On Frozen Water:
Why the Cryosphere Matters for Each of Us

Statement of

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An Update on the Climate Crisis: From Science to Solutions

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Chairwoman Johnson, Ranking Member Lucas, and members of the House Committee on Science, Space, and Technology, I greatly appreciate the invitation to join you here today for a conversation about the climate crisis, the cryosphere, and actions that will lead to the future we all want. I speak today as a mountain and Arctic scientist, an explorer and educator, and as a private citizen who lives in the rural, western United States on the ancestral lands of the Ute, Apache, the Pueblos, Hopi, Zuni, and the Diné Nation.

My approach to communicate climate science is often through narrative with myself a character in the story. Skillful narratives about the changes taking place on our planet due to the high emissions of carbon dioxide from burning fossil fuels are essential to bridge divides, communicate science to diverse audiences, and develop and implement resilience planning. Our actions have led to the Climate Crisis. The commitment of U.S. Congress to action this month and each month this decade is essential to reduce risk and grow resilience to the many environmental threats our country currently faces. Growing our resilience to one environmental threat increases resilience to them all.

The narrative that is part of this written testimony is about my journey in mountain and Arctic science. It's inspiration and basis is from the places I have conducted research, lived in the mountains, and the many people with whom I've spoken about environmental changes to learn about their concerns. To complement the narrative, my testimony begins with a list of key points, summarizing ideas in the narrative, and adding key points that I could not weave into the story and some must-note key points on the climate crisis. I have also chosen to submit as a part of my testimony the *Cryosphere1.5°: Why Cryosphere Dynamics Demand 1.5° Pathways for 2020 and Beyond* report http://iccinet.org/cryosphere15/ led by the International Cryosphere Climate Initiative and released in December 2019. I and many other scientists across different areas of cryosphere expertise contributed to this policy-focused document.

My perspective on key points about the climate crisis, cryosphere science and solutions:

1. Growing our resilience to one environmental threat, such as climate change, increases our resilience to them all. Our goal is resilience and for this we need to protect our planet's frozen water by limiting warming over preindustrial times below 1.5°C.
    a. Resilience planning and implementation are essential. There is tremendous cost-savings and life-savings if we focus our efforts on preventing disasters rather than 'putting out fires'.
    b. One cannot assume that what is important to them is important to others. Thus, when we see a pattern of change over time, we should ask people if it is important to them that for example there are fewer fish or there is less ice. We can explore together what might explain the observed changes and the implications of these changes for the future. Scientists can choose to expand our approaches for science, which would benefit from government support.
2. The Climate Crisis is real and I am concerned about the future. I am concerned that Americans will be harmed much more greatly than they already have been harmed, that livelihoods will be lost, and unprotected public lands that are being developed won't provide critical benefits to people, including carbon storage, soil stabilization, disaster regulation and water supply, in the future.
    a. Land and ocean protection are essential to American resilience at local, regional, national and global scales. Conservation is fundamental to resilience and should be a government funded, national priority.
    b. The wisdom and cultures of Native Americans, Native Alaskans, and Native Hawaiians and Pacific Islanders is essential to grow our resilience as a nation. I am grateful for the lessons I've learned by listening to their narratives. As a nation and in our communities, we can build inclusive spaces that value their perspectives and include them more in decision-making.
    c. People and countries with fewer economic resources will experience greater harm, though they've contributed less to the crisis. Federal actions to limit climate injustice are essential.
3. The world is 70% ocean and very blue. The world is also green and brown and white. The white surfaces of Earth, where the frozen water of the cryosphere is most evident, provide balance for sustaining air flows, the location of climate zones, and the rate of heating on our planet. With less white, a region and the Earth as a whole warms faster.
    a. Ice sheets, sea ice, and glacier ice are being lost at extraordinary rates in nearly every region of the Earth. Loss perpetuates further loss for many reasons. Loss will continue for decades, centuries and millennia even if carbon dioxide emissions from fossil fuels were zeroed out today. For this reason, resilience planning and implementation are critical. The rate of change must slow to allow people to adapt, changing what we do in small and big ways.
    b. When ice is lost, we are losing an ancient resource, one created under greatly different climate conditions. Ice cannot rapidly be restored.
    c. Snow is different than ice, because for many regions of the Earth, including those in the United States, snow falls, accumulates and melts on an annual cycle. The snow supplies our rivers and thereby people across our continent with water, even where snow rarely falls, such as Oklahoma, Texas and Arizona. The paths and

economic value of water from snow in rivers across the United States are well mapped. Snow is a national asset.

