Situating El Niño: Toward a Critical (Physical) Geography of ENSO Research Practice

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Modes of climate variability such as the El Niño–Southern Oscillation (ENSO) have important implications for how climate risks are understood and prepared for. This article establishes a new critical geography of ENSO research practice through examination of the production of ENSO science in three U.S. research centers, chosen for their dominance in ENSO knowledge production and their location outside of “teleconnection” regions. Scientists in these institutions revealed multiple and sometimes conflicting conceptualizations of ENSO and expressed disagreement over which components are most significant for research and wider society. Yet two factors are revealed that tend ENSO science toward the reductive: the increasing conceptualization of ENSO as a modeling problem associated with the importance of general circulation models and an institutional drive for simplicity in indexes and definitions by the National Oceanic and Atmospheric Administration. Both have implications for disaster management and the broader geographies of risk, by reducing a multifaceted phenomenon into a set of indexes, definitions, and methodologies. The article thus argues for a new research agenda on the critical geographies of ENSO research practice, particularly focusing on the role of institutional priorities in constraining the practice and presentation of science. Key Words: climate science, critical physical geography, El Niño, ENSO, situated knowledge.

The significance of projections of climate change and the increasing importance of long-range climate forecasts for disaster risk management place climate scientists in positions of social responsibility. Yet, the knowledge produced by climate science is necessarily partial, and informed by subjective decisions made by scientists. These decisions—the choice of questions to ask, theories to adopt, methods to use, and processes for communicating research findings—can have significant social implications, as scientific outputs translate to policy or action (King and Tadaki 2018). As such, there have been increasing calls for “critical” interventions into climate science, beginning in the 1990s (Taylor and Buttel 1992; Shackley and Wynne 1995) and accelerating during the last decade. These have generally emerged from two broad literatures. The first concerns the epistemological limitations of climate science and its inability to provide meaning in the knowledge it produces (Hulme 2008; Jasano 2010), precipitating calls for a stronger role for human-focused disciplines in climate research (Hulme 2011; Popke 2016). The second responds to the responsibility attached to climate science and positions of power held by climate scientists. Research in this area has focused on the production of climate knowledge (Shackley 2001; Howe 2014), the worldviews it engenders (Jasano 2010), and the voices that it reveals and obscures (Klenk and Meehan 2015; Colven and Thomson 2019). Here, geographers have contributed work on the spatialities of climate science, including how climate knowledge travels (Mahony and Hulme 2012; Meehan, Klenk, and Mendez 2018) and the relationship between science and politics (Demeritt 2001; Mahony and Hulme 2018).

Much research in this area has focused on anthropogenic climate change. Modes of global climate variability such as the El Niño–Southern Oscillation (ENSO), North Atlantic Oscillation, or Indian Ocean Dipole also merit critical attention, however. Just as climate change produces new conceptualizations of scale and temporality (Jasano 2010), these climate modes reassemble the global atmosphere and oceans and affect how meteorological variability and associated hazards are understood (Höhler 2017). Emerging forms of forecast-based financing, for example, raise complex questions regarding postcolonial
equity and the role of expertise, given that the forecasts are usually produced in the Global North and funding is diverted to hazard management in the Global South (Tadaki, Salmond, and Heron 2014; Tozier de la Poterie et al. 2018). These modes also “perform” (Hulme 2020, 277); they are ascribed with agency and personalities that enable them to be blamed for hydro-meteorological disasters and hence absolve authorities of responsibility (Grove and Adamson 2018).

This article explores one such mode, the ENSO, often referred to as the most important mode of natural climatic variability, due to the variety and intensity of associated meteorological anomalies. The phenomenon—primarily related to a coupled relationship between the oceanic El Niño and the atmospheric Southern Oscillation in the tropical Pacific (cf. Rasmusson and Carpenter 1982)—is related to meteorological variability across the tropics and subtropics, “responsible for as much as 50 percent of year-to-year climate variability in some regions of the world” (NASA Earth Observatory 2017). World Health Organization estimates put the number of people affected by hydrometeorological hazards associated with the 2015–2016 El Niño event at 60 million (World Health Organization 2016). ENSO forecasts underpin regional climate outlook forums in many parts of the world (Orlove and Tosteson 1999; Guido et al. 2016) and have long been used to inform commodities futures trading and insurance products (Keppenne 1995; Coughlan de Perez et al. 2015).

The scientific knowledge that underpins these forecasts and indexes is produced by “someone from somewhere … with a specific set of theoretical underpinnings and values” (Tadaki et al. 2015, 162). Hence ENSO knowledge is situated, both in the sense that it is produced by “partial sight and limited voice” (Haraway 1988, 590) and in the sense that partiality is informed by place; that is, the knowledge has geographies (Mahony and Hulme 2018). The dominant site for the formation of ENSO knowledge is the United States, a country that has dominated ENSO research science since the 1950s but lies outside the ENSO “center of action” in the equatorial Pacific (Cushman 2004a). Research centers located in Boulder, Colorado, and New York are particularly important for the production of ENSO science, although meteorological variability in these locations is not considered to be particularly affected by ENSO.

Research produced in these areas is used, either directly or indirectly, to inform disaster management in parts of the world that are both more strongly affected by ENSO variability and overwhelmingly lack resources and training to conduct their own research.

This article explores the production of ENSO science in the United States through interviews with scientists in three organizations: the National Oceanic and Atmospheric Administration (NOAA), National Center for Atmospheric Research (NCAR), and International Research Institute for Climate and Society (IRI). The article examines how personal, institutional, and geographical situat-edness affects scientists’ motivations and research practice. It explores how scientists and their institutions conceptualize what ENSO is and how it should be understood and referred to. The study thus represents an upstream interrogation of a climate mode that has many downstream implications in disaster management and development. It is informed by literature within science and technology studies (STS), as well as by recent scholarship in critical physical geography that seeks to understand the influence of politics, economics, morals, and ethics on the production of environmental science.

