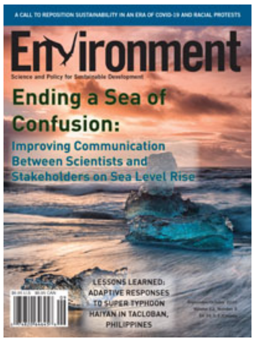

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Ending a Sea of Confusion: Insights and Opportunities in Sea-Level Change Communication

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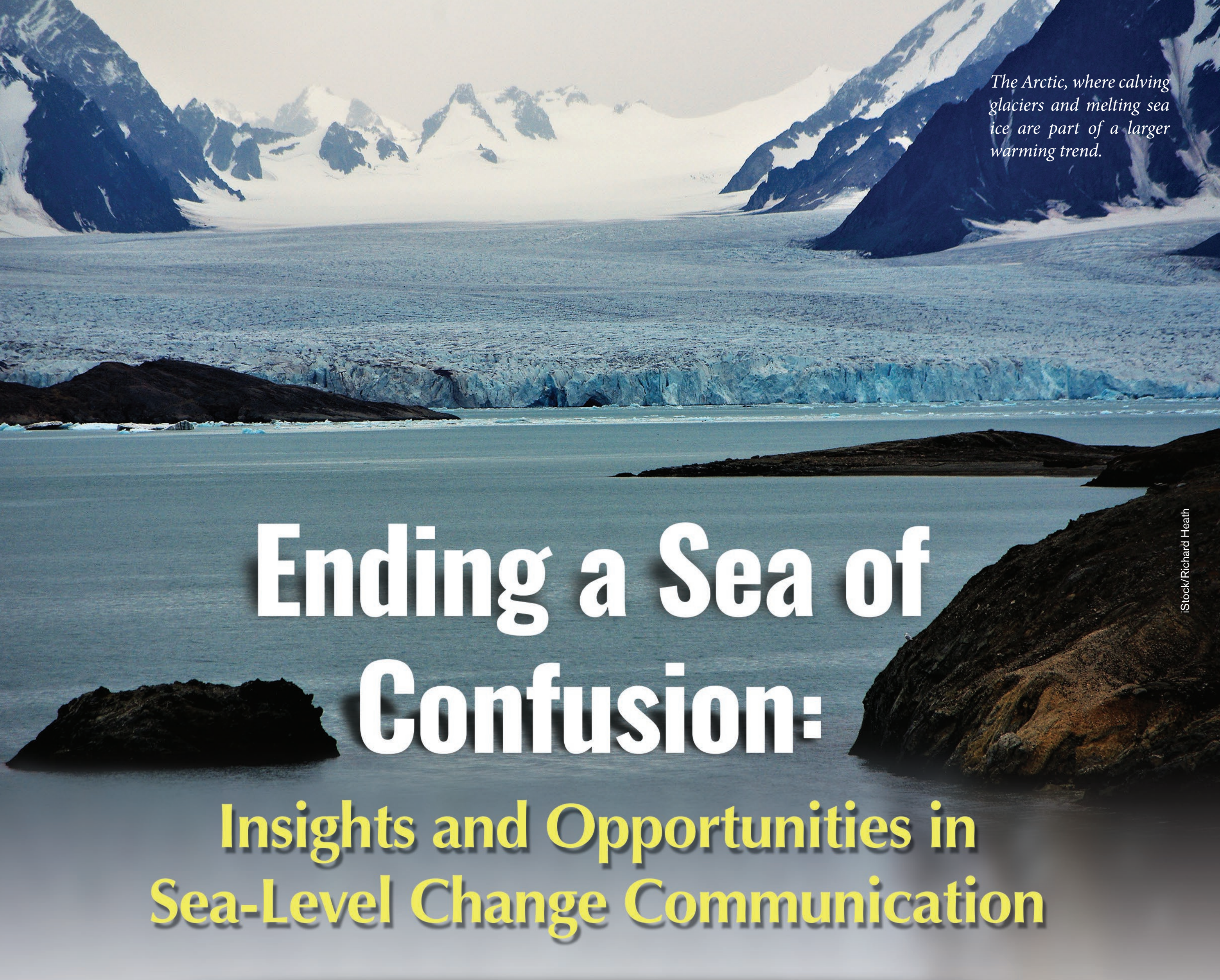


The Arctic, where calving glaciers and melting sea ice are part of a larger warming trend.

iStock/Richard Heath

Ending a Sea of Confusion:

Insights and Opportunities in Sea-Level Change Communication

by Twila Moon, Ted Scambos, Waleed Abdalati, Andreas P. Ahlstrøm, Robert Bindschadler, Jill Gambill, Patrick Heimbach, Regine Hock, Kirsty Langley, Ian Miller, and Martin Truffer

Sea-level rise affects coastal environments, economies, and societies. Effectively planning for and responding to the impacts of rising seas requires interactions among many groups, including scientists, planners, policymakers, engineers, emergency managers, and other decision makers. The value of a well-coordinated effort is enormous: Economic damages associated with sea-level rise may top US$1 trillion by 2100.[1] In California alone, an estimated 600,000 people and US$150 billion of property will be affected by sea-level rise by the end of this century.[2]

Despite the risk, sea-level rise planning and risk reduction activities are in most instances proceeding slowly, or sometimes not at all.[3] This lack of response is partly associated with accessibility barriers, especially for coastal managers and decision makers, to credible and "actionable" sea-level rise projections and related exposure information.[4] Creating consistent and reliable pathways to actionable science—results that are designed for and immediately usable by stakeholders—requires focused effort by scientific, planning, and funding communities.