d. Snow also recharges groundwater reserves that are critical to sustain water supply to rivers, agriculture, industry and citizens in times of low precipitation and low river flows. Our understanding of the sensitivity of groundwater recharge to climate change is poor and improving this understanding is critical to growing resilience.
e. The presence and persistence of snow is changing in the world's high mountains, including in the western United States. Ecosystems are impacted. Many plants are growing less and others are dying, though the death of plants due to less snow is not clear. We don't yet know the consequences of changes in plant cover, biomass, species abundances, and the timing of their growth on water supply, carbon storage or nutrient and metals retention in mountain watersheds.
f. Many of the changes to ecosystems and their benefits for human well-being may be due to changes in ice and snow that have not yet been demonstrated through quantitative observations and analyses published in peer-reviewed science journals. The lived-experiences of indigenous and local people living in mountain regions and adjacent deserts are essential to fill this knowledge gap and inform resilience planning.
g. Permafrost is different from ice and snow; it is the frozen, carbon-rich ground that releases carbon dioxide and methane to the atmosphere as it thaws. This is a destabilizing process that accelerates the heating of our planet and proceeds over time in leaps of abrupt change. We are leaping forward with exceedingly high and uncontrolled carbon emissions from the Earth's frozen ground. The only way to slow this process is to keep the Earth below 1.5°C relative to preindustrial times.

4. Reducing any, and all, other stresses on plants and restoring lands will grow resilience and sustain the benefits of ecosystems, including the diversity and beauty of our mountains. Due to warming temperatures and declining snow, our 'purple mountain majesties' are at risk of long-term changes, some of which would be irreversible.
    a. Due to topography, nooks and crannies as well as great heights, mountains protect biodiversity and people when climate changes. Mountains offer protection from heat and store water. Mountains are a national asset. Migration paths for diverse species and people require protection and international agreements to allow migration out of unsafe climate zones to the south or in lowlands to safe ones.
    b. The western United States may be the only mountainous region for which there are published studies in peer-reviewed scientific journals that demonstrate the link between changing snowpack and wildfires through earlier snowmelt. The link is more evident in Arctic regions. Actions that protect snow reduce the risk of wildfire and its impact on water availability, water quality and air quality. Protecting deserts protects snow by retaining soil in desert lands.
5. The air and water connect us all. To grow our resilience, people need to be connected across air and watersheds. It is essential that we talk about change and what we will do to grow resilience.
    a. I recommend that U.S Congress create a U.S. Corps of Social, Environmental and Engineering Sciences (SEES). The SEES Corps would form an extensive network of centers across the country. Centers would be spaces to gather, exchange

knowledge, build trust and implement innovations for monitoring, restoring and protecting ecosystem benefits for human well-being. These centers would grow our resilience to all environmental threats.

b. The UN Intergovernmental Panel on Climate Change (IPCC) has developed a robust process to assess the causes and consequences of climate change based on published studies in peer-reviewed scientific journals. The SEES Corps could develop a process to synthesize what we know through other knowledge systems, those of people who have long-lived on and directly manage the nation's lands and waters. People could be paid for their investments in knowledge exchange, and their tribes or organizations be provided with funds for resources, such as stream gauges and sensor networks, to ensure reliable water, energy and food.
c. Internationally, U.S. leadership on climate change is irreplaceable. The absence of U.S. leadership at the recent COP in Madrid had a negative impact. If you are from a state that is part of the U.S. Climate Alliance, I encourage that you support the work of your state, including their planning for nationally determined contributions (NDCs) to take to COP26.
d. The climate crisis and increasing loss of our cryosphere can be a tipping point towards compassionate leadership and resilience mindedness in the United States. For many, there are barriers to participate in science and resilience planning. These barriers need to be removed, so that more people of color, more indigenous people, more women, more people from rural regions, and more immigrants have the opportunities that I and others have had. This will lead to new ways of conceptualizing and solving the climate crisis.