The article begins with a brief history of ENSO research, before outlining the methodology adopted in collecting and analysis of interviews with scientists. It examines scientists’ motivations, their collaborations, and the object that is constructed through their research practice, revealing a network of scientists who are highly motivated by the societal implications of their work but unwilling or unable to engage meaningfully with those who their work affects, particularly outside of the United States. The article thus draws particular attention to the institutional pressures and constraints that inform how ENSO is researched and forecast and how the research and forecasts are presented and received outside of the scientific community. The article concludes with a consideration of the implications of these findings for the broader politics of climate risk and presents a major new research agenda on the critical geographies of the production, translation, and use of ENSO knowledge.

The Construction of ENSO

ENSO research has long been dominated by scientists from North America—as well as Australia, Western Europe, Japan, and recently China—
although the phenomenon was first catalogued in Peru and was originally thought to primarily affect northwestern South America (Carrillo 1892). The marginalization of South American researchers began relatively soon after the first scientific interest in the phenomenon, at the turn of the twentieth century. North American interest has been driven by the effects of El Niño on guano production and Peruvian fisheries (Cushman 2004b) and later as an opportunity to spread U.S. soft power through scientific collaboration with Latin American countries during the Cold War (Cushman 2004a). U.S.-based researcher Jacob Bjerknes developed the first—today broadly extant—conceptual model for ENSO in 1969 (Bjerknes 1969), linking El Niño with the Southern Oscillation, itself a product of Western imperial science in British India (Adamson 2020). U.S. scientists dominated the Tropical Ocean Global Atmosphere project from 1985 to 1994 (McPhaden et al. 1998), and U.S. media also dominated international framings from the 1990s onward with the widespread coverage of the 1997–1998 “El Niño of the People” (Glantz 2015, 95; see also Grove and Adamson 2018).

Despite ENSO research being centered on the United States, ENSO is a phenomenon that is considered to be global in reach. It is traditionally associated with flooding and landslides in Peru and Ecuador, including notable recent flooding events in 1983 and 1998 (Grove and Adamson 2018), although the first systematic attempt to map ENSO “teleconnections” (areas where meteorological variability is related to ENSO) by Ropelewski and Halpert (1987, 1607) showed El Niño events to be associated with precipitation anomalies across the world, including Australasia, Central and South America, Indonesia and the western Pacific islands, southern and east Africa and the Indian subcontinent, as well the United States. El Niño has been implicated in famines in Indonesia, Papua New Guinea, and the Sahel throughout the twentieth century. Regions receiving elevated (diminished) rainfall under El Niño conditions are also often associated with diminished (elevated) rainfall during La Niña; that is, years with central Pacific conditions roughly opposite to El Niño.

ENSO forecasts underpin regional climate outlook forums in a number of countries, due to its widespread reach and the apparent increased accuracy of precipitation forecasts during El Niño and La Niña years (Goddard and Dilley 2005). Forecasts are used widely in Africa (Orlove and Tosteson 1999; Tozier de la Poterie et al. 2018), South America (Gülinga and Mascarenhas 2009), the Caribbean (Guido et al. 2016), and fisheries management in Peru (Broad, Pfaff, and Glantz 2002). ENSO forecasts have been labeled both as “science’s gift to the twenty first century” (Glantz 1994) and as “shades of chaos” (Glantz 2015), due to their utility in enabling greater preparedness for hydrometeorological hazards and occasions where forecasts have failed or accentuated hazard impacts. Notable instances of the latter include Zimbabwe in 1997, where farmers were denied agricultural credit on the basis of an anticipated drought that turned out to be less severe than expected (Orlove and Tosteson 1999) and flooding in Peru in early 2017 associated with a “coastal” El Niño that was not anticipated by ENSO forecasts (Ramírez and Briones 2017). Further instances of forecast failure include a widely forecast El Niño in 2012 that was far weaker than expected (Ludescher et al. 2014) and anticipated El Niño conditions in 2014 that did not materialize until 2015 (Glantz 2015).

Definitions of ENSO vary between countries, related at least partly to inconsistencies over the use of the term El Niño between regions and over time. The term originally related to an annual warm water current off coastal Peru and is used now to refer both to Pacific-constrained events and patterns of global variability (Adamson 2019). U.S. definitions, however, remain dominant, particularly the World Meteorological Organization (WMO) definition of “positive sea surface temperature departure … in the Niño 3.4 region,” which was originally developed by NOAA (2003, 2005). The Niño-3.4 index of central Pacific sea surface temperatures (SSTs) that underpins this definition is also an NOAA product (Bamston, Chelliah, and Goldenberg 1997; Figure 1); NOAA and IRI jointly release the monthly IRI-CPC ENSO “Diagnostic Discussions” and weekly updates of “Recent Evolution, Current Status and Predictions,” which incorporate ENSO forecasts produced around the world and are widely used inside and beyond the United States. U.S. scientists are therefore highly influential, both in research and in forecasting of the phenomenon.

Previous work on the use of ENSO forecasts in regional contexts has been primarily user focused, highlighting the importance of information that users recognize as salient, credible, and legitimate.
Research in this area has focused almost entirely on boundary organizations that translate forecasts (see, e.g., Orlove and Tosteson 1999; Tozier de la Poterie et al. 2018) and not on the production of ENSO forecasts or ENSO science itself. The notable failures of ENSO forecasts listed earlier highlight the importance of focusing upstream to understand how ENSO research is practiced and how this itself relates to ENSO forecasting. This study thus responds to this deficit by exploring ENSO research and forecasting as practiced in the United States.