Forecasting future sea level is intrinsically a scientific endeavor. As a result, sea-level rise projections and associated information that can be used to assess risk are often communicated via scientific publications or technical assessments. In contrast, planning for future sea-level rise impacts and risk reduction activities is typically the responsibility of engineers and planners. They must first digest and understand technical sea-level rise projections, integrate them with other project specifications, and then design or integrate adaptation elements into their projects. At the same time, it often falls to these practitioners to justify the impacts and costs of their recommended adaptation investments. This process frequently requires the translation of scientific projections and data for nontechnical audiences. Since these projections inevitably contain a large range of possible outcomes of uneven likelihood and severity, planned responses also span a large range of required actions, timelines, and costs.

Enabling the "user community" of decision makers, planners, and engineers to make good choices about the type and scale of sea-level rise responses requires scientists to more clearly communicate sea-level rise projections, their range, the likelihood of a particular path, and local impacts. Traditional methods of reporting information via scientific journals and agency assessments do not, in general, provide actionable information for users. For example, new research on sea-level change and response measures have featured prominently in national and international assessments such as the Assessment Reports from the Intergovernmental Panel on Climate Change (IPCC) or from the U.S. Global Change Research Program (USGCRP).[5] While these reports provide a powerful link between climate change science and public policy, they often lack the regional and local detail necessary for local planners. To expect that planners and decision makers can extract the needed information for their district from the science sources is unrealistic. Thankfully, insights are emerging on how to recast scientific information to address the needs of the decision maker, planner, or engineer more effectively. Here, we describe our own evolving insights on how to recast scientific information to address the public need, and to improve communication with stakeholder groups about ongoing sea-level research.

Starting in 2015, the SEARCH (see Sidebar: SEARCH) Land Ice Action Team (LIAT) led an extensive effort to improve communication and engagement between sea-level rise scientists and the sea-level rise information user community. The broad synthesis goal for LIAT is connecting environmental change and science—including field observations, computer simulations, and physical system science—to impacts such as glacial hazards, sea-level rise, coastal erosion, flooding, and saltwater inundation. LIAT communication efforts have focused, in particular, on connecting with policymakers and decision makers, planners, and the media. The program included modest funding support to build teams that bridged across the two groups and cooperated in seeking better paths for communication. Here we present a set of lessons learned from those experiences. Most of our group's work has focused on science–stakeholder connections within the United States, but international members of our group have added some global context. We include a brief section on this limited international perspective.

Motivation for LIAT activities has been based on discovered needs. For example, long-standing SEARCH relationships with congressional offices helped to spur the creation of *Arctic Answers*, a still-expanding series of policy briefs addressing key stakeholder questions regarding Arctic and polar climate change (Figure 1).[6] The work of discovering and evaluating effective modes, formats, and content for informing an intended audience is ongoing. Yet all of it is based on the notion of removing the "end" in "end user." The long-standing model has been for scientists to conduct research, develop products (e.g., data, projections, or monitoring), and *then* ask how an end user might use those products. But this "science push" model has proven mostly ineffective.[7] The wider scientific and stakeholder communities are recognizing that iterative interaction *throughout* the research process—often referred to as co-design, co-production, and co-delivery of adaptation responses[8]—creates more effective and efficient pathways to progress.[9] Understanding and attempting to implement better research co-design processes was an important learning activity for LIAT. Our intent with this summary is to improve this process for others by sharing our experiences, challenges, lessons learned, and ideas for the future.

Lessons Learned and Opportunities

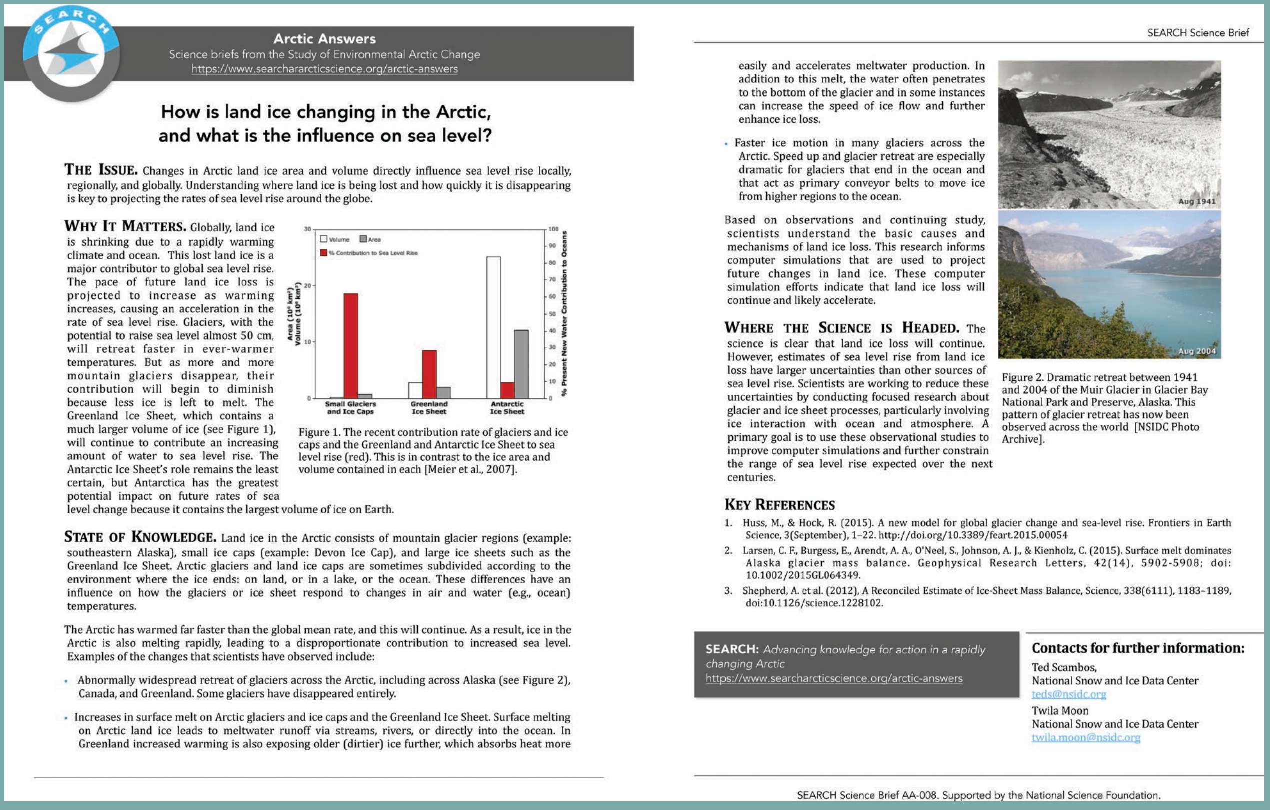
Synthesizing and Translating Science Is Vital

