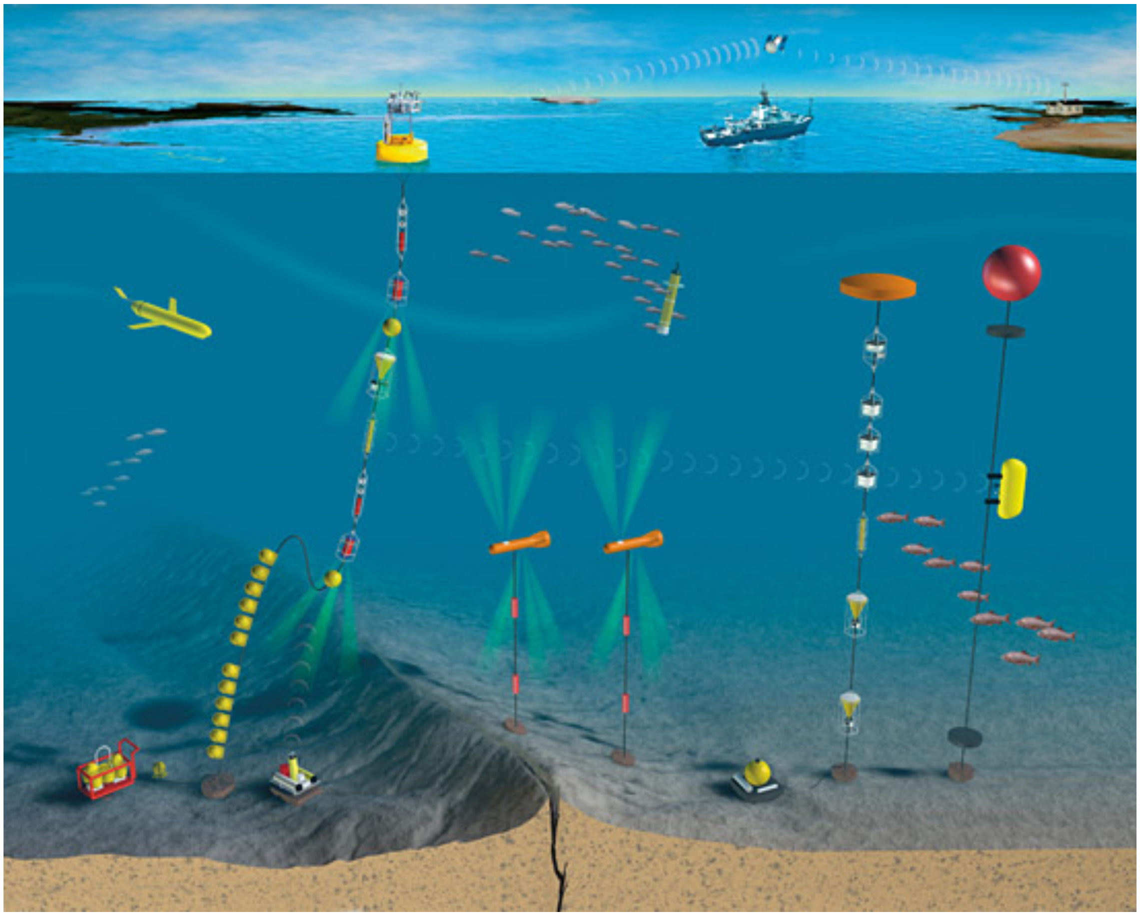

Figure 4.1. Rendering of the interactive instrumented ocean basin to the water column for a future OOI (Image credit: Consortium of Ocean Leadership).

The power of fiction in envisioning futures lies in its mechanisms for thinking through and with the resources available, and leading to the substantiation of those futures via policies and plans (see: Figure 4.1). To these ends, those working within the OOI circulate two fictions connected in turn to two distinct agendas. One of these, a narrative of the Blob, is drawn from science fiction filmography and replicated in the scientific sphere. The other, a narrative of the lifelong scientist, is produced and distributed in part as folklore by those within the OOI to describe itself. Fictions like these perform integral functions for emerging projects like the OOI, providing at once a possibility space, a common and necessary goal to strive toward, an orientation and form of communication, a possible future to inhabit, and a comprehensible path to follow.

There has long been a connection between how oceanographers and policymakers fathom the ocean and the fictions found in the cultural production of authors, artists and filmmakers. Biographies and autobiographies of ocean explorers in the 20th and into the 21st century cite the fictions of The Odyssey, Arthur C. Clarke and more recently James Cameron as formative to developing a love and understanding of the sea. Many of the most well-known technologies of the sea were immediately and eagerly adopted and documented by those outside of the academic scientific workforce: recreational fishermen and divers, filmmakers, photographers and artists. Oceanography exists close to the media it produces and that is produced with it as its subject. Ocean historian Helen Rozwadowski (2004) asserts the distinctly technological characteristic of the ocean as "a place known through imagination as well as through direct experience" (p. 6):

> Because human lungs cannot breathe unassisted in the ocean, our knowledge about the ocean is necessarily mediated through technologies, knowledge systems, or cultural conceptions of this space—or some combination of these. Imagination may, in fact, play a larger role in our perception of the ocean, especially its third dimension, than modern science. (Rozwadowski, 2004, p. 6)

This deeply mediated character of oceanographic work contributes to a particular mysticism of infrastructural development in ocean science. Technologies require fictions that do not act by themselves; the agents that create them supply their meaning. The OOI's figurehead and primary champion, John Delaney, understood the significance of fiction in realizing his vision for a vast network of ocean observatories. Posted to his office wall, a Goethe quote that reads: "If there is anything you can do or dream you can, begin it. Boldness has genius, power, magic in it. Begin it now."

There is a common trope in which the frequently retold autobiography of an infrastructure project is a kind of science fiction itself: the past gets incorporated into unitary origin stories, narratives of imagination and glossy causal chains. For the OOI, this original fiction is John Delaney's impassioned scribble on a bar napkin: one man, one vision, one massive product. Imaginaries and knowledge have a fictional dimension that are, in fact, informed in part by science fiction (as genre). Vision and fiction are central to how the OOI was crafted, reworked, and extended not just through the authorial leadership of a single man, but through a whole process of community consultation, reports, workshops, draft statements, tiger teams, feasibility studies, and requests for assistance.

4.3 OOI Fictions: The Lifelong Learner

> Imagine a grade school student who becomes interested in the oceans and their teacher opens a browser during class to the Ocean Observatories Initiative. They can gaze upon the creatures of the seas via its cameras and see what its sensors see through its interactive charts and graphs. As they explore, mapping one sensor to another over time, they make many small discoveries, just as others all around the world are doing. No matter what data set they look at they're going to make a discovery. Imagine one student becomes particularly enamored with the sea and selects a sensor to be their own. Year after year the student checks in on their sensor, that maybe they have named, making discoveries all along the way, falling in love with the ocean and taking ownership over a part of it, taking part in unlocking the many mysteries below the waves and passing down a love of the oceans to future generations.

This passage is an amalgam of quotations from OOI affiliates. The above fiction is both produced and distributed by oceanographers. These two fictions serve different purposes, engage different audiences and narrators, set different tones, follow different arcs, and are found in different locations within the scientific process. This fiction's primary audience, however, includes oceanographers, the general public, policymakers, and dissidents. It is a narrative intended to draw intrigue and inspiration, to motivate, justify, and define the who and the why of the OOI.

The fiction of the "Lifelong Learner" is a coming-of-age story for a lifelong citizen-scientist. The main character is the student whose antagonist is something like a friendly ghost that follows them throughout their life, presenting many small but surmountable battles rooted in a thirst for knowledge about the ocean. This is a story of endurance and persistence, of growing through a love of the oceans via the OOI, and passing this love down to generations who will sustain that enthusiasm. This kind of fiction situates the science of the OOI in a broader and publicly consumable form, extends its generational thinking not just across generations of scientists for decades to come but across the generational age spectrum. This fiction is also a particular expression of a genre of 'citizen science' fiction that is increasingly to be found across the sciences (and large scale scientific infrastructure projects in particular), in which nonscientists will participate via dedicated technological platforms in the practice of scientific data collection and interpretation, consequential to the flows of broader societal concern, national identity and policy (cf. Lewenstein, 2004).

Figure 4.2. "Twenty First Century Oceanographer," presented during the San Juan workshop. The two individuals presenting would become the Principal Investigators of the Endurance Array from University of Washington and Oregon State University. They also held roles within NSF's Observatory Steering Committee that led to the OOI's development. The slide appears between a schematic of the vertical wired profiling moorings of the West Coast regional scale nodes and a list of its considerations (costs, risk, functionality, reliability, availability) (Image credit: Delaney & Barth, 2007).

This fiction, crafted initially by ocean scientists and members of the project's education and outreach team, quickly became woven in to a network of actors and efforts to mobilize resources for oceanography and science more broadly, and served a number of different purposes for the ocean science community. OOI affiliates leveraged the story to rally support within the project for the OOI's Education and Public Engagement component, as well as to gain momentum, broaden understanding, and generate intrigue with the OOI and its access to the seas among external funding bodies. They also disseminated the "Lifelong Learner" fiction to motivate generational thinking: the OOI is not just an infrastructure for current builders of the system and their contemporaries, but for generations to come. This fiction became equally central to efforts to attract wider support and attention for the project, showing up in the promotional talks of an affiliate on Capitol Hill, in educational materials featured on the OOI website, and in the boilerplate description of the EPE that affiliates dole out to newcomers and members of the media.

4.4 OOI Fictions: The Blob

In 2014, a record-high hotspot in sea-surface temperature—9 degrees Fahrenheit (Monroe, 2015)—was discovered in the mid- to high latitudes of the eastern North Pacific within an area described as the "Ridiculously Resilient Ridge." Nick Bond of the University of Washington's Joint Institute for the Study of the Atmosphere and Ocean (JISAO) nicknamed it "The Blob" (Tisdale, 2016). The Blob is an anomaly in ocean science, uniquely captivating many of my participants and the scientific community at large (Monroe, 2015; Almasy et al., 2015). The ocean science community has since employed the Blob to describe this unusual and unanticipated warm pool moving through the Pacific Ocean, affecting fish migration patterns and the fishing community, as well as mystifying scientific communities whose instruments have captured its metrics.

Sensors first recorded the "mysterious mass" (Monroe, 2015) spanning 1,000 miles in each direction and 300 feet deep (NOAA, 2018) off the coast of Washington State starting in 2014. It disappeared in 2015 and resurfaced in 2016, disturbing whole ecosystems with each presence. A corresponding "cold blob" appeared on the East

Coast in 2015 (Science 2.0, 2015). Tracing backwards, scientists believe that the Blob began forming between 2010 and 2011 during a La Niña, and grew with the Las Niñas and Los Niños of the previous years. Over time, the Blob shifts locations and shapes, dissipates and congeals. By 2016, it was believed to have contributed to a massive toxic algal bloom that has disrupted both micro- and macrofauna and closed lucrative fisheries from California to British Columbia (Consortium for Ocean Leadership, 2016; Associated Press, 2016). The neurotoxins that the ribbon of algae within the Blob has released are harmful to people and marine life. Thus, the Blob was named for its weirdness and potential nefariousness, an entity to be captured and coerced: an indescribable, indestructible, and unanticipated phenomenon that only a coordinated research effort will collect.

The Blob, a science fiction horror film written by Kay Linker, starring Steve McQueen, and directed by Irvin Yeaworth (1958) informs this characterization. In the cult classic, an alien life form or biological weapon of unclear origins in the form of a giant silicon mass crashes into earth and wreaks havoc, growing larger and more aggressive as it burns and absorbs humans in its wake. The Blob often consumes caretakers (a grandfather, nurse, doctor, mechanic, janitor) and is not affected negatively by the threat of electricity. Instead, the Blob's weakness—the cold—is serendipitously exposed and then destroyed through a coordinated mass effort in which citizens wielding common fire extinguishers simultaneously direct their instruments at the creature. After the heroic, large, and collaborative scene and a suspension of disbelief, the Blob is banished to the Arctic to fester for "as long as the Arctic stays cold": the film's last words.

Figure 4.3. One-sheet poster for the Blob (1958) film. Tagline "Indescribable! Indestructible! Nothing can stop it!" (Image credit: Internet Movie Poster Awards).

The Blob serves as an interesting point of reference within an STS and communication theory context. The Blob is a multifaceted metaphor, as the film's release accompanied *I Married a Monster from Space* (1958) on a double-bill intended for the drive-in theater. The Blob identifies a kind of monster, married to STS's long-standing interest in embracing our monsters (Haraway, 1991; 2016). Monster fictions demonstrate charismatic plot devices assigned to nature's uncertainties, creating a kind of us-versus-them narrative and paving the way for technoscientific practices to capture and reveal its monsters. Barad (2011) argues that in science the Blob concerns sacrificing the individual self for the good of the whole. Naming the Proteus, as Barad writes, is a blob with no defined shape, a seemingly uncoordinated aggregate that has organismic functionality. The point is not to question what is and is not individual, but rather that these unknowns are uncategorizable indeterminacies, things without taxonomies that we wish to capture. However, we can only do so crudely, under labels of "Other" or "queer," as something both fearful and scientifically fascinating. The Blob fiction for the OOI follows this form: it is the separation between the human and its Others found in nature; the ability to lay claim to knowing something non-conforming. It is something anthropomorphized as a character and one that is contended with, as potentially villainous, something that must be responded to, captured, and problematized.

The Blob currently inhabiting the North Pacific is a popular topic of conversation amongst OOI scientists, policymakers, and project managers. They view it as both a fascinating research trend and a powerful opportunity for a data-capturing model like the OOI, which is poised to continuously follow the Blob's movement over time through both cabled and autonomous instruments. Scientists have mobilized the Blob in a number of ways, notably by organizing workshops and panels specifically concerning the scientific anomaly and future action (Monroe, 2015). These workshops have been charged with addressing the following questions: What is the Blob? Can scientists identify Blob-like structures in future data? How did the Blob arise? How do these

Blobs impact the environment, climate, food chains, ocean composition and acidification, or atmospheric variations? The OOI appears among the answers and answerers, as its affiliates both lead prominent discussions of the topic and are named as critical pieces of the path toward solutions.

For these researchers, the Blob refers to a specific set of scientific anomalies found in the seas and defines a narrative of coordinated efforts in containing an unwieldy, unknown thing. Through its data-gathering interventions, the OOI is building something new and unknown in order to find something new and unknown. This fiction asks how the OOI will push beyond current understandings to reach into the unknown, grapple with what it finds there, navigate its surprises and discoveries, and mediate its unknowable risks through a collective, technocentric solution that will protect and support generations to come. The arising of the anomaly in the ocean and its recognizable name served as an opportunity for those within the OOI as something that would be captured through the system's data collection alongside other successes like the opening of the hydrothermal vent Axial Seamount (Oregon State University Newsroom, 2015; Boyle, 2016). Whereas prior to the Blob there was much discussion of the possibilities of the OOI to capture unknown phenomena of the seas, the Blob served as one of the first tangible anomalies to point toward.

The OOI seized the opportunity to define itself in accordance with the anomaly: in workshops it was discussed how high resolution and real time time-series allow better and quicker insight into anomalies like the Blob. Suddenly the blob would be invoked as a core reason to use and further develop the OOI. For example, the Blob was noted by one participant in the 2016 UNOLS/OOI Cyberinfrastructure Workshop for the OOI's potential scientific strengths from the shelf to slope base: "Multidisciplinary studies that couple physics, chemical cycling and biology like air-sea-gas exchange and ocean acidification; study of episodic events like biological effects of the Blob; impact of oxygen on zooplankton; longer term measurements on hydrate ridge with more sensors on that ridge for gas seeps… could be useful for resource managers like fisheries or those interested in harmful algal bloom elements" (UNOLS/OOI Workshop participant). The broad scientific interest in the Blob importantly links the OOI to its interdisciplinary hopes: the Blob is covered by NASA space scientists, marine geologists, conservationists, climatologists and climate change activists (Evans, 1988; 2013), fisheries at both the industrial and commercial levels, and more.

4.5 Conclusion

This chapter has shown that in both fiction and scientific practice, creating future worlds like the one imagined and anticipated by the OOI requires imagining something different, becoming sensitized to particular problems as storytellers, and sensitizing an audience to particular aspects of life (ones that new interventions might support). It also involves thinking about how things are now, and assigning future responsibilities. The OOI circulated two dominant fictions that both demonstrate fiction as an animating force and essential tension in the development of large-scale scientific infrastructures:: one, a narrative drawn from science fiction filmography and replicated in the scientific sphere; the other, a narrative produced and distributed like folklore by those within the OOI to describe itself. Fictions like these, made and circulated by those building an infrastructure, provide a possibility space, a common and necessary goal to strive toward, an orientation and form of communication, a possible future to inhabit, and a comprehensible path to follow. When all fictions signal a technological utopia as in the examples highlighted here, we might start to ask about the other forms of utopianism that this world could inhabit and what are the things that foil fictional utopias? This chapter and the chapters that follow regard the OOI as both hopeful and hope-breaking, as many visions of many people come up against the ways of working entailed by the OOI's construction, and some fictions gain credence while others become obscured or foreclosed.

Thus, there is a social need to uncover the underlying assumptions and motivations for technological development, to do a "close read" as in literary theory to locate expectations for whom and what the future is being built. Fictions give way to practices, dialogs and concerns generally absent or sanitized for formalized policy and funding spheres but are importantly driving how the OOI came to be and continues to operate, for answering why individuals will dedicate their lives and careers to this new endeavor and how these fictions find themselves in the structures of OOI practice, policy and structure. Storytelling and the characters who inhabit those stories are consequential in justifying and perpetuating an institutional identity and individual roles within those efforts.

Fictions give us new words and vocabularies and connect new strings of ideas to each other, forming part of the motive force of visions and wider sociotechnical imaginaries (Jasanoff and Kim, 2015). Fiction forces us to think about correlations between things and to imagine things otherwise, placing humans at the center of world-building.