A journey in mountain and Arctic science to inform solutions for the climate crisis:

In the summer of 2000, when I was 28 years old, I was on a bush plane bound for a remote river valley in the Brooks Range, Alaska. I'd recently finished my PhD in December at the University of Colorado, Boulder. I'd camped out in a bouncy castle for Y2K, because I didn't think the electric grid would fail. And, I'd said no to working at a prestigious research institution. They offered the opportunity to be part of National Science Foundation (NSF) funded research at the foremost Arctic field station in the United States. I would have slept in a bed, studied the tundra outside my dorm, eaten meals that I did not have to prepare, and measured the nitrogen and carbon in Arctic plants and soils.

Instead, I chose to step off a bush plane onto a gravel bar, cross a braided river, and walk up a headwater stream of the Noatak River on frozen water. I chose to sleep in a Mountain Hardware tent, eat canned chili and pilot bread, and measure the nitrogen and carbon in Arctic plants and soils. The field work I did was similar, but the learning was far greater.

Why? I immersed myself. I stepped away from books and computers. I walked the land, sinking into frost boils with each step. It was easy to tell where the permafrost began. It was the depth to which my foot sunk in August, when all the ground that would thaw that season had thawed.

There weren't many fish in the river on which I was camped that summer. Over pizza or standing on Front Street looking out across the Chukchi Sea, people in town would ask me if I knew why

and offer their ideas. It was common to exchange ideas about how something that was important, such as fish or ice, was different than in the past, what might explain the change, and contemplate what this might mean for the future. If we do not talk honestly about change and prepare for it, we risk food security, reliable water, safe transit, and safety during catastrophic events. We risk human lives and the loss of essential species. We must find ways past the politics and reinvest in conversation about our changing planet.

As our planet warms, and it is warming, ice is melting, permafrost is thawing, lakes are being lost while others are forming, snowlines are moving up in latitude and elevation, and polar rivers and seas have less ice. Is this important? What do you think might explain this? What might it mean for the future?

This is what brings us together today. Every tenth of a degree matters by influencing the amount of water that falls as rain instead of snow and the amount of ice that melts. If the Earth is less white, which it is, it warms up faster, air flow patterns change, winter and summer precipitation patterns shift, and seas rise. As permafrost warms, it thaws and could add two atmosphere-equivalents of carbon dioxide to our skies. Abrupt thaw process in permafrost-rich lands are a sudden, destabilizing process in the Earth's climate system.

Frozen water is vital for human well-being.
The cryosphere matters for each of us.
The cryosphere must be protected.

The experience of living in a rural Arctic region, in a community with many Inuit, and public radio as it was meant to be led to my choice to live in Colorado's San Juan Mountains, teach at a Native American Serving Non-Tribal Institution, and make sure that the lands I study most often are ones I know well. It's not just through my research that I learn about the land, but also through conversations with people across Colorado where I've lived since I was 22 years old. There once were country doctors who made house calls and knew their patients well. I'm a country scientist with a tough diagnosis to share, one that is informed by my investment in work with the IPCC, conversations with many, and my own research and observations.