Methodology and Conceptual Framework

This article is informed by the idea of situated knowledges (Haraway 1988) and the “idiom of coproduction” (Jasanoff 2006), which argues that science is both a product of and an actor on the society within which it is created. Geographers of science have shown how processes of coproduction of science and the social order occur in, and are shaped by, particular places. As such, this project is also informed by work within geographies of climate science (Demeritt 2001; Laborde 2015; Mahony and Hulme 2018) and by the nascent field of critical physical geography. This field seeks to foster colearning between the physical and human sides of geography and aims to encourage scientists to “understand and recognize the politics that shape both their own research and the systems they study” (Lave et al. 2014, 6). Research in the field is much more strongly engaged than conventional STS and specifically seeks to change how science is practiced. The article is particularly influenced by the work of Tadaki and others (Tadaki et al. 2015; Tadaki 2017; King and Tadaki 2018), which seeks to understand how scientists can bring about “better—rather than worse—social worlds (however defined)” through critical reflection on their own practice (Tadaki 2017, 79). Research within this subfield of critical physical geography effectively operationalizes some of STS’s core arguments; that is, because the choice of research question—as well as theory, methodology, scale, language, the extent to which research is conceived as an answer to a particular problem, and the legitimization of findings within broader network—is affected by a myriad of cultural, institutional, and political factors, a closer attention to these factors could result in a knowledge that is attuned to particular societal concerns, as well as being scientifically valid (Nightingale 2016). This includes a focus on the role of institutions, including those within which a researcher is working and that will draw a researcher toward particular funding models, research questions, and methods (Tadaki et al. 2015), as well as those beyond the research process that might (de)legitimize knowledge or use it to inform particular visions of the future (King and Tadaki 2018).

The interviews for this project were conducted at NCAR and NOAA-ESRL (located in Boulder, Colorado) during June and July 2016 and at IRI (located in Palisades, New York) during July 2016. Additional interviews were conducted with U.S.-based researchers presenting at the session “ENSO: Dynamics, Predictability and Modeling” at the European Geosciences Union General Assembly 2016, incorporating researchers based at NOAA-CPC (Climate Prediction Center), NOAA-PMEL (Pacific Marine Environment Laboratory), and one university-based researcher who conducted their PhD at Columbia University, where IRI is located. One further university-based researcher, who was conducting research at the institution at the time of study, was interviewed at NCAR. A total of fifteen interviews were conducted; interviewees were selected based on extant or former affiliation with NOAA, NCAR, or IRI/Columbia and a research history within the field of ENSO. The nature of this varied due to the differentiation of research foci: Most NOAA employees were directly or indirectly involved in ENSO forecasting, particularly the ENSO Diagnostic Discussion and the associated IRI-CPC ENSO prediction plume; interviewees at
NCAR primarily worked on the Community Earth System Model (CESM) and hence were dynamicists rather than forecasters. IRI was created in specific response to ENSO forecasting requirements (Orlove and Stotson 1999) and is the only establishment that created harm in society (however defined) and not separated from the “concerns of ordinary people” (125). research as practiced today. Four key themes emerged through the coding process: scientists’ motivations and research practices, the path to knowledge for ENSO and the scale at which it is understood (i.e., its epistemology), how ENSO is conceptualized by the scientists, and the role of institutional pressures around definitions and forecasts in constraining these conceptualizations.

Findings

Aims and Practices of ENSO Research

Of the respondents who classified their own disciplines, three defined themselves as climate dynamicists (NCAR1, 2, U1), two as forecasters (NOAA1, 2), and two as oceanographers (NCAR3, NOAA3). Individual interest emerged as the main driver of respondents’ research on ENSO; scientists were attracted by the scale, complexity, and interdisciplinarity of the research problem, the latter discussed as both an appeal and a challenge (NCAR3). Several researchers drew inspiration from their own experiences of previous El Niño events, particularly in 1982–1983 and 1997–1998 (IRI 1, NCAR3, NOAA3, 4). One scientist returned repeatedly to his family’s history of agriculture in an ENSO-sensitive region (U2), and another discussed the substantial job satisfaction received from working with children on the 2009 El Niño on a central Pacific island (U1). There was little evidence of scientists being driven by curiosity alone or of a lack of interest in research applications, as has been assumed in previous studies (Broad, Pfaff, and Glantz 2002). Rather, several researchers discussed the appeal of the research’s societal implications and its applications for various groups (IRI1, 2, NCAR5), be they specific stakeholders (NCAR5, NOAA2) or broader conceptions of society (NCAR1, NOAA4). Researchers expressed a desire to create “useful science” (U2) with “broad applications” (IRI2), with a recognition that ENSO was related to meteorological extremes that created harm in society (however defined) and that the research could help to alleviate this harm. These findings are in line with Bray and Von Storch’s (2016) survey of climate scientists, which found that the majority agree that their research should be linked with “public moral and political concerns” (119) and not separated from the “concerns of ordinary people” (125).
The extent to which participants had considered how their research might affect communities beyond the academy, however, varied significantly. Several researchers had a specific remit toward producing products for other scientists. NCAR, in particular, followed Laborde’s (2015) archetype of a “heterotopic” modeling center, with scientists primarily understanding ENSO through the CESM, rather than as patterns of hydrometeorological variability that affect particular communities. These scientists considered that it was not their role to communicate with “the general public” (NCAR4), and they lacked the requisite skill set (NCAR5). This was explained by one NCAR researcher:

My goal as a researcher is more to provide analyses, information, ways of doing things, building understanding that can have an influence on something that gets into routine operations. … But then it’s the goal of operations to put out different products and to help to disseminate that information; and then there’s the private sector that gets involved in further polishing the information and in dealing with the general public. So, there’s a number of steps along the way there … and I certainly don’t do all of it by any means. (NCAR4)

No scientists, however, considered their research as “blue-sky.” Rather they were all concerned with what Aufenvenne, Egner, and von Elverfeldt (2014) referred to as research that is “socially relevant,” with a “strong orientation toward societal needs” (122); that is, the science was “Mode 2” (see Gibbons et al. 1994). All researchers expressed a strong desire for their research to have societal benefits, with sentiments such as “I do it for humanity” (NCAR1) or “all aspects of humanity that is sensitive to climate information” (NCAR2), echoed by a number of participants. For NCAR scientists, the primary method by which they believed their research would benefit society was through improvements in forecasting. Forecasts were discussed by scientists across all organizations as being a self-evident social good, with little consideration of how they might be used or misused.