Whereas the OOI Science Plan asks scientific questions and answers them through technological means, the fictions of the Blob and the Lifelong Learner enliven the realities of people, nature, affect and struggle in the world and point to important ideology and trajectory. The fiction of the Blob places value on collective action and technological means to attack a threat of societal level concerns. The fiction of the Lifelong Learner encourages generational thinking for ocean engineering: not just what is known now but what will and can persist into the future. The fictions retold in this chapter might seem contradictory at first glance. The Lifelong Learner narrative seems individualistic while the Blob focuses on collective action; the Lifelong Learner slowly develops knowledge for future generations, the Blob is a story about responding quickly to a scientific conundrum. Taken together, these are fictions are generational orientations in which technology serves a central and emancipatory role for a long-term future.

To tell the story of the OOI, fiction and futurism join across multiple fields to demonstrate that simplified worlds with characters, endings, sometimes happy endings, and strife are inspiring and attractive; yet, such narratives cannot impart a sense of cultural logics, nor can they build a comfort with the emergence and uncertainty inherent to the actual practices of science.. This is a cultural process that is not just about building a world but also about bringing people into that world (and at times alienating them). But while imagination controls the future and liberates from the confines of the present, imagination alone does not define everyday experience for the affiliates of the OOI, nor does it define infrastructure's success. Thus, it is necessary to pay close attention to the intimacy of dreams and to the human lives entwined in what ultimately manifests, as will be explored in the following chapter.

Identifying these fictions is a first step in understanding their role in scientific practice, opening questions concerning how these fictions evolve and morph through project discourse – adding and removing characters and their traits, context, affect, plot points. Through these fictions, the OOI affiliates assert their generational thinking, care for the oceans through technological means, and concerns for the uncertainties of climate change. In the worlds of large-scale science projects like the OOI, fictions are inextricably caught up with things (stuff) and programs of practical action, including the varying real-world objects of scientific life - sonars and samples, ships and cyberinfrastructure. Fictions are not simply stories we tell 'about' science in an external or peripheral way; rather, fictions are integral to the organization and practice of scientific life.

What some of these fictions and lessons of infrastructure fiction show us is that we need simplified worlds with characters, endings, sometimes happy endings, and strife, but we also need more of a sense of cultural logics and a comfort with the emergence inherent in the world. In the ways that marriage cannot truly promise "happily ever after," but always inhabits a more turbulent future world in reality, fictions also attempt to marry their designers to a struggle - an effort to build something fulfilling, incrementally better yet still natural with all of its unwieldy times and competitions, its triumphs and its failures. The connection and attention of this labor of love is to view the endeavor at once within its strengths of possibility and within its gaps. Glossy bastions of the technology world like Google and think-tank IDEO heavily circulate publicly-consumable short films of comfortable futures. These futures are not just aesthetically low contrast, there is little fight in the future worlds they portray. This utopia is a fallacy, just as creating blueprints toward a utopia is also fallacy: it ignores the complexities of everyday life and the diversity of nature, the human condition, the animals, plants, air and water. In organizing the world, fictions obscure as much as they illuminate.

Through the example of the OOI, fictions are shared and collective achievements, they are also competitive ones; the collective attention of scientific projects and wider fields is a scarce resource, and not all stories can be told. The gendered implications of this finding are explored in the following chapter; here, what it means is that the particular characterizations and world-shaping properties found in, for example, the tales of blobs and school-age explorers crowds out other possible stories. In this way if fictions call out, amplify and organize, they also silence, obscuring the other real and potential worlds and futures that are also always present in complex collective undertakings like the OOI.

The Blob and the Lifelong Learner offer clear examples that, in the view of the affiliates of the OOI, technology will inhabit the Earth and answer many of humanity's most pressing questions, providing hope and possibility for a new kind of relation of people to the planet. Humans are the recipients of technological advancement's spoils, enabling a break from the constraints of the singular, natural human body and extending new powerful connections to nature through science and technology. But what is often left out of our scientific fictions are the realities of nature and the human condition; acknowledging that things are built, but also fail, break, get maintained, and are repaired into new realities. These practices, and their human costs and consequences, form much of the subject matter of Chapter 5.

5
Troubled Waters and Utopia on the Horizon: Contending with Precarious Labor and Cultures of Inequality Through the OOI

> We are volcanoes. When we women offer our experience as our truth, as human truth, all the maps change. There are new mountains. (Le Guin, 1989)

> "Utopia is on the horizon," declares Eduardo Galeano. "When I walk two steps, it takes two steps back. I walk ten steps and it is ten steps further away. What is utopia for? It is for this, for walking."
> (Solnit, 2016)

The beautiful and ambitious fictions that inform the building of the OOI in the previous chapter contend with the realities of inequality that plague ocean science. This tension between the field's fantastical self-conception and realistic constraints is found across all STEM fields and is gaining traction as a topic of conversation, particularly in public press (Coil, 2017; Shen, 2013; Rosen, 2013). Years of ethnographic observation around the OOI provided a unique understanding of the workplaces of oceanography at large – across the environments of ships, laboratories, docks, academic buildings, warehouses – which intersect in unique ways where harassment and discrimination are able to thrive. Yet, it is also true that the creation of the OOI -- in bringing climate change to a front and center concern for US science and its ambition to produce more participation in the unevenly distributed worlds of oceanography -- is moving the bar, pushing a new norm for what is relevant across formal and everyday conversations about the field.

The vision of the OOI -- with its desire to answer grand challenge questions about the earth and climate change, about community and more participatory thinking, and about the baseline desire for doing good work that supports both people and the planet -- now resonates throughout many conversations about the state of ocean science today. The interest of the community in increased participation is matched by conversations around diversity and inclusion: the goal is not simply to engage more people in the study of ocean science but also to see the OOI open the career possibilities for underrepresented people to participate. Scientists, policymakers, and technicians alike who may not be interested in intersectionality[4] (and do not employ that word or articulate any activism in this way) readily discuss the issues those activists and scholars care about. In this effort, many participants echo the sentiment of Eduard Galeano that Rebecca Solnit quoted above: oceanography is "walking" in part through the work of the OOI toward a presumably better version of this world, whether it succeeds or not.

This chapter names the problems of ocean science that are sometimes difficult to articulate or even see, to demonstrate the gravity and prevalence of issues whose resolutions will not lie in the incoming technical advances of the OOI, to capture the effortful work to address, manage or sometimes simply live with these issues that does not contribute to time-on-task. Through years of ethnographic field work around the OOI, this chapter documents often hidden problems of equity and inclusion, the processes through which they are made invisible, and the multiple ways in which people (especially though not exclusively women) work through, around, and against them. The problems of precarious labor and gender inequality articulated within this chapter in combating gender inequality are not isolated to oceanography nor even academia: as such, this chapter extends a large body of work that highlights tensions and inequalities

[4] Intersectionality arose from the publication "Mapping the Margins: Intersectionality, Identity Politics, and Violence Against Women of Color" (Crenshaw, 1989). Intersectionality is a theory of how different types of power structures and discrimination interact, particularly at the intersections inhabited by black women.

and inequities in the profession participation of women[5] across many contexts, drawn heavily from the worlds of feminist technoscience in sociology, anthropology, and STS.

The sciences, both as subject and as object of study, have long been predicated on the historical overrepresentation of Western and white men (Visperas et al., 2012). Scholars who have addressed this disproportionality include Evelyn Fox Keller (1987), who discussed the "gendering" of scientific knowledge; Emily Martin (2001), who investigated the relationship between gender roles and the science of reproduction; Geoffrey Bowker and Susan Leigh Star (2000), who identified how technical expertise regiments our experience based on our affiliations with gender, race, ability, and socioeconomic categories; and a wide array of scholars, including Karen Barad (2007) and Donna Haraway (2016), who promoted how we might practice science more equitably.

Much research has explored the social forces that facilitate or impede women's paths into science, particularly concerning the low acceptance rates and graduation rates of women in STEM (Ranga and Etzkowitz, 2010; Hill et al., 2010). The factors that undermine women's participation in science have been explored by comparing women's employment paths to those of men (Blickenstaff, 2005), or comparing across sectors (Wilson-Kovacs et al., 2006). These studies have produced a number of key theories that identify that there are both formal and informal mechanisms that keep women out of science: stereotype threat, leaky pipeline, sticky floor, Matilda Effect and

[5] All woman-identified participants who explicitly indicated their gender during my field work will be referred to as "women" for the remainder of this chapter.

Matthew Effect, and work/family conflict, for example. This work, found across gender studies, public policy and sociology, has sought to identity the differences in moving through "the pipeline" across scientific careers, pointing to needs for more effective policies and practices (cf. Branch et al., 2016).

Alongside this research, gender, feminist and post-colonial studies explore not only the mechanisms of exclusion, but also how scientific knowledge is produced and situated.[6] Technoscientific fields such as artificial intelligence (Forsythe, 2001), computing (Abbate, 2012), physics (Traweek, 1988) are dominated by men; the discourses, practices, and habitus of these fields concomitantly embody masculine values.

For examples of such changes to the culture of science, we might look to the platforms that are encouraging women to speak up about their difficulties of navigating these unequal spaces: "What is it like to be a woman in philosophy?" (What is it like to be a woman in philosophy?, 2018) or "The Serial Harasser's Playbook" from Women in Astronomy (Johnson, 2014). Or, we might look to popular articles that detail emails sent to a female journal editor (Neill, 2017) and "When Scientists Say #metoo" (Neill, 2017), to see what noted feminist and postcolonial scholar Sarah Ahmed has powerfully identified as the widespread prevalence of institutional invisibility of gendered work (Ahmed, 2012). Fricker (2006) offers particularly useful insight when we address these sociocultural tensions, identifying that hermeneutically marginalized socialized

[6] Judith Butler (1993) and Anne Fausto-Sterling (2000) both famously detailed the gendered assumptions that constrain research questions modern geneticists ask about sex. This shaping dynamic is found in the kinds of questions scientists ask and how they answer them. We might look to critical theory that includes dependency theory, liberation theology, or participatory action research for lessons on the integration of the intersectional in our science studies.

experiences are about fleeting experiences, practices and localized encounters and the invisibility of this labor in the formalized aspects of performing work:

> The generic definition now called for captures hermeneutical injustice per se as: the injustice of having some significant area of one's social experience obscured from collective understanding owing to hermeneutical marginalization. (Fricker, 2006, p. 102)

There exist several interrelated issues explored throughout this chapter that are linked through hermeneutical injustice: underrepresentation of women in the workplace particularly in more powerful positions; masculine values in the conduct and content of science; and harassment and violence against women in the scientific workplace. There are two sets of rules that faculty are subjected to when applying for reappointment, tenure, and promotion: those made explicit in handbooks, faculty orientations, and determined by union contracts and those that operate under the surface[7] (Matthew, 2016). Each of these investigations of inequality in the scientific workforce unearths a barrage of complex practices and forms of work that build an often informal infrastructure for those whom formal infrastructures fail to support.

These problems will not simply be solved by getting more women into the pipeline of scientific careers. Instead, we must establish new cultures that are hospitable to broader participation. I argue that the pervasive gendered harassment and violence of the scientific workplace has not previously been addressed sufficiently within STS; this chapter fills that gap by highlighting these issues in the OOI and reflecting more

[7] It is this second set of rules that disproportionally affects faculty of color who are often hired to "diversify" academic departments and then expected to meet ever-shifting requirements set by tenured colleagues and administrators.

broadly on how such gendered power dynamics inflect scientific work in the United States.

5.1 Labor, Hope and Work

In a phone interview, an OOI affiliate quickly directed attention to a recent Nature article written about the OOI, regrettably titled "Oceanography's Billion Dollar Baby" (Witze, 2013). He sighed disparagingly when he discussed the article's tone and the unfortunate but admittedly accurate picture that it painted. This participant stressed (and stressed over) a number of tensions about his personal mission, the OOI's mission, and the contents of the article. He spoke avidly about labor, explicitly identifying "labor" and its cause for many breakdowns in the current configuration of the OOI, that the ocean sciences haven't seen an infrastructure project like this before and it has instilled much uncertainty, lack of faith and fear that the future of careers are hanging in the lurch, their future possibilities for employment dependent on the OOI being viewed as a success or failure rather than typical intellectual and service merits.

This interaction speaks to some of the more poignant hardships and sometimes bitter lessons encountered during the 5 years of ethnographic observation that I later conducted for this dissertation. The OOI's aims are powerful, but it is being built within a precarious terrain. Labor issues are frequently cited and found in the observations, interviews and public writings about the OOI, with concerns regularly expressed about the persistence of these issues into the OOI's future. Across genders, these labor grievances looks something like this: the conditions of the OOI are somewhat tenuous (in a time of political uncertainty for any work dependent on US funding sources that might speak to climate change and because of the OOI's rocky progress thus far), where the amount of funding that it will consume from the disciplinary budget in its operations phase "could potentially hurt a lot of people" (participant quotation) and "they [leadership] don't really have an answer for any of it yet" (participant quotation). Many participants avidly spoke about the soft money concerns of ocean science and how these concerns could be exacerbated by the OOI, only worsened by the unavailable Navy grants that used to prop up the field (discussed further in Chapter 1). Other participants questioned the precariousness of soft money work and the sustainability of having a family, mortgage, and certain life plan against this way of operating. Multiple participants feared for the future of oceanography where this is the landscape, worried about enrollment and the sustained participation of new oceanographers – where, in this climate, it is possible only certain kinds of people would sign up for and find themselves successful oceanographers – including amongst groups already most in danger of being excluded or marginalized within the career structures of the field such as women and non-binary identities, people of color, LGBTQ people and particularly people who exist at the intersections of these demographics.

Multiple participants and news articles have bleakly imagined the OOI's future: where money from the NSF directorate grants that once funded PI-driven research projects will instead be consumed by the high costs of OOI's Operations and Maintenance (O&M) budget, leaving little room for the other kinds of research that were the life blood of many oceanographers (Witze, 2013; 2014; 2016; Wilcock, 2014). Participants worry about widespread unemployment or about the necessity to seek funds from private sector or to downscale to fit smaller internal grants from their institutions [also noted in (Wilcock, 2014)] and that those most affected will be those who already have trouble gaining traction in ocean science. One participant lamented the reality of colleagues falling out of oceanography altogether from the uncharted career path of building the OOI infrastructure, questioning: "how could we support both research and technology?"

In interviews, participants walked through what they do during their workdays, what forms and applications, who they are talking to and where, what materials they interact with, what fights they are fighting, what tasks are of stated importance and what fires have moved those tasks to secondary importance. These answers tended to include what participants do when they are both in and not in the office, where the workday frequently does not appear to end until they are sleeping. These answers opened up dialogs about individual biographies and how they are impacted by the OOI infrastructure.

In a particularly memorable interview, a participant responded to this first research question ("Tell me what you do.") with a tearful reply: "working 80 hours a week for four years. I have estranged my family" (participant quotation). It was revealed that this work week filled 80 hours with no overtime. He has ostensibly valued his own time at about $8/hour or less, and no one has stopped him from doing so. His colleagues passively verified his worth at $8/hour.

The other OOI affiliates whose offices reside in his building were some of the best and brightest in oceanography, particularly at the top of the food chain in the OOI. These are scholars who have made discoveries that have changed science textbooks in the past decades. This tearful participant and his colleagues now sit in a quiet room filing paperwork, complaining that they haven't been to sea in years and are worried that they won't for several more. They fear that they won't be able to go back into an academic job when construction is over, because they haven't published since construction began. They note that they have not gathered data, built an instrument, published, spoken at conferences, taken out a research ship or gone on an expedition in year. Their CVs have only one new line, their position at the OOI and, until the long-term impact and benefit of the OOI becomes clear – a process that is years or a decade or more away – it isn't clear whether that line will be viewed positively by future employers and colleagues. This new line also doesn't look academic and instead looks administrative, managerial, and bureaucratic. The OOI removed these actors from scientific work and demoralized them, in the process of building the program's infrastructure.

These worries for career and futures are counteracted by actions taken that stand outside of the formalized plans of the OOI. Important work existed in the writing of grants, in the learning of programming languages on the side of construction activities to prepare for the data-intensive science that is to come, or even in gaining public momentum for a research venture through a photography exhibition at the Smithsonian around a particularly beautiful deep sea creature. These actions were completed in anticipation of certain kinds of futures for the world the OOI would build, but were not recognized as creditable or authority-generating work (aka: paid time on task). Generally these kinds of activities were done in addition to the demands of the daily workday, either wholly extending the day or in the interstices of time between OOI-specific tasks – at times producing a worker like the one detailed in the previous paragraph.

5.2 The Ambient Labors of Civility on Land and on Ships

Women had particularly troubling stories to relay:

> I had lunch with a woman who I don't even like but she's havin' trouble with her male PI so I thought I'd lend support
>
> I spent some time helping my colleague look for jobs. She's having trouble getting on the tenure track and suspects it's because she called out harassment by her superior a few years ago...
>
> Ugh well... I spent all last night looking up institutional policies for reporting sexual assault while aboard a ship because I had a troubling experience on my last rotation and don't want it to happen again next time...

These circumstances point to a world of invisible work which lands on the shoulders of women in the field of ocean science. Such emotional labor creates barriers to completing tasks at hand; it also requires women to prioritize their well-being and safety (both communally and individually) above the milestones and obligations held in place by OOI's Master Schedule or Work Breakdown Structure. These moments signal a striking reality: the stories recounted in this chapter are likely to be only the tip of the iceberg.

In a reductionist formulation of the problem at hand, multiple participants (not just women) lamented the reality in which "men go home to their partners, spend their free time educating themselves and building their skills tying knots, soldering circuitboards and working out" (participant quotation). Participants lamented this gendered reality against the reality of non-male affiliates, particularly those who spend time at sea, who are necessarily immersing themselves in nontrivial bureaucracy and emotional challenges in their free time. Following much scholarship that confirms these stereotypes across career trajectories (cf. Reuben et al., 2014), women lamented the time they spent comparing themselves to their colleagues, looking up statistics and figures of how much more their male counterparts are paid to do the same work (all public record for OOI) and thinking about how, for example, their male colleagues are spending their nights working on circuits, knots, and honing professional skills while they have to worry about creating a livable environment for themselves and future female colleagues.

