Executive Briefing

The Cryosphere1.5° Report

WHY CRYOSPHERE DYNAMICS DEMAND 1.5° PATHWAYS FOR 2020 AND BEYOND

For the complete Cryosphere1.5° Report, including figures, see:

www.iccinet.org/cryosphere15

Preface

Over the next year, governments face the most consequential decision collectively made in the history of humanity: whether to take concrete steps to keep the planet below 1.5°C warming, or make the decision – either explicitly, or de facto through inaction – to force the planet's temperatures higher.

These 2020 NDCs, or Nationally Determined Contributions will mostly cover the years up to 2030, following the Paris Agreement NDCs in 2015 that mostly covered 2020–2025. This decade is what the IPCC Special Report on 1.5 Degrees of Warming (SR1.5) determined as critical to stay below the 1.5° level. So far, not only do combined NDCs to-date risk our reaching 3°C or more in 80 years: present emission trends have us breaching 4°C within the lifetimes of many children born today. Emissions have in other words, continued unchecked on a "business as usual" scenario despite the signing of the Paris Agreement four years ago.

Since Paris, other political and economic forces have caused a growing number of decision makers to place their attention elsewhere, from populist domestic politics to destructive international conflicts. This Report, reviewed by over 30 IPCC and other leading scientists, is an attempt to bring attention back to what inevitably will result if attention remains so diverted, all because of the freezing point of water.

The cryosphere – snow and ice regions – is amazingly sensitive to small changes in temperature: at root, the slight temperature difference between solid frozen ice, and liquid water. This principle holds for an ice cube taken from the freezer, or a mountain glacier or great polar ice sheet: once temperature exceeds 0°C/32°F, it melts. And in Earth's past, the difference between the 1°C above pre-industrial temperatures where we are today, and 2°C has been very different planetary states, including the difference between a few meters of sea-level rise, to well above 20 meters.

Glaciers, snow, permafrost and sea ice all make up the cryosphere: slow to react to warmer temperatures, but even slower to return once temperatures fall again. A decision to allow temperatures to go above 1.5°C – let alone 2.0°C or above – inevitably will cause a change in cryosphere that will in turn, change the Earth to one which has never seen human existence.

The summaries in this Cryosphere1.5 Report, taken from the IPCC SR1.5 and Special Report on the Oceans and Cryosphere (SROCC) and other published research, confirm this physical reality that at some point in the gradient above 1.5°C, processes will be set in motion that cannot be halted or easily reversed, in some cases not even if temperatures return to pre-industrial. This is why policy decisions in the coming years will determine the future state of the Earth for centuries and generations to come. Never has a single generation held the future of so many coming generations, species and ecosystems in its hands. Cryosphere climate change is not like air or water pollution, where the impacts remain local and from which ecosystems largely can be restored. Cryosphere climate change, driven by the physical law of water's response to 0°C, is different. Slow to manifest itself, once triggered it inevitably forces the Earth's climate system into a new state, one that most scientists believe has not existed for 65 million years.

This future however is neither defined, nor hopeless. Instead, pathways to the needed lower emissions levels not only exist, but were very well-defined in the SR1.5 as physically, technologically, and economically feasible.

This is why decision makers in the span of the next year will make the most consequential decision in the history of humanity, let alone the planet. As they – as you – make these decisions, it is important that you know what they will mean. Will the Earth address the cryosphere crisis, or let it fail because other, more short-term issues took precedence?

The choice is ours. The cryosphere cares about nothing but the melting point of water.

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Executive Summary

AVERTING A MUCH-CHANGED EARTH

Decisionmakers today face with a choice between unprecedented but necessary policies and actions that will hold the world below 1.5°C, or take a slower, seemingly more "prudent" and "realistic" path towards 2°C, 3°C or above. The IPCC Special Report on 1.5 Degrees of Warming (SR1.5) laid out those choices in stark and clear terms upon its release in October 2018. Nearly a year later, the Special Report on Oceans and Cryosphere (SROCC) summarized the current status and future of the water and ice parts of the world. In the cryosphere – portions of the globe seasonally or permanently in a frozen state – it detailed a world undergoing rapid and in some respects, irreversible changes, all tied to the freezing point of water; or rather, the melting point of ice.

This Report, authored and reviewed by over 40 IPCC and other cryosphere scientists, combines the findings of both the SR1.5, and SROCC, plus published studies since. Its inevitable, science-based conclusion: failure to choose policies keeping the world below 1.5° is neither measured nor economically prudent. Instead, it will result in a cascading series of disasters; not only for people living this century, but even more so for the generations that follow. Warming above 1.5° will have many impacts, but the physical realities of changes in cryosphere alone will drive much of what follows.