Scientists whose research led them to be directly involved in forecasting had a much stronger sense of their users, particularly those at IRI and NOAA. Water managers and agricultural organizations were mentioned regularly, as well as fisheries and wildfire managers. Several researchers who produced their own forecasts had direct relationships with users; for example, the following forecaster based at NOAA-ESRL:

At one point I suspended the forecasts because we had to re-tool it … and I got this email from the head of the Cattlemans’ Association in Namibia saying you’re putting up your Niño-3.4 forecast but what about your optimal structure, and by the way we found that it actually gives the best forecast at seven months not at nine months like we had at that point. And so, I mean, you know, do not ever think that your users are going to be naive! (NOAA5)

The institutional remit of NOAA, however, constrained these interactions among NOAA employees. Interviewees based here were clear that their intended users were “taxpayers” (NOAA3) or “the American people” (NOAA5), the result of institutional priorities that one interviewee described as having become more U.S.-focused since they had joined the organization (NOAA5). One corollary was to limit the potential for NOAA employees to produce work aimed at ENSO teleconnection regions beyond the United States or to collaborate directly with scientists outside of the country. NOAA’s remit as a “mission-oriented government agency,” however, was also described positively by one NOAA scientist, allowing the organization to “attack long-standing problems that may not pay off right away” such as ENSO forecasts (NOAA3).

Scientists based at IRI showed the closest engagement with nonscientists, reflecting the organization’s unique position as a “neutral broker” between scientists and users (IRI2). One IRI scientist described having “almost canned responses” to questions from the public, because they received them so regularly (IRI3). IRI’s remit to “serve the globe” meant that employees of the organization also had the most direct engagement with communities in ENSO teleconnection regions in the Global South (IRI3). One IRI researcher, however, explained that U.S. science funding discouraged these kinds of engagements, with NOAA diverting only minimal resources to international work and the National Science Foundation (NSF) uninterested in research with a practical focus (IRI2).

One IRI employee discussed a forecast-based financing pilot during the interview, developed with the World Food Program for the 2015–2016 El Niño (IRI2). This new link between ENSO forecasts and capital apparently represents the latest stage in a relationship between ENSO science and finance, dating back to the first forecasts in the early 1990s. An interviewee who had designed an early ENSO
model lamented their early take-up by commodities brokers, rather than as a benefit for poor farmers (IRI1). Commodities or futures traders were mentioned as important users by several researchers, although it is perhaps notable that these were only mentioned by those based or formerly based on the U.S. East Coast; financiers were not mentioned by any interviewees located in Boulder, including those who generated their own forecasts. These emerging relationships between the geographies of finance and climate science would merit closer attention.

**ENSO Epistemology: Models and Scales**

Despite a variety of disciplinary backgrounds and methodologies used by the scientists interviewed for this project, the interviews presented evidence that ENSO research is converging on general circulation models (GCMs) as the primary methodology for understanding variability and forecasting future patterns. Although no interviewees primarily defined themselves as modelers, most highlighted the primacy of models within ENSO research practice, and improvements in models were overwhelmingly given as the most pressing research questions in ENSO science going forward. Several researchers discussed a “hierarchy” of models, with simple and highly parameterized models helpful for understanding underlying ENSO dynamics but GCMs ultimately holding epistemic primacy. One researcher described how their understanding of ENSO dynamics emerged primarily from examining model outputs, rather than the observational record (U1).

Participants discussed a complex and multidirectional “path toward knowledge” (NCAR1) between models and an often incomplete observational data set. Several noted the importance of observations in validating GCMs; one creator of an early ENSO model explained that they had deliberately produced a model that had sufficient spatial complexity to represent the Rasmusson and Carpenter (1982) composite of El Niño observations, which was dominant at the time, believing that the model would not otherwise be considered credible within the scientific community (IRI1). Others described the importance of models in ascertaining the significance of trends in the observational record, which is itself sometimes “part model” if derived from reanalysis data (a method to fill gaps in the observational record using models; NCAR5). One interviewee, who described themself as a climate phenomenologist, described this path to knowledge as:

> Very circular! … But I don’t think … in terms of we’re not getting anywhere. I see it as a two-way street … don’t take the limited sampling that we have from nature as the ground-truth for your model. (NCAR1)

Another summarized this as “the models are king … and there’s the potential for observations to dethrone all models” (NCAR5).