For 24 years I studied mountains and Arctic lands before being asked in 2018 to contribute as a lead author for the chapter on High Mountain Areas for the recently released IPCC Special Report on the Oceans and Cryosphere in a Changing Climate (SROCC). I said yes. Then, I searched for articles in scientific journals, I read them, searched some more, and read some more. It's incredible how many papers one needs to read to find the ones that are relevant to the scope of an IPCC report. I mention this and want to assure you, that as authors, we are not biasing which articles we pick to include based on our views. Authors aren't part of the scoping for the report – the IPCC and governments do this part of the process. Authors are tasked to find articles relevant to the agreed on scope. We consider and include the evidence from all of the articles within the scope, especially the few that show a different pattern from many others.

Here's how this works. In the high mountains of Colorado, where I do my field work to characterize how plants are responding to changing snow dynamics and what this means for water supply to the Western United States, plants are growing less. The changes in snow lead to

insufficient water for at least some part of the summer. Many of the plants, but not all, are adapted to this. Some die. If they are trees and there are many, we read about it in the news, because their trunks and branches remain visible evidence of what was lost. Some plants may die without a trace, unless there are baseline data to know they were there. Many plants just grow less.

Through my review of published scientific articles for the IPCC report, I learned that these same patterns were reported in many other mountain regions, but not in all. On the Qinghai-Tibetan Plateau in China and near Mount Everest in Nepal, it is warming and plants are growing more. Is this important? Why might this be? What does it mean for the future? Scientists in China and Nepal are working to answer these questions, just as we are doing here in the United States. We often lack baseline data. We don't have all the answers and this too is valuable to explain.

In middle school, high school and college, students that excel in science courses are often doing well because they invest time to study and retain information well. Science appears true or false. Science appears 'cookbook'. But it's not. Science is not a cookbook or a short story. It's a saga.

Here's one way that science works. Each year, at winter's end, the researchers with whom I work and I wait for snow to melt. We also melt snow early to have study plots that vary only in one factor from the others, the controls. We measure everything that is possible with the equipment that we have. Sometimes, we have what we most need, a $50,000 field spectrometer to measure light reflectance of plant canopies across 10 nm bands of light for visible, near infrared, and shortwave infrared regions of the energy spectrum.

Sometimes, we don't have the equipment we need, and we just use our eyes to count plants, measure plant height or identify which species have green leaves on a weekly basis. I've done this for many years across different mountain and Arctic regions. Other research teams have observed flowering times, which affect species survival, in the same places for over forty years.

The expensive part of science isn't the equipment. It's our salaries and health care. It's the logistical costs to go to remote mountain and polar regions and sustain field stations, basecamps, and their staff in places where cryospheric changes are impacting climate regulation for our planet. I'm grateful the NSF Office of Polar Programs has a budget for logistics. Growing logistics budgets across programs in environmental sciences and creating more opportunities for field stations and basecamps to receive funds directly for the infrastructure and support they provide scientists would be beneficial. Increasing and sustaining logistics funding for field studies is critical.

Once collected, our data reveal patterns, stories about how plants respond to changing snow. Often it's been different than I expected in Alaska tundra, in alpine basins and across elevation from mountain valleys to their peaks. This leads us to collect more data across different snow years and sites. I recently travelled to China to plan for a snow experiment there and presented a vision for a global network of snow experiments across mountain and polar regions at the American Geophysical Union's annual meeting in December. There is no clear way to fund this international effort on the needed time scale of a few years. Many scientists face this challenge.

Sustained funding of science should match the magnitude and scale of the climate crisis and support diverse approaches to science.

Scientists develop and use new approaches to measure the same things we did before. We integrate our data into models. We develop predictions from the models and use them to plan for new field studies. We retest our initial idea, the model predictions, and the conclusions of our initial results. If we don't scrutinize our ideas, data, models, and conclusions, other scientists will. Published journal articles that underlie IPCC reports are the routine communication of research as chapters, while the saga goes on for decades and involves many.

We, scientists, government and citizens, have been on a journey together to uncover what is changing on our planet due to our actions. We've learned a lot over the past few decades, and we know the Earth is changing in ways we did and did not expect. To limit our risks, we have just one decade to agree it's important, affirm together it is us, and accept responsibility that our actions must change.

