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From ice sheets to main streets: Intermediaries connect climate scientists to coastal adaptation

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Despite the societal relevance of sea-level research, a knowledge-to-action gap remains between researchers and coastal communities. In the agricultural and water-management sectors, intermediaries such as consultants and extension agencies have a long and well-documented history of helping to facilitate the application of scientific knowledge on the ground. However, the role of such intermediaries in adaptation to sea-level rise, though potentially of vital importance, has been less thoroughly explored. In this commentary, we describe three styles of science intermediation that can connect researchers working on sea-level projections with decision-makers relying on those projections. We illustrate these styles with examples of recent and ongoing contexts for the application of sea-level research, at different spatial scales and political levels ranging from urban development projects to international organizations. Our examples highlight opportunities and drawbacks for the researchers involved and communities adapting to rising seas.

Enhancing the decision relevance of our science

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Rift appearing in Larsen C Ice Shelf as photographed November 10, 2016. Credit: John Sonntag, NASA.

High-tide flooding in Norfolk, VA in November 2017. Credit: WTKR News 3 Norfolk

There is tremendous popular interest in our changing planet. Media coverage highlights huge, faraway events, like the recent calving of a large iceberg from the Larsen C ice shelf in Antarctica (Figure 1a), as well as more persistent local changes like frequent flooding in coastal communities (Figure 1b). Meanwhile, climate researchers and scientific organizations have called on their peers to intensify engagement with policy-makers and the broader public (e.g. Lubchenco 2015; Achakulwisut 2017; AAAS 2017), emphasizing the policy relevance of their work. Climate change touches many sectors of society that could benefit from science-based knowledge, yet in many cases research expertise does not make it out of academic literature and into decision-making (McNie 2007; Lemos, Kirchhoff, and Ramprasad 2012; Asrar, Hurrell, and Busallachi 2013; Moss et al. 2013). To fully realize the promise of science for the betterment of society, we must narrow the knowledge-to-action gap (Meyer 2011). The task is made more urgent by decisions already being made that ignore or sidestep the best climate information available, potentially compromising future lives, livelihoods, and adaptation options (NRC 2010; IPCC 2012). As climate change researchers, we suggest that we need to take advantage of the growing body of knowledge on how to make climate information more usable and how to better engage with decision-makers across spatial and political scales of decision-making. In this commentary, we describe three relevant styles of intermediation between science and decision-making: networks of public extension agents, climate consulting firms, and organizations established to bridge the science-policy divide (boundary organizations).

The problem we see is one of potential mismatch between the available science and the needs of decision-makers. We are particularly interested in researchers' engagement with adaptation to sea-level rise, as projections of future sea-level changes draw on various areas of expertise such that it is difficult to know which area matches what decision-makers need. For example, glaciologists can estimate how much ice from the world's glaciers and ice sheets will be transferred to the ocean, but expertise on changing ocean currents and the thermal expansion of ocean water would come from oceanographers. Knowledge of the spatially heterogeneous sea-level effects of a changing gravitational field and the Earth's rotational wobble would come from planetary geophysicists. At the local scale, experts including geologists, coastal engineers, and climatologists work to understand factors including land subsidence (or uplift), coastal erosion, prevailing wind patterns, and extreme flooding, which can modulate changes in global sea level by an order of magnitude. A full picture of sea-level change along with the associated risks for decision-makers to consider requires expertise from diverse fields. Further, the highly local nature of sea-level adaptation and the connected spatial scales of decision-making presage a high volume of demand for sea-level projections and expertise, which the scientific community might not be able to meet. This diversity of knowledge and needs suggest that for information to be usable, it will need to be customized to different decision contexts.

Customized information availability, in turn, is a function of the number of people actively working on problems related to sea-level rise, the amount of free time they can offer to engage with decision-makers, and professional incentive structures to do so (Kirchhoff, Lemos, and Dessai 2013).

In some instances, researchers seeking to engage more with the practical application of their work find that success in this domain is not valued by traditional academic recognition systems such as the tenure process (e.g. Ellison and Eatman 2008). Moreover, to communicate information that informs a complex decision may require both special skills and an extended interaction between scientists and decision-makers to build trust. Such extended interactions drive up the transaction costs of engagement (Lemos et al. 2014), which can tend to detract from the level of effort required to conduct lab research, simulations, or field observation.

