Emerging Climate Risks and what will it take to limit global warming to 2.0°C?

A joint session was hosted by WCRP, IPCC and Future Earth at COP26 to discuss risks and consequences of breaching 1.5°C warming, and possible transformation pathways that can guide decision makers and stakeholders. All speakers were asked to identify up to five priority actions and/or challenges for our research community regarding the transition to a low carbon society and limiting warming to well below 2 °C. This is a summary of these science challenges, science gaps, and some of the actions needed.

1. Overview

Anthropogenic climate change brings many significant challenges and risks that affect almost all aspects of life on Earth. Droughts, heavy rain and flooding, heatwaves, extreme fire weather and coastal inundation are already increasing in frequency and intensity. The scale of these climate changes and the resulting risks and impacts grow with every additional increment of warming, affecting millions of people around the world, especially the poorest with risks to food and water security; ecosystem health and biodiversity that threaten several of the Sustainable Development Goals (SDGs).

To reduce such threats, the COP21 Paris Agreement aimed to limit global warming to well below 2°C above pre-industrial temperatures and to pursue efforts to limit warming to 1.5°C. Given the cumulative effect of CO_2 emissions on global warming, and the small remaining carbon budget, this requires a dramatic reduction of emissions of all anthropogenic climate forcers, especially fossil CO_2, over the next decade. Eventually, net zero greenhouse gas emissions by 2050 are needed to reach this goal.

Given current policies, and updated nationally determined contributions, it appears increasingly likely that the remaining carbon budget associated with a 50 or 67% chance to limit warming at 1.5°C will be exhausted in the 2030s, leading to an overshoot of the 1.5°C goal. Any delay in emissions reduction is committing the planet to even greater global warming and greater risk of more intense and frequent weather and climate extremes. Staying below 2.0°C requires an unprecedented transformation, including increased reduction of residual CO_2 emissions and sustainable approaches to removing excess CO_2 from the atmosphere. Negative emission technologies to remove carbon dioxide will be needed but questions remain about the scale required, feasibility, costs, as well as trade-offs especially when related to land based options.

2. Key Scientific Challenges

2.1 Improved process understanding of the entire Earth system – across all scales and including human (social) systems and climate risks

- **Research to increase our understanding of rare compound events that have a low likelihood of occurrence but potentially devastating effects (at the global scale)**. Observations, process studies and fit-for-purpose models are all needed to understand and simulate rare, extreme events (such as dangerous heat thresholds affecting multiple regions critical for global food markets); successions of events; and the effect of the interplay between internal variability and natural climate drivers.
- **Improved capability to assess climate risk.** To better quantify risks from low-probability, high-impact events; severe compound hazards and large-scale extreme events; and tipping points, such as large-scale carbon release due to forest dieback or permafrost abrupt thaw, ice shelf/sheet collapse, regime shifts and biome collapse, all will require better integration of interactions, feedbacks and resilience in our Earth System models, encompassing the dynamics of the system components *viz* oceans, land, atmosphere, biosphere and cryosphere, as well as human systems.
- **Accelerate progress in Antarctic climate science:** especially related to Antarctic sea ice and ice shelves, given uncertainties about their stability under a changing climate and the implications for sea level rise.
- **Better understanding of social systems:** to accelerate progress across sectors/geographies/cultures.

2.2 Improved information about the climate and Earth System

- **Improving regional to local climate change information:** through better observations and modelling of all relevant processes, and their interactions, on time scales from weather to millennia, and by challenging models with paleoclimate and observed data.
- **Improving the quality and use of climate projections to inform climate risk assessments:** to identify pathways to safe and just planetary guardianship of a stable and resilient Earth system for human development and to address societally relevant questions such as (these are some of the science objectives of WCRP's new Safe Landing Climates Lighthouse Activity):
  - *What **emission pathways preserve habitability and food security**; what are the **adaptation limits**?*
  - *What are the **climate implications of carbon dioxide removal** while maintaining food and water supply, preserving biodiversity?*
  - *What **risks arise from the long-term redistribution of water** due to climate change and direct human activity in land-based natural systems/reservoirs (including glaciers and tropical rainforests)?*
  - *What are the **implications for regions of an intensified water cycle, and increased variability**, leading for example to sequences of very wet and then very dry periods?*
  - *How do we **preserve habitable coasts**, what rate and magnitude of **sea level rise** is acceptable given its irreversibility?*
  - *Better quantifying risks of **low-probability high-impact events** (as also described in 2.1).*

2.3 Building and strengthening bridges

- **Between the climate and ecosystem / biodiversity research communities:** to better understand the effects of a changing climate and local pressures on ecosystems and their ability to store carbon, and to optimize co-benefits. This is related to the potential reduced efficacy of carbon sinks for a >2°C world, the potential and limits of nature-based solutions, and concerns about processes that are currently only partly included in climate models (such as forest dieback, fire, abrupt permafrost thaw, microbes in soils and in the ocean, etc.).
- **Between the "top-down" (global) production of climate information and the "bottom-up", local-scale decision context:** to better guide the adaptation needed to minimize the vulnerabilities of societies, by reducing their exposure and sensitivity to climate hazards, and enhance the capacity of communities to actively adapt to evolving climate risk. This is a focus of WCRP's new My Climate Risk Lighthouse Activity.
- **Between scientists, stakeholders and decision makers**: to achieve joint and complementary approaches to climate mitigation and adaptation, underpinned by robust climate change science and information, that have co-benefits (such as benefits to air quality that result from reduced methane emissions). Mitigation requires globally coordinated, government policies, while the decision-context for adaptation requires a much more local-scale approach.
- **Between the science community and local communities:** to develop a more efficient bottom-up approach that will consider the local complexity (reality) while presenting simple solutions (simplicity) that empower local communities to make sense of their own situation (empowerment).