If you or if many of the constituents in your district, question the data or scientists' conclusions about the causes and consequences of climate change, I encourage you to see for yourself and share what you learn with them. Yes, this is an open invitation for a personal tour of a mountain watershed in Colorado, a tundra walk in Alaska, or a glacier trek in Greenland. These are places I know well, and we can invite others with indigenous knowledge who know them better than I to join us. If you'd like to see the Arctic sea ice or Antarctic ice sheets, I have friends who could help with this.

If you choose Colorado, you might think to come in winter when there is skiing, or in summer for the wildflowers or to escape uncomfortably high summer temperatures where you live. But the seasons to come to understand our changing mountains best are when snow first accumulates, especially if snow arrives late, or during melt season, better known as mud season in the mountains. This is the time of year when the mountains are waking. Water is rushing across the land and to great depths where it recharges groundwater. Much of the water that falls as snow sustains rivers and us indirectly by moving first to groundwater, then in time to mighty rivers, when they are at their lowest flows. In this way, much of the water in my state makes its way to your states, in ways that science can demonstrate well and in ways we still need to figure out.

The saying is that 'seeing is believing' and some of the evidence is in our backyards as well. In my backyard, I've seen double rainbows, red moons, meteor showers and bear. In my backyard, there are dense scrub oak, a plant that I know can carry fire quickly from the valley below to the hilltop on which I live. In 2018, there were helicopters and planes flying across my backyard. They flew for over a month through smoke-filled skies, most often in the evening while we were eating dinner on our deck. They carried fire retardant and reservoir-filled tubs of water. That fire was 10 miles from my home. For many people I know, that fire was in their backyard.

The fires currently burning across Australia feel close to me, because I have many friends in Australia. I have friends who have left their homes to stay safe, are wearing face masks to stay safe, and are putting out and tracking the fires to keep others safe. As I worked on the IPCC SROCC report, the western United States was the only mountainous region for which I could

find published scientific articles that link less snow to increased risk of wildfire. The link has greater confidence for Arctic regions. The lesson of Australia is that it is dangerous and costly to become the poster child for climate change. The United States is providing support to fight the fires in Australia. We should also learn from their mistakes. Their government spent about $2.7 billion per year on recovery from disasters between 2010 and 2013, and only $100 million per year on resilience. A disaster risk reduction framework that the government developed lacked the needed 2019 implementation plan. We can all do better.

In times of crisis, which I consider this to be, governments invest funding, companies invest funding, private foundations invest funding, and people invest time. Firefighting, evacuation, disaster relief and disaster recovery funds are raised to manage in times of crisis. As a country, we may have far more systems in place to make significant and immediate decisions about raising and spending large sums of money as and after loss and damage occur rather than to prevent them. We also have a culture that, as it should, has tremendous respect for firefighters and rescue workers who volunteer their time and risk their lives. Scientists who do research and communicate their insights hoping to avert disaster are often mistrusted, though some risk their lives and many risk their reputation. I'm grateful for their efforts. They are heroic in under recognized ways.

To accept the science and solve the climate crisis, it's important to know scientists and in knowing us, trust the work in which we've invested ourselves. I and many other scientists would like the chance to cultivate trust. If a diagnosis from a doctor is limited life expectancy, we often chose to see another doctor and possibly another. The diagnosis doesn't seem real unless it is a doctor we trust. A*n extensive network of Social, Environmental and Engineering Sciences Centers across the country could advance inclusion and ensure there are scientists with indigenous, local and professional knowledge everywhere.*

I was shocked by the ice on an Arctic river in summer when I began to do field research in the Brooks Range, Alaska. I'd known still water could freeze. I had not realized flowing water could freeze and form ice over a meter thick. Standing on the ice and seeing its cross section made it real. Solid river and sea ice ensure safety for people who must travel across frozen rivers and seas for food, commerce and to visit family in regions where they have lived for thousands of years. Ice and snow provide water and climate stability for human well-being across the Earth. The time is now to build bridges of trust that connect citizens, governments and science.