The fourteenth meeting of the research dialogue, 2022

9 June 2022

Summary report by the Chair of the SBSTA

04 October 2022

Introduction and overview

1. Implementing the goals of the Paris Agreement requires as full an understanding as possible of the imminent changes in the climate system, the global response of Earth's systems, and the knowledge and ability to adapt to and mitigate climate impacts. Research in these areas increases our practical knowledge of the interconnectedness between all parts of the Earth's system, the natural world, and people as we continue to accelerate urgent climate action.

2. Meetings of the SBSTA[1] research dialogue provide the opportunity to discuss needs for climate change research and research-related capacity-building, particularly those of developing countries. It acts as a forum to convey research findings and lessons learned from activities undertaken by regional and international research programmes and organizations relevant to and supporting the implementation of the Convention[2] and the Paris Agreement.[3] Meetings enable engagement between a wide range of experts from the research community, Parties and non-Party stakeholders. The COP decision on research needs relating to the Convention provided the foundation for the research dialogue, which has been guided by further decisions and mandates of the COP, the CMA, and the SBSTA.[4]

3. Research is considered annually in the summer session of the SBSTA under the Research and Systematic Observation agenda item of the SBSTA. The research dialogue is scheduled during sessions to allow Parties the opportunity to engage with experts to support the informal consultations on RSO.

4. The fourteenth meeting of the research dialogue[5] was held during the Bonn Climate Change Conference on June 9.[6] The dialogue is themed according to the submissions of Parties in response to the call issued by the SBSTA Chair and in consideration of the mandates and the wider context of ongoing work under the UNFCCC.[7] The fourteenth meeting of the dialogue explored four themes: **Near term climate projections and regional modelling**; **Ocean and cryosphere**; **Carbon Dioxide Removal**; and **Integrated solutions for adaptation and resilience**.

5. The meeting was chaired by the SBSTA chair Mr. Tosi Mpanu Mpanu, Democratic Republic of the Congo. An information note was made available in advance of the event to provide an overview of the themes addressed as well as guiding questions to help focus presentations and discussions.

6. This summary report provides an overview of the plenary presentations and discussions as well as the posters from the dialogue. Key messages from the plenary discussions are also provided. The SBSTA Chair encourages Parties to consider the information in this summary report as part of the basis for negotiations on research and systematic observation at upcoming SBSTA sessions.

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1 See Abbreviations and acronyms, page 3.
2 Available at https://unfccc.int/resource/docs/convkp/conveng.pdf.
3 Available at https://unfccc.int/sites/default/files/english_paris_agreement.pdf.
4 An overview of the mandates founding and guiding the research dialogue are available here: https://unfccc.int/sites/default/files/resource/Mandates_research.pdf.
5 See https://unfccc.int/event/fourteenth-meeting-of-the-research-dialogue.
6 See https://unfccc.int/SB56.
7 See https://www4.unfccc.int/sites/submissionsstaging/Pages/Home.aspx, search "Research", tag SBSTA 56.

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Abbreviations and acronyms

AOSIS	Alliance of Small Island States	**IPCC**	Intergovernmental Panel on Climate Change
AR5 / 6	IPCC Fifth / Sixth Assessment Report	**IUCN**	International Union for Conservation of Nature and Natural Resources
CBD	Convention on Biological Diversity	**JMA**	Japan Meteorological Agency
CDR	Carbon Dioxide Removal	**LDCs**	Least Developed Countries
CliC	Climate and Cryosphere	**LULUCF**	Land Use, Land Use Change and Forestry
CLIVAR	Climate and Ocean: Variability, Predictability and Change	**NAPs**	National Adaptation Plans
CMA	Conference of Parties serving as the meeting of Parties to the Paris Agreement	**NbS**	Nature-based Solutions
CMIP5 / 6	Coupled Model Intercomparison Project Phase 5 / 6	**NDC**	Nationally Determined Contribution
CoCO2	Copernicus CO2 project	**PBL**	Netherlands Environmental Assessment Agency
COP	Conference of Parties	**PIK**	Potsdam Institute for Climate Impact Research
CORDEX	Coordinated Regional Climate Downscaling Experiment	**RCP**	Representative Concentration Pathway
EWS	Early Warning Systems	**RSO**	Research and Systematic Observation
GCOS	Global Climate Observing System	**SBSTA**	Subsidiary Body for Science and Technological Advice
GCM	Global Circulation Model	**SDGs**	Sustainable Development Goals
GCP	Global Carbon Project	**SIDS**	Small Island Developing States
GGA	Global Goal on Adaptation	**SSP**	Shared Socioeconomic Pathways
GOOS	Global Ocean Observing System	**UNFCCC**	United Nations Framework Convention on Climate Change
GHG	Greenhouse Gases	**WASP**	World Adaptation Science Programme
GST	Global Stocktake	**WCRP**	World Climate Research Programme
ICCI	International Cryosphere Climate Initiative	**WG**	IPCC Working Group
IIASA	International Institute for Applied Systems Analysis	**WMO**	World Meteorological Organisation
IOC UNESCO	Intergovernmental Oceanographic Commission of the UN Educational, Scientific and Cultural Organization		

Key messages

Near term climate projections and regional modelling

- Average global surface temperature will reach the 1.5° threshold within the next 10 years
- Strong trends associated with climate change cannot be mitigated in the near term (20 years)
- Sea level will continue to rise in response to ongoing ocean heat uptake and changes in ice sheet mass in the long term. It is irreversible over hundreds to thousands of years
- Open access to climate data is vital to provide support, particularly for developing countries, in the development of national climate plans and communications to the UNFCCC

Ocean and Cryosphere

- Measuring changes in the deep ocean and ocean biodiversity is informing planning for current and future climate impacts
- An integrated global system understanding of processes affecting ocean-atmosphere-cryosphere interactions, such as 'atmospheric rivers', is required to fully explain and project future changes in climate and weather patterns
- Newly modelling of processes affecting ice sheet loss show that these processes may have a dramatic effect on sea level rise
- Research in ocean CDR is increasing, but CDR in general has limited potential for mitigating long-term sea level rise

Carbon Dioxide Removal

- Multiple CDR technologies, with associated opportunities, limits and trade-offs, are being developed. Methods of enhancing natural or biological CDR are being researched
- Any and all net-zero planning must include some methods of CDR to balance hard-to-abate emissions and additionally achieve net negative emissions
- Any assessment of CDR options must account for their implementation and their vulnerability to reversal
- Research gaps that must be addressed include defining storage durability, establishing MRV of carbon flows, characterising methods and developing effective governance and policies

Integrated solutions for adaptation and resilience

- We must achieve an integrated understanding of the systems experiencing the impacts of climate change. Human, ecosystem, and planetary health must be considered together, and optimising each will require careful spatial planning
- A common language, metrics and goals must be developed to measure progress and define adaptation successes in the context of climate resilient development and the global goal on adaptation. This will inform national planning, especially the NAPs
- Managing compound risk at local or regional levels may require transnational or global action. Early warning systems that account for transboundary socioeconomic shocks will contribute to these efforts
- Consulting local actors at the site of change helps to identify key adaptation gaps.

I. Summary of plenary presentations, discussions and posters on Theme 1: Near term climate projections and regional modelling

7. Presenters contributing to Theme 1 were Ms. June-Yi Lee and Mr. Francois Englebrecht, IPCC WGI; Mr. Michael Sparrow, WCRP; and Ms. Iréne Lake, CORDEX International Project Office. Proceedings are summarised here, see the research dialogue webpage[5] for a full recording and all slides in pdf format.

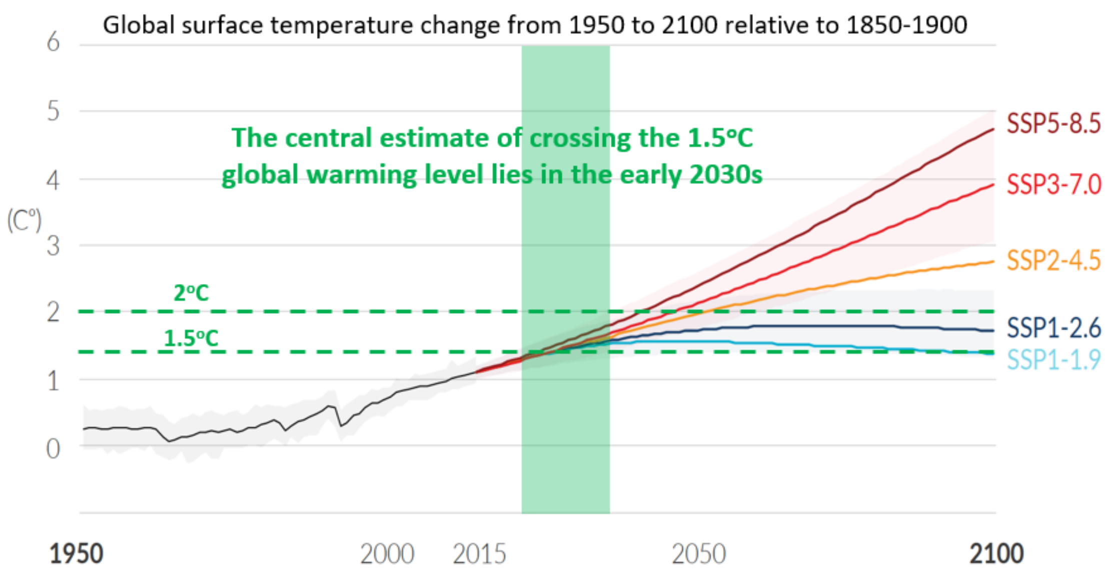
A. Summary of Presentations

8. **Our understanding of key drivers of the near-term evolution of the climate system has substantially enhanced.** The IPCC Sixth Assessment Report (AR6) details the near term (2021–2040) evolution of the climate system following several scientific advancements. Drivers of near-term change have been further identified and described, allowing a more comprehensive assessment than in previous Working Group I reports CO_2 and key Non-CO_2 drivers (methane, aerosols, and ozone precursors) are projected to lead to a net global surface warming in the near to long term. Natural drivers and internal variability will regionally modulate this warming but will have little effect on the scale of centuries.