3. Risk has a scale: what science is needed to support actions at the decision-scale?

There is ample robust climate information at the global and regional scale but weak actions. Yet, at the local scales where impacts are experienced, there is generally a willingness to act even if robust climate information is limited. Tensions therefore arise between where resource decisions are made and where the impacts occur.

Several of the priority actions to address this and ensure that climate science is effective in enabling policies and decisions to manage local-scale climate risk and reduce its impacts on vulnerable communities and regions around the world, are within the scope of WCRP's Regional Information for Society Core Project and My Climate Risk Lighthouse Activity. They include:

- Address critical gaps in **observing network capacity, access to the historical data, and event attribution studies for key high impact events** for many of the most vulnerable regions.

- Better integrate the **decision-making context, stakeholders' values and ethics, and non-climate stressors** into the research design, information construction, and communication to the policy and decision makers.
- Invest in **capacity development in regions of high vulnerability** to develop locally informed, decision-relevant climate information. Weak scientific capacity creates an intellectual dependency on others, with a resulting poor alignment between climate information and the decision context.
- **Assess the effectiveness of adaptation responses** to ensure that the outcomes are demonstrated.
- **Reconcile the contradictions** that arise due to method-dependency (i.e. different methods to produce climate information) and urgently **evolve the communication modalities and practice.** The diversity of information sources and results confounds the message and weakens decisions.
- Better resource **transdisciplinary science and real intellectual partnerships**, between and within regions, to address the lack of context-relevant information.

4. What is needed to accelerate progress and action?

- **A better understanding of how collective decisions are made and how risk analyses are perceived.** Despite the strong voices of the science and activist communities over the last three decades, the political responses remain impervious with solutions largely relying on deferred actions or new technologies. Greater account of the psychologies that impede hearing warnings until it is too late is needed. This applies to both climate adaptation and mitigation.
- **Citizens and countries will need to define, design, and implement major changes in the way they live their lives.** Can the social sciences help to understand and address why policy makers and citizens alike see the problem as conceptual, with solutions lying elsewhere or in future technologies? Can they help to build the understanding and acceptance that trade-offs in complex systems affect different stakeholders in different ways?
- **Address the issue of social license** so that society can realise the benefits of existing technological solutions, without the necessary trade-offs required preventing these partial solutions being implemented.
- **Are changes in our multilateral governance system needed?** Some evidence that it may not be is that at the very time that the world needs an effective multilateral system we face emerging nationalism. Nations must see that it is in their enlightened self-interest to work together.
- **Science itself must change**. Climate science has quantified and diagnosed anthropogenic climate change; simulated future scenarios so that society and decision-makers clearly understand plausible climate futures; and advanced the science of adaptation and mitigation. The International Science Council's science communities, including Future Earth and WCRP, are all making critical contributions, but physical science and technology alone do not solve the problem. We need social scientists, decision scientists, political scientists, ethicists, economists, and practitioners (e.g. engineers), well as strengthened bridges to link them as highlighted in section 2.3 above.

5. The path to net zero – science and technology needs

To reduce climate risk and comply with the ambitious goals agreed to under the 2015 Paris Agreement, CO_2 emissions must fall to net zero by mid-century; yet the world is very slow in getting on track for this goal. Although many elements required for the transformation are already clear – such as rapid reduction in fossil fuel use and production, stopping deforestation and reducing emissions from land use – it is also clear that CO_2 removal (CDR) technologies will be needed at scale to limit warming. For example, the 2018 IPCC Special Report on Global Warming of 1.5 °C shows that those 1.5°C pathways with limited overshoot, aiming to reduce the dependence on CDR, still remove a significant amount of CO_2 from the atmosphere (specifically, 100 Gt CO_2 cumulatively until 2100).

Comparing these pathways (to 1.5 or 2^{o}C) to our current reality reveals a striking gap in innovation and policy, and in societal dialogue. Scaling the technologies and approaches to remove CO_2 from the atmosphere raises questions like: *Where should the biomass come from without jeopardizing other SDGs if bioenergy is to be significantly scaled-up*? *How permanently can CO_2 be stored in forests, agricultural soils and other terrestrial* *and marine ecosystems given the impact of ongoing climate change on them*? *What can other approaches such as direct air capture, enhanced weathering, biochar, and other natural climate solutions, contribute to a more resilient portfolio of removal technologies that minimize risks to other SDGs*? Such questions clearly show the urgent need for solutions to residual emissions and CO_2 removal.

In the short term, innovation, funding and pilot projects are all required to catalyze the science and technology needed not just for emission and CDR technologies but also for robust and transparent methods of monitoring and verification. The latter is especially important to avert discrepancies between stated commitments and actual actions that will lead to a shortfall in the global emissions reductions needed to stabilise the climate. In the medium term, clear governance structures will be needed to address concerns about moral hazard. In the long term, a comprehensive carbon pricing architecture that considers just transition dimensions, can help to reward and finance carbon removal, while charging for the remaining carbon emissions.

Moreover, a lens that takes a broader view than just carbon will be needed, accompanied by a carbon-focused policy architecture with safeguards and regulation that ensures sustainability. Science must play a critically important role in filling the knowledge gaps with actionable knowledge.