Collecting, synthesizing, and interpreting the varied results of individual,

SEARCH

The Study of Environmental Arctic Change Program (SEARCH) has, for more than twenty years, supported scientific research and the science community in understanding the state of the Arctic, the breadth of system changes and their causes, and the implications for local to global communities. Over the last 5 years, SEARCH has emphasized developing scientific knowledge and synthesis that is relevant to decision-making, and engaging or strengthening scientist-stakeholder community connections to ensure that science is understood and actionable. Over this time, SEARCH has supported three topic-focused action teams to concentrate on permafrost, sea ice, and land ice, and shorter-term working groups that have focused on topics like communication and Indigenous community connections. The Land Ice Action Team has focused on the topic of land ice loss and related impacts, especially sea level rise.

Figure 1. Example of one of six *Arctic Answers* policy briefs produced by LIAT (19 so far in the full SEARCH collection). These briefs provide succinct information addressing the state of the science on specific questions of interest.



Arctic Answers
Science briefs from the Study of Environmental Arctic Change
https://www.searchararcticscience.org/arctic-answers

How is land ice changing in the Arctic, and what is the influence on sea level?

THE ISSUE. Changes in Arctic land ice area and volume directly influence sea level rise locally, regionally, and globally. Understanding where land ice is being lost and how quickly it is disappearing is key to projecting the rates of sea level rise around the globe.

WHY IT MATTERS. Globally, land ice is shrinking due to a rapidly warming climate and ocean. This lost land ice is a major contributor to global sea level rise. The pace of future land ice loss is projected to increase as warming increases, causing an acceleration in the rate of sea level rise. Glaciers, with the potential to raise sea level almost 50 cm, will retreat faster in ever-warmer temperatures. But as more and more mountain glaciers disappear, their contribution will begin to diminish because less ice is left to melt. The Greenland Ice Sheet, which contains a much larger volume of ice (see Figure 1), will continue to contribute an increasing amount of water to sea level rise. The Antarctic Ice Sheet's role remains the least certain, but Antarctica has the greatest potential impact on future rates of sea level change because it contains the largest volume of ice on Earth.

Figure 1. The recent contribution rate of glaciers and ice caps and the Greenland and Antarctic Ice Sheet to sea level rise (red). This is in contrast to the ice area and volume contained in each [Meier et al., 2007].

STATE OF KNOWLEDGE. Land ice in the Arctic consists of mountain glacier regions (example: southeastern Alaska), small ice caps (example: Devon Ice Cap), and large ice sheets such as the Greenland Ice Sheet. Arctic glaciers and land ice caps are sometimes subdivided according to the environment where the ice ends: on land, or in a lake, or the ocean. These differences have an influence on how the glaciers or ice sheet respond to changes in air and water (e.g., ocean) temperatures.

The Arctic has warmed far faster than the global mean rate, and this will continue. As a result, ice in the Arctic is also melting rapidly, leading to a disproportionate contribution to increased sea level. Examples of the changes that scientists have observed include:

- Abnormally widespread retreat of glaciers across the Arctic, including across Alaska (see Figure 2), Canada, and Greenland. Some glaciers have disappeared entirely.
- Increases in surface melt on Arctic glaciers and ice caps and the Greenland Ice Sheet. Surface melting on Arctic land ice leads to meltwater runoff via streams, rivers, or directly into the ocean. In Greenland increased warming is also exposing older (dirtier) ice further, which absorbs heat more easily and accelerates meltwater production. In addition to this melt, the water often penetrates to the bottom of the glacier and in some instances can increase the speed of ice flow and further enhance ice loss.
- Faster ice motion in many glaciers across the Arctic. Speed up and glacier retreat are especially dramatic for glaciers that end in the ocean and that act as primary conveyor belts to move ice from higher regions to the ocean.

SEARCH Science Brief

Based on observations and continuing study, scientists understand the basic causes and mechanisms of land ice loss. This research informs computer simulations that are used to project future changes in land ice. These computer simulation efforts indicate that land ice loss will continue and likely accelerate.

Figure 2. Dramatic retreat between 1941 and 2004 of the Muir Glacier in Glacier Bay National Park and Preserve, Alaska. This pattern of glacier retreat has now been observed across the world [NSIDC Photo Archive].

WHERE THE SCIENCE IS HEADED. The science is clear that land ice loss will continue. However, estimates of sea level rise from land ice loss have larger uncertainties than other sources of sea level rise. Scientists are working to reduce these uncertainties by conducting focused research about glacier and ice sheet processes, particularly involving ice interaction with ocean and atmosphere. A primary goal is to use these observational studies to improve computer simulations and further constrain the range of sea level rise expected over the next centuries.

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SEARCH: *Advancing knowledge for action in a rapidly changing Arctic*
https://www.searcharcticscience.org/arctic-answers

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and sometimes disparate, research programs is critical for providing comprehensive information to nonscientists. This usually involves a high degree of "information compression": reducing an expansive analysis, complete with associated graphics, to a very limited set of words and visuals. There are many options for synthesized information products, with each serving somewhat different audiences and with a range of efficacy. LIAT participated in creating several different product types and tested each with a number of audiences.