9. **Sources of uncertainties in the near-term have been further identified**. Internal variability is the dominant source of uncertainties particularly at regional scales, but single model initial condition large ensembles and storyline approaches are providing a more comprehensive spectrum of possible changes associated with this internal variability. Model uncertainty has been reduced using better constraints for scenario-based predictions of global surface temperature based on past warming simulations and our understanding of the role of natural and anthropogenic aerosols has been greatly improved.

10. **Average global surface temperature will reach the 1.5°C threshold within the next 10 years.** The AR6 assessment of the change in global surface temperature is now based on multiple lines of evidence, a combination of scenario-based projections, observation constraints, and an updated assessment of climate sensitivity. This comprehensive assessment and reduced uncertainty has contributed to estimates of when the 1.5°C threshold will be exceeded under five different Shared Socioeconomic Pathways (SSPs). The midpoint of the first twenty-year period to exceed an average global surface temperature of 1.5°C above 1850 to 1900 levels lies in the early 2030s, (Figure 1). Global surface temperature for any individual year by 2030 has a 40–60% likelihood of exceeding 1.5°C.

Figure 1: **The threshold-crossing time is defined as the midpoint of the first 20-year period during which the average global surface temperature exceeds the threshold**



Source: Slide 4 of Ms. Lee's presentation, AR6 WGI Figure SPM.8; Chapter 4

11. **Sea level will continue to rise in response to ongoing ocean heat uptake and changes in ice sheet mass in the long term.** The AR6 assessment of changes in global mean sea level combines climate, ice sheet and glacier simulations with updated climate sensitivity data. Because the ocean responds more slowly than global surface temperature to forcing from greenhouse gas emissions, there is less variation in sea level

across SSPs over the 21st century. This slow response means that sea level is committed to rise over the next centuries to millennia, regardless of a cessation in emissions.

12. **Previously strong trends are committed to continue at least over the short term.** Any component of the climate system that has shown clear increasing or decreasing trends in recent decades (such as global surface temperature and sea level rise) will continue these trends for at least the next twenty years. Better constraints are needed for other climate variables whose short-term trends are masked by internal climate variability. Regional projections of future climate change are especially important, as regional factors such as mean temperature, precipitation, soil moisture and changes in extremes and impact drivers increase with each increment of global warming.

13. **High resolution, downscaled climate modelling can be used to better understand and project regional climate changes in the near-term.** The Coordinated Regional Downscaling Experiment (CORDEX) produces regionally relevant information for scientists and policymakers on local climate phenomena, variability and change. Ten CORDEX core regions are mapped on a 25 kilometre squared grid and display downscaled information on the IPCC Representative Concentration Pathways 2.6 and 8.5 for the period 1970–2100. CORDEX flagship pilot studies provide high-resolution information for decisions makers, such as convection maps capable of representing precipitation at a resolution of 3km.

14. **Open access to climate data is vital to provide support, particularly for developing countries, in the development of national climate plans and communications to the UNFCCC.** CORDEX data is open-access and subject to standardisation and quality control. It is the product of an international community of modellers and may be used by Parties to provide observational support to national climate planning efforts. The WMO currently leads a project to package this information in the most useful form for Parties.

Discussion

15. **How will the El-Nino Southern oscillation (ENSO) affect the timing of crossing the 1.5°C threshold?**

Using a 20-year window to project when the average global surface temperature will exceed the 1.5°C limit for that period eliminates any internal variability of the climate system, such as ENSO. ENSO does play a substantial role in individual years however, and the calculation of the 40–60% likelihood that an individual year will cross the limit by 2030 accounts for this.

16. **Are there clear simulations or forecast projections on the frequency and intensity of tropical cyclones for the near-term?**

Tropical cyclones now occur with more intense rainfall than in the past and there is strong evidence that increases in the frequency of intense tropical cyclones, category four and five hurricanes, can already be detected globally. In the near term, we should expect further intensification of rainfall brought by tropical cyclones and increased frequency of category four and category five hurricanes. Our understanding of the likelihood of unprecedented impacts of tropical cyclones and where they will occur over the next twenty years constitutes a research gap.

17. **Does the position of a region within a CORDEX domain affect the accuracy of the projections, for example if it is more to the middle or at the sides of the domain?**

Various techniques are used to ensure that domain boundaries are not a source of error. The position of a region in a CORDEX domain should not affect the accuracy of projections for that region.

18. **Does the IPCC evaluate the accuracy of previous CMIPs against observations?**

Chapter two of the WGI assessment reports on an improvement of model performance. Previous models did perform well in their projection of climate trajectories, despite some limitations to CMIP. The WCRP and the scientific community’s evaluation of previous CMIP results is available in the literature. Successive generations of CMIP have seen the project grow in scope and WCRP continuously leads the scientific community in assessing the model results. In the planning process for the next phase of CMIP, a “CMIP6 Community Survey” was conducted which will support ways to increase the project's scientific and societal relevance, improve accessibility and widen participation.

19. **Do differences in terrain within a region affect the uncertainty of projections for that region and how can modelling accuracy be enhanced and scenarios developed to account for this?**

More work is needed to build research capacity at regional levels and incorporate regional specificities with respect to climate. This includes work to produce climate simulation and projections at the required spatial resolutions for use regional decision-making for example with regard to freshwater resources.

20. **To what extent does increasing model complexity also increase uncertainty in modelling results?**

Multiple lines of evidence have been used in the latest AR to reduce uncertainty ranges, and our understanding of those uncertainties as increased. This has increased confidence in current projections of the future evolution of the climate system. Increasing complexity in models also helps us to improve our understanding of the uncertainty range. The better we understand this, the better we can understand processes in the Earth systems and represent these in Earth System Models. Understanding the uncertainty range does not necessarily mean it will decrease, regardless of model complexity, but means we understand the response of the system better.

21. **Was it possible to project the timing of reaching the 1.5°C threshold based on modelling in 2015?**

While it is possible to project that a high emissions trajectory would lead to a crossing of the 1.5°C threshold, models and assessment processes in the AR6 use multiple lines of evidence to more accurately project the timings of reaching 1.5°C. This is an important threshold associated with a large range of increased climate change impacts in most regions of the world, and it is vital that we use the best available science to get the best possible estimate of when this threshold may be exceeded.

22. **What are key current gaps in attribution science and how do these affect coverage of vulnerable regions?**

Attribution science is growing, but gaps remain. Closing these may be aided by the formalisation of attribution science by the World Meteorological Organization. The WMO Global Data Processing and Forecast System (GDPFS) regulates many types of forecast system, allowing national meteorological services to become global producing centres by satisfying quality control conditions. These centres, combined with quality control for short range, including seasonal and decadal forecasts, would go a long way toward addressing operational attribution knowledge gaps.

23. **What impact will rapid reductions of short-lived climate forcers have on warming? How has our understanding of short-lived climate forcers advanced since the last AR and what knowledge gaps remain?**

Reduction of anthropogenic aerosols leads to a net warming especially in the low and very low GHG emission scenarios, while reductions in methane and other ozone precursor emissions leads to a net cooling. Because of the short lifetimes of both methane and aerosols, these climate effects partially counterbalance each other, though reduction in methane emissions also contributes to improving air quality.

24. **How can modelling of precipitation patterns and change be enhanced in the next assessment cycle?**

One method could be through initiatives such as the Global Precipitation Experiment (GPEX), a new initiative that aims to improve precipitation predictions worldwide, both through observations and modelling.

B. Posters

25. Eight posters were presented on Theme 1. Posters are accredited here to the first and first supporting authors. Full author lists and all posters are available by following the hyperlinks and on the research dialogue webpage.[5]

26. **The chain from global to local: from data to knowledge to societal benefit**

Iréne Lake, WCRP and the Swedish Meteorological and Hydrological Institute (SMHI)

Global collaboration is producing coordinated, high-resolution, validated climate information that is open access and easy to use. These data and the scenarios built on them are informing decisions globally and across sectors including agriculture, health, urban infrastructure and land use.

The climate information[8] portal, based on CMIP and CORDEX outputs, can help LDCs to get support from the Green Climate Fund. It also provides methodology for use of climate data and indicators to support NAPs via indicators in web-based tools developed by the SMHI.

27. **A coordinated global greenhouse gas (GHG) monitoring infrastructure in support of research needs**

Lars Peter Riishojgaard, WMO Secretariat

Greenhouse gas monitoring provides critical input to scientific research and support for the implementation of the Paris Agreement. However, some key aspects can be addressed to provide even greater support, including an integrated, internationally coordinated global approach to enhance existing capabilities, unify observing systems, and enhance funding of, and access to, standardised data.