The prominence given to GCMs within ENSO research was related to a widespread perception that the primary mode of translating the research into societal benefit was through the process of forecasting. GCMs were commonly expressed as offering the greatest potential for future improvements in forecasting, although they currently produce only slightly higher skill than simpler dynamical or statistical models. Several interviewees also drew attention to the importance of GCMs in understanding future changes to ENSO under anthropogenic climate change, with one researcher—themself a statistician rather than a modeler—describing GCMs as being “in the long term … the only way to understand climate change” (NOAA2). Climate change was brought up by most researchers during the interviews, generally without prompting, with all respondents agreeing that climate change would affect ENSO in some way, although with little agreement on the specific nature of anticipated changes (Vecchi and Wittenberg 2010). Two interviewees suggested that this focus on climate change impacts, and hence GCMs, might be related to constraints in funding. One researcher described the NSF as “notoriously bad about wanting to fund anything practical,” pushing researchers toward subjects more likely to be successfully funded such as “El Niño and climate change or something like that” (IRI2). Another university-based researcher reflected on this more explicitly in the context of grant applications:

> The first sentence of every proposal that you have to connect with the bigger picture, … and it’s a problem in climate science because there’s so many direct impacts that we’re all always, I think, exaggerating the impacts of our research. And I think it has hurt us because science can also be done without a clear application. … The oceanographers have hurt themselves a lot, because they try to ride the climate change bandwagon and then they realize you also need to understand how the ocean works. Independently of whether it’s important for climate change or not. (U2)
Höhler (2017) showed how the introduction of remote sensing imagery in the 1990s shifted the scale at which ENSO was primarily understood toward a top-down, global-scale conceptualization. The increasing importance of GCMs highlighted in the interviews is likely to accentuate this shift, something that Leyshon (2014) previously described as a “path dependency of scale” (362) that has affected many forms of climate research. Several scholars have written about how such a focus can crowd out research on local-scale meteorological extremes and obscure cultural readings of weather and climate (Jónslóttir 2012; King and Tadaki 2018; Heymann 2019). This looks to also be the case with ENSO: Although the scientists expressed a recognition of the need to understand variability at the local scale, this was generally to be achieved through downscaling or translation of global-scale forecasts and through the use of boundary organizations rather than scientists working directly with affected communities. Given that global-scale formulations of ENSO have the potential to inform local understandings of the phenomenon, how ENSO is conceptualized in these forecasts and for whom the conceptualization has been developed become important questions.

Conceptualizing ENSO

All participants in this study specified that ENSO constituted an aperiodic, coupled ocean–atmosphere phenomenon with its primary manifestation in central Pacific SST. There was general agreement that El Niño constituted the oceanic component of the phenomenon and the Southern Oscillation the atmospheric, although one interviewee mentioned divergence from this definition among the oceanography community:

A lot of folks think of ENSO as just the ocean. There’s a lot of oceanographers in this field, and so as such there is a propensity for some oceanographers to want to call it El Niño when the ocean [alone] qualifies. … I want to see the atmosphere respond, the winds, sea level pressure, convection, because ultimately that’s what it is, it’s a coupled phenomenon. (NOAA1)

Beyond this, participants displayed considerable variability in their conceptualization of ENSO, related to their disciplinary background, primary methodology, and the purpose for which ENSO was being defined. Researchers disagreed on whether ENSO is a bounded or holistic component of the atmosphere, with responses ranging from ENSO as a distinct tropical or equatorial phenomenon that could affect and be affected by the changes elsewhere to a holistic feature of the entire climate system. One interviewee classified ENSO as “tropically confined” in the oceans but “global” in the atmosphere (NCAR3). Another specifically defined teleconnections as distinct from ENSO, representing “the response of the global atmosphere to ENSO variations in sea surface temperature” (U2). Several researchers questioned the expediency of the terms El Niño and La Niña, notably the “very mistaken notion that El Niño is bad and La Niña by implication is not so bad” (NOAA2). One interviewee expressed a preference for the term “El Viejo” (NOAA2), an alternative name for La Niña offered in the 1990s but not widely adopted (Meyers and O’Brien 1995). Another argued that the three-stage categorization of ENSO (El Niño, neutral, La Niña) is insufficient to capture diversity and there should be more reference to ENSO flavors (NCAR4). Finally, there was some inconsistency over the use of ENSO to refer to the whole system, with seven researchers using the term “ENSO event” to refer to El Niño or La Niña events (IRI1, NCAR1, 3, 4, 5, NOAA2, 3).

Disciplinary norms were evident, with conceptualizations reflecting the scale at which the researchers were working and at which they encountered ENSO. Oceanographers were more likely to view ENSO as an oceanic phenomenon, climatologists as a coupled–ocean atmosphere event, and statisticians as a holistic feature of the climate system. Those with a particular interest in ENSO forecasting classified it as an entity with its own agency in regulating meteorological conditions elsewhere, and those who encountered ENSO through research on other aspects of the climate system defined it as a holistic component of the atmosphere and ocean. Similarly, three of the researchers who located ENSO in the equatorial Pacific did so because they used or wrote models that could replicate ENSO variability only by representing this region (IRI1, U1, 2), and the researcher who argued most coherently for a holistic understanding of ENSO worked primarily with GCMs (NCAR5).

There was also some disagreement on whether El Niño and La Niña should be considered events or
part of a continuum. Some researchers were clear that both are events, others forcefully argued for acontinuum, and others stated that the phenomenon could be conceived of as either an event or continuum depending on the research question being asked. This was again partly related to disciplinary background, with two researchers who had devised statistical representations or forecasts of ENSO arguing most strongly for continuum-like behavior (NOAA5, IR13). Another two interviewees suggested that El Niño should be considered as an event, but not La Niña (NCAR2, 3), with the latter only event-like because “once we’ve isolated one phase as an event the climatology around such events demands there be a negative phase” (NCAR2). One scientist described the “consensus in the expert community” as ENSO being a “weakly-damped stable system” (NOAA3); that is, El Niño should be considered as discrete events but there are certain times of year—notably boreal summer—where the system adopts continuum-like behavior and it would be easier for an event to occur.