First, we wrote a review paper in an open-access, peer-reviewed journal about Arctic land ice loss and associated sea-level rise.[10] However, its presence in a classic scientific journal likely limits visibility in the broader stakeholder community. While the paper received citations in other science journal articles, we have not found it referenced by stakeholders and the information and language it includes is likely too specific to the research community. In a second synthesis article, LIAT partnered with the SEARCH Permafrost and Sea Ice Action Teams to discuss the rapid Arctic system changes and clearly demonstrate their connections to U.S. impacts. [11] The article includes a system graphic and striking photographs of sea-level rise impacts. This article has garnered more attention across nonscientist audiences and was a top-downloaded Earth's Future article for 2019. We believe this success was connected to (1) an accessible writing style, (2) powerful imagery, and (3) a communication and media push when the article was published, with content shared via press releases from co-author institutions and highlighted by the American Geophysical Union.[12]

Second, LIAT participated in writing several two-page policy briefs as part of the broader SEARCH *Arctic Answers* series (Figure 1).[13] Each brief introduces the issue, discusses why it matters, summarizes the current state of knowledge, outlines where the science is headed, and provides key references and expert contacts (usually two or three experts who co-authored the brief). LIAT briefs addressed questions including:"How is land ice changing in the Arctic and what is the influence on sea-level rise?," "How does land motion influence sea-level rise?," and "How will coastal communities be affected by climate change?" The briefs underwent a rigorous peer review to validate content and improve the general accessibility of the information. There was a significant challenge in writing a short and easily understood "state of science" overview. Vigilance and multiple revisions were needed to remove jargon, introduce clear and compelling images, simplify graphics, or develop more concise bullet points. But the end products are clear, accurate, and easily shared (hard-copy and online) documents.[10]

Diverse Communication Pathways Are Necessary

Our experience has also emphasized the importance of scientists producing and contributing to content outside of peer-reviewed science journals. We heard from stakeholders that classic scientific papers are often not helpful for several reasons: (1) Stakeholders are often not in the practice of connecting with scientific publications; (2) the content is not understandable because of jargon and a lack of context; and (3) articles can be hard to access because they are behind paywall subscriptions. If scientists want their science to inform the decisions, planning, and policy of society, they must get that science into other media, which can further filter into stakeholder and decision-maker communities.

In one example, a LIAT member participated as a congressional expert witness in testimony to the U.S. House of Representatives Committee on Science, Space, and Technology for a hearing on "Earth's Thermometers: Glacial and Ice Sheet Melt in a Changing Climate."[14] A Hearing Charter developed by legislative staff was provided to every committee member and outlined the purpose of the hearing and substantial science background information, including footnote citations. Unlike within the scientific community, however, most of the background content was not sourced from scientific peer-reviewed literature. Rather, references were primarily more easily accessed sources, including education websites (e.g., from the USGS, National Snow and Ice Data Center, NASA) and articles written for popular media (e.g., *National Geographic*, BBC News, *Scientific American*). The few traditional science papers cited were suggested by the expert witnesses. This experience highlights the importance of shepherding science results from peer-reviewed literature into digestible and accessible popular media and education sources to ensure that results are available to inform decision makers. Many scientists can now call on institution press offices and communication professionals to help to create such content.

Another mechanism by which this transfer or translation of science occurs is through so-called "boundary organizations," which work at the interface between the scientific community and community-level planners and managers. Boundary organizations often have access to peer-reviewed science and relationships with scientists, and can help to digest, condense, and translate information trapped in pay-walled literature. Over time, LIAT developed relationships with, and recruited, boundary organization workers to test this mechanism of scientific transfer, and we discuss the value of working with boundary organizations more in a later section.

Direct Conversation Is Required

Trust is an essential component of successful climate communication.[15] This is particularly important when communicating uncertainties in risk and outcomes or when there are seemingly contrary views coming from the science community.[16] Face-to-face interaction is an effective tool in building trust and ensuring complete communication of science results and incorporating the specific needs of the audience. Even the ideal product benefits enormously if it can be delivered personally. Relatively few *Arctic Answers* briefs have been downloaded (~100 downloads per brief). One of the most productive ways we delivered briefs was through in-person meetings with staffers, policymakers, or stakeholders. Not only was the feedback valuable to us from those who received the briefs personally, but many engaged in lengthy discussions about them. In one example, sharing a brief with a Senate staffer led to a longer exchange about ice loss and sea-level rise with the Congressional Research Service. We have also shared the briefs at scientist and stakeholder conferences. Feedback from these interactions is anecdotal but suggests the briefs, especially those delivered personally, are useful.

Throughout our activities we were also consistently reminded of the importance of taking a step back from sharing information to instead embrace active listening. One way we sought to accomplish this was by attending stakeholder-centric events. The first challenge was identifying events where the best target audience was assembled. The initial Land Ice Action Team members were primarily physical scientists directly studying land ice changes. As the team recognized the limitations of this, it expanded to include experts more engaged in the stakeholder side, allowing LIAT to strengthen relationships with several decision makers. These team members were essential in helping to identify stakeholder events and communities with whom we could seek closer connection (see Sidebar: Boundary Organizations).