A coordinated global greenhouse gas monitoring infrastructure can address these gaps to benefit global GHG observing efforts, enable research and development based on the new and complementary data, and contribute to the implementation of the Paris Agreement. Recommendations for immediate action may be taken from the May 2022 WMO GHG Monitoring Workshop.

28. **Combined dynamical and statistical downscaling and its application in the development of socio-economy**

Zhenyu Han, Ying Shi and colleagues, China Meteorological Administration (CMA)

High-resolution combined dynamical and statistical downscaling for multivariables (HDM) was performed over China and several sub-regions (e.g., Beijing-Tianjin-Hebei, Huang-Huai-Hai, etc.) by using observations from CMA Land Data Assimilation System (CLDAS), a regional climate model (RCM), and quantile mapping.

The higher resolution outputs produced by the system compared to the direct dynamical downscaling would provide valuable scientific support for scientists conducting climate impact studies and for policymakers making climate change mitigation and adaptation decisions.

29. **Efforts to develop climate models and to reflect the knowledge in the adaptation plans**

Hiroyuki Tsujino, Izuru Takayabu and colleagues, Japan Meteorological Agency (JMA)

The Meteorological Research Institute of the JMA has been involved in research themes that use high-resolution and precise global and regional climate models to describe “possible future scenarios” which include probability information on climate change and weather phenomena in and around Japan by developing methods for statistical analysis and assessment.

The goal of one study is to contribute to formulating countermeasures against future weather/climate-related disasters, in particular adaptation plans at national and local levels. Recent outcomes include advances in event attribution for extreme weather phenomena and climate projections by the Atmospheric/Oceanic model.

30. **An enhanced downscaling methodology for the elaboration of high-resolution climate scenarios for Peru to 2050**

Acuña Delia, Llacza Alan and colleagues, National Service of Meteorology and Hydrology of Peru

Peru has a great variety of climates due mainly to the interaction of ocean-atmospheric systems and complex orography (e.g. Andean, Amazon, and Coastal regions). It is also vulnerable to the effects of climate change.

To better adapt to climate impacts, SENAMHI develops a methodology to elaborate high-resolution climate scenarios including the preparation of CMIP models, dynamical downscaling, bias correction of downscaled GCM output, and the application of geostatistical methods. Through this methodology, it was possible to obtain consistent information of precipitation and temperature at 5 km resolution that can inform climate risk analysis and climate change impact studies.

31. **A harmonized scenario framework can help to align national climate policies with global goals. Pathways for Asia**

Shinichiro Fujimori, National Institute for Environmental Studies, Japan; Detlef van Vuuren, Netherlands Environmental Assessment Agency (PBL); and colleagues from PBL, IIASA

[8] See climateinformation.org.

A study of climate targets and greenhouse gas emission reductions of six Asian countries found that short-term targets do not match long-term ambitions or meet global climate goals. Economic burdens vary widely and the most cost-effective approach to mitigation will vary across countries.

32. **Current fossil CO2 emissions trends and road to net-zero**

Pierre Friedlingstein, Alissa Howard, GCP

Achieving net-zero emissions requires society to decarbonise the whole economy. Estimates from the Global Carbon Budget suggest not enough progress is being made. In 2020, global fossil CO_2 emissions fell as a consequence of COVID-19, a drop of 5.4% from the year before. Estimates for 2021 suggest that global fossil CO_2 emissions are back to pre-COVID levels.

The remaining carbon budget we can emit in the future and keep global warming below 1.5°C is about 420 $GtCO_2$. This budget would be exhausted in 12 years at current rates of emissions. Global CO2 emissions need to decrease by about 5% per year to reach net zero by 2045. The longer we delay action the stronger the mitigation measures required.

33. **The European observation-based system for monitoring and verification of greenhouse gas fluxes (the VERIFY and CoCO2 projects)**

Philippe Peylin, National Centre for Scientific Research, France (CNRS); Richard Engelen, European Centre for Medium-Range Weather Forecasts (ECMWF); and colleagues from the VERIFY and CoCO2 project teams

The two Horizon 2020 projects, VERIFY and CoCO2, support the development of a European regional monitoring and verification support (MVS) system. The projects provide a pre-operational system to support national GHG inventories. They integrate in-situ and satellite observations, inventories and modelling to inform and support climate policy.

The VERIFY project has produced results including high resolution annual CO_2 emissions maps, land biosphere CO_2 fluxes at 10km resolution, and monthly estimates of natural and anthropogenic sources of CH_4 and N_2O. These outputs can support Parties reporting' and planning by providing top-down complementarity to bottom-up inventories.

II. Summary of plenary presentations, discussions and posters on Theme 2: Ocean and Cryosphere

148. Presenters contributing to Theme 2 were Ms. Margaret Leinen, Scripps Institution of Oceanography; Mr. Robert DeConto, University of Massachusetts Amherst; Ms. Helene Hewitt, IPCC WGI. Proceedings are summarised here, see the research dialogue webpage[5] for a full recording and all slides in pdf format.

A. Summary of Presentations

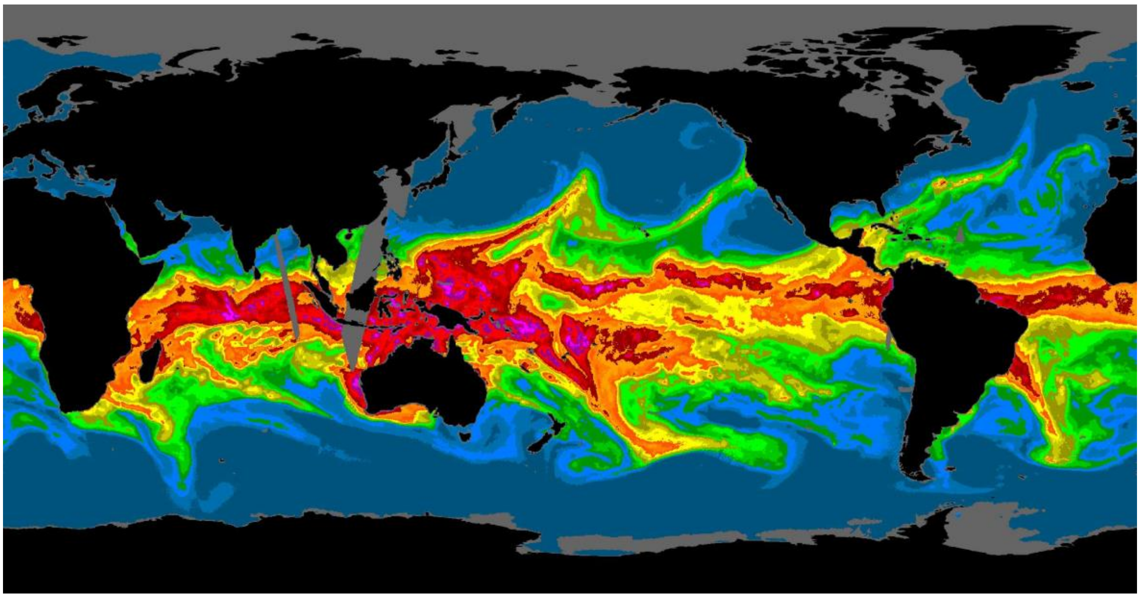
149. **Measuring changes in the deep ocean will advance our understanding of future climate effects near the ocean surface.** The Argo programme has shown us that the upper 2000m of the ocean have warmed from 2005 to 2022. Argo and GOOS are now working to develop deep floats that can measure depth, temperature, salinity and position of the entire ocean depth profile. An understanding of the deep ocean and its stability will advance our understanding of how changes here can impact the surface ocean.

150. **Environmental DNA and onboard analysis strengthen knowledge on ocean biology and how it affects and is impacted by climate change.** Climate change has extensively impacted ocean biology, including fisheries and marine ecosystems but achieving a persistent or synoptic view of the biology of the ocean has proven difficult. New biomedical and biotechnology innovations have given us the ability to use 'environmental DNA' to identify single or multiple species presence in an area given a sample of seawater. This has proved especially useful in studies of plankton, at the base of the marine food chain. Autonomous vehicles have already advanced this bio-molecular sampling and on-board eDNA analysis will allow the combination of biological knowledge with our understanding of atmospheric and oceanic change as a result of climate change, substantially advancing our knowledge of the ocean-climate system.

151. **Atmospheric rivers heavily influence polar precipitation and inform knowledge on glacier breakup.** Satellite imagery has been used to image atmospheric water vapour transport from the tropics to the poles. These 'atmospheric rivers' hold vast amounts of water vapour and have a major impact on precipitation in temperate and polar regions. Atmospheric rivers account for about 60% of the water vapor transport over the oceans to the poles and control more than 70% of the variance in precipitation above 70°

of latitude. Modelling has suggested that, under warmer conditions, atmospheric rivers will be fewer, but will carry more water and produce more rainfall. Positions of marine rivers have been shown to align to areas of increased Antarctic snow cover and enhanced understanding of this transport mechanism will also complement what we know about the breakdown of glaciers.