It is notable that there was little evidence that researchers considered their own conceptualization of ENSO as more correct than others. Rather than appeals to the production of “objective truth” (Aufenvenne, Egner, and von Elverfeldt 2014, 121), researchers were clear that their understanding of ENSO was necessarily partial, and in some cases context specific. One NCAR researcher, who defined themselves as a climate dynamicist, stated that they liked the “broad global view of things, energetic view,” but this was “just not the way I do things” (NCAR1). Another university-based researcher adopted a pragmatic position, arguing that it was helpful to view El Niño and La Niña as events primarily for communication purposes, which allows communities to prepare for impacts (U1). The same researcher stated that their understanding of ENSO would vary depending on the purpose of the research:

I think it depends on what you’re looking for, why do you think it’s useful, like if you’re interested in the impacts then you see them as events because seeing them as a continuum, it doesn’t help you that much. ... [If] I’m looking at how El Niño is recorded in palaeoclimate proxies, they would record events, they wouldn’t record necessarily a continuum in the sense that you will see it in a model and in a more dynamically driven study.

**Institutional Pressures and Constraints on ENSO Research**

In response to the question regarding ENSO’s nature as an event or continuum properties, one NOAA employee provided the following answer:

So my agency likes to have a definition and there is some push-pull there because I think most scientists working in the field recognize it not to be a binary on-off thing. I’m certainly one of those folks ... but, however, we work with an organization ... a government and their demand, really—ultimately it is a demand—is for you to define it. And so there is some push-pull there. (NOAA1)

The role of NOAA in constraining conceptualizations of ENSO was mentioned by a number of the scientists, both inside and outside the organization. This particularly related to the preponderance of three related NOAA products: the NOAA-WMO operational definition of ENSO (discussed earlier), the Niño-3.4 index on which it was based, and the IRI-CPC ENSO Diagnostics Discussion, which partly relies on the definition. The former was first adopted in the United States in 2003 following the 1997–1998 El Niño and subsequently across WMO Region IV in 2005 (NOAA 2003, 2005), following a concerted drive by senior officials in NOAA to obtain international agreement on the operational definition of ENSO (Mullan 2007). The definition uses the Niño-3.4 index, developed by Bamston, Chelliah, and Goldenberg (1997) from average SSTs in a region of the central Pacific defined as being “strongly correlated to the core ENSO phenomenon” (367). The ENSO Diagnostic Discussion is a joint release by NOAA and IRI that presents weekly and monthly summaries of ENSO conditions and forecasts of various ENSO parameters, centering on a plume of ENSO models compiled by IRI and presented as a forecast of Niño-3.4 SSTs.

Two researchers discussed the background and justification for the NOAA-WMO definition, deriving from a desire among NOAA management for a simplistic classification that could underpin ENSO forecasts and the operational declaration of ongoing El Niño or La Niña conditions (NOAA1). This was apparently precipitated by experiences during the 1997–1998 El Niño, as explained by one researcher at IRI:

If this were just this sort of wish-washy not set down in stone definition of El Niño; some forecaster at Climate Prediction Center just said, “Well, looks like
an El Niño to me!” … and then they’re like “What’s this even based on? These people at the Climate Prediction Center they don’t know what they’re talking about!” In the 97–98 event actually there were people, in California again, who wanted to sue NOAA because in December the rains hadn’t come yet, … and they had invested all this money to change their roof etc. … He didn’t succeed in his lawsuit, but you kind of need to have a definition. (IRI1)

The NOAA-WMO definition replaced an earlier definition put forward by the Scientific Committee for Oceanic Research (SCOR) in 1982 that was never widely used (IRI1), representing ENSO as “the appearance of anomalously warm water along the coast of Ecuador and Peru as far south as Lima” (SCOR 1983, cited in Trenberth 1997, 2772). The decision to define ENSO based on a broad spatial understanding of ocean and atmosphere variability—rather than patterns of variability in the eastern Pacific—is significant, because it effectively excludes Peru from the official conceptualization of ENSO. The implications of this manifested in 2017—six months after these interviews were conducted—when conditions defined as El Niño Costero (coastal El Niño) produced severe flooding in northern Peru but were not picked up by the NOAA products (Ramírez and Briones 2017; Garreaud 2018). This event was classified as El Niño under the Peruvian Indice Costero El Niño (ICEN; Takahashi et al. 2014) but classified as a weak La Niña under the NOAA-WMO definition, due to a lack of warming in the Niño-3.4 region. The implications of this are discussed further in Adamson (forthcoming) and returned to later.

Scientists interviewed here expressed mixed views of the Niño-3.4 index, although few were strongly positive. Some adopted nuanced positions, highlighting the usefulness of Niño-3.4 as a “credible climate index” that is helpful for user understanding and communication (NCAR1, 2, IRI2) and highlighting the high correlation of Niño-3.4 SSTs with other indicators of ENSO variability (IRI1, 2). Others were more critical, citing lack of historical SST data and the tendency for Niño-3.4 to overclassify El Niño and La Niña events (NOAA2) and the inability of a single definition to capture changes in baseline conditions or seasonal variability (NOAA5). Interestingly, this criticism included a researcher who had been instrumental in the production of the Niño-3.4 index, who supported the “compromise” index but criticized the decision by NOAA to base their definition on uniform deviations from the mean, hence obscuring the annual temperature cycle (IRI3). Several researchers criticized SST-based indexes altogether, which fail to capture seasonal variations or diversity in ENSO conditions; one NOAA-ESRL scientist described Niño-3.4 as “as good as any, and they’re all bad!” (NOAA5). Two researchers (NOAA2, 5) suggested the Multivariate ENSO Index as a more suitable alternative (Wolter and Timlin 1993), although one NCAR scientist suggested that this index “sometimes kind of goes off on its own thing and deviates a little bit away from what’s really going on in the ocean” (IRI2). One NCAR researcher discussed the importance of having multiple indexes without overtly focusing on one:

It depends on what question you’re asking again. … If you’re trying to ask the question of “Was 2015–16 stronger than 97–98?” that’s going to be dependent on the nuances of the index you look at. Whether, if you’re going to ask the question of whether 2015–16 was an El Niño, that’s not going to depend so much! … But some of the nuances can definitely depend on the index you’re looking at, and they can also be modulated by other modes of variability. (NCAR5)