This is because the gradient between today's 1°C above pre-industrial temperatures, to 1.5° and 2°C and above, represents a drastic and on human timescales, essentially permanent shift in the state of our planet *because of the cryosphere response*. The Report's main findings:

Ice Sheets and Sea-Level Rise

We see far greater risk of massive irreversible sea-level rise (SLR) at 2°C, on a scale of 12–20 meters or more in the long term. The climate record of the earth over the past few million years is quite clear:

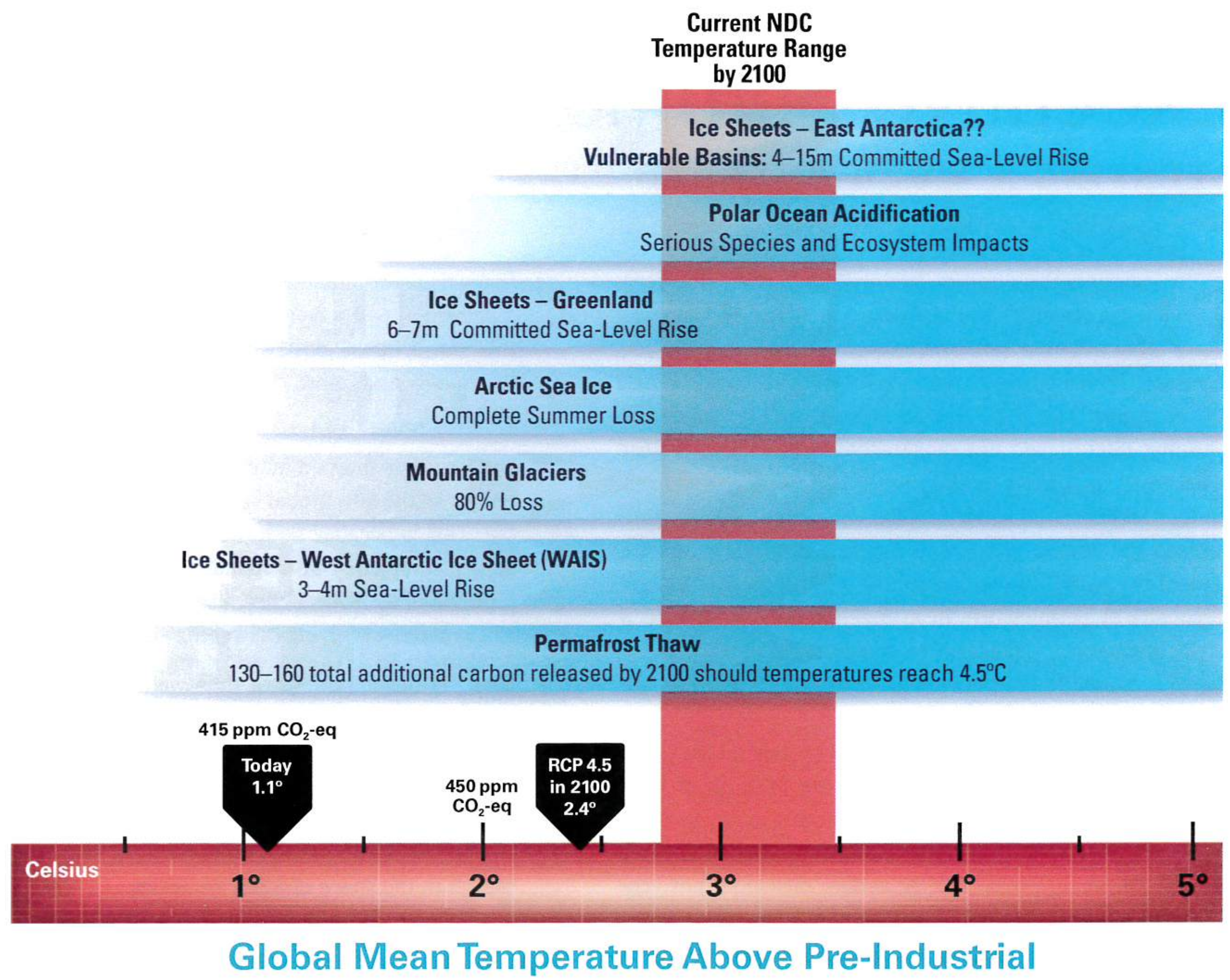
- At today's temperature of 1°C over pre-industrial, we have locked in about 1–3 meters of sea-level rise over the next centuries from loss of mountain glaciers and a portion of the polar ice sheets, even if we could hold temperatures at 1°C.
- Risks rise substantially at 1.5°, with the Earth showing a pattern of 6–9 meters compared to today when it was this warm in the past; coming from additional loss of Greenland and most of the West Antarctic Ice Sheet (WAIS).
- 2°C however shows a much sharper rise: between 12–20 meters as the new global sea level, locked in over millennia. This is because both the WAIS and Greenland melt nearly completely at a sustained 2°C; with vulnerable portions of East Antarctica also posing a threat; and up to 25 meters occurring between 2° and 3°C.
- Most seriously, periods of time well in excess of 2°C – especially if we reach 3°C, 4°C or more, which is our current emissions pathway – increase the risk, speed and potential inevitability of the above changes. The rate of change can itself become a risk: at the end of the last Ice Age, sea levels rose by up to 4 cm per year, and 12–14 meters in the space of a few centuries.