Figure 2: **Integrated atmospheric water vapor in the atmosphere. Warmer colours indicate more water vapor. cooler colours indicate less water vapor**



Source: Slide 9 of Ms. Leinen's presentation, NASA

152. **Ocean heat waves have increased and strengthened, as have the tools to measure and understand their impacts.** Ocean heat waves, detected as sea surface temperature anomalies, are becoming more intense and persist for longer. We now have the tools, such as eDNA, to measure the impacts of these heatwaves on the base of food chains, on ecosystems, and ultimately on society also.

153. **Understanding the Southern Ocean can inform global climate action.** New sensors have been deployed in the Southern Ocean to assess changes in the ocean itself and in areas with ice margins. Greater understanding of this region will contribute to our knowledge on how climate change is affecting the ocean, and what action can be taken to respond to climate change, mitigate further ice sheet loss, and safeguard ocean biology.

154. **Small changes in the Antarctic ice sheet can produce major effects.** The ice sheet holds enough water to raise sea level by 57 metres. Sea level rise projections in the AR6 include a high impact, low confidence scenario related to ice sheet mass loss outside the range of the more standard higher likelihood projections. This reflects the effects of changes in the Greenland and Antarctic ice sheets, drawing on expert judgment and a single continental scale Antarctic ice sheet model that includes previously described but newly modelled processes that may profoundly affect the magnitude and rate of sea level rise.

155. **Ice shelves may play a greater role than previously thought in ice transport to the ocean.** Floating extensions of the Antarctic ice sheet, ice shelves, form as ice flows downhill from where it accumulates and into the Southern Ocean. Some ice shelves rest on the seafloor, supporting the shelf and the ice margin, and generating friction to resist the flow of ice into the ocean. Losing these ice shelves could therefore allow faster flow into the ocean, faster iceberg calving rates and potentially forming ice cliffs above the sea surface where the ice is thick. These ice cliffs could produce stresses at the edge of the ice sheet, which could exceed the strength of the ice and cause it to break apart.

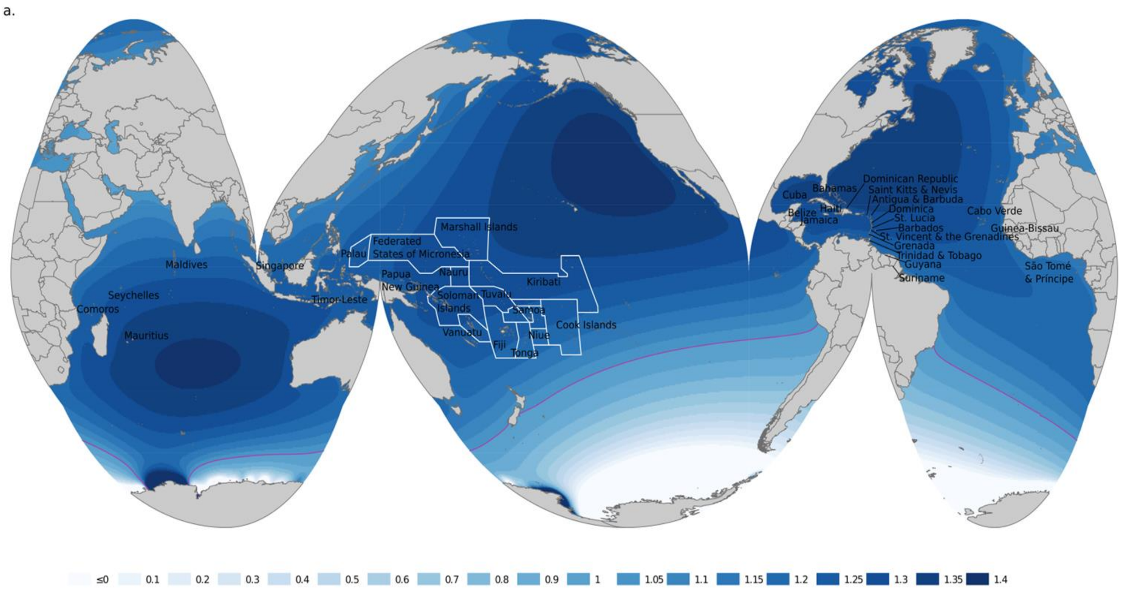
156. **If brittle processes affecting ice sheet loss become widespread, their contribution to sea level rise could be significant.** A continental-scale ice sheet model simulating the breakup of Antarctic ice shelves when covered with meltwater, thinned by ocean melt from below and combined with an increased calving rate and faster flow resulted in a 10 meter average sea level rise by 2300 in a high emission (RCP 8.5). This is well above the less than 3m projected in AR6 assessed information that does not include these processes and may breach the limits to adaptation in many areas. Research into brittle processes is increasing and is expected to improve confidence in their quantification before contributing to AR7.

157. **A tipping point specific to Antarctica may exist between 2 and 3°C of global warming.** Under a 2° warming scenario with no overshoot, simulations including these processes do not produce a major

increase in sea level rise by 2100 compared to standard simulations. Under a 3°C scenario, a rough analogue reflecting the current NDCs, sea level rises by as much as one centimetre per year as a consequence of these processes in Antarctica alone. Under the 3°C scenario including these processes, the Thwaites glacier retreats deeper into the basin, flowing faster and forming tall ice cliffs that further breakup the ice margin. The widespread loss of such glaciers would make a substantial contribution to sea level rise, and the described processes would accelerate their loss.

158. **Sea level rise will not be equal across the ocean.** AOSIS nations are projected to experience on average between 13 and 33% more committed sea level rise from Antarctica, (Figure 3).

Figure 3: **Regional sea level rise compared to the global mean in 2100 under RCP4.5 with no brittle ice sheet collapse**



Source: Slide 21 of Mr. DeConto's presentation, Fingerprint data: Dr. Natalya Gomez and Jeremy Roffman. Image: Sadai et al., in review

159. **Ocean CDR is being heavily invested in, and the ocean decade is catalysing greater understanding of its deployment, opportunities and affects.** Venture capital from the private sector is funding early stage experimentation with ocean CDR, from technological sources to blue carbon, such as mangroves and seagrasses. The scientific community is actively engaged on the subject and supported by these investments. Preliminary assessments of multiple ocean CDR techniques are expected as ocean decade outcomes.

160. However, **CDR in general has very limited potential, such as to prevent Antarctic ice loss.** In a scenario corresponding to current NDC commitments in which 3°C is reached by 2100 and including brittle processes, rapid Antarctic ice loss is triggered even if CDR commences by 2070. Beginning CDR before 2060 will reduce ice loss, but cannot fully mitigate it.

Discussion

161. **How will the committed loss of glaciers affect the Least Developed Countries, particularly those in high mountain areas?**

Mountain glaciers globally hold the equivalent of less than 40 centimetres of potential sea level rise, so, their loss has the most direct impact on water resources, agriculture, and culture. Some basins will experience peak water supply as melting increases, which carries its own risks.

162. **What uncertainties and risks are associated with the lower confidence, high impact projections of sea level rise? How can this be mitigated under the Paris Agreement?**

The inclusion of projections outside the likely range in an IPCC SPM is important, highlighting the potential risks of more extreme sea level rise. Further research on this is needed to further clarify risk and uncertainties. Sea level rise is directly emissions dependent, regardless of the inclusion of brittle processes. Beyond 2050, sea level rise increases significantly faster due to thermal expansion and melting ice sheets. Processes such as brittle ice flow are also emissions dependent, triggering with the loss of ice shelves, but even with long term committed sea level rise, urgent mitigation can avoid triggering these processes, and so aligning to the core projections in the AR6 will minimise the risk of low-land areas passing limits of adaptation.

163. **Are there more details available on the variations of sea level rise across the ocean?**

The AR6 partnered with NASA to provide online, location-specific guidance on sea level rise in places with a tide gauge. This guidance is provided in terms of the magnitudes and rates of sea level rise at different points in time.

164. **When, and under which scenarios, could the Arctic become ice free in the summer? To what extent is this reversible, especially given the possibility of overshooting the 1.5°C limit?**

Under the highest mitigation scenarios, the Arctic ocean becomes practically ice free by about 2050 and remains ice free for the century. Theoretically, given some form of global cooling the sea ice is projected to return. It is therefore not truly an irreversible change, as is the case, for example of melting of the Greenland ice sheet.

165. **How can related research gaps related to SIDS be assessed?**

Each country must identify research gaps in their context before the international community can contribute to closing them, but a diverse set of knowledge gaps does exist. These include gaps around freshwater availability, cyclone patterns and intensity, and sea level rise. National research institutions can be supported in these efforts by international support. The WCRP, for example, attempts to ensure regional representation in its steering groups to ensure all regions are effectively covered and collaborates in regional associations globally.

B. Poster Session

166. Twelve posters were presented on Theme 2. Posters are accredited here to the first and first supporting authors. Full author lists and all posters are available by following the hyperlinks and on the research dialogue webpage.[5]

167. **Building knowledge to weave the protection and restoration of coastal blue carbon ecosystems into decision making on mitigation and adaptation to climate change**

Elisabetta Bonotto, Kirsten Isensee, IOC-UNESCO

Coastal Blue Carbon ecosystems play a significant role in carbon sequestration and long-term carbon storage around the world, providing some of the highest density stores of carbon in the biosphere. In 2013, the IPCC released technical guidance on including wetlands in national greenhouse gas inventories. Only a handful of countries have started this endeavour.