Despite these criticisms, several researchers highlighted the widespread uptake of the NOAA definitions and index within the United States and beyond. Interviewees related this partly to NOAA’s power and influence and partly to a lack of resources in other countries:

There is a tendency … with governments around the world trying to come up with one index so they don’t have to have debates whether or not it is an event or not, it’s the same with the index itself. … It’s not a landslide if you will, the vote for Niño-3.4, it’s just that when you have a big, powerful organization like NOAA saying that this is the index we use, people will tend to follow suit. It’s a bit like the influence of Germany on the European Union. (NOAA2)

I think a lot of users are interested in what their climate is going to do because of the ENSO. And it seems like a lot of their local governments don’t give them enough information, so they come to [IRI], or maybe to NOAA. NOAA has very high respect I’ve noticed, like when I go to training, everyone has their maps. … I think NOAA has the clout, because their products are regarded as official. (IRI3)

One NOAA scientist involved in the production of the IRI-CPC ENSO Diagnostic Discussions reflected
on this international influence in the production of
the bulletins, which are easily accessible online:

I know there’s an international audience, but I’m
almost uncomfortable with that because ultimately
we’re at the behest of the U.S. taxpayer. … I’m
actually fairly good friends, I guess you would say, with
the Australian ENSO lead and also the Peruvian one,
and they do a great job with their updates. … So I
informally will tell them, heads up … because I’m
aware that there is a ripple effect from what we say.

But with that said, we try and make it clear that we’re
doing this for U.S. interests, and … we’re not trying
to step on other people’s toes … because obviously,
one of the reasons we’re probably going to fail to find
that perfect index is that ENSO affects different places
differently. (NOAA1)

Researchers involved in the production of the
Diagnostic Discussion explained its generation. The
Discussion incorporates forecasts from multiple
dynamical and statistical models, produced in seven
countries and selected by IRI using expert judgment.
Unweighted means of the various forecasts are used
to produce the “plume” of values in Niño-3.4. This
underpins generated probabilities of El Niño, La Niña,
and neutral conditions over the coming months, derived from the forecasts and other indica-
tors of ENSO conditions, produced using a mixture
of objective and subjective analysis by a panel of
eleven forecasters, with feedback sought from around
fifty others across a variety of disciplines (NOAA1,
IRI3). Decisions on whether to classify existing con-
tions as El Niño or La Niña are made using a com-
bination of the NOAA operational definition and
expert judgment, in the form of a democratic vote of
the panel of forecasters, with the NOAA ENSO
lead providing the casting vote. At the time of inter-
viewing, NOAA-CPC had recently launched an
online blog to “provide some of the nuance … so
that [the users] can begin to understand some of
these … subtle distinctions and why we’re declaring
and why we’re not” (NOAA1).

Scientists involved in the production of the vari-
ous ENSO forecasts and the Diagnostic Discussion
therefore clearly recognized the diversity in concep-
tualization of ENSO. There was a strong sense, how-
ever, that the reductive and simplistic outputs of the
products constrained conceptualizations of ENSO,
both in the United States and beyond. The apparent
simplicity of the NOAA products obscured some of
the diversity in understanding exhibited by the
scientists and, moreover, presented a global unified
definition of ENSO that was particularly suited to
U.S. applications. This had particularly stark impli-
cations in 2017, when El Niño–like conditions in
Peru were excluded from global ENSO forecasts as
conditions did not match the NOAA definition,
contributing to the scale of devastation from the
associated flooding (Ramírez and Briones 2017).

Discussion and Conclusions: Toward a
Critical (Physical) Geography of ENSO
Research Practice

This study has explored the practice of construct-
ing ENSO through interviews with scientists based
at IRI, NOAA, and NCAR. The study revealed
ENSO to be multifaceted, with scientists holding
multiple partial and sometimes conflicting conceptual-
izations. ENSO is, however, primarily and increas-
ingly understood at a global scale, largely due to the
increasing dominance of GCMs in ENSO research.
This was chiefly an outcome of the belief that
research could be best translated to impact through
forecasting and partly due to the importance placed
by the scientists and funders in understanding ENSO
variability under anthropogenic climate change. This
increasing tendency toward the global has the poten-
tial to produce “epistemological tensions” between
the global ENSO constructed by science and the
local meteorological phenomena experienced in
regions considered to be affected by ENSO (Höhler
2017, 2), and merits further analysis.

The findings here reveal these tensions to be
enacted primarily at the site of ENSO forecasts.
Although scientists understood that ENSO could be
conceptualized in multiple ways, the preponderance
of the NOAA definition and forecasts generates a
specific view of ENSO as being reducible to specific
derivations within a single SST index. This ten-
dency toward a reductive understanding of ENSO
might be a corollary of the scale at which the phe-
nomenon is understood by the scientists: Viewing
ENSO at the global scale requires unpicking an
ENSO signal within a myriad of temperature, sea
level, thermocline depth, atmospheric, and ocean
current anomaly data across the entire globe. A
desire for a simple index that can capture all vari-
ability is therefore understandable, either a compro-
mise index such as Niño-3.4 or an index
incorporating multiple lines of evidence like the Multivariate ENSO Index.

A more significant driver, however, is apparently NOAA’s influence and its status as an official forecaster. This can have significant implications: The Niño-3.4 index and associated definition were created through a desire for simplicity and accountability in forecasting. The ubiquity of NOAA forecasting products, however, can create an impression that Niño-3.4 is ENSO, with implications for disaster management, as occurred in 2017. It also has potential repercussions for other branches of science. For example, one university-based researcher discussed the implications of this simplistic understanding of ENSO on paleoclimatic research (U2): Simply correlating these indexes with past climate variability revealed in proxy records can create a partial and often distorted understanding of historical ENSO variability and its relationship to variability in other parts of the world.