5.2.A Shepherding in New Generations and Mentorship

Women speak about how they will form their future research around the computational world of the OOI with excitement, that the OOI brought more women to their institutions, ripe with possibilities for new collaborators and mentors for future generations. At first this looked like an incredible turn but, but as one participant noted, "there are just as many more men as there are more women, just more people in general, and instead of seeing one other women I am now seeing ten other women" (participant quotation). She calculated that OOI brought proportionally more men and the statistics stayed more or less the same over time,

> It's a positive in that there are literally more women in the track! When you are working with really low numbers then when you have more at least percentage-

> wise it really makes a difference! If you only have 10 women and you hire 10 more women it is a huge change! (Participant quotation)

Participants described few opportunities for women to find other female colleagues, never mind mentors and champions for them. One participant wished she had had more guidance in how to break through the "boys club of oceanography" (participant quotation). While the tides are turning on many of the inequalities, participants noted that particularly around technology and equipment development and use, there are still a lot of issues concerning mentorship and authority for women in ocean science. Many participants expressed the work of connecting across generations both downward and upward in order to develop more of a chain of strength across women and minorities within the system.

Many participants of all genders described the importance of mentorship in their scientific practice and within the infrastructure's development cycle. As one participant said, "A lot of our career opportunities, mentorship and advisorship are real important for the direction you end up going." (Participant quotation) Participants also described how their connections with women at higher levels "allows you to better understand how they made it":

> You need more mentoring… in any hard science or oceanography being a subset of the geosciences or engineering here being a subset of mathematical engineering, anything that has a tradition of more men than women, I just feel that you need to obtain and do some connections and interactions with women in the higher levels so that you understand better how they made it. And sometimes women have very strong male mentors and they get through but I think that there is a benefit when you are in the minority to interact with others in your own minority that have made it. I would say that for any type of minority not just gender. (Participant quotation)

Women described the need for those with similar life experiences to develop mentorship models, for bridging and building generations. There was a pronounced emphasis on the role of the OOI itself in bridging and growing generations of ocean scientists through mentorship:

> We see an increase in our abilities. We see the ability for them to realize that there's something, you know, a connection, that we're all connection. They learn the science from their advisors like me and then they learn culture about the different cultures of the world from interacting with other students. So those are all of the things we hope to enable further with the OOI. We hope to break down even more barriers to participation with the OOI. And that's what we're working hard to do. And that's why we believe in it. (Participant quotation)

Mentorship occupies a particularly tenuous realm of work. Mentors who intentionally take on women or more precarious mentees find themselves in a particularly arduous space. They must prepare their mentees for the workforce while providing social support to help manage their mentees' emotional, social, and sometimes bureaucratic fallout after a discriminatory incident. Female mentors are often in more direct communication with their mentees: creating emergency support structures via phone numbers or Facebook chats, as one participant noted. One participant discussed memorizing care-giving policies and parental leave policies (both on ships and on land) because they are consistently regurgitated back to students in different ways by administrators; they also mentioned having to contact and correct administrators who have supplied misinformation.

Women almost categorically engage in outreach work outside of the OOI in service roles that extend beyond the OOI that are often built for young women in science, which they believe serves the program's broader vision of participatory science. To connect across generations, one participant worked as part of the Gender Equity Committee at her institution and expressed a personal interest in gender bias. Her role within this committee was to respond to any affiliate's questions about employment or demographic information and statistics, not just raw numbers but more complex facets that include community workshops, speakers and co-authorship networks. Another participant runs a Girls Science Camp that she got her students involved in, which consists of many field trips involving graduate students who will devise labs to teach them about research. It is an attempt to get girls more involved in scientific research, but the participant found that it was harder to get them involved in the first place. This work is about moral responsibility and legitimizing and supporting the kinds of people who find oceanography a less friendly space than others but also about trying to demonstrate that oceanography can be a viable place for people who do not fit the traditional mold of oceanographer. Multiple participants noted that they will not see inclusivity in their time with OOI, whether building or using it, or even their own careers, but that they hope through this effort that their students and future generations will see a worth in oceanographic careers, and reap the benefits of the work they've done to build support networks.

5.2.B Building a More Hospitable Workplace

The OOI unintentionally exacerbated these issues. In a monthly institutional newsletter, delivered monthly, the OOI announced the movement of everyone dispersed on UCSD campus to a single shore location at Scripps. The one photograph representing this move portrayed two older white males. One participant (not affiliated with Scripps) noted,

> It was kind of a symbol. It was kind of representative that feeling that you could get that it could be an old boy's club in oceanography. The image that was chosen was two older white men. I thought about it… The way to engage more young people into OOI would have been to show... I mean, you have to show the people that founded it, they're the big deal. They did it, you know but… it would be good to have an image mosaic to show there are young people like the new programmers! To show the variety of people working in it and how it is new… OOI will be more successful if people think they're part of it! So I think that you should highlight the diversity of roles in the OOI. I'm sure it's going to involve everything from people sitting at a computer to people hanging over the side of a ship deploying something… and people of all ages! (Participant quotation)

The day prior to our interview, this participant had interacted with a number of her female colleagues in the hallway to discuss the "ridiculous" nature of the image, followed by emailing the editor of the newsletter and developed a list of recommendations for future publicity releases. The task to complete this work was both trivial (fleeting hallway conversation, short emails) and non-trivial (meetings).

The effort here provoked particularly important and illuminating discussion with the participant during the interview concerning the differing treatment of women in science compared to men in science and her hopes for future communications that demonstrate inclusivity (both as desire for and as a reality which is more inclusive), not just through words. This participant followed this small discussion of the newsletter with a passionate detailing of complex, awkward, emotive scenes of a passion for ocean science: how she both signed up knowingly for a passionate life of science and for a gendered power structure that it is distinctly tiresome, unsatisfying and heartbreaking, finding herself powering through the ways in which the world works to take the beauty and the bliss out of the work. She describes the frustrations of women who are not being depicted in the same ways that men for the same work. We joked together as we rattled these sorts of common lines, “She's a woman!” “A mother!” “Has a family!” “The first woman to!” “Persevered despite latent misogyny!” “She walked a harder road than her male colleagues!” “She was pregnant at the time!” Instead of simply highlighting the strengths of her career, these gendered stereotypes are the more common narratives found when describing a woman in ocean science. When men are written about in science they are largely not recognized as fathers or husbands. A hard road for men, she explained, is not defined by the gender binary but instead socioeconomic status, sickness, or disability. This participant and others described how they would like stop seeing womanhood treated as a genetic deformity which needed to be overcome; they believed that womanhood doesn’t require reference at all when evaluating whether the road to discovery was a hard one.

Multiple participants described the difficult terrain of navigating the bureaucracies of oceanography. One participant described her role as caregiver to her boyfriend who was recently diagnosed with cancer. She described how her supervisors encouraged her to go on a 6-week research cruise to a very remote island, shortly after she made the announcement about her partner's illness. To arrive at this particular island destination there is only one flight out and it is often unable to depart because of fog and other extreme climate conditions. When she told her boss that she didn't want to go because of the precariousness of her boyfriend's condition, her boss exclaimed, "I saw him last week and he looked fine!" She was then told that she couldn't receive family medical leave assistance (FMLA) because her partner was not blood and they were not married. This superior insisted that she would have to join on the cruise. The participant spent time investigating her state's FMLA policies, working with administrators and appealing to other female colleagues who have been caretakers. She learned one can claim FMLA when co-habitating for a period of time, which signals a negligence or misunderstanding by her boss of the basic policies that provide support to his employees and a more masculine culture where FMLA is rarely invoked.

5.3 Harassment and Participation in the Oceanographic Workplace

> Ships provide the perfect environment for harassment to thrive. They are isolated, hierarchical and authoritative. (Participant quotation)

I have named the threat of and reality of sexual harassment as one of the most prominent and difficult aspects of oceanographic work by women, one that is not in any way limited to the world of OOI but has potential to be addressed through the OOI (see: Stout & Wright, 2016). The Service Academy Gender Relations Survey (SAGR) reported that 17.1% of female U.S. Merchant Marine Academy (USMMA) students had experienced harassment which is roughly double the rate reported at the other Federal Academies (USMMA, 2016). USMMA, a federally funded facility, cancelled its year-long sea internship in 2016 due to a decade of unresolved problems with sexual harassment (Rein, 2016).

Oceanography is not removed from the realities of reporting sexual harassment found elsewhere. Because cruise duration is short and principle investigators claim to be more focused on science ends than on inequalities in experience aboard ships, there is much discomfort in talking about issues of sexuality and harassment. In addition to the troubles of navigating the bureaucracies of reporting harassment, participants fear that nothing happening as a result of reporting. In addition to the aforementioned "psyching up" for shipwork, participants described the tenuous decisions concerning how to act when someone tells in confidence that they have been harassed -- whether to fight for them or to sit back and just watch it happen repeatedly. Given the statistics in the sections that precede this one, it becomes clear that women have trouble rising to permanent and tenured positions in the ocean sciences, which only exacerbates the complexity of and vulnerability to harassment, and leaves holes where policy could have supported them. One participant described an encounter with sexual harassment aboard a ship at which she was a contractor and the reasons why she did not file a report. This participant noted,

> I would not have been protected by Title IX since I we did not receive U.S. Department of Education funds and I was not a student. I was not protected by equal opportunity rules at the U.S Environmental Protection Agency because I was not a federal employee. And though the company I worked for had rules against sexual harassment within the company, it did not have authority over U.S. EPA. I do not know what the outcome would have been if I had made a report. (Participant quotation)

University resources are more available when on land than when at sea (in part for the difficulties of seamless communication and of keeping a low profile) and there is a longstanding emphasis on solving ship-based problems within the confines of the ship rather than seeking outside help.

The National Science Foundation (NSF) which gives funding to 2,000 colleges, universities, and other institutions takes Title IX infractions seriously:

> For any NSF-funded entity that fails to adhere to Title IX, NSF will work with the Departments of Justice and Education to ensure compliance with nondiscrimination laws. NSF may terminate funding to any institution found to be in noncompliance with Title IX regulations and that does not voluntarily come into compliance. (NSF, 2016)

Even feminist tellings of women in oceanography shy away from discussion of sexual harassment within the field. Published a decade apart, the special issue entitled "Women in Oceanography" in the journal *Oceanography* (Syvitski, et al., 2005) and the more recent issue, "Women in Oceanography: Continuing Challenges," (Kappel, 2014) explore the advances, stasis and road ahead for achieving gender parity in the ocean sciences highlighting in detail many of the autobiographical challenges expressed by women within oceanographic fields. In the more recent (Kappel, 2014) issue, it is noted that there exists no formal survey of harassment in modern oceanography and the topic is only substantively discussed in one paragraph in its entire 264 pages. Much has already been written about the masculinities that are performed as part of participating as a non-white non-male in oceanography [cf. autobiographies of Betty Bunce, or the histories of women who stowed away, cross-dressed or joined their husbands like Jeanne Baret French, Marie Poland Fish, Helen Raitt and Barbara Lawrence (Orcutt & Cetinic, 2014)], but little has explored the realities of gendered harassment by masculine hands in the field. While all fleets and oceanographic institutions have policies in place for reporting and deterring harassment on cruises, it has been reported by participants that there is no standard practice within or across institutions. Many institutions do not adequately protect victims of harassment particularly at sea.

Fortunately, there has been a sea change in the treatment of and roles available to women in oceanography (cf. O'Connell, 2014 for a list of women oceanographers and their groundbreaking institutional and national awards and honors). In the year 1990, the anti-discrimination and anti-harassment Title IX law and Women in Science and Technology Equal Opportunity Act were introduced in the United States. In 2001, the NSF also launched the ADVANCE program which has seen some notable successes. In 2012, 56% of undergraduates in Oceanography identified as women according to a report from the National Science Foundation on Women, Minorities, and Persons with Disabilities in Science and Engineering published in 2018 with data up to 2014. 48% of doctoral students in Oceanography identified as women and 46% of postdocs (National Science Foundation, 2018). At the institutions that received NSF ADVANCE awards, women constitute 17% of the oceanography faculty compared to 14% of the faculties of the remaining 15 institutions that did not receive ADVANCE awards (Holmes, 2014). However, the percentage of women on faculty is lower than would be expected, according to a study by Orcutt and Cetinic (2014). The percentage of women decreases as faculty rank increases: occupying 35% of assistant professors, 33% associate professors, and a mere 20% full professors in the fields of oceanography (O'Connell, 2014). These statistics are markedly lower for under-represented minority women in the past decade who have earned only about 12% of the PhDs in Earth and Atmospheric

Sciences broadly, far below the percentage of representation in the nation broadly (O'Connell, 2014).

This disparity is reflected both inside the academic institution and aboard ships, as more tenured faculty typically inhabit the role of chief scientists on cruises. As Lehman (2018) reports, "Of 428 cruises with principal investigators (PIs) on global-class research vessels logged in the University National Oceanographic Library System (UNOLS) database between 2010 and 2016, only 96 had female PIs." This finding is consistent with an earlier survey that reported 30% of chief scientists on UNOLS research vessels of all time identified as women, with an even lower 12% on drilling vessels (Orcutt and Cetinic, 2014).

In requesting additional information about gender dynamics in oceanographic spaces, one oceanographer shared with me a working paper which noted:

> The International Maritime Organization (IMO) reported that just 1 or 2 percent of the 1.25 million global maritime workers were women (IMO, 1992). NUMAST (now Nautilus International), an international trade union representing the U.K. Netherlands and Switzerland, reported in 2000 that 1.4% of its 19,500 members were women (NUMAST 2000). The U.S. Merchant Marine Academy (USMMA) reports that the class of 2016 will be comprised of 15% women and will increase to 19.7% women in class of 2020 (U.S. Merchant Marine Academy). (Informant report)

This is an international issue, though it is shifting. For example women now occupy 30% on Polarstern (a major German research vessel) from the previous standing at 15% a decade prior. The statistics continue,

> The proportion of ocean science doctoral degrees awarded to women has increased from 0% in 1966 (NSF, 2004) to 40% in 2002 and 48% in 2012 (NSF, 2013). (Informant report)

Despite over 50 years since the end of policies that explicitly prohibit women on university research cruises, women have yet to be equally considered in ocean science workplaces. While strides have been made [cf. Most ADVANCE institutions have enacted "stop-the-tenure clock" policies for births, adoptions, care giving, health issues, and eldercare. See, e.g., Holmes, 2014], there is much room to grow.

These improving yet unequal statistics mirror the experiences of my participants. All but one of the women I interviewed verbally expressed their gender – and I believe the one who did not verbalize their gender identifies as a woman because she is regularly written about using feminine pronouns. All but this one woman spoke avidly of career disadvantages despite the more progressive rhetoric of the community in the modern day, without provocation. One senior male participant explained that in more recent years as women rose in the ranks and were allowed access to ships, those roles for women did not include officer. As one participant noted,

> There was so much effort put in the '90s in terms of handling women on ships that the at-field support is not a problem but the problem still exists at faculty which is how to move up the ladder, how to get into the faculty ladder. It is hard for women. (Participant quotation)

This difficulty in ascending through the pipeline of oceanography is often cited as stemming from discriminatory practices against women on ships. Women weren't allowed on ships until the last half century, and only in the last 10 years have they been allowed on submarines (as discussed in Chapter 1). Many participants noted that the

1990s were a particular turning point in the fields of ocean science toward participation, openness and thinking toward more inclusivity and diversity. Yet during this same period there were cultural norms that demonstrated a perceived difference, both material and affective, between men and all others aboard the ship:

> In the '80s and '90s there wasn't really space for women on ships so I would have to sleep in the medic's room! If one of the others on board had an emergency in the night they would have to wake me up and kick me out before taking care of the patient. Now there is space for women, but it is still a male majority so they say things like "OH! Lila is coming! We'll have to clean the sheets for her! (Participant quotation)

One interviewee described that when he began in the field in the 1970s there were very few women and those that were involved couldn't assume leadership roles, in large part because mentors in the field as part of their lessons taught that women “complicated the atmosphere of a ship” and that understanding this dynamic was “a fundamental part of leadership” (participant quotation). Because of this exclusionary dynamic in which women could not gain expertise, men were selected for any prestigious panels at conferences, received significantly more citations (Larivière et al., 2013), and received more funding and awards because they could demonstrate the skills necessary to answer research questions. NSF (2013) reports, as cited by Orcutt and Cetinic (2014) demonstrate “the number of proposals submitted by women to the Division of Ocean Sciences increased from one in five to one in four over the 2002–2012 period; within this time period, the average success rate of proposals submitted by women was roughly equal to or 5–10% lower than the success rate for men” (p. 10).

This longstanding gendered difference presented itself in many different ways through my observations within the OOI. For example, a majority of my participants across the gender spectrum internal to the OOI's Cyberinfrastructure team (the specific implementing organization tasked with all coding the backend) remarked that it is an anomaly that I am a woman who has been a programmer and noted that in ocean science that is especially rare. In the period of time when OOI's Cyberinfrastructure development was grown to its largest employee pool, two senior OOI affiliates noted that of approximately 60 developers there were only 2 non-males. One of these participants commented that one of those women held a more managerial position that did not deal with code directly. Some participants from the technical branches of OOI lamented the statistics are "just as bad" (participant quotation) as a traditional computer science world, if not worse, despite that they are reaching for more progressive ends. For many academic departments and even individuals, equal numbers of male and non-male admitted students are the end goal. Some departments are interested in hiring more non-male faculty to provide mentorship opportunities. Some take this one step further and at least acknowledge retention as the next goal, but this is again a numbers game of equality in graduation statistics and not a measured approach to the deeply rooted problems of diversity and inclusion that plague STEM fields.

