to people to do science with them, that doesn't advance the frontier. Staying at the frontier as science evolves costs money. If the budget stays flat, we'll have to make more really tough choices."

NSF is conducting environmental impact studies at Arecibo, Green Bank, and NSO's Sacramento Peak in New Mexico. The possible recommendations are to continue running the facilities with no change, continue running with less NSF funding but with money from new collaborations, partially shut the facilities but keep open educational aspects, mothball, or permanently shut down the observatories.

The studies look at social and economic factors in addition to financial and environmental ones. The Green Bank Observatory is the second-largest private employer in its county, notes O'Neil. And shuttering Arecibo would quash morale and be a big loss for education in already financially devastated Puerto Rico (see PHYSICS TODAY, January 2016, page 28). NSF says it will decide this summer about Arecibo and by early next year about Sacramento Peak and the GBT.

Toni Feder

Citizen observers chart Arctic change

Researchers are increasingly partnering with local residents to obtain climate and environmental data. But the endeavor calls for interpersonal savvy.

For the past decade, Joe Leavitt, an Inupiat subsistence hunter in the coastal Alaskan town of Utqiaġvik (formerly Barrow), 500 km north of the Arctic Circle, has filled notebook after notebook with his observations of the sea: the buildup of *qinu*, or slush ice, before the fall freeze-up; the thrusting up of ice ridges by colliding floes; the fracturing and healing of the winter pack ice. Once a month he mails his notes to a team of geophysicists at the University of Alaska Fairbanks, who collect them, along with the dispatches of a dozen or so other observers scattered along the Alaskan coast, as part of a project known as the Seasonal Ice Zone Observing Network. The hope is that the observations, paired with the team's traditional fieldwork, can shed new light on Arctic sea-ice trends—trends that still aren't fully explained by climate models.

The NSF-funded project is one example of what's come to be known as community-based monitoring. The practice has proliferated in the Arctic, where local residents can often obtain information that would be impractical, if not impossible, to acquire by more conventional means. The Atlas of Community-Based Monitoring and Indigenous Knowledge in a Changing Arctic lists the Seasonal Ice Zone Observing Network as one of four dozen such projects under way throughout the region.

According to Henry Huntington, science director of Arctic ocean projects at the Pew Charitable Trusts, the rise of community-based environmental monitoring has coincided with a sea change in scientists' attitudes toward the endeavor: "Twenty years ago it was, 'Hmm, that's an interesting little curiosity.' Now, even in the hard-science and glaciology worlds, they're beginning to see it as a serious line of inquiry."

Yet the pursuit isn't without its growing pains. Piecemeal funding has hampered efforts to establish sustained, large-scale projects, and some scientists still struggle to cultivate relationships in the Arctic's typically small, predominantly indigenous communities. But recent gestures by the US government—including a joint commitment with more than 20 other governments to expand scientific partnerships with the Arctic's indigenous communities—signal that the region's growing league of citizen observers may play a rising role in research.

Climate collaborators

Although the vast majority of global greenhouse gas emissions are released outside of the Arctic, communities inside the Arctic are bearing an outsized share of the consequences. In its 2016 Arctic Report Card, the National Oceanic and Atmospheric Administration noted that the region is warming at twice the rate of lower latitudes and is already 2 °C warmer than its 1981–2010 average. Last

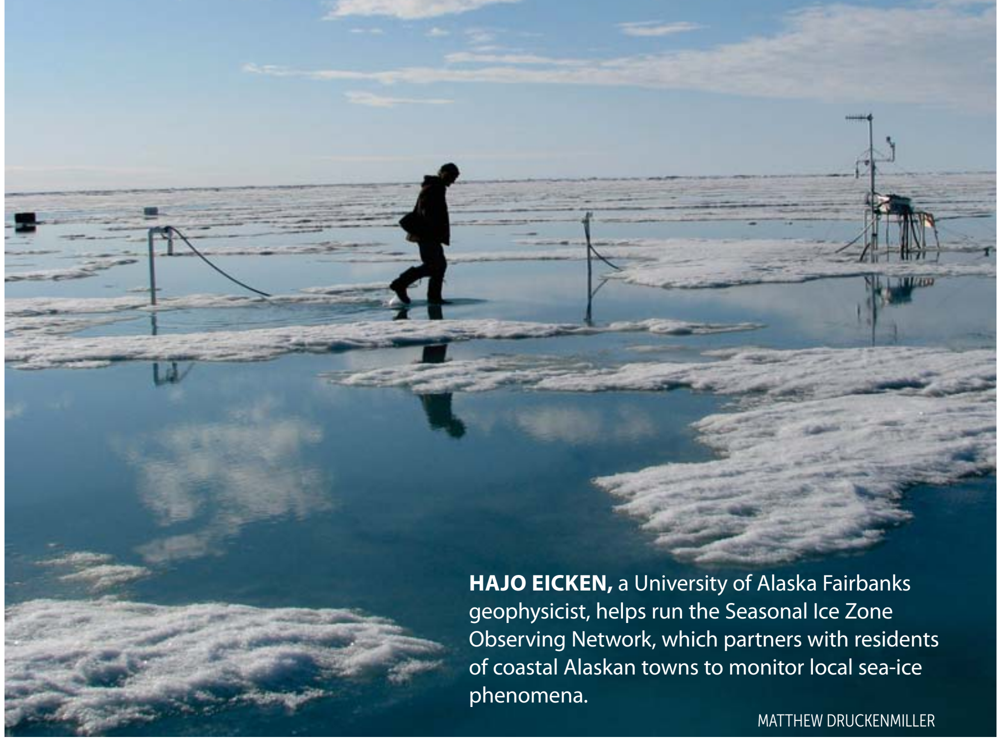
September, Arctic sea-ice cover retreated to its second-lowest annual minimum on record. (More precisely, 2016's minimum tied with 2007's; the record low was in 2012.)