The good news: these processes, especially the collapse of the West Antarctic Ice Sheet can be slowed if temperatures remain close to 1.5°, allowing far more time for communities to adapt to the rising seas. Much of the WAIS may have passed a threshold of collapse sometime between 2010 and 2015, at around 0.8°C; but at lower temperatures such as 1.5°C, this collapse can be slowed to perhaps thousands of years, rather than (in the worst projections) just a few centuries. Even at today's 1°C, Greenland's ice loss has doubled in the past 20 years; and Antarctica's has tripled.

Mountain Glaciers and Snow

Few glaciers near the Equator, such as the northern Andes and East Africa can survive even today's 1°C. Some of these were shrinking anyway after the last ice age; but global warming has speeded their disappearance by many centuries. Glaciers and snow in the northern Andes provided a reliable seasonal source of water, and their loss especially will impact rural populations in Peru and Chile.

FIGURE S-1. Cryosphere Dynamics and Temperature



Approximate temperature ranges at which five important cryosphere dynamics or "thresholds" may be triggered, some irreversibly on human timescales, based on updated observations and models.

Mid-latitude glaciers and snow in the Alps, southern Andes/Patagonia, Iceland, Scandinavia, New Zealand and North American Rockies can survive at 1.5°, but these glaciers will disappear almost entirely at 2°C, and snow cover decrease. For these glaciers and mountain snowpack, that half a degree spells the difference between sufficient seasonal water supply, such as in the American West, Tarim and Indus river basins; and water scarcity.

The essential watersheds of the Himalayas/Central Asia at 1.5°C maintain around half to about two-thirds of their ice. At 2°C, much more will be lost, with regional impacts on water supply and increasing political instability, especially as monsoon rains become far more unpredictable at 2°C as well.

Permafrost and Carbon Budgets

Limiting warming to 1.5° rather than 2°C saves 2 million square kilometers of permafrost. Permafrost carbon release (as both methane and CO2) is greater at 2°, especially in "overshoot" scenarios because once thawed, former permafrost irreversibly continues to release carbon for centuries:

- If we can hold temperatures to 1.5°C, cumulative permafrost emissions by 2100 will be about equivalent to those currently from Canada (150–200 Gt CO_2-eq).
- In contrast, by 2°C scientists expect cumulative permafrost emissions as large as those of the EU (220–300 Gt CO_2-eq).
- If temperature exceeds 4°C by the end of the century however, permafrost emissions by 2100 will be as large as those today from major emitters like the United States or China (400–500 Gt CO_2-eq), the same scale as the remaining 1.5° carbon budget.

These permafrost carbon estimates include emissions from the newly-recognized abrupt thaw processes from "thermokarst" lakes and hillsides, which expose deeper frozen carbon previously considered immune from thawing for many more centuries.

The "anthropogenic" carbon budget to reach carbon neutrality and remain within 1.5° of warming must begin to take these "country of Permafrost" emissions into account. Only lower emissions pathways that preserve as much permafrost as possible can minimize this potentially large contribution to future global warming, and the need for future generations to maintain negative emissions efforts to compensate for those from thawed former permafrost.

Sea Ice and Polar Ocean Acidification and Fisheries

At 1.5°C global warming, it is unlikely that Arctic sea ice will melt completely in any given summer; and if it does melt completely, that ice-free period will be brief. In contrast, by 2°C the Arctic Ocean is expected to be ice free in summer for several months. This long ice-free period will warm the Arctic Ocean, feeding back to raise regional air temperatures and accelerating Greenland melt and associated sea level rise; increasing permafrost thaw and associated carbon emissions; and also leading to a decrease in snow cover. All of these will in turn make for faster rates and scale of overall global warming, making efforts to address the problem that much harder.

