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.

Christiana Figueres
Former UNFCCC Executive Secretary
Co-founder, Global Optimism Ltd.

Jean-Pascal van Ypersele,
Former IPCC Vice-chair
Professor UCLouvain, Belgium

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:

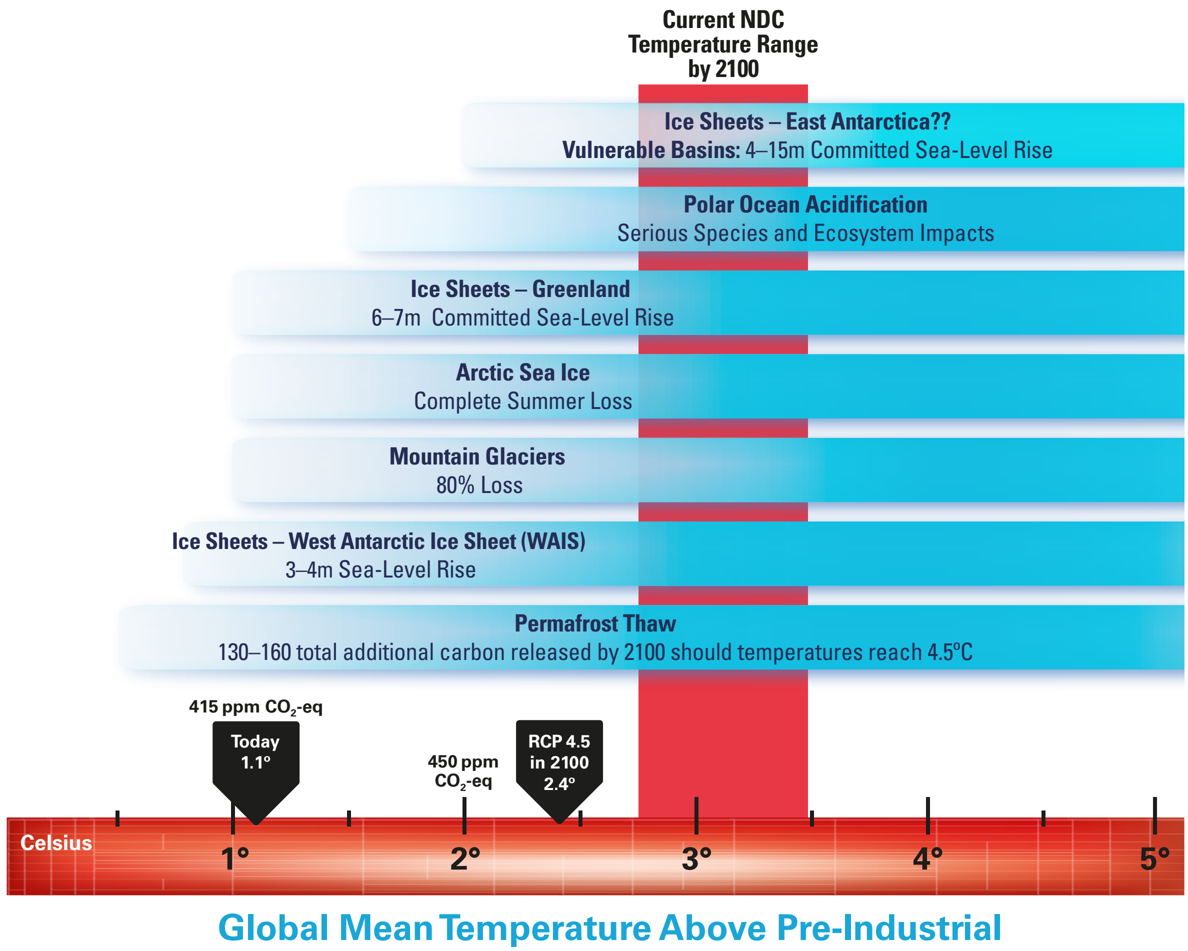
- At today's temperature of 1°C over pre-industrial, we have locked in about 1–3 meters of sea-level rise over the next centuries from loss of mountain glaciers and a portion of the polar ice sheets, even if we could hold temperatures at 1°C.
- Risks rise substantially at 1.5°, with the Earth showing 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].