Another participant described a woman at the University of Hawaii in the 1980s that "took advantage" (participant quotation) of an oceanographic expedition of nuclear submarines in the Arctic and explained that the Navy notoriously made an exception to get her in on the ship and under the ice. This particular participant continued to say that "unicorn" mentality is in stark contrast to the world of oceanography today where there exist many available roles for women. Participants rightfully expressed excitement about the moving bar at one of the largest undergraduate programs in oceanography, at UCSD, which in 2016 boasted more women than men and whose graduate program approached 40% women. While retention statistics are less favorable, many participants identified this is as a positive move and direction for the field:

> More than 50 percent of undergraduate students are female. Almost 40 percent of faculty are women. Many of the new hires have been women across the different fields. It's changing. It's good. It's more like the real world. (Participant quotation)

Many of the participants across the gender spectrum who noted this example are looking forward to what happens when these women stay and rise to faculty, tipping the scales for the whole field and putting in place structures which support their careers:

> I guess the same problem is in the computer sciences. Everyone in the administration and faculty for that matter would like to have more women but it just doesn't seem to be a very attractive field somehow. (Participant quotation)

Participants who mentioned the difficult questions of inclusivity in oceanography also noted the disparate paygrades between males and non-male affiliates as a thorny problem to overcome. Because pay grades start low, there exist very few examples of women “rising to the tax bracket” (participant quotation) of their male counterparts and therefore able to direct financial support to the next generation of non-male oceanographers. One participant laments that she is still underpaid because she started out underpaid and never caught up, noting, “Even in some of the best places to work you will find inequity” (participant quotation). Another participant added to this sentiment, "You first have to deal with it on a personal level" (participant quotation).

Multiple participants discussed the more intimate dynamics that this kind of power dynamic leads to:

> Most people aren't even aware that they are subjected to a gender bias, instead they just feel hurt and inferior and they don't know why. It helps to talk about the behaviors that are exhibited that you realize are not you personally but just somebody's biases or perceptions. (Participant quotation)

Mundane interpersonal microinteractions, sometimes microaggressions (cf. Sue et al., 2007), were reported as having significant macro-effects, that receiving a lack of respect and constant affirmations of a lower social position produced various labor-intensive outcomes. One participant had trouble describing the difficulties of being a woman in oceanography, despite the fact that she led multiple initiatives for woman and girls. She decided that the place to begin was a mundane one: she told a story of the Gordon conference, a prestigious field-wide chemical oceanography conference, where a group of scientists were standing around at a coffee break. The participant was the only woman in the group. As the group conversed, one of the men kept moving in front of her, cutting her out of the conversation. The participant wanted to be sure that I understood this person wasn't making this move on purpose necessarily, despite that, as she'd move he'd move accordingly and cut her out again. She explained that very often in meetings men do not respond to a woman's voice as they do a man's voice, and physically or verbally cut women off, and that this dynamic is learned, behavioral, and very often unconscious (Sue et al., 2007):

> There are still gender bias behaviors in our society, but they're everywhere. So I would say that certainly in terms of the awareness of it, people are aware that it happens and are a bit more sensitive to it. And are more willing to listen when you say 'hey! stop doing that to me!' but a lot of people do it more unconsciously. (Participant quotation)

While participants described the changing bar and that in most cases they believed these actions were not done maliciously, the interactions also provoked desires for change and actions toward that change.

As noted earlier, female participants say they are underpaid because they start underpaid and never make their way up, that even in some of the best places to work there will be inequity. Participants at times perform a lot of guess-work about why and how they might have been compensated or treated differently than their counterparts:

> You first have to deal with it on a personal level. Most people aren't even aware that they are subjected to a gender bias, instead they just feel hurt and inferior and they don't know why. It helps to talk about the behaviors that are exhibited that you realize are not you personally but just somebody's biases or perceptions. (Participant quotation)

Participants describe the expense of emotional time and weight into navigating the workplace and especially “psyching up” (participant quotation) for shipwork. One participant described the ship as a "hypermasculine place" where if she asserts herself too much she'll get called a "bitch" and people won't want to work with her and, if she asserts herself too little, she is "relegated to the back of the bus and can't fight back to the front" (participant quotation). This participant continued to describe that she has to decide how to act when someone tells her in confidence that they have been harassed and whether to fight for them or to sit back and just watch it happen repeatedly. Participants claim they have to do this kind of work for sustaining their jobs that they believe the men in the field don’t “even think about for a moment" (participant quotation).

5.4 Safer Oceanographic Workplaces

Multiple participants have noted the threat of sexual harassment and violence within the world of oceanography, both on and off the record. Many participants across all genders spoke of the often funny but sometimes very un-funny ways in which the close quarters of a ship can sometimes signal misinformation, where friendliness can be mistaken for flirtation, and action follows that misinformed logic. In the close quarters of a ship, everyone receives a lot of face time. Participants reported the difficulty of dispelling romantic feelings while also sustaining a collegial smile. One participant who breached the topic of sexual harassment noted the need for training for others to understand the nature and boundaries of harassment and how to prevent it or protect others from it,

> The beginning of cruise “training” varies across institutions but could be as simple as stating "Harassment will not be tolerated, report any incidents to the captain or chief scientist." I see some holes in this approach. A dynamic that is common in harassment against women is the power differential, so what if the captain or chief scientist is the harasser? (Participant quotation)

The participant described the work of understanding how each institution has separate forms of reporting harassment that also tends to vary across status: students, graduate students, researchers and faculty, largely overlooking consulting or fixed term employees.

Oceanography is also not removed from the realities of reporting sexual harassment found elsewhere. Many noted that there is much discomfort in talking about issues of sexuality and harassment, and, in addition to the troubles of navigating the bureaucracies of reporting harassment, there is much fear of nothing happening as a result of reporting. One participant noted the secrecy of harassment and the culture of "what happens at sea stays at sea" that is protected by everyone on board a ship,

> My personal experience tells me that reports don't get made. How widespread incidents of harassment are in Oceanography can't be determined unless a study like Clancy et al. [(2014)] were repeated for Oceanography, including not just scientists (who are high in social status), but crew and technicians as well. (Participant quotation)

This particular participant laments that the work has become so exhausting she's not sure she can continue. The public knowledge that men make more money than her in the same position is never far from her mind—nor is the fact that she and her colleagues have watched male harassers continue to thrive as they anguish. These inequities have created an ambient feeling of frustration and battling uphill. This particular oceanographer had spent multiple years with the OOI and was in a position to continue through some portion of its Operations, with the ability to build a career to its end (expected 25 years).

Many participants have discussed the work and emotional investment in navigating sexual harassment policies or fielding questions about how to handle sexual harassment from their colleagues, as previously mentioned: looking into equality initiatives, memorizing care-giving policies and parental leave policies because they are consistently regurgitated back in different ways by administrators who don't know their own codes, taking time to create informal-but-intentional female bonds (and having to deal with personalities that they wouldn't care for otherwise), creating female mentorship opportunities and grievance-airing spaces like lunches or happy hours, or undertaking the massive affective labor involved to determine whether and how to take that instrument back from that guy on the deck who stole it out of your hands. One participant noted the rage that can sometimes be blinding in calculating the imposition of a male taking over their work without question: (1) if that male just let the woman perform the task then the woman could at least get better at that task and perform it again in the future, or (2) if the woman was already better and more experienced at the task they would have done the task right if they had not been inhibited. And, encountering the intellectual gymnastics in which (1) and (2) are in many ways contrary to each other.

Those who fight for this system work against the perils of harassment. They are pitted into a sticky web of institutional policies and of cultures of cover-up that make the task at hand seem insurmountable, while they hesitate with the fear that reporting harassment might dissuade other women from entering the field. I recognized a widespread fear of lost connections, lost efforts and, as one participant noted, of “lost minds” finding themselves trapped inside a complex labyrinth of different ways a report will likely “go wrong."

This lack of trust in institutional support suggests that the experience of harassment or assault during the early career stage may have the most negative impact on the most professionally vulnerable in our disciplines. Moreover, bystanders to workplace incivility, particularly women, are demoralized even though they are not the direct targets of the perpetrator. Barling et al. (1996) suggests that the cognitive and emotional strain of workplace aggression directly impacts job performance and energy to complete work-related tasks.

As one participant importantly noted in regards to the shifting culture of ocean science and building OOI:

> We can never move forward unless we can acknowledge, talk about and work on all of the people we fail. (Participant quotation)

A few participants noted that oceanography is a realm in which going to the HR department does not help and in fact only creates a tense relationship, particularly around issues that concern femininity, health or care-giving. In everyday life women experience these problems. The harm is difficult to capture. It is found in small moments of everyday lived experience in these ambient labors of civility that create injustice, cumbersome-ness, and difference. Modern dialogs have termed these "microaggressions." When multiple participants name these kinds of inequalities as their reason for a setback, for leaving the OOI, or dropping out of the world of oceanography altogether, these social dynamics require attention, conceptualization, amplification, and problem solving.

5.5 Conclusion

The OOI was built with upon rhetoric of openness that was woven into its administrative and technical structures of participation and democracy. But the culture(s) of ocean science remain unequal, and the policies meant to protect its members from harm often fall short or do not exist at all. Those involved in the OOI's construction and use are “the usual suspects” (participant quotation), much as we find in other places of platform-driven democracy (Nguyen, 2013; Reagle, 2013; Pappas, 2014). Time and again both research and experience remind us that technical structures are not enough to ensure principles of openness and participation for changing culture, drawing in new members and retaining diversity. Despite the promise of a progressive inclusionary infrastructure, there remain challenges in achieving these goals that are often only made visible in what some may call “everyday” interactions: conflict that derails the success of a meeting, the work of establishing new human relations or formalized social programs to support life and work, or creating new avenues for mentorship or informal grievance outlets like regular lunches and women’s-only reading groups. These are mundane and sometimes taxing activities. However, as Haraway (1990) and Star (1999) have suggested, by thinking of things otherwise it may be possible to see these very sorts of "boring" interactions as recognizable and creditable forms of work and authority-building.

This chapter uncovers the work of combating, self-management, and mentoring in the face of inequality, through documenting how gender bias works in oceanography. This chapter has demonstrated the active role that women play in managing, fixing, and correcting inequality. Inequality is not something that simply happens: it provokes labor to combat it and protect against it in the future. The OOI both continues and attempts (with only partial success) to remake these precarious worlds – the initiative is trapped within and transformative of the longer history of inequalities in the fields of ocean sciences. The OOI is a powerful story of labor precarity, where involvement in the development of the initiative takes scientists out of the practice of science, developing their CVs in less recognizable ways, drawing new questions about how or if they will return to research should participants leave o. The perils of the soft money traditions of the field become more pronounced when there are less resources and CVs are being developed in less recognizable ways, possibly exacerbating the inequalities of who and what gets funded to perform ocean science work moving forward.

The OOI reconstructs what a technology means to us and how we live around it. This is all to say, we are not far from the technologies that we create, so if we are building policies that sustain long-term technology development like the OOI we need to follow suit with policies that sustain human development over that same period. How might we built infrastructures to sustain both life and technology? What are the types of injustices, inequalities and challenges that are sometimes captured under new phrases in scholarship across disciplines such as “infrastructural power” (Mann, 1984), “infrastructural violence” (Rodgers & O’Neill, 2012), or “infrastructural warfare” (Graham, 2005)? How do actors approach these challenges? How might STS scholars approach them? While these forms of oppression are more visible in spaces specifically built for social justice or public works (water, electricity, food, urban planning) this dissertation demonstrates that these injustices also demand attention in science. What does it say about our country that an infrastructure which fundamentally shapes the answers to our most pressing questions of climate change is built by mostly middle class white males? How could that arrangement help or hurt a future in which the ocean plays a critical role in understanding how to make policies that slow or reverse the effects of climate change? And, how do some of these considerations impact the health and sustainability of the initiative itself and lead to bottlenecks or lasting failures?

As we learn as scholars to tackle the thorny problems of big data and society, it seems imperative to begin attending more readily to affect, intimacy, labor, experience and everyday practice. This turn is evocative of Bowker’s infrastructural inversion (1994; 2000), only one which is instead concerned with micropolitics, self-management and everyday resistance. Influenced by the "atmospheric attunement" of Kathleen Stewart (2011), we must labor ourselves to become sentient to the labor of others, to the bodies and to the rhythms of others: "a practice of being in noise and light and space." Attuning in this way brings to the foreground the remarkable extent to which women in science are ambiently confronted with the harsh realities of harassment and assault, working regularly and with difficulty toward reconciling their trajectories inside these difficult terrains. The workspace of oceanography breed challenges that are both unique to the field and that resonate across scientific professions who report alarming statistics on sexual harassment like archaeologists (Meyers et. al., 2015) or anthropologists (Clancy, 2014; Ross, 2013) who too find themselves at times in isolated, hierarchical environments. Without this acknowledgment of the lived experience of women in ocean science, an important dialog about work and the nature of collaboration and systems-building is missing. In telling the OOI in this way what comes to the foreground is the intricate meshwork of practices and artifacts, the interlacing of regularities and routines with moments, and the gendered difference in experience between its participants-- each of which sheds light on breakdowns that have occurred within the OOI that do not have an easily identifiable bug to fix or part to replace.

To the participants I have interviewed, success and failure are moving targets and the metrics of success are varied. Many participants claim that merely the existence of the OOI as a field-wide goal is a win, that the connection of community around shared concerns and that the influx of new resources to the field are monumental wins. But, it is not solely within design that we will find the answers to the problems of innovation that face our newest constructions. Problematic cultures of power have been put in place and solidified by these infrastructures.

In this way, both successes and faults are not individual and instead are collective and institutional. When not all policy outcomes are planned, the functioning and malfunctioning of a system can provide gateways for understanding, approaching and resolving the deeply relational issues that impact everyday life. The ways in which participants organize and govern are indications of where values and priorities lay.

We cannot accept, enable and carry support structures that allow harassers to thrive as the harassed fall off the ladder. The value of a system like the OOI is not in its budgets but in the incalculable cultural progress that creates opportunities for productivity. We might think how growing scales of technological endeavors might guide and re-appropriate in ways that support labor, care, relationships and life. Time and again research and experience tells us it is not just about getting diverse bodies to science in the first place, but it is also about keeping them there. This chapter uncovers the work that requires institutional support to keep people there and create the inclusive, participatory collaborative cultures we envision for the future.

5.6 EPILOGUE

Race is conspicuously absent from this chapter for the reason that race is conspicuously absent from my data set, both in its participants' demographics and as a topic of discussion amongst them. Only one person across my observations and interviews identified his race and spoke of his experiences as such: the conversation happened on the deck of a ship, a few days into a cruise, just after it had rained. The sun had begun shining brightly through the clouds, opening rainbows on the skyline next to dark streaks through the sky where you could see the rain still falling further away. The crew and scientific staff were just returning to their work. As he hurriedly filed out of the lookout and into the area where I was standing, he stopped and turned to me in a tone that was one part frustration and one part acknowledging, "I can't do this anymore! They just don't care for people like me in places like this!" His manner was striking in that he wasn't expressing sadness or victimization. Instead, he felt almost sorry for his coworkers and colleagues that they "just don't get it." He claimed that this would be his last cruise (he was scheduled for at least 5 more weeks at sea from that day) and then laughed that this wasn't the first time he's said that but maybe it'll be his last. "Why do they have to only see the color of my skin?" he said. The conversation continued, in fact echoing some of the sentiments the women have expressed detailed within this chapter: the frustrations of trying to remain friendly when someone tells something that feels uncomfortable or crossing a line (and, that the friendliness can be mistaken as a sign of the injustice being "okay"); the different ways he's called for and cared for (or not) than the others; or, the way he's never included when they all go out for drinks. He leans in to me. He says he doesn't see color like that. "Hell," he leans in, "I've got a very cool ski bunny in just the next port.

6
Infrastructural Vents:
Breakdown, Maintenance and Repair at Science's Margins

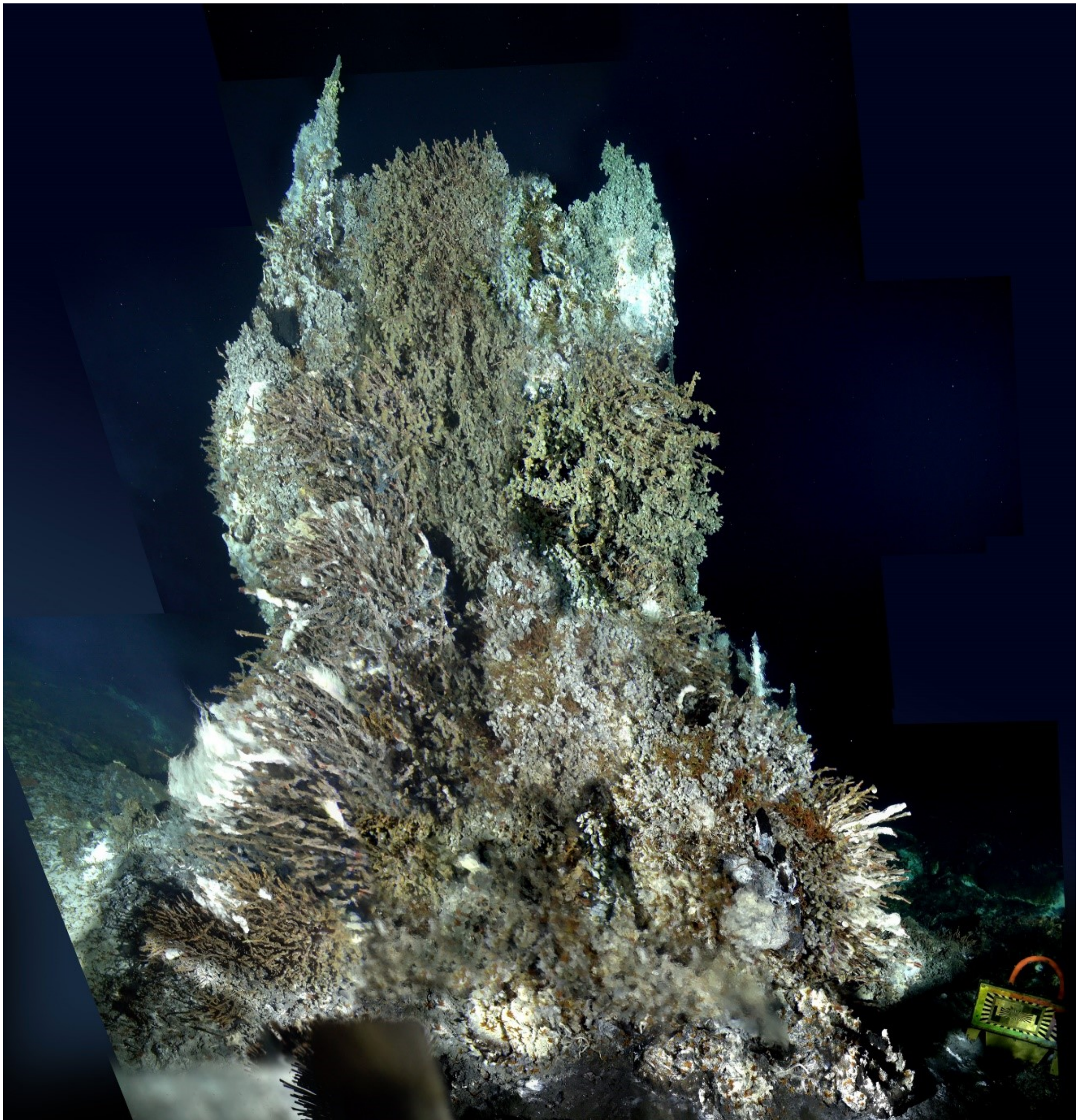

Figure 6.1. Composite photo of Axial Seamount eruption. A photo-mosaic assembled from still shots gathered from regularly scheduled computer-programmed HD Video Survey of the 15 feet high "Mushroom" hydrothermal venting structure at Axial Seamount (Image: Consortium of Ocean Leaderhsip/OOI).