Based on this input and perceived need, six LIAT members attended the 2019 National Adaptation Forum to engage in conversation about the connections between land ice research and sea-level rise planning and to learn directly from planner and stakeholder presentations on related subjects (e.g., adaptation planning tools, sunny day flooding and coastal impacts, and local case studies). LIAT also hosted a session on "Polar Ice Loss, Sea Level Rise, and Coastal Forecasts Through 2100," which included a short presentation, panel discussion, and questions and answers.[17] The panel included professionals across land ice research, coastal community resilience, and urban/coastal utilities planning.[18] We also distributed a short survey to learn who audience members were, how they use science, and their thoughts on improving the science-to-action pipelines. Responses highlighted

Boundary Organizations

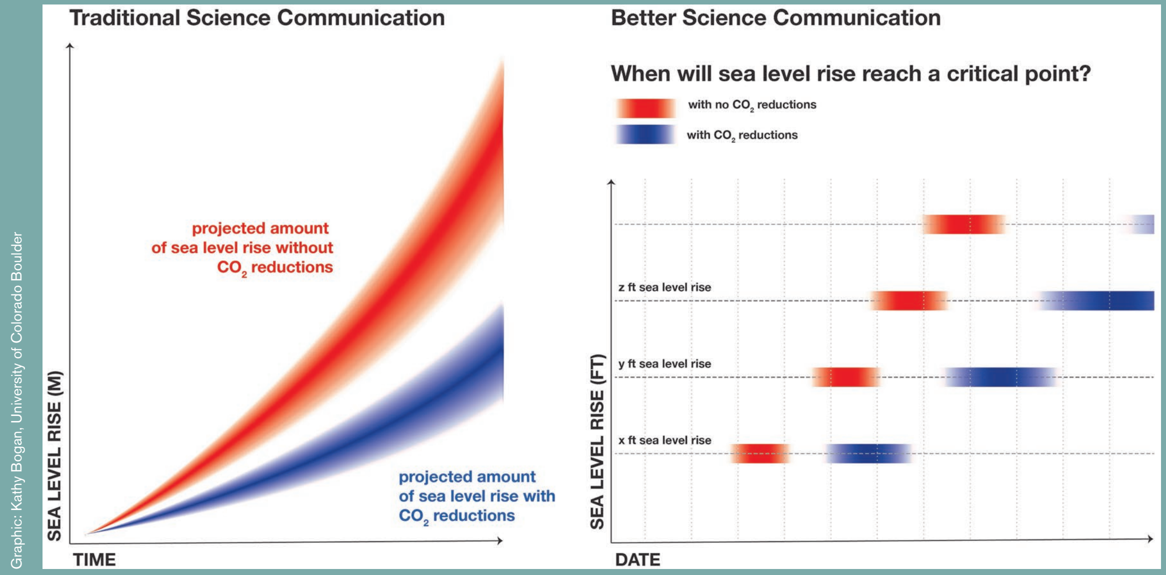
Inspired to expand your network? Consider connecting with boundary organizations nationally or within your state or community. Here are examples connected to sea level rise:

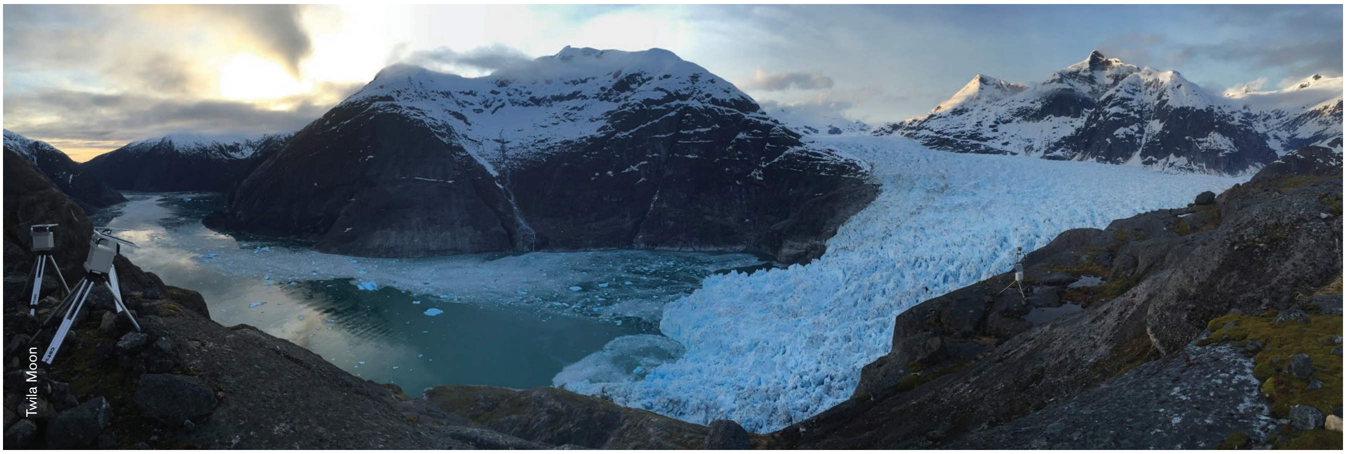
- Sea Grant programs
- Land-grant extension programs
- USGS Climate Adaptation Science Centers
- American Planning Association
- Water Utility Climate Alliance
- American Society of Adaptation Professionals
- National Estuarine Research Reserves
- USDA Climate Hubs
- NOAA Regional Integrated Sciences and Assessments (RISA) programs
- Association of State Floodplain Managers (ASFPM)

three top ways in which scientists can best serve planners: (1) provide local information, (2) conduct science with an emphasis on application and solution, and (3) engage in information translation. By participating across the wide range of other forum events, we were also able to appreciate the broad (and sometimes conflicting) swath of considerations on each stakeholder's plate. Coastal resource managers and decision makers must consider information concerning budget, public interest, health, infrastructure, and more, along with the science. With this in mind, scientists cannot expect these stakeholders to have the time and resources to seek out science from scientific venues or journals, or to learn the language of science, or to always put scientific findings at the top of their list of considerations and priorities. Instead, scientists must bring the information—and in particular, its most actionable interpretation—to the stakeholders in the places where stakeholders meet, via the resources they routinely reference, and using the language of their community. In this way, scientific knowledge can become easier to access and understand, effectively lowering the barrier to its application.

Direct and ongoing discourse is also important for discovering the most productive formats for information exchange. As we heard about the planning process and data needs, we discovered that the manner in which scientists represent results does not always match the way planners want to reference or use data. For example, scientists are commonly graphing future sea-level rise projections by showing the widening envelope of projections in the decades to come (Figure 2). However, we heard

Figure 2. Conceptual graphic demonstrating a common method for plotting sea-level rise (left) using cumulative sea-level curves, versus a method that can more easily answer the question "When will *x* amount of sea-level rise arrive here?" (right).