The Blue Carbon Initiative and the International Partnership for Blue Carbon provide platforms to connect, share and collaborate to build solutions, take actions and benefit from the experience and expertise of the global community, supporting scientists and countries to increase ambition directed towards the inclusion of coastal Blue Carbon ecosystems in decision-making on mitigation and adaptation to climate change.

168. **Global Ocean Acidification research and observation – connecting Climate and SDG indicators**

Kirsten Isensee, Katherina Schoo, IOC-UNESCO

Ocean acidification threatens organisms and ecosystem services, including food security, by endangering fisheries and aquaculture. As the acidity of the ocean increases, its capacity to absorb CO_2 from the atmosphere decreases, impeding the ocean's role in mitigating climate change.

National ocean acidification datasets submitted on SDG 14.3 and indicator 14.3.1 highlight the need for sustained, repeated observation and measurement of ocean to improve understanding of its consequences, enable modelling and predictions of change and variability.

The Global Ocean Acidification Observing Network's programme "Ocean Acidification Research for Sustainability", will address SDG indicator 14.3.1 and help to improve the availability of site-specific information, suitable for mitigation and adaptation strategies addressing local conditions.

169. **Ocean Acidification Research for Sustainability – OARS**

Jan Newton, GOA-ON; Steve Widdicombe, Plymouth University; and colleagues from IOC-UNESCO

Ocean acidification is caused by the absorption of atmospheric CO_2 and the ensuing change the carbonate chemistry of the ocean, along with an observed decrease in pH. As ocean acidification continues to increase at unprecedented rates, it threatens organisms and ecosystem services, including food security, by reducing biodiversity, degrading habitats, and endangering fisheries and aquaculture. Building on the work of the Global Ocean Acidification Observing Network (GOA-ON), the UN Ocean Decade Programme OARS – Ocean Acidification Research for Sustainability, provides a roadmap for ocean acidification research for the next Decade. By delivering on its seven outcomes, OARS will create a number of benefits: providing a clean, diverse, productive ocean capable of supporting the health, well-being, and livelihoods of human societies dependent on marine resources.

170. **Global Sea Level Rise: Latest scenarios and limits of adaptation**

Robert DeConto, Julie Brigham-Grete, University of Massachusetts-Amherst; and colleagues from the Arctic Monitoring and Assessment Programme and ICCI

The Earth's climate record shows that warming of 2°C above pre-industrial levels has resulted in slow but extensive melting of the West Antarctic Ice Sheet, Greenland and likely parts of East Antarctica. However, the observed temperature rise over the last few decades is much faster than anything documented in Earth's past. Combined with new approaches to ice sheet modelling, this means that future rates of ice sheet loss and sea level rise may be potentially rapid, several meters per century. However, such rise might be slowed if temperatures remain close to 1.5°C and return to below that level as soon as possible.

171. **Marine Heatwaves: latest science on its negative impacts on biodiversity and people, and what we can do about it**

Dorina Seitaj, Aurelie Spadone and colleagues, IUCN

Anthropogenically driven climate change is causing ocean warming globally, and regionally Marine Heat Waves (MHWs) are driven by unusual weather patterns and disruptions in ocean currents and mixing. Marine Heat Waves are occurring more often and lasting longer, affecting surface and deep waters, and the present ecosystems, in all latitudes.

MHWs exacerbate extreme weather, impact aquaculture and fishing, and cause mass die-offs of marine species. In parallel with urgently reducing GHG emissions, addressing MHWs requires additional research, enhanced forecasting, further awareness, and the design and implementation of adaptation strategies.

172. **Roots of hope: The value of mangroves in the Western Indian Ocean region for planet and people**

Save Our Mangroves Now![9]

Mangroves have gained growing attention as a "flagship" nature-based solution for climate change. Still, policymaking in many mangrove countries requires enhanced and effective action to protect, sustainably manage and restore mangroves.

In order to inform policy- und other decision-makers about the stacked services and necessary action to protect these "blue forests", the Save Our Mangroves Now! Initiative, a joint effort of the Federal Ministry for Economic Cooperation and Development (Germany), IUCN, Wetlands International and The World Wildlife Federation, assessed the extent, socio-economic value and carbon storage capacity of the mangroves of Kenya, Tanzania, Mozambique and Madagascar and developed guiding principles for sustainable mangrove ecosystem management.

173. **Ocean-based climate action and human rights**

Elisa Morgera, Mitchell Lennan, University of Strathclyde and One Ocean Hub

Key opportunities have been identified to align ocean-based action to support both the Paris Agreement and international biodiversity law, the law of the sea, and international human rights law in the context of achieving co-benefits across different SDGs.

Recommendations for action include addressing human rights in the context of ocean action, mitigating CO_2 emissions and their resultant impact on loss and damage, using guidance adopted under the CBD on human rights, and developing similar guidance under the GGA. Additional finance is required to support

[9] Contact Laura.puk@wwf.de and Menno.deBoer@wetlands.org.

these and other actions, while partnerships and co-development between state and non-state actors must be mainstreamed across UN agencies.

174. **Oceanic extreme events associated to climate change off Peru**

Jorge Tam, Alice Pietri and colleagues, Marine Institute of Peru (IMARPE)

The national oceanographic and monitoring service of Peru will be upgraded with gliders to provide high resolution data on subsurface ocean circulation and biogeochemical conditions, and operational modelling to identify extreme ocean events associated with climate change.

Modelling will take into account the rise in frequency and intensity of marine heat waves, harmful algal blooms, and hypoxic events. Characterising these events will allow a forecast models to be developed and act as an early warning system, benefiting aquaculturists and fisheries. Data from satellites and gliders will further enhance these models and enable high resolution downscaling to specific bays.

175. **Innovative approaches for strengthening coastal and ocean adaptation: integrating technology and nature-based solutions**

IUCN; Friends of EbA (FEBA) Network; UNFCCC Technology Executive Committee; UNFCCC Nairobi Work Programme

Integrated approaches to adaptation are required to respond to knowledge gaps in implementing innovative adaptation strategies. Examples include ecosystem-based adaptation (EbA) and disaster risk reduction, hybrid approaches combining EbA and engineered adaptation, early warning systems, cross sectoral approaches such as integrated coastal zone management (ICZM) and coastal hazard and flood risk mapping.

Gaps and challenges for implementing adaptation solutions were also identified, as well as opportunities to enhance their effectiveness. Recommendations address actors across the range of ocean adaptation actors, highlighting the need for policy and governance inclusion, blended finance, evidence-based decision making, and the broad participation and inclusive leadership of affected actors. A policy brief is available.[10]

176. **'Country of permafrost': Current and future permafrost emissions as large as major emitters**

Gustaf Hugelius, Bolin Centre for Climate Research; Rachael Treharne, Woodwell Climate Research Center; and colleagues from ICCI

Observations confirm that permafrost is rapidly warming and releasing part of that thawed carbon into the atmosphere as both carbon dioxide and methane. Permafrost thaw is projected to add as much greenhouse gas forcing as a large country, depending on just how much the planet warms (recent estimates range from an additional 150–250 Gt CO2 equivalent by 2100). Once permafrost thaw is initiated, including by extreme summer heat events, the resulting emissions continue for centuries. As a result, permafrost emissions will continue even if temperatures slowly decline. Future generations will need to deploy and continue CO2 removal strategies equal to these long-term emissions until they cease, simply to hold temperatures steady.

177. **Melting of mountain glaciers: Large regional impacts and limits of adaptation**

Matthias Huss, ETH-Zurich; Carolina Adler, Mountain Research Institute; and colleagues from the University of Oslo, University of Alaska Fairbanks, University of Bremen, Arctic Monitoring and Assessment Programme, ICCI

With very low emissions, much of the world's glaciers and snowpack can be saved, especially in the mid-latitudes. Losses would begin to slow slightly around 2040, though many glaciers would not stabilize until 2200. Some glacier regions, such as the Alps, may even begin to show very slow re-growth (a few percent per decade) by 2100. Others may require temperatures closer to pre-industrial for greater recovery. Once 2°C is passed however, nearly all mid-latitude glaciers will disappear, along with their important seasonal contribution to water resources; and even the Himalayas will lose up to two-thirds their mass.

178. **Polar oceans as a carbon sink: Permanent ecosystem and fisheries loss due to polar ocean acidification**

Nina Bednaršek, National Institute of Biology, Slovenia and Oregon State University; Richard Bellerby, East China Normal University and Norwegian Institute for Water Research; and colleagues from the Arctic Monitoring and Assessment Programme, ICCI

The Arctic and Southern Oceans have absorbed up to 60% of all carbon taken up by the world's oceans thus far. This makes them an important carbon sink, limiting global warming despite sharp increases in

[10] See https://unfccc.int/ttclear/coastalzones/.

human carbon emissions. This ecosystem service however comes at a high cost: increasing acidification of polar waters at levels today not seen for the past three million years, with shell damage visible already today. Both polar oceans appear to be nearing a critical ocean acidification threshold; until, and unless, CO_2 levels begin to fall sharply. Such acidification will take 50,000–70,000 years to reverse.