For Leavitt, who hunts whales and other marine mammals, the impacts of those changes are both tangible and ubiquitous. "Winter comes in one month later and it thaws out one month earlier," he says, noting that hunting on the thinning Arctic sea ice has become increasingly perilous. Leavitt recalls using seasonal ice roads to reach ice fishing ponds as early as September in decades past. "Now I can't even make it up there 'til November." In other locales, the combination of retreating ice cover and thawing permafrost have left communities vulnerable to coastal erosion.

Arctic dwellers' position on the front lines of climate change makes them natural partners for the scientists who study it. Not only do the communities have proximity in their favor, explains Andy Mahoney, a sea-ice scientist at the University of Alaska Fairbanks, "they've got the expertise to get out in what is quite a harsh environment, and they have a vested interest in that environment. They can get very locally specific information that's valuable to them but also valuable for understanding the Earth as a whole."

Mahoney collaborated with Shari Gearheard, of the National Snow and Ice Data Center in Boulder, Colorado, on the NSF-funded Siku-Inuit-Hila project, a 2006–13 sea-ice study that teamed scientists with members of Inuit communities in Utqiaġvik; Clyde River, Nunavut, Canada; and Qaanaaq, Greenland. As part of the project, Mahoney and Gearheard provided inexpensive sea-ice monitoring stations to the local observers, who then collected ice-thickness data at significant locations off their respective coasts. The study revealed unexpectedly thin ice in the fjords off Qaanaaq, evidence that warm Atlantic waters were encroaching farther into northwest Greenland than previously thought.

Data like those obtained in the Siku-Inuit-Hila project can be difficult to collect by conventional means. Visiting scientists tend to flock to the Arctic during the summer but rarely stay long enough to make field measurements through the winter. Satellites can detect the areal extent of an ice sheet but not its thickness—and the resolution is often insufficient to pick up on subtle changes in ice texture that can be relevant to coastal dynamics. "The coastal zone is a boundary for the Arctic Ocean," says Mahoney. "Unless you get the circulation and the ice properties correct there, you're not going to get the rest of the model right either."



HAJO EICKEN, a University of Alaska Fairbanks geophysicist, helps run the Seasonal Ice Zone Observing Network, which partners with residents of coastal Alaskan towns to monitor local sea-ice phenomena. MATTHEW DRUCKENMILLER

Building ties

Peter Winsor, a physical oceanographer at the University of Alaska Fairbanks, is working with residents in communities along the coasts of the Gulf of Alaska and the Bering and Beaufort Seas to measure water-column properties in shallow areas that can't be reached by large research vessels. Although "there's an enormous amount of good science that can be done in the near-shore region," says Winsor, historically, "many of us scientists didn't go to the near shore."

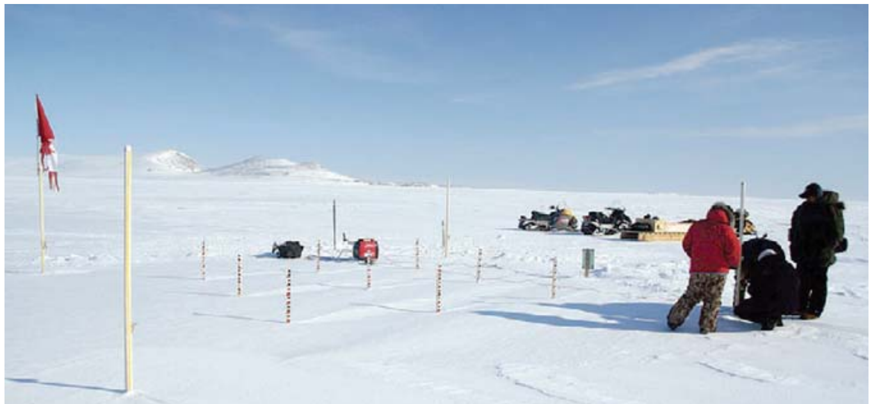
But, he adds, "you can't just barge into a community and say, 'Hey guys, we want you to dip these instruments in the ocean.' " Winsor notes that he had established close ties with members of the communities he partners with long before launching a formal project. For him and other scientists who are collaborating with Arctic residents, successful projects are as much a product of relationship and trust building as of scientific savvy.