Finally, adaptation planning and implementation involve different social, political, and economic structures at different scales, which may obscure or delay tangible outcomes and frustrate researchers. Engagement at one scale, e.g. a city planning process, might not translate to eventual outcomes at other scales, e.g. regional or national plans. We believe intermediation can help scientists and decision-makers to overcome these challenges.

Styles of intermediation

Sea-level rise is not the only domain of climate science where demand for information outpaces researcher capacity. Empirical research that explores intermediation in other areas, especially agriculture and water management, is growing (e.g. Klenk et al. 2015, Haigh et al. 2015). Research in this area suggests that intermediary actors and organizations can be invaluable to ensuring a sound scientific and engineering basis for decision-making (Bessant & Rush 1995, Guston 2001), be an important partner in climate information dissemination (Prokopy et al. 2015), facilitate the use of climate information (Cash et al. 2003; Hoppe, Wesselink, and Cairns 2013) and reach decision-makers more efficiently than scientists could (Brugger and Crimmins 2015).

Here we suggest three possible styles of intermediated engagement that may enhance sea-level adaptation decision-making: public intermediation, boundary organizations, and private intermediation.

- **Public intermediation** relies on a large network of extension agents who interact with researchers and disseminate knowledge to large numbers of users and the public. For example, each of the Environmental Protection Agency's National Estuarine Research Reserve sites supports a Coastal Training Coordinator, who performs an intermediary function between relevant coastal management science and regional coastal managers (http://coast.noaa.gov/nerrs/training/). Public intermediation recognizes the value of longer-term relationship building with and embeddedness in communities that are the end points for knowledge application (Brugger and Crimmins 2015): Specialized local agents in public intermediation networks can build on their social ties with end users to tailor scientific information for their specific needs.

- **Boundary organizations** bring together researchers and decision makers to co-create usable knowledge (Guston 2001). The NOAA Regional Integrated Sciences and Assessments (RISA) program exemplifies the boundary organization approach (see e.g. Kirchhoff, Lemos, and Dessai 2013; Stevenson et al. 2016), and an extensive empirical literature has documented boundary organizations' effectiveness in climate decision-making (e.g. Cash et al. 2003; Sarewitz and Pielke 2007; Tribbia and Moser 2008). Non-profits with relationships across science and practice are another example of boundary organizations. For example, researchers working with the Consortium for Climate Risk in the Urban Northeast have collaborated with the City of New York to model and evaluate coastal adaptation options for the city.
- **Private intermediation** occurs when researchers contribute their expertise to the work of for-profit consultants and engineering companies. Private intermediary companies may be contracted to advise decision-making in the public or private sectors, or they may be encouraged to design and carry out adaptation actions themselves, as in the example of Lagos, Nigeria below. Commercial actors may be more empowered than their public counterparts for rapid decision-making under uncertainty. However, the primary objectives of for-profit consulting are self-evident—to make a profit—and thus the price paid by public entities for these services may be higher and less publicly accountable. However, private intermediation may be appropriate where very site-specific science is required and thus more general tools and resources are inadequate.

All three styles of intermediation offer resources beyond standard research grants for scientists and engineers to make their work more usable for decision-makers. For example, extension agents in public intermediation networks can help researchers frame new studies that respond broadly to user needs, and can further help to tailor that broadly relevant information for localized adaptation. Boundary organizations can provide funding, physical space, and structure for productive interactions between researchers and coastal communities. Private companies may invite researchers to consult on specific adaptation projects, or they may offer full-time career opportunities. The different styles of intermediation also give rise to different modes of researcher involvement, with more or less direct interaction between researchers and community stakeholders. Boundary organizations, with their explicit focus on co-production of knowledge, involve the most direct interaction. The costs involved (e.g. finances, time and trust building) for all parties involved are relatively higher. Public intermediation, by contrast, relies on researchers' indirect interaction with end users via a large network of locally specialized extension agents, which can lower costs for both scientists and decision-makers.