Part of the enduring scientific allure of the OOI is its ability to capture hotbeds of activity that were impossible to study until recently. In the short years since data first streamed through sensors, cameras, and sediment collectors, the OOI has begun to unlock some of the mysteries of the sea; its greatest early successes were found in the fault lines around tectonic plates (Witze, 2014; Boyle, 2016). This chapter describes how the OOI tried to leverage these early successes in order to legitimate their threatened lines of funding; it argues, too, that just as the OOI must look to the margins between tectonic plates for new scientific knowledge, STS and other scholars of large-scale infrastructures in the sciences can benefit from studying the distinct kinds of pressure and hybridized realities that form at the boundaries and margins of initiatives like the OOI.

As argued in previous chapters, in order to understand an initiative as unwieldy and multifarious as the OOI, we must do more than look at how it produces scientific knowledge: we must study the social, material, organizational, institutional and political ways that inflect the implementation of its futuristic dreams, and, as discussed below, the exigencies of the infrastructure that keeps the OOI running. In the ways that the OOI continuously monitors the fault lines of tectonic plates in the hopes of capturing the opening of a hydrothermal vent, this chapter encourages ethnographic and sensorial attention to the margins of infrastructure in hopes of capturing the complexities and irruptions where discrepant systems and realities meet, the forms of breakdown and repair that characterize and constitute such margins, and the myriad ways in which infrastructures draw and redraw their territories across material, geographical, political, and human lines.

If we consider the OOI an infrastructure, then any person, organization, technology, or other actant that is not a part of the OOI is at the "margins" of that infrastructure. But "margin" seems an insufficient metaphor metaphor for describing certain aspects of the dynamic relationship between the OOI and the entities it interacts with. This chapter develops a theory of infrastructural vents to better describe particular characteristics of the meeting point between large-scale science infrastructure projects like the OOI and those who stand in varying practical, material and organizational ways "outside" of it. But outside here does not mean unrelated, unconnected, or irrelevant; margins (or vents as argued in this chapter) are also sites of proximity and adjacency, the places where nearer and more distal worlds push back on large-scale infrastructure projects, sometimes in surprising, unanticipated, and troubling ways. From a social worlds (Clarke and Star, 2007; Strauss, 1978) or more contemporary anthropological (Tsing, 2005) perspective, this is a place where worlds meet (though this meeting includes elements that are far more than 'just' social). The concept of infrastructural vents developed in this chapter is meant to convey three basic properties or aspects of such meeting points. First, an infrastructural vent is characterized by slowly building pressures and periodic irruptions, pointing to a more ecological and affective understanding of infrastructure that is attentive to the shared events of breakdown that cut across boundaries between the OOI and the people, worlds and things immediately outside of and beyond it. Second, infrastructural vents are sites of deep uncertainty, including not knowing if, when, or where such pressures will erupt. Lastly, infrastructural vents are places of generativity: as the territories and break points are repaired, new things – new objects, new questions, new stakeholders, new scientific roles, and new forms of life – are produced or emerge at the vents.

There are people and things that are affected by the everydayness of the OOI that are not considered by actors within the OOI as their responsibility. These marginal actors impact and are impacted by the OOI, partially accounted for but not necessarily integrated under the umbrella of the infrastructure. These actors do not find themselves adding the OOI to their CVs and the OOI does not lay claim to them or define how they perform their work. These are the entities that are at the margins of the OOI. One example is found in the West Coast observatory where the inshore site is laid just outside of state waters, on the border of the trout fishing community and Oceana Mesa in the Animal Marine Sanctuary, which also happens to be indigenous waters. When physical instruments of the West Coast OOI observatory come loose and go adrift, they travel up the coasts along with the tides into locations only accessible through native lands. These breakdowns of the OOI instrumentation and then become a shared event between the local indigenous group and the OOI, one that is indicative of an infrastructural vent. As a result of the breakdown, an OOI project manager became a native liaison, regularly communicating with one of the tribal leaders. However, those indigenous groups are not considered a part of OOI, aren't found in its plans or its outreach efforts and rarely even in the dialogs about what the OOI is and means.

The chapter that follows details OOI's continuous monitoring of a hydrothermal vent on the West Coast, Axial Seamount, found in the fault lines of the Juan de Fuca plate (see: Figure 6.1). It then locates resonances between the key characteristics of a hydrothermal vent within STS scholarship around boundaries and margins, breakdown and repair. In doing so, the present chapter develops a theory of infrastructural vents. An empirical vignette is then explored through another example of a broken instrument, identifying a vent between the OOI and an industry manufacturer. The vignette exposes the many layers and hybridizations of the breakdown, beginning at the surface-level empty data set found on the front-end of the OOI's portal to the cyberinfrastructure, then deeper to a deployment of the instrument at sea in which it was not producing data at its launch, and finally to the industry manufacturers who produce important understandings of how and why the breakdowns occurred. The chapter concludes on a discussion of the value of infrastructural vents in extending STS understanding of boundary work.

6.1 Hydrothermal Vents and Axial Seamount

Before returning to infrastructural vents to describe the OOI and its ecology, it is important to understand the scientific value of the OOI's work monitoring fault lines and hydrothermal vents. Fault lines map the margins of tectonic plates, which border other tectonic plates and cover the earth both underwater and on land. They are often the site of severe weather and earthquakes, more chaotic and less understood forms of natural activity, and are therefore of critical interest to climate and seismology communities. Ocean scientists have long been interested in fault lines because they can teach us about such ecological phenomena as friction and energy transfer; the motion (or "slip") of plates (which often leaves residues from one plate to the other); textures and mixing of fauna, flora, and rock; discontinuities of soil, water, and lifeforms; and relationships that are bonded within those ecologies that may have lain dormant or looked different in other locations. In particular, the ridges or fault lines of tectonic plates offer space for addressing two outstanding problems in ocean science: (1) understanding how submarine volcanoes (hydrothermal vents) support life in the absence of sunlight; and (2) understanding the impact of perturbation events such as magmatic intrusion and earthquakes and hydrothermal vents on geological, chemical and biological processes (Interactive Oceans Axial Seamount, 2018).

The OOI is the first U.S. ocean observatory to span a full tectonic plate, outfitted with a stream of near-real-time data from seafloor through water column to surface. This unprecedented plate-spanning observatory array extends by fiber optic and telecommunications cables across the Juan de Fuca plate off the West Coast of Oregon, Washington and lower British Columbia. Advances in studies of these areas are increasingly dependent on the ability to collect long-term data using diverse networks of sensors and samplers. The continuous presence of OOI sensors at fault lines provides the opportunity to capture the dynamics of an erupting hydrothermal vent (a deep sea volcano), a phenomenon that multiple participants noted was heretofore observed only "by luck" (participant quotation) and "if you happen to be in the right place at the right time" (participant quotation). It was not until more recently that deep sea sensor technologies enabled access to these locations and data collection in such a consistent way. Inside these peripheries of the Juan de Fuca plate are the answers to many of the grand challenge questions of ocean science.

Within the Juan de Fuca ridge lies the Axial Seamount -- the most robust volcanic system in the area, simultaneously seismically, magmatically, and hydrothermally active (Interactive Oceans Axial Seamount, 2018). The Axial Seamount is a mid-ocean site of seafloor spreading that separates the Pacific Plate to the west and the Juan de Fuca Plate to the east off the coast of Washington and Oregon. The site is so deep that, in the absence of the sunlight necessary for photosynthesis, a diverse community of organisms has learned to thrive on thermo-chemical outputs fed by water emerging from the ocean floor at temperatures up to 250 degrees Celsius (UC San Diego, 2017).

Axial Seamount is also the site of the first underwater cabled observatory built in 1996, NOAA's NeMO (an acronym named in part for Jules Verne's infamous protagonist, Captain Nemo) and is now home to a robust global site of the OOI: NOAA Axial Seamount Educational Resources. The array includes 900 kilometers of high power and bandwidth electro-optical cable extending from Pacific City, OR, across active portions of the Juan de Fuca tectonic plate and up into the overlying ocean. It is also one of the most advanced and operational elements of OOI infrastructure; multiple participants noted that while there were delays in many portions of the OOI's schedule, the Axial Seamount array was delivered on time and under budget. By October 2014, the mesoscale fiber-optic sensor array had started producing real-time, high-bandwidth, 2-way communication with seafloor and water-column sensor networks across: 1) a portion of the global Mid-Ocean Ridge (MOR), 2) a section of the Cascadia Subduction Zone, and, 3) a cross-section of the California Current, a component of the North Pacific Gyre (Delaney et al., 2016). Much of the data generated from more than 130 fiber-linked instruments was available for scientific, educational, and public user communities. As of 2018, the Axial Seamount instrumentation remains the largest single observatory in the global ocean focused on long-term measurements of underwater volcanoes (Rosen, 2016).

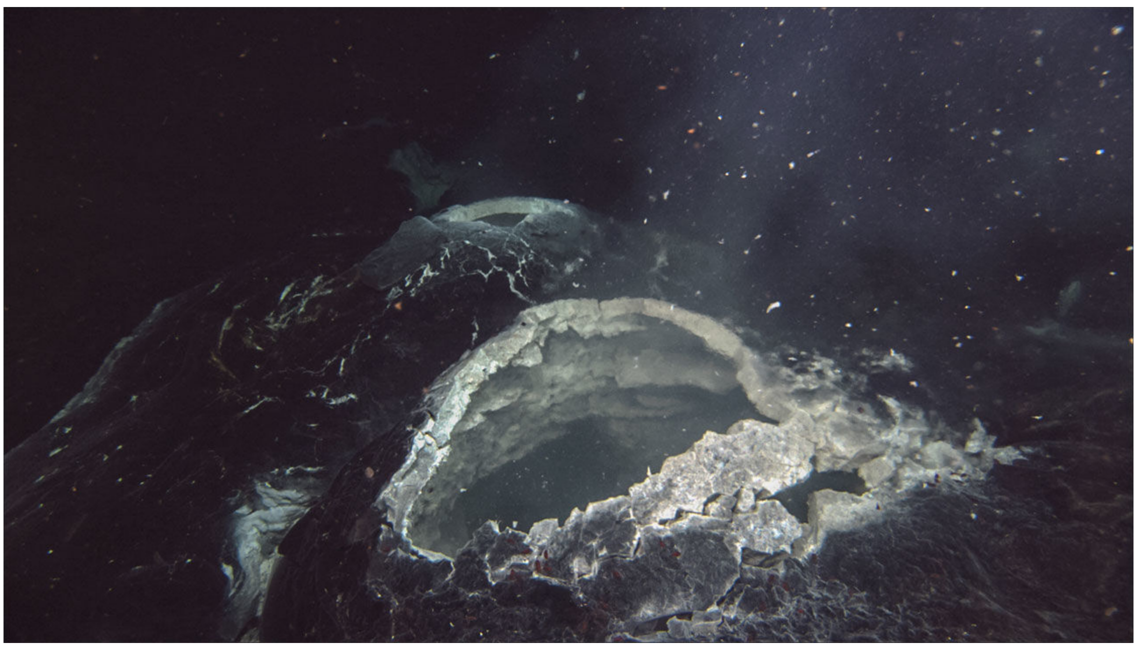

Figure 6.2. Axial Seamount eruption as captured by HD video, 2011 (Image credit: Bill Chadwick).

In 2015, from 300 miles offshore and far below sunlight penetration depths, scientists and the public were able to watch real-time data – including visuals from cameras with sound – as the volcano erupted (see Figure 6.2). The undersea volcano at Axial Seamount was continuously recorded through multiple mechanisms of sediment, sound, video, and sensors, by 20 remote, hardwired instruments distributed across the floor of the summit caldera (see Figure 6.1). Scientists were able to follow the rhythmic rise and fall of the seafloor as magma flowed into and through the hydrothermal vent at Axial Seamount. Live, streaming video of an active hydrothermal system within one of the vent fields inside the caldera revealed new and subtle changes taking place in the Axial system that had not previously been thoroughly documented (Delaney et al., 2016). The OOI Axial Seamount global site is the first array to track seafloor deformation through several eruption cycles of a hydrothermal vent (Jenkins et al., 2016; Rosen, 2016). Scientists affirm that Axial Seamount erupted previously in 1998 and 2011, the latter of which was captured in part by NeMO, providing a contextualizing and pattern identification of hydrothermal processes over time that was previously inaccessible through short-term ship-based data collection methodologies. The OOI's presence during the eruption was cited and widely celebrated as "profound." The official press release describing the eruption characterized the event and the scientific endeavor built around it as indicative of "a new era in human-ocean interaction" (Consortium for Ocean Leadership, 2015).

The successes at Axial Seamount provided an important rallying cry against the winds of scrutiny, skepticism and critique that had been turned on the initiative in recent years (Wilcock, 2014; Kintisch, 2015). The early years of extensive support and seemingly unlimited optimism for the OOI waned as schedules slipped, the scientific community felt isolated from its operation, and functioning features that were promised in early designs would not come to fruition (Wilcock, 2014; Witze, 2016). In its 2015 "Sea Change" decadal survey and corresponding report, the U.S. National Academies of

Figure 6.3. OOI instrumentation laid over the Axial Seamount caldera (Image credit: Qualcomm Institute, 2015).

Sciences, Engineering, and Medicine recommended shrinking OOI budgets to fund other oceanographic research during a time of contracting and uncertain science budgets. The report concluded that the "OOI is an expensive project that appears to have limited appeal and is coming online at a time when budgets are highly constrained" (Committee on Guidance for NSF on National Ocean Science Research Priorities, 2015). The OOI was singled out for the greatest cost reduction because, in the report committee's opinion, the different OOI components—global moorings, coastal arrays, and the regional cabled observatory— "are not all at the same level of alignment with the science priorities" (Committee on Guidance for NSF on National Ocean Science Research Priorities, 2015). This assessment reflected the weakness in support for the project in the wider ocean science community, and growing awareness and broader concern with the ongoing operation and maintenance costs. As noted in the report,

> Scientists suggest a lack of broad community support for this initiative, exacerbated by an apparent absence of scientific oversight during the construction process. OOI is an expensive new piece of infrastructure; estimated operational costs are at least $55-to-$59 million per year for the next five years. (Committee on Guidance for NSF on National Ocean Science Research Priorities, 2015)

Soon after the release of the report, the OOI's Operations and Maintenance (O&M) budget – the money required to support and operate the project beyond its construction phase – was decreased from $55 million to $31 million annually: $23,980,000 less than the initiative was built to support and a 43.6% decrease from the first year of O&M funding (United States Government Accountability Office, 2018). The OOI's development and launch in April 2016 was marred by delays, high turnover, and problems with data management and distribution.[8] Under such darkening skies, affiliates of the OOI saw the successes at Axial Seamount as both vindication and rationale for further funding: "Scientists hope the results, published today in two *Science* papers, will shed light on volcanic processes, and also help quiet the OOI's detractors, who have criticized the project's $1.8 billion lifetime cost." (Rosen, 2016)

Inspired by the successes of the OOI's Axial Seamount monitoring, this chapter explores a theory of infrastructural vents – sites of pressure, breakdown and repair that emerge at the margin between infrastructures and their surrounding worlds – and argues

[8] "A key lesson - learned from the entire 2015 Axial eruption exercise is the fact that, despite having unprecedented information about the processes, locations, and events taking place on Axial during the eruption, our scientific community was not able to gain access to the site for another 3.5 months" (Delaney et al., 2017).

that attention to marginality and breakdown exposes important understanding of collaborative infrastructure dynamics that are often left out of policies and plans, where there exist both new hybridized formations and new chasms between entities, new alignments and determinations of what and who the infrastructure will support or turn away. What precedes is an exploration of the OOI's successes in monitoring hydrothermal vents along the Juan de Fuca plate at Axial Seamount. What follows are examples of the kinds of infrastructural vents that shape, challenge and define the OOI itself: from an instrument breakdown aboard a ship during deployment, to the empty data inaccessible at a workshop on the OOI's Cyberinfrastructure, to the inside of warehouses of industry manufacturers who supply the OOI. The chapter concludes with an argument for how infrastructural vents can extend our imagination and analysis of large-scale infrastructures in the sciences, calling attention to the forms of pressure and emergence that characterize life at the margins of new scientific endeavors.