"You get there by really listening to what their needs are, so that you're not just addressing your own narrow scientific interests but also responding to their science needs," says Mahoney. Although those needs and interests are rarely identical, they often overlap. The same information that's valuable for forecasting weather trends, oceanographic properties, and tundra conditions may help local residents to, for example, plan hunting and fishing seasons, chart safer travel, or better allocate natural resources. Mahoney thinks those kinds of opportunities for mutually beneficial research are too often overlooked. "I think there has been a history of people coming into communities just looking for labor—help lifting heavy boxes or guiding to get into certain areas—and not recognizing the contributions the community already makes to the actual science."

A rising profile

Although pilot projects have flourished, funding for sustained, Pan-Arctic networks of citizen observers remains scarce. As Winsor sees it, such networks—comprising geographically diverse communities making identical measurements, year after year—could potentially be a key to illuminating how regional changes in climate propagate from one part of the globe to another. His initial grant provided funds to work with three communities, but he's looking to grow that number to six. Ideally, he says, "we'll stick with those six and keep them going for decades and decades."

Recent indications of support from the US and other Arctic nations may justify Winsor's optimism. In 2013 the Interagency Arctic Research Policy Committee, a subcommittee of the US National Science and Technology Council, added community-based-monitoring and traditional-knowledge components to its five-year Arctic Research Plan. Last March President Barack Obama and Canadian prime minister Justin Trudeau jointly pledged "to more broadly and respectfully include indigenous science and traditional knowledge" on several science and policy fronts, including "advancing our understanding of climate change." And in September, at a White House ministerial meeting, the US, the European Union, and 23 other governments committed to expanding international collaboration on Arctic science—and to doing so in partnership with the Arctic's indigenous peoples.



THE SIKU-INUIT-HILA PROJECT was a 2006–13 collaborative study of sea ice that teamed scientists with members of Inuit communities in the US, Canada, and Greenland. Here, team members install an ice-thickness monitoring station. (Image courtesy of Shari Gearheard.)

Martin Jeffries, executive director of the Interagency Arctic Research Policy Committee, points to several tangible gains that emerged from the ministerial gathering, including the planned expansion to Canada and Finland of the Environmental Protection Agency's Local Environmental Observer Network, an online forum in which scientists and community members discuss unusual environmental occurrences. Jeffries says the most important development, however, may have come before the meeting was gaveled in: "The day before, we had an afternoon listening session where about 40 senior leaders from the federal government sat down with about 40 leaders of Alaska native and international indigenous peoples organizations to listen to their concerns, their needs, and how they'd like to be involved in Arctic science."

That's progress, says Pew's Huntington. But he nevertheless sees a gap between the rhetoric and actual investment. "It's terrific that it's getting that high profile," he says. "But it still feels at times like an uphill battle to get beyond the pilot project and workshop stages."

Ashley G. Smart

Effort in asteroid defense under way despite funding constraints

A US interagency program is refining methods of deflecting asteroids as it works toward finding tens of thousands of undetected near-Earth objects.

In 2013 a meteor estimated to be 17 m in diameter exploded with the energy of a 450 kt nuclear weapon in the sky 23 km above the Russian city of Chelyabinsk. Although no lives were lost, more than 1600 people were injured, mostly from flying glass shattered by the shock wave. Regional hospitals were overwhelmed.

That was before Russia annexed the Crimea and relations with the US soured. Collaborations between US and Russian national laboratories dating to the immediate post–Cold War period were ongoing. It was natural for Russian lab directors to seek help from their US counterparts to mitigate a future asteroid strike, says Don Cook, who as the director of defense programs and deputy administrator of the Department of Energy's National Nuclear Security Administration (NNSA) oversaw the US nuclear weapons labs and arranged their participation in the bilateral research effort.

In seeking interagency approval for that effort, Cook met some resistance from staff at the National Security Council. The suspicion was that the NNSA labs might use such a program as a pretext to resume nuclear testing, in the event that an existing weapon couldn't be used against an asteroid. Ultimately, the skeptics at the security council were mollified when the NNSA and NASA signed a memorandum of understanding to cooperate with each other on what has become known as planetary defense, with NASA designated the lead agency.

The program has grown even after collaborations with Russia were terminated in 2014. Today, scientists and engineers at NASA work on planetary defense with counterparts at the NNSA's Lawrence Livermore, Los Alamos, and Sandia National Laboratories.

NASA and its contractors continue to discover near-Earth objects (NEOs)—comets and asteroids that have perihelions of 1.3 astronomical units or less—at a rate of a few per day. As of January, approximately 15 000 asteroids and 107 comets have been uncovered and have had their orbits calculated, according to NASA's near-Earth asteroid survey. Of those, around 1700 are considered potentially hazardous, meaning their orbits pass within 8 million km (1250 Earth radii) of Earth. (See PHYSICS TODAY, September 2015, page 22.)

The number of NEOs rises steeply with diminishing size. Although NASA long ago met a 1998 commitment to Congress to locate at least 90% of NEOs larger than 1 km, some 3500 NEOs of 300–1000 m diameter predicted to exist remain undetected, nearly as many as the 3855 that have been located. Approximately 14 500 asteroids of 140–300 m are undiscovered; just 2500 of those in that