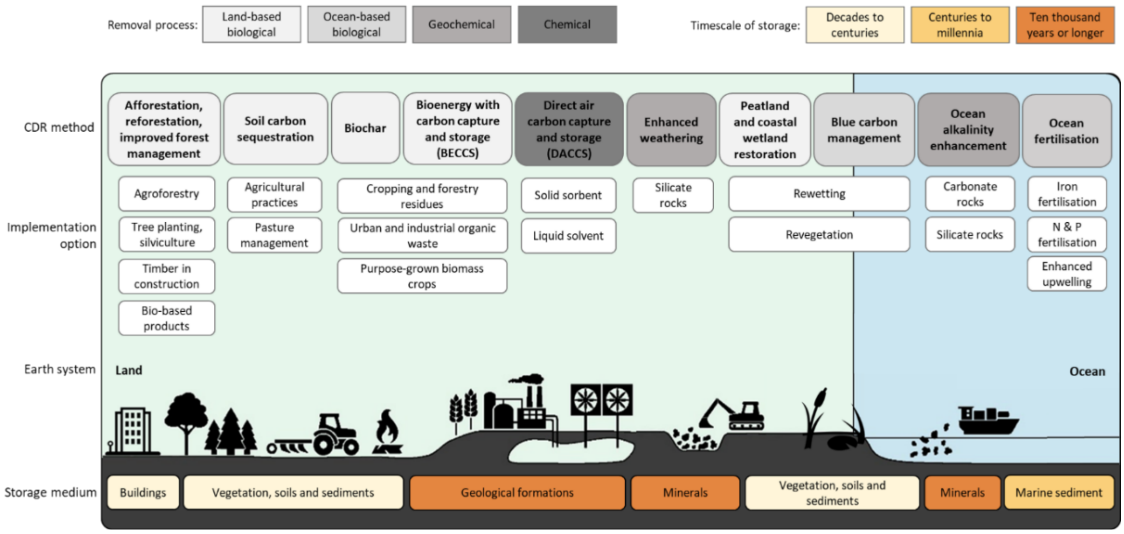
III. Summary of plenary presentations, discussions and posters on Theme 3: Carbon Dioxide Removal

179. Presenters contributing to Theme 3 were Mr. Oliver Geden, Mr. Andy Reisinger, Mr. Jim Skea, IPCC WGIII; and Mr. Naif B. AlQahtani, King Abdulaziz City for Science and Technology. Proceedings are summarised here, see the research dialogue webpage[5] for a full recording and all slides in pdf format.

A. Summary of presentations

180. **A wide range of potential CDR options can be developed and a portfolio of them is required to achieve mitigation targets.** Carbon Dioxide Removal is defined in the IPCC WGIII report as “anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products”. CDR options vary widely (figure 4), as do their storage methods, estimated storage times and vulnerability to reversal.

Figure 4: **CDR techniques**

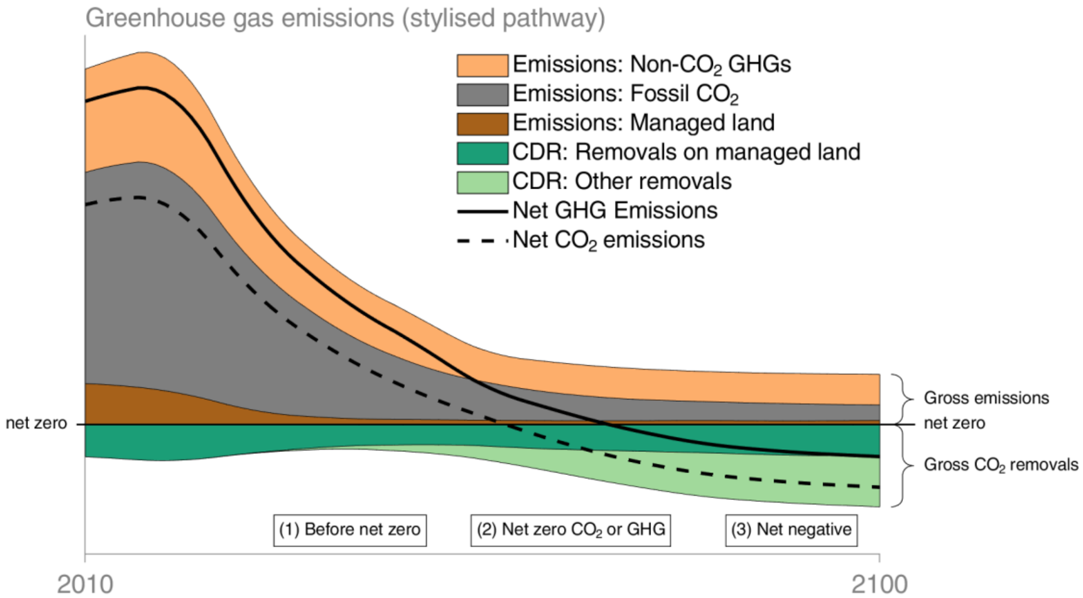


Source: Slide 6 of Mr. Geden’s presentation, AR6 WGIII Chapter 12, Cross-Chapter Box 8, Figure 1

181. Methods of removing CO2 from the atmosphere differ. For example, land based biological methods may involve afforestation to store carbon in soils and in timber. Ecosystem restoration efforts, such as restoring mangrove forests, also sequester some carbon in addition to their other benefits. Geochemical CDR may include methods that enhance the weathering of rocks such as basalt or waste mining material, absorbing carbon from the atmosphere through mineralisation and forming carbonate rock. Chemical methods such as DACCS capture CO2 directly from the ambient air using a reusable chemical agent. The storage times of CDR methods assessed in the AR6 range from decades to tens of thousands of years, and each method comes with different vulnerabilities to reversal.

182. **Any net-zero planning must include CDR.** Reaching net-zero emissions, (whether net-zero CO2 or net-zero GHG), reducing the time taken to achieve net-zero, and reaching net negative emissions all require the use of CDR. Even in a net-zero scenario, CDR must still be used to abate residual emissions. In ambitious management strategies, CO_2 and other GHG emissions decrease rapidly until only residual emissions remain from hard-to-abate sectors such as agriculture, industry and transport (figure 5). These are counterbalanced by removals on managed land, relevant to LULUCF, and eventually other CDR techniques. The mix of techniques that must be used depends on the available options and on the global residual emissions at the time. Net-zero GHG emissions will be reached 10–40 years after net-zero CO_2, in part as CDR only removes CO_2.

Figure 5**: Stylised pathway of greenhouse gas emissions reaching net zero and becoming net negative before 2100**



Source: Slide 4 of Mr. Geden's presentation, AR6 WGIII Chapter 12, Cross-Chapter Box 8, Figure 2

183. **Any assessment of CDR options must account for their implementation and their vulnerability to reversal.** Each CDR techniques has a variety of different implementation options, but they differ in energy and land use. Some techniques may be vulnerable to reversal, especially as the climate changes and the conditions in which they store carbon is altered, as is the case for vegetation, sediments and soils. Carbon capture and storage (CCS) and carbon capture and utilisation (CCU) can be part of CDR methods, such as via DACCS or bioenergy and CCS (BECCS), but CCS by itself is not a CDR method and cannot be used alone.

184. **Key research gaps must be addressed to effectively deploy CDR.** These include:

- The definition of 'durability' of storage and MRV of carbon flows.
- Characterisation of CDR methods and inclusive pathways to guide deployment, including their costs and potential, risks and co-benefits, as well as how they can be used to counterbalance residual emissions globally and nationally.
- Issues regarding the scaling of CDR and location suitability.

185. Development of governance and policies related to CDR must be developed to determine how to effectively deal with the feasibility and sustainability constraints of certain methods or pathways, how to set up certification and accounting for these methods, and how to implement targeted incentives. Achieving the net-zero or net-negative targets set by countries will require some CDR, as will counterbalancing residual emissions. However, CDR cannot act a substitute for rapid and deep emissions reductions.

Discussion

186. **How can investments in and carbon storage of ocean CDR techniques deployed beyond national boundaries be accounted for under global processes?**

How to account for ocean CDR remains a gap that has not been sufficiently answered. Some ocean CDR methods will become an element of integrated assessment modelling in the future.

187. **How may ocean CDR affect biodiversity beyond national jurisdiction?**

There are a broad range of ocean CDR techniques. Blue carbon management usually has very positive effects for biodiversity but may have more limited carbon removal potential than often thought. Ocean iron fertilization, or ocean alkalinity enhancement may have transboundary risks that are already constrained by international agreements such as the London Protocol and Convention, and by the CBD.

Risk assessments informing CDR approaches will need to be widened beyond current international regulations such as the London Convention and OSPAR, especially in the case of ocean based CDR. Future joint efforts by WGs II and III would be beneficial.

188. **What are the limits of the potential of CDR and CCS?**

The potential of CDR is not unlimited, and all techniques come with resource constraints. Land based options require trade-offs in terms of land availability, enhanced mineralisation requires extensive mining operations and must be balanced against the energy used in mining, and the effectiveness of DACCS depends on carbon intensity of its energy source. All methods also require a durable and nearby storage medium.

Assessing what will work globally may not be feasible. Assessment based in countries who have set net-zero targets and are deploying context-specific CDR may serve a more informative guide. Some countries are already implementing LULUCF-related options, such as via wetlands and biochar, and research on technological options will evolve alongside the increasing deployment of CDR technologies.