SCIENTIFIC REVIEWERS

Joeri Rogelj, Imperial College London/IIASA and Drew Shindell, Duke University, IPCC SR1.5 Coordinating Lead Authors (Chapter 2, Mitigation Pathways); and Michiel Schaeffer, Climate Analytics, IPCC AR5 Contributing Author

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

Acknowledgements

Scientific Editors revised initial drafts of Report chapters written by Pam Pearson of ICCI. Scientific Reviewers shown at the end of each chapter also provided text (sometimes extensive), corrections and commentary to the Scientific Editors. Final content is the responsibility of ICCI. The extensive time and invaluable contributions of both Editors and Reviewers are hereby acknowledged, and deeply appreciated.

Special thanks also to Tyler Kemp-Benedict for extensive work with figures, design and layout.

TEXT BOX TEMPERATURES, NDCS AND CARBON BUDGETS

Scientific Reviewers

Joeri Rogelj, Imperial College London/IIASA, IPCC SR1.5 Coordinating Lead Author (Chapter 2, Mitigation Pathways)
Drew Shindell, Duke University, IPCC SR1.5 Coordinating Lead Authors (Chapter 2, Mitigation Pathways)
Michiel Schaeffer, Climate Analytics, IPCC AR5 Contributing Author

1 ICE SHEETS

Scientific Editors

Julie Brigham-Grete, University of Massachusetts-Amherst
Robert DeConto, IPCC SROCC LA, University of Massachusetts-Amherst

Scientific Reviewers

Richard B. Alley, Pennsylvania State University, IPCC AR4 Lead Author
Jonathan Bamber, University of Bristol, IPCC AR5 Review Editor
Carlota Escutia, Spanish Research Council and University of Granada
Michael Schaeffer, IPCC AR5 LA, Climate Analytics
Martin Sommerkorn, IPCC Coordinating Lead Author, SROCC Chapter 3 (Polar Regions)
Roderik van de Wal, IPCC SROCC LA, University of Utrecht

2 MOUNTAIN GLACIERS AND SNOW

Scientific Editors

Heidi Sevestre, University of Svalbard
Heidi Steltzer, Fort Lewis College and SROCC Lead Author

Scientific Reviewers

Regine Hock, University of Alaska, SROCC and AR6 Lead Author
Georg Kaser, University of Innsbruck, AR5 WG1 Lead Author
Ben Orlove, Columbia University, SROCC Lead Author and AR5 WG1 Contributing Author
Ben Marzeion, University of Bremen, SROCC Lead Author and AR5 WG1 Contributing Author
Philippus Wester, ICIMOD, AR6 Lead Author

3 PERMAFROST

Scientific Editors

Sarah Chadburn, University of Exeter
Gustaf Hugelius, Bolin Centre for Climate Research, Stockholm University
Susan Natali, Woods Hole Research Center

Scientific Reviewers

Julia Boike, Alfred Wegener Institute
Örjan Gustafsson, Stockholm University
Dave Lawrence, National Center for Atmospheric Research
Vladimir Romanovsky, University of Alaska-Fairbanks
Christina Schädel, Northern Arizona University
Ted Schuur, IPCC LA SROCC, Northern Arizona University
Martin Sommerkorn, IPCC Coordinating Lead Author, SROCC Chapter 3 (Polar Regions)
Merritt Turetsky, INSTAAR / University of Guelph

4 ARCTIC SEA ICE

Scientific Editors

Dirk Notz, Max Planck Institute for Meteorology/University of Hamburg, Germany
Julienne Stroeve, University College London/University of Manitoba

Scientific Reviewers

Jennifer Francis, Woods Hole Research Center
Walt Meier, National Snow and Ice Data Center
Ronald Kwok, NASA Jet Propulsion Laboratory
Paul Wassmann, UiT - The Arctic University of Norway

5 POLAR OCEAN ACIDIFICATION, WARMING AND FRESHENING

Scientific Editors

Nina Bednaršek, Southern California Coastal Water Research Project
Helen Findlay, Plymouth Marine Laboratory

Scientific Reviewers

Richard Bellerby, East China Normal University/Norwegian Institute for Water Research
Sam Dupont, University of Gothenburg
Humberto E. González, University Austral of Chile/Fondap IDEAL
Peter Thor, Swedish Meteorological and Hydrological Institute (SMHI)
Paul Wassmann, UiT – The Arctic University of Norway

International Cryosphere Climate Initiative
www.iccinet.org