Many parts of the Arctic ecosystem depend on the existence of thicker, multi-year sea ice. These will likely collapse with the complete disappearance of multi-year ice cover at 2.0°C global warming. This impact is amplified by our observation already today of more frequent ocean "heat waves." Human communities are of course also impacted, especially Arctic indigenous cultures reliant on the reliable presence of sea ice for many thousands of years.

Fish stocks such as cod are much more negatively affected by changes in the polar oceans at 2°C global warming than at 1.5°C global warming. These changes include ocean acidification, warmer and less salty sea water from increased river runoff, glacier melt and ice sheet melt; as well as greater competition from mid-latitude species moving polewards. In contrast, polar species and ecosystems have nowhere further to migrate.

Today's rates of ocean acidification are greater than at any time in 3 million years, and pose an immediate and serious threat in cold polar waters, which absorb CO2 more quickly. The oceans will need 50–70,000 years to return to normal pH levels, a key argument for keeping CO_2 levels as low as possible and against schemes aiming to decrease solar radiation rather than CO_2.

Conclusions

Current rates of warming and CO2 increase have not occurred in the past 60 million years of Earth's geologic history. Most "uncertainties" trend towards greater damage and risk, not less. There is no real geologic precedent for predicting the cryosphere response and its risks.

Overshoot is not an option. The risk of triggering these dynamics irreversibly grows with each tenth of a degree over 1.5°, and especially once we exceed 2°C.

1.5°C remains both possible, and imperative. The SR1.5 made clear that pathways to remain below 1.5° globally remain, but will require immediate and transformative action. Many countries and sub-national stakeholders are moving to answer this call, taking concrete steps towards emissions that if adopted globally, will keep the planet below 1.5°. More countries and actors need to join their ranks and intensify their 2020–2030 reductions to 1.5° levels.

The message is clear: 2°C means a completely unacceptable risk of loss and damage to human society, from cryosphere dynamics alone. We must aim for 1.5°C, and to be frank, to the extent possible plan for a return to 1°C as soon as possible because of the way the cryosphere will respond even at the long-term 1.5° level, through negative emissions measures.

This is an issue of generational justice, and the legacy we leave behind.

Temperatures, “Nationally Determined Contributions” and Carbon Budgets in This Report

To calculate future temperature impacts, scientific studies largely use a set of three greenhouse gas pathways (called RCPs, for “Representative Concentration Pathways”) through 2100 that lead to changes in the planet’s energy balance, expressed as watts per square meter (W/m^2). So RCP 2.6 results in 2.6 W/m^2, RCP 4.5 leads to 4.5 W/m^2 in 2100, and so on.

These different levels of “climate forcing” translate into certain temperature ranges by 2100. RCP2.6 is used by many scientists and policy makers as a proxy for 1.5°C pathways, but actually overshoots a 1.5°C limit by a bit (see Table below). For the purposes of this report, RCP4.5 is used as a proxy for 2°C; though in the models, RCP4.5 actually results in a temperature above 2°C, reaching about 2.4°C in 2100.

“High emissions” scenarios refer to RCP8.5, the highest level of human emissions considered. Despite the Paris Agreement, emissions today still appear to follow such a “business as usual” pathway, which has the world exceeding 4°C by 2100. Although far above what cryosphere scientists would define as a lower-risk pathway, this report occasionally outlines what scientists project will occur if emissions continue on a high emission, RCP8.5 pathway.

Because the cryosphere in the past has responded most clearly to temperature, much of this report focuses on temperature rather than CO_2 emissions, because changes in Earth’s temperature in the past sometimes came from other shifts such as slow changes in the Earth’s orbit around, or orientation towards the sun. For polar as well as global ocean acidification, however, CO_2 concentrations are key; and once this CO_2 is absorbed into the ocean and acidification occurs, these more “acidic” waters will persist for tens of thousands of years, as outlined in the Polar Oceans chapter.

In reality, scientists today are quite certain that today’s temperature rise does come from human emissions of CO_2; so one way to express human decisions to either continue, or slow down warming is through carbon budgets: the amount of CO_2 and other carbon emissions that can occur before a certain temperature level is breached. The table below lists the remaining range of possible carbon emissions as outlined in the SR1.5. The limit amount – or budget – of carbon emissions related to a specific temperature boundary is especially important as regards the contribution of permafrost emissions due to thaw at higher temperatures, a main focus of the Permafrost chapter. Usually such emissions are not included in carbon budgets, and would need to be added in order to accurately guide mitigation efforts limiting anthropogenic emissions.