6.2 Pressure at the Margins: Toward a Theory of Infrastructural Vents

When the Obama Stimulus Package helped to fund the OOI in 2009, it catapulted new worlds within and around the initiative that took the form of new funding and administrative departments and roles; new or renovated buildings, offices, warehouses, laboratories, storage units and dedicated dock spaces; and new relations to the scientific community, its industry partners and its public interests. The initiative itself mobilized multiple communities and organizations and was constructed physically and digitally by five of the largest oceanographic institutions in the nation, including the Scripps Institute of Oceanography in San Diego, the Woods Hole Oceanographic Institute in

Massachusetts, Oregon State University, the University of Washington, and Rutgers University in New Jersey. It was a grand, otherworldly endeavor that placed industry-manufactured and smaller-run academic instruments, cameras, and other forms of data and sediment collection all over the seafloor across the globe. Through various partnerships with the Navy, Coast Guard, national parks, dockworkers, UNOLS ships, and telecommunication companies, the OOI transmits extensive data from its thousands of instruments to the internet publicly in real time. As discussed in previous chapters, this interactive "instrumented ocean" brought together many disciplines and joins multiple facets of government from climate and science policy, energy, environmental and technology policy, to academic science in biology, chemistry, seismology, physical oceanography, and physics to industries like instrument manufacturers, fisheries and telecommunications companies. The massive expanse of disciplinary, physical, computational and human territory the OOI aimed to support is indicative of its grand, transformative, participatory vision. This territorial work is accomplished by strikingly passionate individuals who invest themselves in the OOI and the future it promises—people who want to see answers to questions of climate change, ocean acidification, and urbanization through new big data resources about the ocean from sensors, satellites and instruments laid across the globe. In the boundary between the OOI and the world exists regulators and manufacturers, industry and recreational fisherman, tribal communities and nature preserves – and the OOI carved out distinct lines of accountability and responsibility to each of them.

Much of the work of the OOI involves reconciling changes and reconfiguring or redefining its territory of in the face of the unexpected, in failures or scale-downs, or simply delays. Instead of the normative narrative of innovation and newness, much of the progressive construction of the OOI has been about scaling down, ending, or "throwing [projects] on the backburner" (participant quotation) [cf. (Steinhardt, 2016)]. When construction began, the OOI was prepared to install more instrumentation, cables, buoys, gliders and platforms that did not make it to its launch, pieces were cut in the intervening years in which budgets and schedules were moved and tightened over time. In particular, as explored in Chapter 1, the Cyberinfrastructure delays greatly impacted the course of the infrastructure development. In 2015 when the West Coast UCSD implementing organization was wholly removed and its charge was given to Rutgers, a nontrivial process of unmaking and remaking plans ensued, a complex and uncertain array of turning down and ramping up from coast to coast, including the designation of and transportation of valuable resources across institutions and the uprooting of skilled workers from all implementing organizations (Rutgers University, 2016). At some point the number of changes in organization were so time- and resource-constraining that multiple participants feared the entire project was headed for inevitable failure. In April of 2016, what went live with the OOI was not the same as what it set out to complete in 2007.

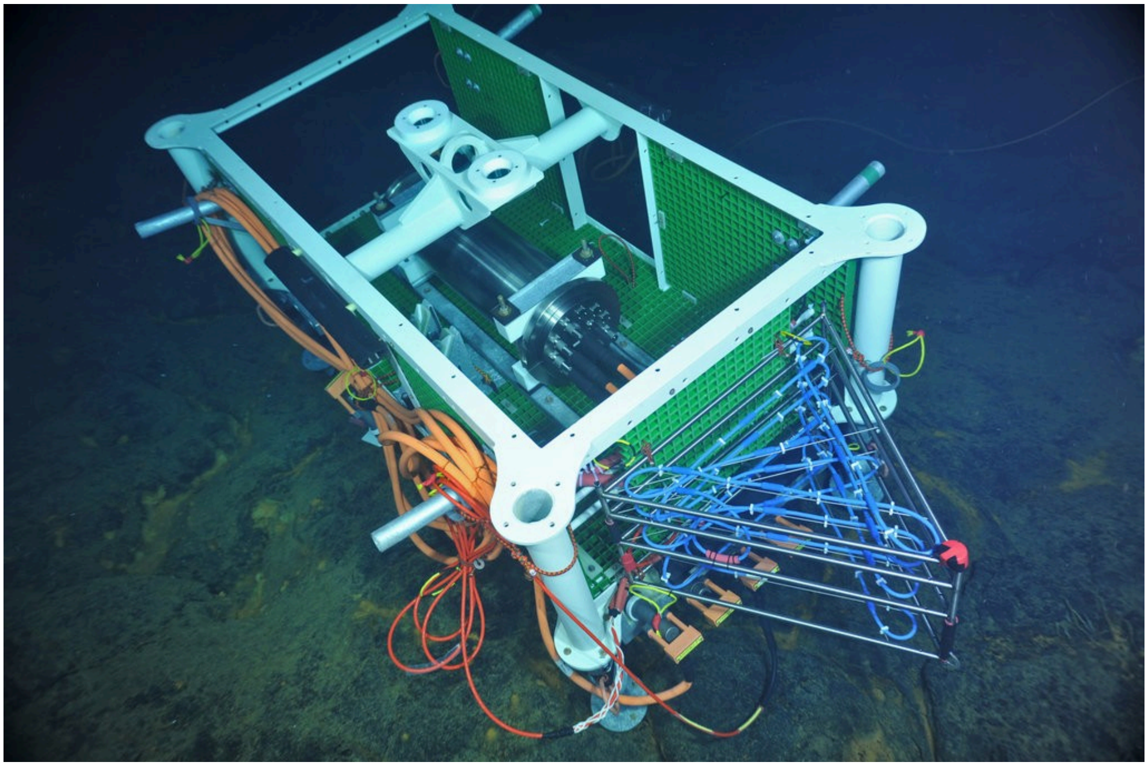

Figure 6.4. Array of instruments set to capture data about hydrothermal vents on the Juan de Fuca Plate (University of Washington/National Science Foundation-Ocean Observatories Initiative/Canadian Scientific Submersible Facility).

Much as the successes of the OOI's scientific monitoring looked to the margins for critical understanding of the world and how it works through hydrothermal vents (see Figure 6.4), I assert the value of ethnographic attention to the *margins* of infrastructure development: those sites where the formalized dreams and plans of project leaders and funders bump up against the exigencies, instabilities and profusion of the worlds around them. Leveraging boundary and repair research found in STS, anthropology and design, this chapter reflects on the presence and problem of *infrastructural vents*: between infrastructure and its margins lies a brewing and often irruptive pressure that makes visible key challenges of collaborative work. From this perspective, we might imagine infrastructure itself as a kind of tectonic plate, with a structure and territory delineated by plans and the people within it, which is nevertheless constantly pressed upon and shaped by the messy world pressing against its boundaries. Much like the hydrothermal vent at Axial Seamount, infrastructural vents provide space ripe for understanding how to support life and the impact of perturbations on the environment. This leads to new categorizations and hybridizations of what actors consider inside and outside, introduces new and critical understandings of the way things relate and change, and creates new and unexpected forms of labor as people work to manage and repair those boundaries. In such locations, we might see a chasm between two infrastructures, or we might see new communities and odd hybrids that build new homes across continuously renegotiated borders. We might come to see intersections between infrastructures and their wider worlds as a kind of fault line, under which great pressures progressively and unevenly brew, only to erupt in unpredictable and sometimes erratic ways. We might come to see evidence of such vents in the distinct and un-subtle breakdowns that exist in these boundary conditions, producing flows of new actors and knowledges, and renegotiating and redefining settled territories. Rather than a more well-defined geography or network, infrastructural vents point to the fluidity of space that divides and marks difference between two places while proliferating new and unexpected hybrids.

Science studies has long been concerned with the complexity and generativity of borders. Plans and their territories are continuously broken and reshaped (cf. Suchman, 2007), drawing attention from the centers of infrastructure to its margins, and the forms of work (and often breakdown) that frequently characterize such zones. These themes connect long-standing discourses on infrastructure and its peripheries (Avle & Lindtner, 2016; Chan, 2013), seams (Vertesi, 2014; Singh & Jackson, 2017) or boundaries (Star & Greisemer, 1989). The move to look to infrastructure's margins resists the presumption that an infrastructure is ever fully closed and complete, recognizing instead the rich ecologies (of social, natural, political and economic form) that surround our field sites. Infrastructural vents as explored in this chapter joins these concerns with the growing body of current scholarship around breakdown (cf. Star, 1999) and repair (cf. Jackson, 2014) in STS, anthropology and information science which turns attention to the laborers and maintainers, and that which is at the heart of what makes infrastructures: the often thankless, dirty, grunt work. An advantage of this approach is the ability to see beyond the defined borders of projects, to account for stakeholders not formally affiliated with the project, to identify those whom infrastructures are hospitable to and whom they are not. By attending to infrastructural vents, I attempt to look past the dominant narratives of technoutopianism and project planning, and draw attention instead to the alternative discourses, to those stories of infrastructure found in the pressurized, less lustrous often more irruptive places of breakdown and repair at the margins.

Infrastructural vents extends these formulations of boundaries by following from marginal spaces of brewing high pressure into the eruption of a breakdown and past its reconciliation, attending to the territories that are marked as part of the infrastructure and how that identity and relations change as a result of the breakdown. Rather than distinct insiders and outsiders, infrastructural vents acknowledges the fuzzy overlapping slipping boundaries between infrastructure and its marginalia. Scholars have identified key issues at these nexuses, drawing attention to the "boundary work" (Geiryn, 1983) that manages the relationship between science projects and their externalities, particularly between science and its oversight by regulatory agencies (Jasanoff, 1987), and in managing the fuzzy lines between academy, industry and public found in "boundary organizations" (Guston, 2001). Vertesi (2014) pronounces the opportunities that exist in the messy overlap between sociotechnical systems and the heterogeneous nature of infrastructures, saying: “As each infrastructure presents its own inclusions and exclusions, interactions in multi-infrastructural space present implications for what work is done and how it gets done.” (Vertesi, 2014, p. 266).

Infrastructural vents arise from forms of pressure and irruption at the margins. Infrastructural vents extends previous conceptions of boundaries by its attention to a shared event in particular, bringing together lessons concerning the generativity of breakdown and repair in the collaborative and contested boundaries of infrastructure. There exist many treatments of these boundaries and boundary conditions, largely catapulted by the formative and inspiring work on "boundary objects" by scholars like Susan Leigh Star, Anselm Strauss, Karen Ruhleder, James Greisemer, and Geoffrey Bowker (1989, 1996, 1999) or in the conception of "trading zones" by Peter Galison (1997). Important in the conception of boundary objects is the notion that boundaries are "betweens" in which there is some shared space but also a recognition of different social worlds, different habits and, different tensions; that people and things move and operate differently but converge around some shared boundary (often found in a particular object or space). Boundary objects arise as a focal point within a sea of multiplicity. Rather than thinking toward restoring order or finding a linear logical pathway within that multiplicity, the boundary object provides a lens and a vocabulary for identifying both our known categories and that which has not yet been categorized or standardized as consequential.

Infrastructural vents build upon the countless examples of both scientific success and failure that show us that project outcomes are never predictable or safe because of the innumerable contingencies that could never be tamed by any plans. When interferences occur in these boundary spaces, some things (such as relationships, boundaries, materials, or protocols) are repaired or discarded, forgotten or ignored with intention, and important decisions about futures, structures and accommodations are made. The complex, storied explosion of the Challenger o-rings (Vaughan, 1997) or the end of the WATERS (Jackson and Buyuktur, 2014) demonstrate how fully shaped plans can fall apart, surfacing the reality of infrastructures as simultaneously both hopeful and painful, and demonstrating the interconnectedness of the outside to inside of infrastructure. In these overlapping spaces at the seams of infrastructures there is often failure and contestation, and we find nearly continuous negotiations, showing us that breakdowns and problems are moving targets. This orientation is not unfamiliar to transnational researchers, who have long been aware of the productive understanding of "frictions" in crossing boundaries (Tsing, 2005; Shklovski et al., 2014). In particular, Anna Tsing describes this boundary-crossing as "friction" in the “the awkward, unequal, unstable, and creative qualities of interconnection across difference." This work demonstrates that marginal spaces are very often navigated by marginal peoples: the precariat is profoundly aware of the margins of infrastructure, whether they will find themselves inconvenienced or accommodated[9].

Among their other implications, these observations demonstrate to analysts that breakdown can be a critical resource for understanding differentiation, who and what is being supported, and whether our efforts mirror that which we intend to support. Through these breakdown and repair examples, we see these moments of breakdown are tightly coupled with the work of valuing and discarding, intrepidly human narratives that provide us understanding of such important questions of infrastructure and change over time, power dynamics and sustainability.

There is a constant and contingent nature of repair work that connects local practice to power, and to global constructs past the peripheries of any single infrastructure of study (Houston and Jackson, 2017; Suchman, 2007; Orr, 1996). Houston's (2014) study of repair economies in the unraveling of mobile phones on workbenches in Kampala, Uganda, for example, highlights the inevitability of malfunction and repair, and its deep connections to worlds beyond the bench: for example, to the day-to-day transactions that constitute informal economies of Kampala; or to the Nokia Hardware Library and the multiple corporate and national economies that provide technical support or material resources to seemingly local acts of repair. As seen in the infrastructural vents of the OOI, in some cases these infrastructures blend seamlessly with each, while in others

[9] The epigraph of the preceding chapter serves as an intentional bridging between infrastructural vents and gendered labor.

there is a clash, revealing hierarchies of power, structures of subservience or rebellion to capitalist constructs, and arrays of different forms of repair work.

This section joined literatures around boundary objects, marginal spaces and breakdown to define key resonances between the hydrothermal vents captured by the OOI and the productive analytical frame of infrastructural vents in drawing out key tensions in the development of infrastructure around marginal bodies and differentiation.

6.3 Looking to the Margins for Infrastructural Vents

A 2016 workshop hosted by UNOLS and OOI was oriented toward ascertaining whether the OOI sampling plan in place was answering the kinds of questions the community wanted to address and whether there were interventions that were either through the OOI or adjacent to them that would help to answer the major questions in these locations. For example, one attendee discussed their remotely-operated vehicle (ROV) working immediately adjacent to the OOI's shallow profilers on the West Coast containing a variety of physical samples that both validate and create connections to the data coming in from the OOI. Attendees discussed the impossibility of identifying precisely what samples were taken on a given cruise, or to see what onshore and offshore data came in through those more ad hoc experiments or to look at the glider tracks before they are turned on to see where samples may have been collected, particularly in the gliders that leave "a straight line from Woods Hole to Iceland where it's dropped" (attendee quotation). There is a Google Sheet controlled by one member of the West Coast team that keeps track of all glider deployments, though that sheet is not widely shared. This work runs in parallel to or competition with the OOI. These adjacent projects do not require the data-sharing and processing of OOI data and therefore there is no standardized method for scientists to access it. Recognizing the lack of standardization as a problem, members of the workshop suggested, "Maybe NSF can answer that!" or "Write a proposal or a request through UW and NSF" (to figure it out) or something more direct like the gleeful "It's in my freezer if you want it!" from the crowd. Individual members were interested in what to do as marine operators who want to see the OOI's vision through, at times indicating some discomfort with how OOI is currently passed through to the public through the hit-or-miss cyberinfrastructure. Some attendees and participants in later interviews discussed the priorities, recognizing there is a need to be attuned to the communities which may find themselves using OOI but also to those who feel unrepresented, who might be eager to see parts or all of the project fail. In reference to this multifaceted ecology that links OOI to multiple external parties, one participant quoted: “A man's gotta know his limitations” (Clint Eastwood, qtd by participant). Workshops are one mechanism in which the affiliates grapple with the OOI’s peripheral and marginal worlds, where there is generative possibility and scrutiny, pressure and anticipation, and at times breakdown.

The following vignette begins inside this workshop where participants are grappling with the pressures inside those marginal worlds, looking to the jointly productive and destructive relationship between the Ocean Observatories Initiative and the industry manufacturers which create its instrumentation. The following is just one of these relationships: these manufacturing collaborations look distinctly different despite the fact that each are formalized through the rigid MREFC procurement process.

6.2.A On the Front End

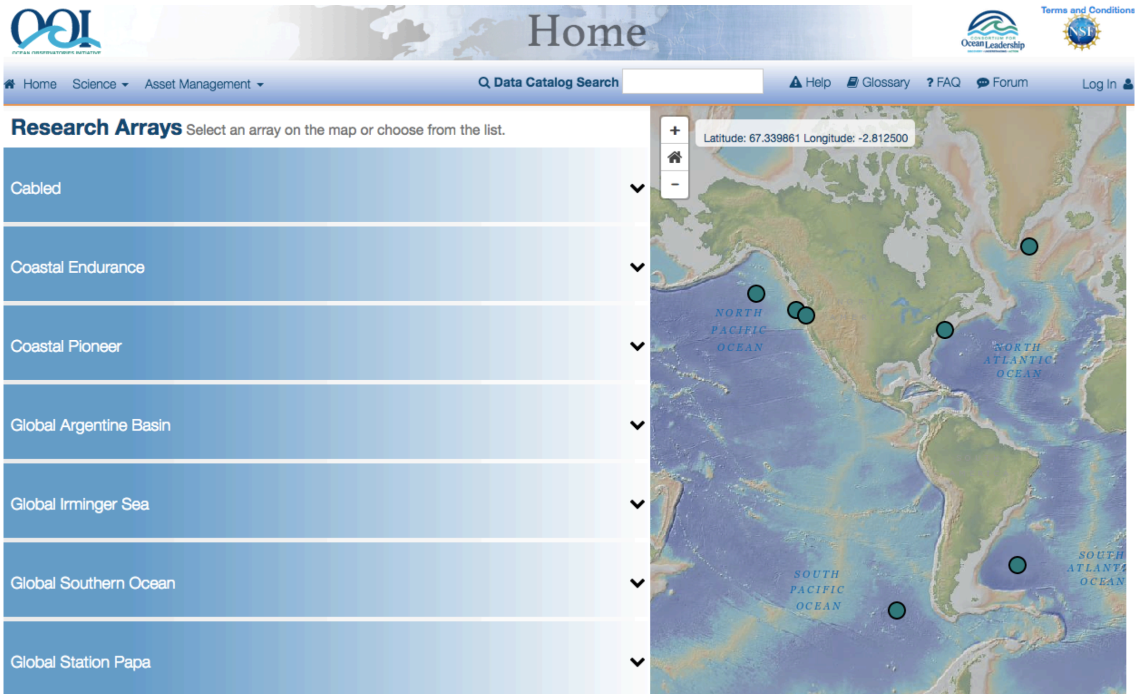

Image 6.4. The OOI Data Portal. Within each of these categories is a description of the site, a list of sensors and data collection devices with geolocation. Each instrument has an option for data access and information visualization plotting as well as asset management including information like serial numbers and manufacturers. Retrieved from http://oceanobservatories.org/data-portal/.