All forms of intermediated engagement raise ethical concerns that ought to be addressed. When researcher involvement with decision processes is indirect, lines of accountability become less clear. In cases of private intermediation, research findings may support narrow interests specific to the client, at the expense of the broader public good. The scope of need for informing decisions related to sea-level rise is so vast that efficient, scalable approaches of all styles, including client-driven private sector approaches, are likely to be essential and commonplace. Ethical guidelines are therefore urgently needed. Currently, there are few formalized standards of ethical practice for applying research expertise to climate adaptation planning purposes, though professional groups such as the American Society of Adaptation Practitioners are working to develop such standards.

Intermediaries in practice: a few experiences

To illustrate the process of applying science to plan for sea-level rise, we examine examples of sea-level adaptation at three different scales— an international boundary organization, a nationwide program that can engage both public and private intermediaries, and an urban revitalization plan utilizing private intermediation. The three types of intermediation outlined above are present to differing degrees in each. The examples shed light on the kinds of opportunities and complications arising from different styles of intermediation as implemented in practice.

The IPCC. At the international level, the Intergovernmental Panel on Climate Change (IPCC) is a prominent example boundary organization that, among its other tasks, assesses global projections of sea-level rise and articulates implications for coastal regions. The IPCC draws together scientists and policy-makers from all over the world—though developing nations have historically been under-represented (Hulme and Mahony 2010; Biermann 2002)—to produce policy-relevant assessments and special reports on the state of climate science. Representatives of national governments contribute to determining report outlines (i.e. what topics will be covered) and approving Summaries for Policymakers, but the design of the report-drafting phase in practice limits interactions between scientists and policy-makers (Siebenhüner 2003). As a United Nations-sponsored organization, the IPCC is governed by elaborate and internationally-agreed procedures. Such extensive institutionalization around the science-policy interface is designed to promote accountability between scientists and policy-makers. However, the IPCC's high standard of scientific accountability may sometimes be counterproductive. For example, the large estimated sea level contribution from ice sheet dynamics was excluded until the Fifth Assessment (2013) because the physical processes involved were considered too new and too uncertain (Meehl et al. 2007, Church et al. 2013). Time commitment for scientists participating in the IPCC is high, which may trade off with professional commitments in other areas if not managed well, but offers the potential for societal impact on a very broad spatial scale. While the work of the IPCC may inform National Adaptation Plans of Action, including those of island nations for which sea level is a forefront concern, sea-level change is extremely variable at local scale, and the flow of knowledge from IPCC reports to local implementation is less clear (e.g. Viner and Howarth 2014; Petersen, Blackstock, and Morisetti 2015). This murky path to implementation, along with the low participation of scientists and policy-makers from the global South (e.g. Hulme and Mahony 2010; Biermann 2002), raises questions regarding the most equitable avenues for public engagement. We suggest that sea-level researchers could be more effective by seeking out local- or regional-scale boundary organizations.

Coastal communities and insurance. United States coastal communities participating in the National Flood Insurance Program can apply for discounted insurance rates by completing a selection of eligible risk-mitigating actions under the Community Rating System. The local actions supported by the nationwide Community Rating System may use private (for-profit consultancy) or public (extension agent) intermediation, both of which can facilitate decision-making based on highly tailored information but risk losing a transparent scientific basis. For example, action 410 described in the *Coordinator's Manual* (NFIP-CRS 2017), "Floodplain Mapping", asks planners to demonstrate that they have developed new maps of flood hazard for their area; action 440, "Flood Data Maintenance", asks planners to "use better base maps" (with no indication of what "better" means); and action 510, "Floodplain Management Planning", asks communities to develop and maintain "a comprehensive flood hazard mitigation plan using a standard planning process". The true risk-mitigating capacity of these actions depends strongly on the quality of scientific knowledge they employ. In particular, intermediaries who supply communities with out-of-date or poorly-supported information may help secure lower insurance rates but fail to fully characterize actual flood and other hazard risk. By working with public intermediaries, however, sea-level researchers could train extension agents to incorporate a broader understanding of the physical processes responsible for sea-level rise in their engagement with communities, potentially amplifying the role of research in decision-making. Public intermediation also offers clearer lines of accountability, both between scientist and intermediary and between intermediary and local communities, which in turn may promote more equitable outcomes among residents of adapting communities.