Country commitments, or “Nationally Determined Contributions” (NDCs) were first made in connection with the Paris Agreement in 2015, and are scheduled to be updated by COP-26 in November 2020: in most cases, covering the period 2025–2030. Scientists agreed in the IPCC Special Report on 1.5 Degrees of Warming (SR1.5) that 2030 is the outer boundary for remaining on a 1.5°C pathway, which this Report makes clear has become an outer boundary for avoiding the most catastrophic future impacts from cryosphere dynamics. The SR1.5 identified different actions, or “emissions pathways” that will allow the Earth’s global mean temperature to remain within 1.5°C. This Report uses the calculations of the Climate Action Tracker (CAT) to evaluate where current NDCs, or climate commitments will take the globe in terms of future temperatures, whether at the country or global level. The CAT is produced by a consortium of European research institutions[1].

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TABLE S-1. **Emissions Pathways, Temperatures and Carbon Budgets**

RCP	T in °C, 2100	Peak T in °C	Peak Emissions Year	Peak PPM	Remaining Carbon from 2018 (Gt CO2-eq)
2.6	1.6	1.6	2020	450	420*
4.5	2.4	3.1	2040	650	1170*
8.5	4.3	8–12+	2100	1250+	N/A

* from SR1.5, Table 2.2. Refers to 1.5°C and 2°C rather than RCP2.6 and 4.5, respectively, both with at least 66% chance with respect to uncertainties in the carbon cycle and in the climate system’s response to emissions, but not including the effects of – and uncertainty in – permafrost thawing.

[1] Climate Analytics, NewClimate Institute and Potsdam Institute for Climate Research

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TEXT BOX TEMPERATURES, NDCS AND CARBON BUDGETS

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1 ICE SHEETS

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5 POLAR OCEAN ACIDIFICATION, WARMING AND FRESHENING

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

Statement of

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before the
Committee on Science, Space, and Technology
U.S. House of Representatives

for the hearing
An Update on the Climate Crisis: From Science to Solutions

15 January 2020

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.

Dr. Heidi Steltzer

Dr. Heidi Steltzer is a Professor of Environment and Sustainability and Biology at Fort Lewis College in the San Juan Mountains, Colorado. Dr. Steltzer is a co-Principal Investigator on the U.S. Department of Energy's Watershed Function Scientific Focus Area that is led out of the U.S. DOE Berkeley Laboratory, California, with field studies based at the Rocky Mountain Biological Laboratory in Gothic, Colorado. She is on the board of directors for the Center for Snow and Avalanche Studies in Silverton, Colorado, and the Western Alliance for Restoration Management at Western Colorado University, Gunnison, Colorado.

Dr. Steltzer is a lead author for the chapter on High Mountain Areas in the 2019 Intergovernmental Panel on Climate Change (IPCC) Special Report on the Oceans and Cryosphere in a Changing Climate. She is also a science editor on the 2019 Cryosphere 1.5C Report produced by the International Climate Cryosphere Initiative. She is a member of the American Geophysical Union (AGU), and an advocate in AGU's Voices for Science program launched in 2018 to promote communication about the value and impact of Earth and space science to decision makers, journalists, and public audiences. She was a participant in the inaugural year of Homeward Bound, an Australian-based leadership program for women in science, which aims to increase the influence of women in science in solving environmental issues.

Dr. Steltzer is a mountain and Arctic scientist, explorer, and science communicator. She studies how environmental changes affect mountain watersheds and Arctic ecosystems and their link to our well-being. She has spent 25 years conducting field studies on mountain and Arctic hillslopes in Colorado, Alaska, Greenland and recently China. She's pioneered studies on the impacts of earlier snowmelt through experimentally accelerating snowmelt and monitoring plant and ecosystem responses. Her field studies lead to an experiential approach to higher education, in which she creates opportunities for student-led inquiry into environmental issues. Fort Lewis College, where she has been a professor since 2009, is a Native American Serving Non-Tribal Institution in the American Southwest. Her experiences engaging with students have influenced her choice to invest in science communication and climate diplomacy. Dr. Steltzer earned her BS in Biology at Duke University. Her doctorate is in Ecosystem Ecology from University of Colorado at Boulder. Find her on social media @heidimountains.