Five months after its launch, in September 2016, the OOI and UNOLS hosted the first workshop to teach interested parties how to access the OOI data portal for an array of potential uses. Eighty-seven scientists and technicians filtered into seated rows across a conference room with the windows drawn in a large hotel in downtown Portland, Oregon. The primary intentions of this workshop were to educate and to collect information about specific potential uses, bring in new ideas, help collaborations form and, identify new leadership and interest groups in the OOI. Over the course of three days in that room from 9am-5pm, participants and presenters traversed the road that led to OOI (some of which is covered in Chapters 1 and 2), discussing its major findings so far and comparing lessons learned from other time series instrumentations which could be useful to the OOI moving forward. Together, attendees celebrated the early successes of OOI, in particular the Axial Seamount, and how it has excitingly drawn public and scientific attention to OOI across those interested in both the deep ocean and the upper ocean. One member boasted that there is so much new data and so many connections to be made that, "no matter what data set they [any users] look at they're going to make a discovery" (attendee quotation). This workshop was an incredibly powerful experience to witness, as it was explicitly directed at unearthing both the hopes and frustrations that are at the forefront of the OOI, solicited in the first presentation: “There will be information presented today about what is working and not working. We want to know what the community is thinking and wanting” (Presenter quotation).

During this workshop, for three-hour blocks in the middle of each day, organizers held "Cyberinfrastructure Info Sessions." With the OOI data portal projected on a large screen at the front of the room, an OOI affiliate walked through the process of retrieving various kinds of data from various kinds of instruments that are currently operating at sea. Workshop attendees were encouraged to explore on their own laptops collaboratively or individually, to ask questions, to be vocal about what works and doesn't and about what more they want to see in the OOI.

Workshop attendees learned quickly that there were instruments that were not feeding data to the portal as intended. As the days carried on, attendees appeared at once curious with piqued interest in the incoming data resources of the OOI and also frustrated at the level of capability that was delivered in that moment. As the days passed, frustrations over unusable pieces of the cyberinfrastructure seemed to rise and at times cloud the more enthusiastic voices in the room. Multiple attendees critiqued that best practices seem to be made up as they go along and that better feedback is sorely needed, especially from the cyberinfratructure team. Attendees pushed for more up-to-date evaluations of instruments so they could apply for grants for companion, or redundant, instruments to be placed in the water to answer the kind of questions the OOI set out to answer without interrupting the time-series, interruptions that were noted through these data portal explorations. Multiple mentions of interruptions underscored the participants concern about how these repairs would impact their data stream. This workshop brought to the surface some major issues of the data portal in detecting real events in the ocean and the need for better understanding across the program of what is working and what is not in order to pull quality, continuous data. While some attendees expressed visible frustration, others were more hopeful – this is an opportunity to fix and build into the OOI while there is money for improvements. Some attendees viewed this as an integral part of the process: no science at this scale could be smooth and easy.

Particularly of interest to the workshop attendees were long-term issues with the deep profiler, a wire crawler. “Every year is a different issue" (attendee quotation): bad connectors from the company, bad connections from inside the OOI, or firmware issues.

One attendee noted that they might lose critical time-series data from a profiler instrument's power-sucking malfunctions, "If it's lost its brain we are going to drain its batteries out and clear it" (Attendee quotation). One attendee described that the profiler at Axial Seamount worked for four months when they installed it but it will only be reinstalled next year, emphasizing the time loss between four months and a year. In the OOI there are very formal design reviews where scientists and engineers collaborate extensively to identify and address malfunctions: engineers will take apart the profiling moorings and attempt to increase the time of reliability from four months to a full year, as planned. While frustration in this meeting was directed at the developers of the cyberinfrastructure, it was also identified that instrument malfunctions or differences in capabilities across instruments were not always in the hands of the OOI scientists and engineers and cyberinfrastructure team.

6.3.B On the Backend

Aboard one of the largest research vessels in the UNOLS fleet, a large mechanical bright blue winch moves outward at a slow pace toward the sea, buzzing and clicking, combining with the slow rise of crashing waves against the sides of the boat. The boson shouts to the winch operator, “A little bit more, Leah!” The waves below are moving in multiple directions, crashing against both the sides and back of the ship: an instability generally not ideal for doing deck work, but this particular ship is so large that it remains dry and stable enough for the many crew, scientists, and engineers to be physically unfazed. Hanging from the winch a few feet above the hard hats protecting human heads is one of the largest instruments in modern oceanography: a buoy containing hundreds of sensors and collectors of all kinds. The workers customize their hard hats: with the institution from which the person hails, with nicknames written carefully with Sharpie, with images of skulls or crowns. Some are spray-painted gold and look like trophies. Their multi-colored heads shuffle around the deck like the ghosts of Pacman, running starboard toward the stern to grab thick ties and connectors from cases and cabinets and then grafting them onto the large instrument to stabilize it[10]. Any wrong movements could damage the expensive equipment (particularly the more fragile solar panels or transmitters at its top) and could render the deployment a failure before it even hits the water. The scientific and ship crew pay particular attention to the tension in the lines, to the sounds of the water, and the moving winch. The weight of this instrument, should it fall or should the winch falter in some way, particularly against the competing waves, could cause the ship to move in unpredictable ways, if not take with it the humans below who are attending to its stability. The creeping, deliberate movements of the winch build a tension in the air like being seated on a rollercoaster and gradually rising to the first drop. Many seafaring oceanographers have described the moment of a large instrument being released into the water as "literally breathtaking," and a few of the crew members on this cruise claimed to lose stability in their legs from the release of tension/from the release of the instrument, including one who said he wholly fell to his knees.

[10] I watch as a woman runs to grab some previously-neon-now-pastel heavy-duty tie and returns to the buoy and readies herself to graft it onto the instrument. Then, one of the male crew takes the tie out of her hands, without question, without flinching, and begins to attach it to the buoy. The woman herself flinches, looks at the man, and then carries onto a new task without a word or gesture.

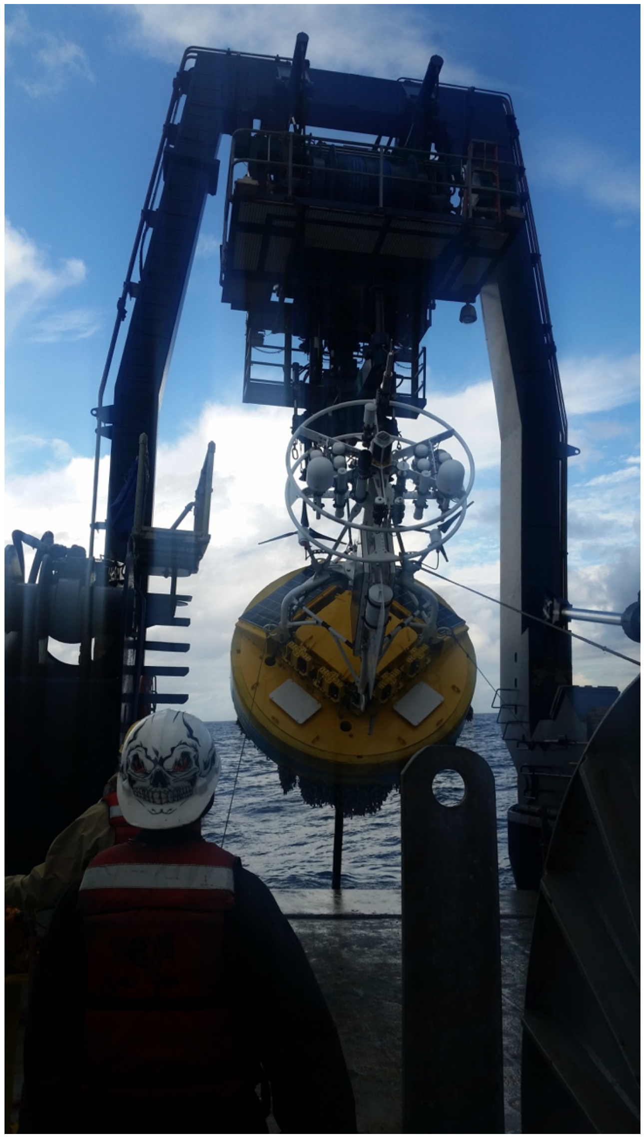

Figure 6.5. The deck of a ship in which an OOI buoy will be deployed (Atlantis, 2016).

Smoothly and assuredly the instrument drops into the water as a flurry of congratulations circulates the deck and hand waves are sent up to the crew in the captain's lookout. Before heading to the mess hall to celebrate this occasion, scientists and crew check into the indoor lab where a computer will be streaming the data live as soon as the instruments connect to know if this whole endeavor really worked.

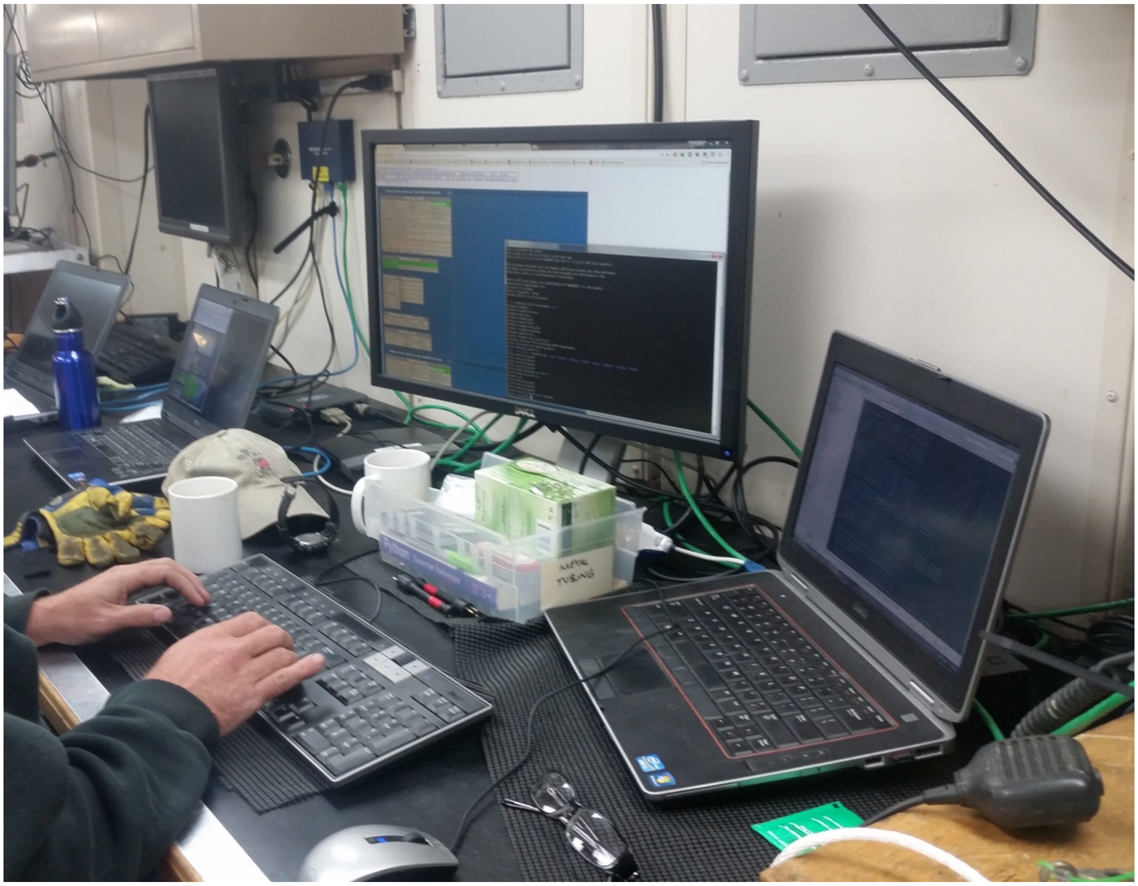

Figure 6.6. Computers streaming live data from the instruments just deployed. The technician here uses a combination of networked computers, one desktop and one laptop.

The heavy door to the lab swings open to reveal a cacophonous sound, maniacal laughter and cursing. The technician is smiling and simultaneously releasing some the worst language I have heard since I was an undergraduate at a large state school. He exclaims that two of the instruments are not sending data. He laughs with a smugness: he knew this would happen, he has been watching this happen cruise after cruise[11].

[11] On land, virtually every participant in my study assured me that - despite the complications in development and some setbacks, audits and closings that I have witnessed firsthand - the instruments are at least collecting data. This was a telling moment in which it became clear that stories of land do not always mirror stories at sea.

The technician rails about how OOI did not understand manufacturing and entrepreneurship enough to do this work. He says the quantities of instruments that are part of the OOI are so far outside the scope of production that any academic research institution could possibly bear. Therefore, private manufacturers carry out the construction, testing, maintenance, repair and replacement of most of the infrastructure in the ocean - a paradigm many participants have previously described but in positive terms. While some participants expressed the difficulties of navigating new relationships with industry manufacturers and production timelines that were not present in their previous scientific workflows, most describe the new relationship with manufacturers as an asset, a symbiosis that allows more space for completing scientific work. This technician reveals that while this relationship is necessary and full of potential, the integration of external sectors into the flow of the OOI has not been without its trials.

In particular, the technician explains that the procurements of the OOI are generally factors of 10 to even 100 above what some of these manufacturers were previously producing. The two "silent" (participant quotation) instruments in this case came from a mom-and-pop shop on the West Coast that typically designed three of this particular instrument in a year. In the same time frame, the OOI has tasked the manufacturer with producing 300, necessitating new working models and protocols, new roles, new warehouses, new training, new needs for sustaining retention of employees and new production of these instruments. The technician lamented that it is often the case that where once stood a productive relationship between a PI and a manufacturer now exists an unimaginably costly bottleneck or even a break in a formal contract with the OOI because of these unreasonable expectations of scaling and their associated tensions. Mom-and-pop instrument manufacturers, largely spawned by academics, with facilities located near large oceanographic institutions, have been tasked with scaling upward to accommodate OOI's demands but some have not been not up to the task. Multiple participants noted that OOI's schedule has shifted dramatically and ungracefully to accommodate the void of instruments that could not be delivered on time (or at all) by industry manufacturers and telecommunications companies.

This technician then casually noted that these instruments from this mom-and-pop shop are a new cutting edge device which has never been tested in the sea before.

6.3.C In the Warehouses

Industry manufacturers who were supplying instruments to the OOI consistently detailed the opportunities but also challenges attending the accommodation of the OOI into their production lines (including the significant forms of growth this relationship sometimes drove). The story of industry instrumentation for oceanographic research is often rooted in academic institutions: for example, members of the University of Washington Applied Physics Lab would later leave to begin businesses in ocean engineering. Some of the industry manufacturers were intergenerational, passed from fathers to sons, while some were new.

The industry manufacturers were very aware of their marginality, the heavy bureaucracies and difficult communication lines that allow crossing over the borders between their institutions, and of those others who exist in similar peripheral relation to the OOI. To test and then place the instruments of these institutions requires negotiations across multiple stakeholders, ship scheduling, facility reservations, crew members and time. Instrument testing and deployment, tribal fishing, commercial fishing, dams and the production and laying of power lines were cited as being in contestation with each other. Some of the instrumentation is suited for ship-based deployments onto buoys while others are deployed directly from ships, therefore there are negotiations between fleets and ship schedules, both commercial or private lines and the UNOLS research fleet.

Industry manufacturers discussed the difficult communication lines to the OOI, juxtaposing a very rigid call for procurement through the MREFC that defined the kind and amount of instrumentation that would be delivered by the industry manufacturer against less easily workable feedback and shifting timelines. Some people inside these industry manufacturers came and left as a result of other bad partnerships with materials or parts, bad contracts or bad internal hiring that led to slowdowns on the manufacturers end that did not come from the OOI itself.

6.4 Conclusion

The example of incommunicado sensors from industry manufacturers brought to light the unique ways in which actors worked to bring infrastructures in and out of alignment from many angles. Infrastructure's plans mark territory (like a tectonic plate) and between infrastructure and its outsides is an unevenly pressured margin (like a fault line) that sometimes erupts in disruptive and occasionally catastrophic events (like a hydrothermal vent). Attending to infrastructural vents requires us to look to the margins of infrastructure, to identify spaces of brewing pressure, to pay attention to what is categorized as insiders and outsiders, and to signal the effortful work that continuously redefines those categories while maintaining project momentum. Infrastructural vents mobilize nature, ecologies, institutions, policies, chaos, degeneration and movement over time into our understandings of technological systems.