Arctic glaciers are retreating rapidly, but loss of ice from the large ice sheets will be the greater concern for the second half of this century.

from decision makers at a NASA-hosted workshop that the question they are asking is "When will *x* amount of sea-level rise arrive in my area?" While this information is embedded in the "envelope" graphic, extracting that information is not necessarily intuitive. Instead, scientists can answer the stakeholder question directly by adopting a different graphing technique when sharing data, one that shows uncertainty in time for a given sea-level rise, rather than uncertainty in sea level for a given time. If possible, data for more localized areas are also more useful.

Apply the Art of Communication

- Evaluate and address the audience's interests and values.
- Create an engaging science story that addresses 'why' and leads with results.
- Choose words carefully (avoid jargon, double meaning) and use words already familiar to your audience.
- Use striking photo images.

Learn and Practice the Art of Communication

Another lesson emphasized across our efforts was the critical importance of learning and applying fundamentals in the art of communication. Few scientists have formal training in communication, and many of its tenets are counter to how communication usually occurs within the science community. Yet we have found that applying good communication practices increases efficacy across audiences and is essential for connecting with nonscientists. Across our written, spoken, formal, and informal communication, we identified four primary goals in the art of communication to create a message that is memorable and effective (see Sidebar: Apply the Art of Communication).[19]

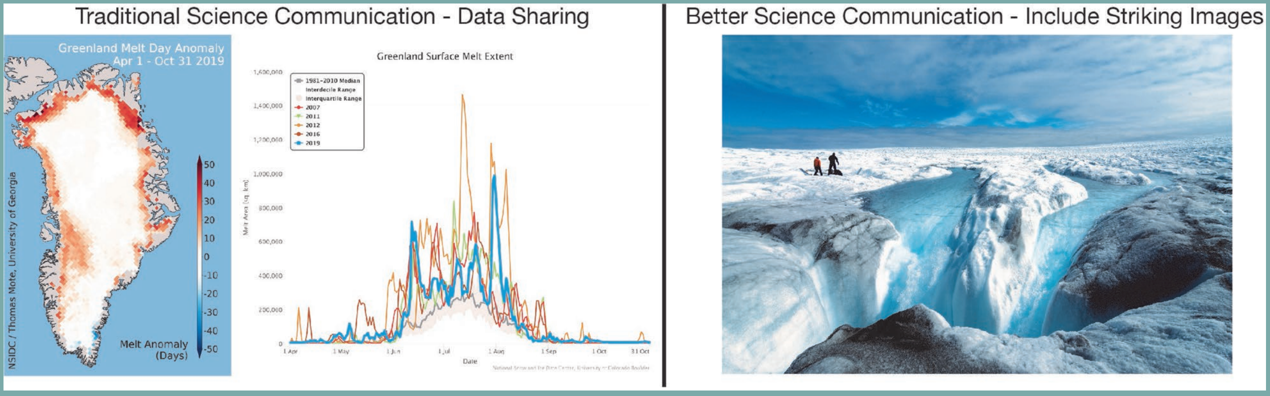
First, emphasize how the science connects to the big picture. In many cases this connection is not provided or is assumed as background knowledge in published research, but it is a fundamental element of capturing stakeholder attention. Take time to identify the stakeholder values and interests. Conversation and engaged listening are among the best methods to learn about stakeholder interests, but reading websites and reports and finding casual conversation with loosely connected acquaintances can also be helpful. Also recall that earth scientists are likely to come to the table with a unique perspective that includes a heightened awareness of the earth as a complex and connected system, an appreciation of geologic time scales, and skills in spatial thinking.[20] Bring this perspective to your communication and connect it with context that links directly to stakeholder values. Also, remember that those with whom you are talking may not be in the practice of valuing scientific information, or it may have taken a back seat in decisions in the past. Do not shy away from demonstrating how science can be helpful. Doing so in a positive, forward-looking manner can provide a path to the best outcomes.

Second, embrace the structure and practice of storytelling. Because science research generally addresses a specific question, probing it via data and analysis, and then providing a full or partial answer, science research naturally contains a story. That story tells us about the challenge, the action of investigation and analysis, and the conclusion based on evidence. In this way, the research usually contains a plot, but the science communicator must carefully shape how the science is described, providing a narrative, structure, and perspective. Providing a story narrative helps to create memorable content. Include anecdotes, metaphors, or examples that drive home the science message. When building a story, also consider the order of information. Scientific articles typically follow a format that starts with background information followed by methodological details, before presenting the results and conclusions. However, inverting this communication pyramid is usually more effective: Provide the bottom line and key messages first, before delving into supporting details. One legislative staffer emphasized to us that a Congressperson was unlikely to remember facts and figures, but that a short story could be remembered and retold to colleagues and constituents, and passed on. This is the power of story.

Third, the message must be crafted to resonate with the target audience. Word choice and phrasing are critical. Scientific products are often rife with jargon, including words that have entirely different meanings for scientists versus nonscientists. Scientists use "uncertainty" to describe the range of

A clear statement of the time-range for a given future sea level is critical to sea defense infrastructure planning.