189. **What is needed to accelerate the deployment rates of CDR to align with the projected emission pathways?**

The rate of deployment can be accelerated with support from the private sector. The sector invests in multiple technologies and is accumulating experience on the feasibility and limitations of different techniques in different areas. Preventing deforestation and promoting afforestation are important to accelerate net removals from forestry.

190. **What is required to reach, and what is limiting, the potential of CCS and CCU with durable storage in the industry?**

All factors must be considered. CDR technology requires more research and development, its costs must be reduced, and there will be a steep and rapid learning curve involved in all aspects of its implementation, but the basic approaches of doing so are known. Implementing governance and policies to define the roles for such technological CDR approaches, defining incentives, and clarifying accounting will be more challenging.

Only CDR will capture carbon directly from the air, but CCS and CCU will be extremely important to counterbalance residual emissions, especially in the industrial sector.

191. **How is CDR considered in the SSPs in line with limiting warming temperatures to 1.5°C?**

The majority of CDR considered comes from BECCS, afforestation and reforestation. The AR6 incorporates enhanced mineral weathering and DACCS in some models and scenarios. More methods will be considered in the future, as well as in national mitigation modelling, but representing them all in integrated assessment modelling is impossible.

192. **What is the risk that deployment of CDR could impede near-term mitigation efforts?**

Though some literature exists, this is not easy to prove scientifically. Implementing CDR in the context of net-zero targets should allow effective implementation in parallel with deep emission reductions. More caution is necessary if discussing net negative emissions in the long term to balance out global carbon budgets, as that could give the false impression that we are already fully prepared to reach net-zero during the 21st century. It is therefore important to build a narrative to distinguish between CDR to counterbalance residual emissions and reach net zero, and CDR to reach net negative emissions at the systems level, both of which are necessary to reach 1.5°C in this century.

B. Poster Session

193. One poster was presented on Theme 3. Posters are accredited here to the first and first supporting authors. Full author lists and all posters are available by following the hyperlinks and on the research dialogue webpage.[5]

194. **The importance of Carbon Dioxide Removal (CDR) for reaching Paris Climate Goals: Current research activities and new insights**

Keywan Riahi, Joeri Rogelj IIASA; and colleagues from IIASA, PIK

Carbon Dioxide Removal (CDR) reduces net greenhouse gas emissions and plays an important role for reaching the Paris Climate Goals. However, deeper emissions reductions can reduce reliance on CDR.

Sectoral and regional potentials differ, and the resulting distributional and justice issues need to be taken into account.

IV. Summary of plenary presentations, discussions and posters on Theme 4: Integrated solutions for adaptation and resilience

195. Presenters contributing to Theme 4 were Mr. Hans-Otto Pörtner, IPCC WGII; and Mr. Anand Patwardhan, WASP and Adaptation Research Alliance. Mr. Titus Letaapo, Sarara Foundation and GEO Indigenous Alliance was unfortunately unable to present on *Indigenous understanding of addressing adaptation knowledge gaps and enabling action* due to connection problems. Proceedings are summarised here, see the research dialogue webpage[5] for a full recording and all slides in pdf format, including Mr. Letaapo's.

A. Summary of presentations

196. **We must achieve an integrated understanding of the global systems experiencing the impacts of climate change.** Knowledge must be built on the mechanisms, warming levels, and tipping points associated with the vulnerability of individual species and ecosystems at the regional scale, including human society. Limits to adaptation in this context must be considered both in terms of human adaptation action, but also evolutionary adaptation, as this constrains biodiversity and ecosystem services.

197. **Human, ecosystem, and planetary health must be considered together.** Quantifying social and ecosystem risks, adaptation and hard limits will improve our understanding of how heat stress and human thermal performance affects societal functioning. Risks may present impacts at human, ecosystem, and planetary levels, and so further knowledge is needed on how the environment, ecosystems and biodiversity, interacts with the social criteria necessary for human wellbeing and health and vice versa. Observations in the ocean have already shown the migration of species from lower to higher latitudes, and a biodiversity vacuum developing around the equator. How global warming is affecting the thermal ranges of species and the ecosystem services that they depend on is not well understood, but a similar mechanism playing out on land is likely that will affect biodiversity, livestock, and human societal performance.

198. **Societal consequences of vulnerability and the limits to adaptation will be felt in areas most at risk of experiencing climate impacts.** Vulnerability will vary regionally due to location-specific overlapping challenges and the effects of compound risks. Improving adaptation capacity yields currently undetermined benefits in poverty reduction, equity, justice and resource distribution. Building knowledge in this area will require building a greater quantitative understanding through integrating different knowledge systems, implementing Climate Resilient Development and avoiding maladaptation.

199. **Optimising the strengthening of the biosphere and human resilience will require extensive spatial planning.** 'Mosaic-scapes', adjoining areas of different land uses, can be tailored to the spatial needs of species and ecosystems. This form of spatial planning is especially important in protected, shared and heavily used spaces to have the potential to support self-sustaining biodiversity, migration corridors, and nature's contribution to human wellbeing. At least 30 to 50% of land, freshwater and ocean ecosystems need conservation, and must match with requirements for human uses and human needs. So, quantifying effective and specific uses and conservation needs is much needed in order to develop this mosaic approach to natural and human habitats.

200. **Risk and risk trajectories need further quantification to be understood in the context of climate action.** The IPCC burning embers diagrams allow us to quantify, qualify and compare risk to some extent across sectors, but how risk factors into adaptation and mitigation over time is not yet clear. Risk trajectories require quantification over different scenarios and a common language of metrics must be developed to integrate risk reduction in the assessment of climate action. An understanding of quantified compound risk, adaptation challenges and the associated societal implications, costs, barriers and tipping points will inform risk reduction action under these scenarios. The SROCC uses a schematic risk trajectory to project how risk evolves over time in relation to sea level rise scenarios and how the total risk reduction through mitigation and adaptation differs between these scenarios. Similar work in other areas can inform national climate plans.

201. **Managing compound risk at local or regional levels may require transnational or global action.** Vulnerability can be amplified by compound risks, where risks co-occur and cascade over a short period of time or in the same area. This may create stresses both regionally and across system boundaries that are economically and socially connected. Cascades can limit the window of time to recover from impacts, necessitating forward planning to achieve optimal outcomes and mitigate long term consequences.

Responding to these cascades requires collective action across scales and sectors, up to and including regional and global levels, to manage individual interconnected risks and the possibility of cascades. This is an emerging area of work by the policy and research communities that will yield more insights as our understanding of response processes increases.[11]

202. **Early warning systems must also factor socioeconomic change.** The effectiveness and requirements of early warning systems to predict and broadcast information on impending disasters and climate hazards is improving as experience and expertise in their use and deployment increases. This experience can be leveraged to inform adaptation and manage risk. Future risk depends on climate hazards as well as shifting patterns of exposure and vulnerability, necessitating observing systems also for socioeconomic processes and outcomes in addition to Earth and biosphere systems. Building these early warning systems requires intersectoral and interdisciplinary collaboration to ensure their capacity to account for changes in socioeconomic statistics and extremes.[12]

203. **A common language, metrics and goals must be developed to measure progress and define successes.** Climate change combines with the unsustainable uses of natural resources, habitat destruction, urbanization, and inequity which enhance risks and reduce the capacity to adapt. Common metrics and language will allow the use of comprehensive approaches to consider risk across scenarios and measure the success of adaptation in the context of Climate Resilient Development. Objectives and indicators of Climate Resilient Development must consider a common goal on adaptation in light of equity and justice to ensure risk levels are minimised across regions and sectors. These shared common definitions will allow progressed to be monitored and assessed as the scale and pace of action increases.

204. **Work is needed to develop metrics for and further applications of the Global Goal on Adaptation.** The operationalisation of the GGA will benefit from additional research on metrics, its interactions across processes, and adaptation governance. Metrics must be developed and tested for the different components of the global goal, and then applied to track progress and evaluate actions. More research is also needed to delineate how adaptation action interacts with the SDGs and identify the critical synergies and trade-offs that determine how adaptation strategies can be optimised to create multiple benefits. Overarching all of this, a better understanding is needed on how processes such as the GGA can aid the response to collective governance challenges across scales in the context of adaptation.[13]

205. **Determining the effectiveness of adaptation action is key to improving the underlying economics of adaptation.** Comprehensive metrics to measure adaptation will inform both investments in the scaling up of adaptation interventions, particularly by private actors, and also the economics of adaptation with regards especially to the estimation of both public and private costs and benefits. While the process of determining effectiveness takes place, standard methods and approaches for learning by and while doing can be formulated to accelerate improve understanding of future interventions.

206. **The mechanisms of enhancing urgency and increasing the pace of action must be understood.** Increasing urgency in reaching sustainability and implementing climate resilient development is vital, but accelerating action will require rapid learning from experience in multiple areas. Understanding the psychology of systematically accelerating transformative adaptation and mitigation will inform the necessary rapid changes institutions, development of political and societal will, and kickstarting of societal transitions needed for a sustainable future. Motivating change can come from enhanced knowledge of impacts and risks, and this can be driven by closing information gaps in society, among policymakers, and in education to achieve climate and biodiversity literacy.