Privatizing risk. In Lagos, Nigeria, where millions reside on coastlines exposed to sea-level rise and resulting enhancement of dangerous storm surges, a large adaptation project is being led by the private sector. Nigerian business conglomerate, The Chagoury Group, with the assistance of Dutch engineering firm Royal HaskoningDHV, has begun construction of a new luxury district, "Eko Atlantic", atop 10 square kilometers of land reclaimed from the Atlantic Ocean and protected by a seawall. The project's sea defenses do not extend to other heavily-populated parts of Lagos; indeed, residents and external observers have expressed concern that the Eko Atlantic development might increase flood risk in other parts of Lagos (Adelekan 2013). Nevertheless, the Lagos State Commissioner for Waterfront Infrastructure Development describes Eko Atlantic as a "life-saver" sea defense for the wealthy and economically important Victoria Island (Ayeyemi 2013). In this example, Royal HaskoningDHV acts as a commercial intermediary for sea-level science, working under contract for the Chagoury Group, whose sole stated aims are "developing industrial links between Africa and China as well as Latin America" (http://www.chagourygoup.com/about). As a private intermediary, Royal HaskoningDHV is only directly accountable to the party who hired them—the Chagoury Group—and not to broader Lagos society. Accordingly, actions prioritize the economic and industrial aims of the Chagoury Group rather than general public welfare, raising important equity issues (Adelekan 2013). Hence while working with private intermediaries can be unencumbered and quick, perhaps conferring more immediate professional benefit of seeing one's work applied, realizing the public value of science may be less straightforward. The inequity looming behind the Eko Atlantic seawall should serve as a cautionary tale, urging scientists and private intermediaries to carefully consider the equity implications of actions we inform.

Engaging with intermediaries for sea-level adaptation comes with a variety of trade-offs. Where public decision-making is often paralyzed by the inherent uncertainty in sea-level projections, the work of private intermediaries may circumvent inaction, as demonstrated in Lagos's Eko Atlantic project. In contrast, with the benefits of adaptation more likely to accrue to wealthier stakeholders, the private intermediation employed in Lagos contributes to environmental injustice. Private and public intermediation both allow researchers to spread their expertise more widely with lower relative transaction costs, but intermediaries may communicate sea-level exposure differently than those researchers would. For example, economic metrics such as "assets at risk" or the local price of insurance under the National Flood Insurance Program depend on many more factors than the projected rate of sea-level rise alone, which may or may not align with coastal residents' priorities and serve to obscure the scientific basis of sea-level projections. Formal boundary organizations promote the most direct interaction between scientists and community stakeholders, enabling decision-making with a very clear basis in current science and giving researchers the most control over application. However, boundary organizations operate at various scales, not all of which translate easily to local decision-making, and the intensive time commitment required for direct interaction may act as a constraint.

Based on the above examples and the broader academic literature, we suggest that maximizing the social utility of sea-level research, and climate change research more broadly, requires us to consider the adaptation needs of diverse communities and the tradeoffs involved in supporting them. While this effort is often resource intensive and context-specific, engagement through intermediaries can mitigate costs and amplify the impact of science and engineering in preventing negative impacts of sea-level rise. Each of the three styles of intermediation has its place in furthering our community engagement, but we stress the need for deeper understanding of the implications of each style for society in general and adaptation in particular. As such investigation continues, we must strive to promote both accountability and equity in our decisions about societal engagement.

Author contribution statement

LU and MCL conceived of the work. JB, MCL, and JCA suggested relevant examples. LU and JCA wrote large portions of the manuscript. All authors contributed to editing the manuscript and approved its final form.

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This paper is a Commentary and does not present new data or models.

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Figure Captions

Figure 1. (a) Rift appearing in Larsen C Ice Shelf as photographed November 10, 2016. Credit: John Sonntag, NASA. (b) High-tide flooding in Norfolk, VA in November 2017. Credit: WTKR News 3 Norfolk.

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