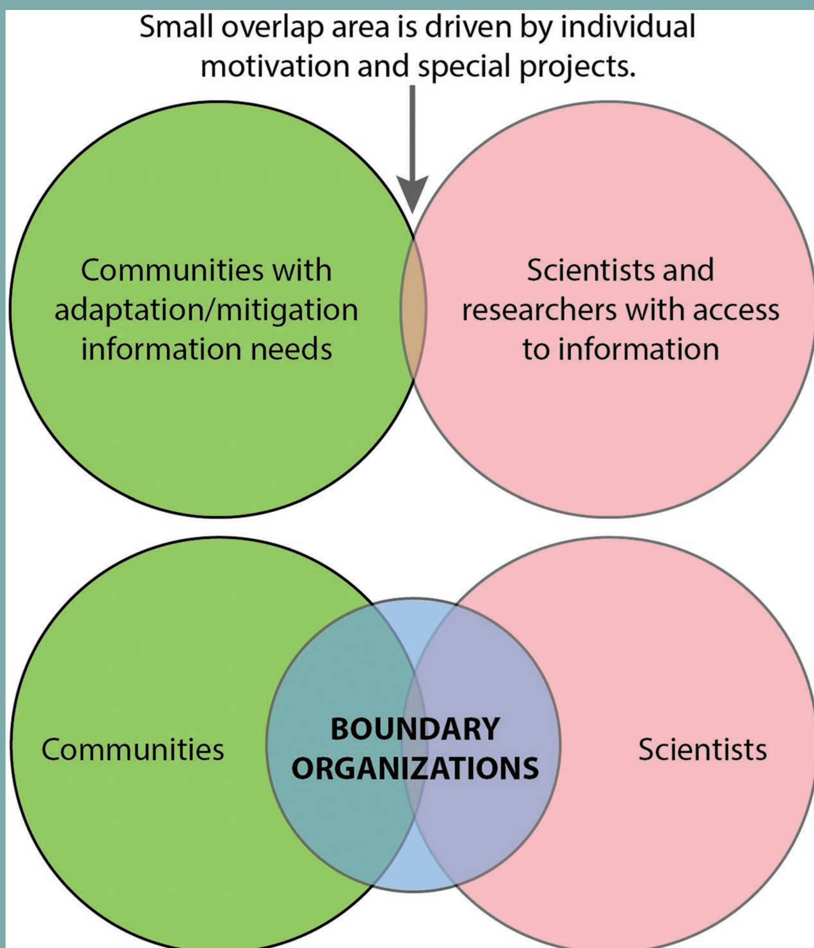
Figure 3. Examples of more traditional science communication content on the left and impactful imagery on the right. Including striking imagery, especially with people and human things in the image, is more memorable for nonscientist audiences.



Map and plot: NSIDC/Thomas Mote, University of Georgia. Photo: Jason Gulley

the results, but "uncertainty" can be misconstrued as "ignorance," and talking about uncertainty can lower audience confidence in scientific information.[21] It is easy to turn this around and emphasize what is certain. Rather than present "uncertainties," explore the topic by applying a risk framework, a concept well understood by planners.[22] Also, work to translate probabilities and other quantitative or semiquantitative metrics into common language. The IPCC

Figure 4. Conceptual diagram of the benefits of working with boundary organizations (bottom) versus without boundary organizations (top).



provides an example: Probabilities of 99–100% are described as "virtually certain," 66–100% as "likely," 0–10% as "very unlikely," and so on.[23] Spend time evaluating the terms you will use in written and spoken communication, and clarify their meaning with user community partners.

Fourth, scientists need to employ focused, visual messaging. By creating a story structure and a carefully worded central message, we set ourselves up for success. Combining clear spoken prose with strong imagery allows for a point of connection and understanding. For example, to talk about the increase in surface ice melt on the Greenland Ice Sheet, a scientist's first inclination may be to show only a map of melt extent across the ice sheet or a graph of melt data (Figure 3). These graphics speak to the scientific instinct to show real data and demonstrate the quantitative state of the problem. We have found, however, that it is much more effective to include a striking photo image of the surface melt (Figure 3). Images that include people and human items (e.g., a field camp tent) are particularly valuable for connecting the audience to the data or event, giving a sense of scale and helping the audience to feel "right there." An image allows the audience to immediately feel that ice is melting and that this can happen on large scales, adding substantial water to the ocean. Then, recalling the first point in this section, explain how ice sheet melt impacts members of the particular audience, making the data relevant to their lives. Including strong images, clearly explaining their relevance, and adopting a story structure can provide a message that is straightforward and that a stakeholder can remember and repeat.

Engage Boundary Organizations

During the last 5 years, we have discovered exponential benefits in expanding partnerships with individuals and boundary organizations that have already established relationships and reputations with desired audiences. Operating at the science–policy interface, boundary organizations facilitate two-way dialogue and cooperation between producers and users of scientific information (Figure 4).[24] Teaming up with key "boundary spanners" already embedded within stakeholder communities can lend credibility to scientists seeking to reach new audiences and forge new collaborations, and can enable longer term engagement and continuity in relationship building. These partners can also provide bilateral translation of scientific information in the context of community needs, capacities, barriers, and decision-making processes.

We experience many benefits to partnering with boundary spanners. First, adding boundary organization representatives to our own group aided in identifying the meetings, resources, and discussions happening on the stakeholder side. Second, it helped us to expand our own conversations and more fully appreciate the myriad of individual topics that weave together to inform sea-level rise planning on the local level. Third, our scientist-heavy group benefited from having boundary-spanning "translators." Through our work with David Behar, the San Francisco Public Utilities Commission Climate Program Director, and participation in the National Adaptation Forum, we experienced how boundary organizations

Co-production of knowledge requires detailed sharing of information and perspectives between scientists and stakeholders.

can play a key role by filling critical functions that are often not rewarded on the scientist side. For example, stakeholders want local information from local or regional sources. Boundary organizations can synthesize or translate regional science to local interests and also lean on existing local connections to act as trusted information sharers. Boundary organizations are also more likely to understand the local planning timelines so that they can provide information updates that align with planner activities.

Just as the science research community continues to work toward better internal organization, we discovered that stakeholder groups are grappling with similar challenges. The fields of adaptation and mitigation are still young, with technology and knowledge changing quickly. Working with boundary organizations helps both sides connect without getting lost in the internal community discussions. And boundary organizations can act as the next step helpers to move science to action. As Kelly Valencik, Planner, State of Delaware, said, "One part of my job is telling someone 'this is the next person you need to work with.' Science needs the same service for sharing or creating actionable information after paper publication." Boundary organizations are already primed to fill this need. If utilized to their full potential, boundary organizations can enable the co-generation of transferable and transformative science between researchers and decision makers.