207. **Consulting local actors at the site of change will identify key adaptation gaps.** The Adaptation Research Alliance have conducted consultative processes to identify research needs and opportunities through providing micrograants to support local actors in developing countries and strengthen capacity in the process. Supporting these grassroots initiatives allows local actors to identify the investments needed to support action research and ensure that gaps are effectively addressed. Aspects that have already been emphasised include enhancing collaboration and communication between research and practice; better monitoring, evaluation and learning systems; securing long term funding for adaptation; and integrating capacity building into the process of doing the research itself.

[11] See https://wasp-adaptation.org/wasp-publications/wasp-brief-5-the-risk-of-cascading-climate-change-shocks-and-stressors.

[12] See https://wasp-adaptation.org/wasp-publications/wasp-brief-4-early-warning-systems-for-adaptation.

[13] See UNFCCC secretariat technical paper "Compilation and synthesis of indicators, approaches and metrics for reviewing overall progress in achieving the global goal on adaptation," https://unfccc.int/documents/613843.

208. Micro grants were used as a tool alongside coproduction processes to identify needs and opportunities grounded in the priorities of communities and adaptation actors. Key needs identified include:

Building capacity and integrating and coordinating existing knowledge,

Leveraging intersectionality to connect adaptation with other parts of the development agenda.

Building capacity to engage in design and facilitation at regional and local levels,

Integrating learning and reflection into the process of action.

Discussion

209. **Does CORDEX include ocean coupled models that could capture the Aguilas current more effectively?**

The WCRP is running a pilot project on a coupled regional modelling of land, atmosphere and ocean interactions over Western Southern Africa. The CLIVAR project also runs many activities focused around the Aguilas current region.

210. **How can mitigation action be conducted in line with national contexts to avoid worsening socioeconomic conditions?**

Closing implementation gaps in adaptation and mitigation will require the collaboration of policymakers and scientists to develop strategies inclusive of understandings from the social sciences and psychosocial research. This will allow progress to be made on closing gaps while respecting the national social contexts. Studies of underpinning values and priorities could provide guiding principles for national action.

211. **How important is it in your view to further assess the linkages between different global tipping points?**

Tipping points can occur both in the biophysical and socioeconomic system. Focussing on risk one of the ultimate outcomes in the processes that may lead to tipping points will require a comprehensive consideration of exposure and vulnerability. Further research to understand the determinants of tipping points and chart the paths to possible outcomes.

212. **What are the key research gaps identified in the AR6 regarding adaptation and resilience for SIDS?**

Several types of gap exist. Some are context specific, and some are regarding complex impacts as well as interactions between different types of impacts, impact drivers, and adaptation. Closing gaps on how to build resilience, adapt and respond in different contexts, and between different contexts will require strengthened collaboration between academia, donors, the private sector, community and governments.

Research gaps also relate to the interactions between human and ecological systems, for example, the impacts of climate change on island ecosystem services and habitat loss, and how this interacts with adaptive capacity, livelihood conditions and community-based solutions. Another research gap in this context is where the limits to adaptation lie, and how those limits will affect loss and damage.

213. **How can limits to adaptation, particularly those related to finance in the most vulnerable countries and LDCs, be overcome?**

A better understanding of limits, including to what extent they are inherent and whether they are hard or soft limits depending on choices, can contribute to overcoming them.

Adaptation action and other interventions must be grounded in local information, including information on risks, that is tailored to particular decisions and decision-making contexts. This constitutes a needed change in how climate and risk information is thought about and made available. Information products and climate services must be driven by the decisions that they will inform as well as by the processes of climate change itself.

214. **What are the most important areas for future research in vulnerable countries and the LDCs?**

Capacity building for research at regional levels to produce information complementing the global picture and differentiating it with respect to specific regional requirements is an important challenge. The Africa chapter in the WGII report is one of the best and most comprehensive chapters, reflecting substantial progress between AR5 and AR6, but more work is needed.

The resolution of most CORDEX domains is around about 25 kilometres, in which several different terrains could occur together. Some new pilot projects increase resolution to three kilometres. The WCRP Digital Earths lighthouse activity,[14] for example, will leverage advances in computing and observing systems to provide regional high-resolution modelling. European Commission's Destination Earth is also aiming to produce models with resolution up to 1km using global and blended models.[15] In addition, regional models developed for specific purposes, such as imaging the Antarctic ice sheet, are also advancing.

B. Poster Session

215. Seven posters were presented on Theme 4. Posters are accredited here to the first and first supporting authors. Full author lists and all posters are available by following the hyperlinks and on the research dialogue webpage.[5]

216. **Climate science information for climate action**

Amir Delju, Ilaria Gallo, WMO Secretariat

Climate science information for climate action is one of a number of WMO activities that translates science into policy support to help tackle climate change drivers and impacts and to build resilience to increasingly extreme weather. Under this initiative, knowledge products are produced to characterize the climate system of the past, present and future, which are particularly useful for adaptation planning and in the development of proposals for climate finance. The correlation between climatic contributing factors and non-climatic contributing factors is studied to find the best evidence-based solutions for adaptation.

217. **Toward a global target on systematic observation: support for research and operations as part of the Global Goal on Adaptation**

Lars Peter Riishojgaard, WMO Secretariat; Lorena Santamaria, WMO SOFF Secretariat

Weather and climate services depend on a functioning meteorological value chain, but initial links are weak in many areas, especially SIDS and LDCs. This limits the ability to monitor the local climate, which in turn limit scientific progress toward understanding and modelling climate-related risks, and therefore also the ability to design meaningful adaptation measures.

A global goal on systematic observation is essential to achieve the objectives of the GGA and advance capacities and coverage for and of systematic observation globally. Targets for such a goal can be defined by the WMO Global Basic Observing Network and part funded by the Systematic Observation Financing Facility.

218. **World Adaptation Science Programme (WASP) Science for Adaptation Policy Briefs (SAPBs)**

Anand Patwardhan, WASP

Traditional early warning systems need to evolve to encompass climate change adaptation to better help communities prepare. Building these new systems will require collaboration of multiple disciplines of scientists, policymakers, and sectoral experts, coupled with financial support to develop impact-based climate risk assessment and forecast-based early actions to inform strategies.

Cascading impacts of climate change amplify human vulnerabilities and risks. Responding to compound risk requires a similar collaboration, while mainstreaming considerations of equity and justice. Stressors increase with the impacts of climate change, and each additional stress narrows the window to recover.

219. **Exploring the roles of local communities and local knowledge in integrated solutions for adaptation and resilience: Case studies of APN activities in Viet Nam and the Pacific cited in IPCC Sixth Assessment Report**

Asia-Pacific Network for Global Change Research, (APN)

Two IPCC AR6-cited projects by the APN have contributed to a better understanding of the role of local communities and local and indigenous knowledge in integrated adaptation solutions. The first, conducted in the mountainous region of Vietnam, highlights the complex farming systems, cultural practices and a knowledge base developed by local communities to address climate change impacts. The second, conducted with Fijian and Micronesian communities in the Pacific, concludes that sustainable futures depend on

[14] See https://www.wcrp-climate.org/digital-earths.
[15] See https://digital-strategy.ec.europa.eu/en/policies/destination-earth.

combining traditional knowledge and climate science, and calls for more research into equitable conversations for adaptation in the Global South.

220. **Action research for adaptation in practice**

Anand Patwardhan, WASP and Adaptation Research Alliance (ARA); Rosalind West, ARA; and colleagues from the ARA Secretariat

The Adaptation Research for Impact Principles is a framework for action-oriented research (AR) driven by user needs, co-produced with local experts, and equitable in practice. The adoption of these principles helps overcome barriers in the uptake of AR, such as a disconnect between research and the needs of the most vulnerable, limited capacities in communities, or misaligned incentives.

It is hoped these principles will instigate a systemic change in the landscape of AR – one that puts the needs of the most vulnerable front and centre, and which leads to enhanced and effective actions for adaptation and resilience.

221. **The nature funding gap: Building better for biodiversity**

The Nature Conservancy

Biodiversity compensation requires developers to make a simple pledge: make biodiversity retention a top priority, and when destruction is truly unavoidable, restore a similar ecosystem of at least the same size, health and ecological value to ensure 'net-gain' for nature.

222. **The nature funding gap: Unlocking funding to lock up carbon**

The Nature Conservancy

Our planet faces two urgent and interconnected crises: biodiversity loss and climate change. But there is hope. By better protecting, managing and restoring natural ecosystems, we can tackle both problems at once.

V. Looking ahead

223. One poster was presented looking ahead to the next SBSTA session. All posters can be viewed on the website for the fourteenth meeting of the research dialogue[16]. Full author lists per poster are available online.

224. **The 2022 GCOS Implementation Plan**

Anthony Rea, GCOS Secretariat; Han Dolman, GCOS Steering Committee

Climate services depend on robust, accurate and timely climate observations. Despite successes and advancements in systematic observation, the 2021 GCOS Status Report on the Global Climate Observing System identified several areas of concern, such as deficient ECV observations over certain regions and gaps in satellite coverage.

Observations are essential to implementing the Paris Agreement, placing additional requirements on the global observing system. Closing additional observation gaps related to the carbon, water, and energy cycles will improve modelling capabilities and provide warning of major changes. The 2022 GCOS implementation plan will address these issues.

[16] See https://unfccc.int/event/thirteenth-meeting-of-the-research-dialogue.