The findings here point to a need for a new research agenda to explore the implications of the dominance of the Niño-3.4 index and the NOAA forecasting tools, beyond science and in allied fields such as paleoclimatology. One purpose of this project was to assess the extent to which ENSO scientists could “enact better … social worlds” by adopting a critical sensibility within their own research (Tadaki 2017, 79). The scientists were highly motivated by the societal implications of their own research and “critical” of their practice, to the extent that they understand that their research is necessarily partial and that models “are human constructs” (NOAA1). The researchers were limited in their commitment to specific normative concerns, however, and many had a very partial understanding of the societies that their research was impacting. Several had never visited areas considered to be affected by ENSO variability outside of the United States or even collaborated with scientists outside of the Global North. They instead had a normative commitment to forecasting: The hope that their research would improve forecasting was considered sufficient in itself to meet their aims of a societal benefit.

ENSO knowledge production would therefore benefit from greater engagement between modeling centers and regions classified as affected by ENSO, given the significance of ENSO forecasts to disaster risk management and the strong belief held by all of the researchers here that forecasts can produce a direct societal benefit. If we accept, following Haraway (1988), that knowledge is partial and it has geographies, a greater understanding by the scientists of the places that are affected by these forecasts would likely have a positive impact on the research being produced. For example, the legitimacy of a forecast model is presently determined largely by the scientific community. A shift in focus toward users would be helpful, as has occurred with success in some areas such as Queensland, Australia (Orlove and Tosteson 1999). Forecasts could be legitimized through, for example, their ability to predict specific meteorological anomalies in regions considered sensitive to ENSO-related meteorological variability, rather than SST variability in Niño-3.4.

Many scientists interviewed here, however, had limited space to connect the “specific content of science with the specific political and institutional contexts in which it is made meaningful” (Tadaki 2017, 80). This was often constrained by the institutions within which the researchers were situated. Unlike university scientists, who have much more freedom over their research commitments, the researchers here were restricted by the remits of their organizations. For example, some researchers at NCAR had a primary responsibility toward building and using the model outputs of the CESM, limiting their potential for understanding the implications of the research beyond the academy. NOAA employees were constrained by the focus on generating forecasts for U.S. applications, with engagement beyond the United States often occurring on an ad hoc basis. As others have previously argued (Dilling and Lemos 2011; Glantz 2015), it is therefore perhaps unfeasible to expect that all scientists can take responsibility for the uses and meanings applied to their research.

Future research on the critical geographies of ENSO should therefore focus on the role of institutions in constraining and informing how the research is practiced and, more important, how it is translated and presented beyond science. A particular focus should be NOAA, given its apparent influence in informing the global conceptualization of what ENSO entails and what its associated risks are. The findings presented here show that Mode 1 science (i.e., science with theoretical rather than practical aims) is rarely being practiced. Research is instead designed to inform forecasting, and most forecasts—whether built in the United States or not—are ultimately being filtered through NOAA,
in the form of the IRI-CPC forecasts and bulletins. A critical analysis of how this research is being produced and the societal formulations that it reflects and enables would need to go beyond a focus on scientists’ own practice. It is not enough simply to view scientists as “institutional subjects” capable of questioning and reworking their own institutional practice (Tadaki et al. 2015, 163). Rather, attention needs to also be turned to those who have a greater influence over the priorities of NOAA; that is, the bureaucrats and politicians who constrain the organization’s mission and to whom or what they are answerable. What are their motivations and constraints? Which subjects do they produce their outputs for (if it is “the American people,” how do they construct these people?)? How does this affect the objects that are being produced through the forecasts, in this case ENSO? Research in government agencies such as NOAA might avoid the metric-driven push to publish characteristic of the twenty-first-century university, but what other (perverse) research incentives are put into place, and how do they affect the particular formulations of the atmosphere that are generated in NOAA’s meteorological and climate science and forecasting?

A deeper understanding of NOAA’s influence on ENSO science and disaster management across the world would therefore be highly valuable. This could include, for example, an understanding of how NOAA products are used by meteorological services and other decision makers outside of the United States and how these products affect the way they understand local hydrometeorological risks. An analysis of the responses to NOAA ENSO forecasts in Peru in 2016 and 2017 would be a useful start. It also would be helpful, for example, to understand the particular manifestation of ENSO that is being used to derive forecast-based financing, which has become significant since the 2015–2016 El Niño (Coughlan de Perez et al. 2015; Tozier de la Poterie et al. 2018). For example, are finances being released on the basis of real-time Niño-3.4 index values, or another quantitative measure, and how does this relate to local readings of ENSO-related drought and flood? Likewise, the relationship between ENSO forecasting and finance hinted at by several researchers would merit further analysis. Although the researchers themselves were not always comfortable with this use of their products, it is intriguing that only those who were based near Wall Street mentioned the use of forecasts by financial traders. A deeper understanding between the geographies of finance and the geographies of forecasting would be expedient, building on work by Randalls (2010) and others on weather futures and the commercialization of meteorology (see, e.g., Pollard et al. 2008).

This article should therefore be seen as part of an emerging critical geography of ENSO research project. Where previous research has focused downstream on boundary organizations, this research has focused upstream on the scientists themselves. Attention should now turn to the institutional structures that constrain the scientists’ practice and how their research is made visible and meaningful to wider society. As a final point, it should be noted that this article is in no way designed as a critique of ENSO scientists. It has shown, however, that ENSO science is essentially Mode 2, with scientists holding a strong belief that their research can be annotated toward specific social requirements through the generation and improvement of forecasts. Turning a critical eye to ENSO science, and the communities affected by it, therefore remains important.

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