Elements that affect the OOI that participants do not consider a part of their infrastructure form a kind of "vent." I deploy the metaphor of the vent because it connotes aspects of these relationships that are not accounted for by the more traditional "boundary" or "margin" metaphors. Relationships between OOI and non-OOI actants are vent-like in three specific ways. First, they are spaces marked by pressure and irruption. Second, there are deep uncertainties in the margins of large scale scientific infrastructures, including not knowing if, when, or where the pressures will erupt. Lastly, infrastructural vents are places of generativity: new things – new objects, new questions, new stakeholders, new scientific roles, and new forms of life – are produced or emerge at the vents.

The infrastructural vents explored within the example of the OOI illuminated that not only actors within a system need aligning but also the system must be aligned within a broader ecology and context of other systems, natures, policies, plans, importantly drawing together understandings of marginality with understandings of breakdown and repair in understanding infrastructure. In some cases, like the story of the profiler above, infrastructural vents at the margins between institutions highlighted an important understanding of context and change over time and the messy pressurized realities and relationalities of infrastructure, of communication lines and contingencies. Part of the work of understanding and identifying boundaries of the OOI, how they changed over time, and who the infrastructure was aiming to support was grappling with its known categories and the infrastructure's discontents, its insiders, co-conspirators and outsiders. In the many moments of breakdown revealed through this ethnographic study, infrastructural vents revealed that often what was forensically labeled as a technical failure, like the instrument on the buoy at sea, was actually a failure to pay attention to human and organizational factors of both individuals and communities, an affirmation of an almost routine kind of account in STS and sociological literature on technical failures. In many ways, the OOI has been defined by its acknowledgment of the boundaries of its scientific worlds and by its attempt to break those boundaries down. These were vulnerabilities that came from the outside of a project's plans or vulnerabilities of a project's plans that extended outside of its reach.

Infrastructural vents unearth important narratives of breakdown that run through even the progressive parts of the development cycle: found in the natural world, the complex ecologies of politics and policies, and at the intersection of institutional bounds. This orientation is about involvements, ecologies, and reflects a feminist understanding of the situatedness of knowledge (cf. Puig de la Bellacasa, 2012; Haraway, 1988; 1991). These interdependencies justify the attention to labor, human life and affect that resonate throughout this entire dissertation. The industry manufacturer and the indigenous groups both elevate these ecologies and relations that are categorized as "not" OOI. In this way, the description within this chapter attempts to be attuned to the withinness and outsiderness, and to the OOI's plans and its discontents, and how individuals work to reconcile them. Rather than position productivity as only innovative and creative forms of work, this relational understanding of infrastructural vents looks to conflict itself as productive; as illuminating of important values, lessons learned and goals to work toward.

Like other large-scale science projects that the OOI is sometimes compared to (things like telescopes, particle accelerators, or satellites, and certainly the new class of distributed environmental observatories (NEON, GEON[12], etc.), the OOI faces challenges attached to the distinctly distributed nature of the institutions and geographies that it lays claim to. Thus while the workspaces and associated industries that exist at the borders of the OOI are unique, the distributed nature of the OOI also finds kindred in initiatives such as the Human Genome Project, LTER or NEON. This attenuated infrastructure requires negotiations with land grants and private residencies, with national parks and the Coast Guard and a tight relationship with the gatekeepers to certain geographic areas like the Navy, the commercial fishing industry and recreational fishermen, as well as tribal communities who live along the coasts. These marginal relationships encircle the initiative and push on its boundaries in important ways, often

[12] National Ecological Observatory Network and Geosciences Network, respectively.

defining and redefining stakeholders and pushing the project's trajectory into unanticipated directions.

Those within the OOI react, organize, and navigate breakdowns located in these marginal spaces, just outside of anything considered in the formalized plans, and into the resulting new configurations of responsibility, labor and care done to recuperate. And, when breakdown results in a liquidation, the consequences of those ends spill into new spaces and places, never truly indicating a full-stop ending (further explored in Steinhardt, 2016). There is much flail, frustration, and resuscitation but also importantly productivity, ingenuity and innovation to be found at these margins. Thus events of breakdown and failure at the margins of infrastructure are also moments of productivity and of opportunity. Further emphasizing this, the OOI has remained resilient despite a series of nearly catastrophic downturns in funding, facilities, and faculties. This chapter investigates what happens when the OOI faces more than "teething troubles" (Wilcock, 2014) inside the realities of continuous ongoing repair work at the margins of infrastructure, in the aftermath of the eruption of an infrastructural vent, yet maintains its momentum.

Conclusion

How do we design the future? What are the wicked problems of building infrastructure that will sustain the passing of generations? How does one study the future of blue water science and global oceans: what does this future bring forward and what does it leave behind? The questions of this dissertation are vast, oriented to the multifarious implications of individual action against broad scale vision-building, to question when to design and when to listen, to find the sociotechnical problems whose solutions are not rooted foremost in technology. The example of the OOI shows us that the hopeful sheen of futurism is key for understanding how to transform blue sky ideas into blueprints, but just as critical are the less flashy ends of futurism: the broken, the breaking, the anticipation, the pressure-building and boundary-setting. Through ethnographic and archival methods, this dissertation has explored the forward-thinking anticipatory practices across individual, collaborative and more abstracted scales to understand the challenges of distributed infrastructure development. These anticipatory practices point to the novel challenges and changes that come with long-term future building: how are the many temporalities reconciled from the immediate to the generational? Who are the actors who get to define these futures and who are the actors who carry out their plans? Who cares for the future and what is the cost of caring (or not caring)?

Chapter 1 tells the history of the OOI and how it came to be; who its major players are; about the process by which the visions of the OOI crystallized into its planning and construction, refined through many workshops, reports, and policies at the institutional and national scale. The efforts to build the OOI were democratic and participatory in their aims, both in designing the process as well as in their charge to represent and unite the field under a common, extendable infrastructure. Chapter 1 explores the OOI as an emblem or inauguration of an unprecedented transformative undertaking in the ocean sciences, a future whose stakes are high and far-reaching. According to its enthusiasts, oceanography will no longer simply increase understandings of the ocean, but, via the computing paradigm, will provide answers to pressing questions of survival in the face of climate change and urbanization; will enable agricultural advancements and solutions to world hunger that will calm violent political dissent, and will shed light on other contemporary problems from war to the digital divide. The OOI enthusiasts imagine a future in which oceans could occupy a more visible and central role for all humankind.

Chapter 2 embeds this vision in a longer trajectory of the ocean sciences, inside a wave of history in which data-driven research infrastructures like the OOI became a political imperative over time, growing from years of changing tides in the ocean science, away from individualistic adventurer-explorer paradigms into more collective omniscient data efforts. The chapter explores who and what supports and has been supported by the infrastructures of modern oceanography and asserts the productivity of a relational infrastructural lens on the understanding of oceanography on a whole and of the OOI in particular. The non-fictional history of oceanography is often told as a series of great men, fantastic discoveries and heroic colonialist tales of seafaring where often the protagonist is male or displaying masculine traits and other gendered roles represented are often found in the names of a ship. The chapter uncovers the shifting roles and labor of the ocean sciences as new technologically-bound skillsets reorient what it means to be an oceanographer: from knot-making and breaking, hand-drawing and navigating into the modern worlds of model-making and code-breaking, CAD drawing and GPS navigation. The values of the field are driven by the kinds of funds that are available to scientists to do what kinds of work and what kinds of career tracks are possible: hiring, promotions, salary, tenure, equity, etc.

Chapter 3 asserts the productive power of ethnographic method for understanding the planning, construction and future of an unwieldy endeavor in the sciences like the OOI. In the increasingly complex environments in which we use and build technology, ethnography presented itself as a powerful tool for surfacing what does not get easily captured: the in-depth nuances and tensions in that which is underlying or muted, those things often completely unknown to participants themselves, and the things that are driving, contentious or damaging about the system.

Chapter 4 argued for the central role of fictions in shaping the practice, vision and imagination of large-scale science projects like the OOI, from the literary science fictions that have long been central to the imagination of oceanography as a field to the more mundane fictions by which audiences are oriented to particular aspects of life (ones that new interventions might support), possibilities and priorities are scoped, and future responsibilities assigned. The chapter explored in particular two dominant fictions: one, a narrative drawn from science fiction filmography and replicated in the scientific sphere; the other, a narrative produced and distributed like folklore by those within the OOI to describe itself. Fictions like these, made by those building an infrastructure, provide a possibility space, a common and necessary goal to strive toward, an orientation and form of communication, a possible future to inhabit, and a comprehensible path to follow. In doing so however, they may obscure, crowd out, or foreclose other stories and other possibilities, making certain experiences and versions of the future less thinkable, and therefore ultimately the paths not taken.

Chapter 5 investigates how the beautiful and ambitious technoutopian fictions that inform the building of the OOI contend with the realities of inequality and gendered and precarious labor that plague ocean science. This tension between the field's fantastical self-conception and realistic constraints is found across all STEM fields and is gaining traction as a topic of conversation, particularly in public press (Coil, 2017; Shen, 2013; Rosen, 2013). Years of ethnographic observation around the OOI provided a unique understanding of the workplaces of oceanography at large – across the environments of ships, laboratories, docks, academic buildings, warehouses – which intersect in unique ways where harassment and discrimination are able to thrive. This chapter presents the lived experience of women in ocean science, one in which sexual harassment is a present and non-negligible reality, without which an important dialog about work and the nature of collaboration and systems-building is missing.

As argued in previous chapters, in order to understand an initiative as unwieldy and multifarious as the OOI, we must do more than look at how it produces scientific knowledge: we must study the social, material, organizational, institutional and political ways that the world pushes back on the implementation of its futuristic dreams. In the ways that the OOI continuously monitors the fault lines of tectonic plates in the hopes of capturing the opening of a hydrothermal vent, chapter 6 encourages ethnographic and sensorial attention to the presence and importance of infrastructural vents, sites of pressure, irruption, and generativity at the margins of infrastructure where discrepant systems and realities meet, crucial forms of breakdown and repair are accomplished, and the boundaries of infrastructures get drawn and redrawn across political, technological, geographical and human lines. This leads to new categorizations and hybridizations of what is inside and outside, introduces new and critical understandings of the way things relate and change, and creates new and unexpected forms of labor as people work to manage and repair those boundaries.

7.1 Implications for Policy and Organization

The example of the OOI demonstrates that with any technological endeavor there should also exist programs that support human careers and lives. In particular, it appears that with any investment in long-term large-scale technical infrastructure there should exist a corresponding long-term large-scale investment in social programs that address critical holes in participation and diversity, as well as improve upon the poor grievance reporting procedures and training around workplace hostility. The case of the OOI signals a need for further research that illuminates the barriers to marginal groups in building a sustainable life in and around any infrastructure project and for the results of intersectional and diversity studies in science to be applied to the operation and future-building of scientific endeavors. Building from important lessons of the OOI infrastructure drawn out in particular in Chapter 5, the development of any endeavor in the sciences requires particular attention to gendered labor and inequality, sexual harassment and violence across the multiple workplaces of the ocean sciences. The example of the OOI demonstrates that women perform nontrivial work that does not contribute to time-on-task in order to keep up with or to make safe their oceanographic workspaces. The MREFC defines a strategic and rigid set of rules under which an implementing organization can be selected for planning, construction and operations & maintenance: the case of the OOI indicates that part of this selection process should include a traversal of the institution's grievance policies and reporting procedures; an effort to improve vague language within harassment, disability and caretaking policies or to introduce them where they are missing; to educate those who are in positions of power on the policies they may have to advise; and to introduce some basic training about workplace inclusivity. Some institutions perform some of this cultural work but these efforts need to be multidirectional. Recognizing the distinct ways in which funding bodies can shift the culture of a scientific workplace on the ground as evidenced by the histories of Chapters 1 and 2, the case of the OOI suggests that a productive intervention in fulfilment of the participatory goals of the OOI would be an organized effort coming from the NSF that allocates time and resources to diversity and inclusion. Part of this charge is to include more accessible grievance reporting, not solely around gendered labor concerns, but of labor and project tensions more broadly. Rather than finding catharsis in detailing the problems of infrastructure to a journalist, into a blog post, or to an ethnographer like me, it was clear from interactions with the OOI's affiliates that a mechanism of grievance reporting (one that would be heard and attended to) was needed in order to communicate what was working and not within the program, in large part to avoid the realities of burnout and high turnover that the OOI weathered. NSF has promisingly launched the ADVANCE program which begins to tackle some the thorny problems of diversity, inclusion and fair labor in science that echo throughout this dissertation, but this solution runs only part way toward the end goal.

Taken together, Chapters 5 and 6 indicate a need for better support for infrastructure-building as career track, one that follows into and out of construction. Participants described significant forms of work needed to be done to maintain their scientific credibility -- vis a vis the OOI – yet are not given time to support CV-building in recognizable ways that allow for reintroduction to the academy as a research faculty or a clear pathway into more managerial roles. Many of the participants building the OOI had already received tenure and those who did not were often spoken about by participants in ways that signaled their precarious futures and fears. Corporate solutions to this issue like the 80/20 rule have not translated from theory into practice (Sherman, 2013; Towsend, 2013), instead resulting in full work weeks with what would normally be considered overtime dedicated to extrascientific or extracurricular skill-building. However, dedicated time imposed hierarchically and given resources for vocational identities and other career aspects need to be carved out, respected and honored. Particularly acknowledging the high turnover rate of the OOI, it appears critical to introduce structured time set aside for affiliates to maintain scientific identities with support for retraining.

The efforts of the OOI in its earlier stages promised a democratic process, an inclusion and participation within the community that did not carry through its construction nor into its operations. Many of the negative reports written formally by national academies (Committee on Guidance for NSF on National Ocean Science Research Priorities, 2015), through journalistic means (Witze, 2016), or through self-report by scientists on the ground (Wilcock, 2014) noted two failures of communication that would have brought the initiative more into focus for the broader world of the ocean sciences at large.

First, in the early stages of the OOI's development there was a strong emphasis on identifying collaborators, interested parties, and stakeholders and how they could benefit from the data-driven infrastructure. Yet even a superficial traversal of the attendees of the early workshops and the roles of those who were writing their corresponding reports will reveal that academic oceanographers and ocean policymakers from major institutions defined the OOI. The longer histories of ocean science explored in Chapters 1 and 2 illuminate the kinds of ways in which particular kinds of voices get heard more than others, in the case of the OOI participants reported in interviews that quite literally loud voices from the major institutions would "get their way" when it came time to write up the reports. Additionally, much of the strife exemplified by the infrastructural vents in Chapter 6 could be approached through project mandates for identifying the marginal stakeholders of the OOI and integrating them into the planning process more directly and regularly through the tenure of the system's planning, construction and operations. As part of my ethnographic work, I contacted many of the external advisory board members only to learn that these committees were not active and were largely filled with academic oceanographers. The case of the OOI presented here suggests that it would be productive to assemble a panel of external advisors who are consulted regularly as any large-scale program progresses, ones who are not necessarily field members who will one day use the infrastructure. The external advisory committee instead could consist of those who can help to uphold democratic practices, provide insights and lessons learned from large-scale technological development more broadly, or represent the interests of the marginalities such as recreational and industrial fisheries, national parks, indigenous groups, earth scientists, etc.

Second, the OOI garnered significant scrutiny both from inside and outside its walls, a feedback loop which generated poor morale and a lack of confidence in the possible success of the program [reported in detail within (Committee on Guidance for NSF on National Ocean Science Research Priorities, 2015)]. Communication was often cited as lacking, participants felt siloed in their institutions and siloed from their broader field from within the OOI. Participants were discouraged from making any public appearances, from speaking at conferences or with the public press, from performing work that did not contribute directly to the construction of a physical tangible object of the OOI. Additionally, many participants interior to the OOI desired program updates about its progress or lack thereof, where help may be needed, where members have been promoted or moved, where significant plans have been reoriented, where new national policies or new internal procedures were introduced that bear on the operation of the OOI and its mission. I had the opportunity to sit in on some of the initiative-wide calls in which updates were provided to the participants. I also was witness (heard through the wall of an interview) to the raised voice of one of the program officers assigning blame to members of the cyberinfrastructure team. The tone and form of feedback and signposting coming from the upper levels of the OOI was not being received by the affiliates of the OOI even when the words were being delivered. Participants described a cloak of mystery surrounding the OOI that presented itself as obfuscation of either corruption or impending closure, which triggered a paranoia amongst its affiliates about the security of their jobs and the fulfillment of their passions. This multifaceted communication problem that is turned both interior and exterior to those invested in the OOI signals a need for a Communications Officer, possibly within each implementing organization, who is in charge of maintaining the flash and bang of a project like the OOI. The role of the Communications Officer would be a positive reinforcement feedback channel akin to the public relations person(s) often found in larger institutions whose outputs may be press releases and newsletters, internal and community-wide email updates, promotional videos, interviews with OOI affiliates, reporting of OOI or its affiliates in the news and other public spaces, an avenue for affiliates to report their successes to a broader audience outside of their immediate team, and morale-building organizational strategies.

Lastly, the MREFC is typically bestowed upon those who have not undertaken any endeavors remotely familiar to its systems engineering approach. Most participants reported an unease with the transition into the MREFC's project management regime. Project leaders may benefit from networking opportunities both across the project and within the broader NSF MREFC, like the now defunct annual Project Science meetings noted in Chapter 6 and the previous FEON workshops in the Earth Sciences. Some of the tensions and challenges of the OOI are inherent across scientific infrastructures writ large, signaling a need for comparative learning across fields. This is an opportunity for the NSF and MREFC.

This dissertation is an effort to unearth new aspects of the ecologies of the invisible (cf. Star, 1995; Star and Strauss 1999; Denis and Pontille, 2015), pulling with child-like curiosity on the loose threads that expose themselves in flaws of infrastructure and its inhabitants as they conduct and work through everyday life. This dissertation asks as many questions as it answers: What policies and practices create healthy, sustainable environments both for humans and the planet? Who and what is exceptional? Who benefits from that exceptionalism? What is innovation supposed to look like? What does innovation actually look like? Who are the makers of infrastructure? Who are the recipient of its spoils? Who chooses? Who cares?

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