Co-Production Support Is Needed

Our experience endeavoring to create stronger relationships across the scientist–stakeholder divide highlighted both the necessity and the challenge of co-production. The value of co-production has been established through research and practice.[25] But implementing co-production has challenges. First, we must collectively capture the interest of scientists and stakeholders, and create or strengthen a shared understanding of the co-production process. Second, there must be mechanisms to support the participation and work across all parties. Even for those who are interested, adding this long-term effort to a crowded plate of job duties can be a major barrier. In some instances, the activities are not a part of assigned or rewarded job duties and adding this important work is difficult. Progressing past this barrier may be hard if institutions do not support improved communication and linkage of science and application through professional reward, targeted time allotment, and financial support for activities across participating groups and through the potentially long project lifetime. We cannot rely on the personal motivation of individuals to get such critical work done. Most LIAT members and our partners volunteered their time, which inevitably limited the scope of our activities and our ability to follow through on

The impact of sea-level rise this century on landscape, infrastructure, and coastal environmental assets will be large.

long-term relationship building. Recognition and financial support of boundary spanners and other partners is necessary to ensure the sustainability of this important work.

Notes From International Partners

Because of the substantial challenge in the United States regarding acceptance of climate change in some circles and related impacts, the bulk of our efforts focused on increasing efficacy within the U.S. science–stakeholder ecosystem.[26] But international participants in LIAT, including Andreas P. Ahlstrøm (Geological Survey of Denmark and Greenland, GEUS) and Kirsty Langley (Asiaq Greenland Survey), provided context on how science–stakeholder interactions are supported in Denmark and Greenland. In Denmark, current scientific findings are overall well known and embraced by decision makers, and while the Ministry of Climate, Energy, and Utilities can call on scientists for briefings, it rarely needs to because policymakers are in the practice of staying well informed about climate science and sea-level rise. Nonetheless, GEUS has strengthened institutional capacity for science communication during the last 5 years; journalists are commonly embedded in the field with Greenland researchers, and GEUS scientists, like U.S. scientists, are supported to work on policy-driven efforts like the IPCC reports[27] and the Arctic Monitoring and Assessment Programme, a working group of the Arctic Council.[28] Large-scale European Union-funded projects also require competitive plans for stakeholder engagement and road maps targeting policymakers. On the national level, Denmark science–stakeholder connections are also likely aided by the smaller national population, a factor that is even more evident in Greenland. Within Greenland, scientific institutions are in regular contact with government ministries and utilities. The consistency and long-term strength of these relationships allows scientists to share information across a broad topical spectrum. Interestingly, since they are based in Greenland, organizations like Asiaq are commonly asked by international groups to act as boundary organizations themselves, translating between Greenlandic interests and international researchers.[29]

While not a primary point of discussion within our team, one lesson learned that we hope is passed from the scientific to the policy community is the value of international cooperation. While geopolitical tensions in the Arctic are growing, the scientific community maintains—and in many cases is strengthening—significant international cooperation.[30] These connections allow scientists to speak with a more unified and objective voice, facilitate spreading information across countries that are far apart but simultaneously impacted, and can provide examples of decision making to be shared within emerging scientist–stakeholder projects in the United States. Rather than have an internationally cooperative science community and divided political communities,

To Do for Scientists

• Communicate outside of the science journal ecosystem or reach out to your press office or journalists to ask them to cover your science.

• Attend stakeholder events and use the language and framing of the stakeholder community (not the science community).

• Build relationships with stakeholders.

To Do for Science-Supporting Organizations

• Value engagement outside of the science community.

To Do for Policymakers and Science Funders

• Support mechanisms that fund scientist-stakeholder co-production activities.

• Build relationships with scientists.

we hold that scientific connections with domestic decision makers will help to increase international cooperation on decision making.

Conclusions and Moving Forward

Applying the ideas outlined here will surely boost individual success in connecting across the science and stakeholder communities. But long-term success also requires larger scale changes (see Sidebar: To Do for …). As the Land Ice Action Team looks toward the future, our lessons learned have inspired two top recommendations:

- The science, boundary organization, and stakeholder communities need to work toward a coordinated network that crosses the interfaces among them and spans the full range of interests and activities. We heard from stakeholders that they value local information coming from trusted local or regional sources. But we also heard that it is helpful if decisions on planning projections—for example, that a county should plan for a particular range of sea-level rise by 2050—are made at a state or national level. This provides consistency and ensures that important local decisions are facilitated by wider (e.g., national) considerations. A coordinated network, perhaps forming as a multitiered organization, could move information from a national to a local level and vice versa, to bring scientific findings to planners and provide information on widely agreed-upon needs back to funding agencies and national science efforts.
- Federal and state agencies (including science-focused ones and others, such as the Department of Housing and Urban Development), nongovernmental organizations (NGOs), and industry leaders should work together to bring the resources and facilitation needed to implement scientist–stakeholder co-production. With sea-level rise impacting so many facets of society, this likely requires advances in organizational structure that will demand increased interagency or intergroup collaboration and may challenge traditional scopes of work. For example, sea-level rise data are not under the purview of a single U.S. federal agency, and the many different geophysical processes contributing to sea-level change mean that no single agency alone has the capability to provide the requisite expertise. Cooperation and coordination across NOAA, USGS, NSF, NASA, and the U.S. Army Corps of Engineers are required to ensure research and action move forward at pace. An effort across private sectors and agencies can add co-production to the job duties of scientists and decision makers, demonstrate and teach best practices for developing and sustaining co-production, provide time and space resources to do the work, and encourage employers to value it as well.

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