Subsidiary Body for Scientific and Technological Advice 09 May 2022

Earth Information Day 2021
03 November 2021

Informal summary report by the Chair of the Subsidiary Body for Scientific and Technological Advice

Overview

Data, services and information on the state of the global climate system are vital for informing decision making on mitigation and adaptation.

The Earth information day 2021 provided updates on the state of the global climate and its observation in 2021. It also provided updates on the developments, opportunities and challenges of interpreting Earth observations for implementing the Paris Agreement.

This summary report provides an overview of the presentations and discussions, as well as the posters presented. Key messages from the discussions are also provided. Seventeen individual presentation were given during the dialogue. The virtual poster session consisted of 30 posters.

Contents

Key messages

Earth system observations are an essential driver of progress in our understanding of climate change

Observations are essential for collecting information on climate change, understanding potential solutions and assessing the effectiveness of these solutions so that we may take effective climate action

The integration of disparate sources of data and information is both a challenge and a great opportunity for observation systems, and Parties and organizations should enhance cooperation and collaboration schemes to share data openly

Advances have been made in systematic observation for supporting climate change action, however gaps and improvements are still needed, and opportunities exist to address these gaps. In this regard, the following points could be useful:

The GCOS Status Report identifies a number of areas where improvements are needed:

- Surface-based observations
- Sustainability of funding for many ocean, atmospheric, and terrestrial observing systems. Many of these systems rely on short-term funding;
- Gaps in geographical coverage in areas, particularly in the ocean and in terrestrial areas in Africa, South America and the Pacific;
- Data stewardship, archiving and access, all of which also require sustained funding and effort.

Our understanding of extreme events is limited by the currently available observational records and spatial data gaps. Progress could be achieved by making past historical observations available and filling gaps in monitoring networks. Historical observations from the global South are particularly understudied within the event attribution framework.

Long term investment and sustainability of ocean observations is critical to enhance understanding of, among other things, the global energy budget, changes in global sea level, ocean circulation, transport of carbon in ocean systems and regional implications for coastal ecosystems of ocean acidification and changes in the carbon cycle. Comprehensive efforts to address climate change require these observations to be effective.

Furthermore, marine citizen science approaches could support the needed strengthened ocean observations through the use of user-friendly sensors and the deployment of sensors in non-scientific ships to expand ocean observations and for early ocean warning of climate change-related marine hazards.

Trends in polar regions, including trends in the carbon cycle feedbacks associated with abrupt permafrost thaw, have global relevance. Improved monitoring systems in these remote regions is also crucial to better understand the processes at play and improve understanding of and planning for future climate change.

The observation community is improving observation of GHG emissions, including via the CEOS greenhouse gas satellite constellation which will be operational by 2026 and will lead to further refinement of atmospheric greenhouse gas inventories. There is increasing collaboration between public and private sector for GHG monitoring to support policymakers in developing robust and measurable mitigation policies at all levels and to report on emissions.

There is a need for global collaboration and the consolidation of efforts around the research and measurement of Earth System Variables. Political commitments to strengthen collaboration and system interoperability will greatly further the global understanding of climate change and our capability to act on it.

Both public and private sector entities need continued financing to continue to bring the data and information from complementary capabilities to tackle local, regional and global issues.

The systematic observation community provides the observations that underpin climate science and services and can support the Paris Agreement and its global stocktake by:

- Providing atmospheric GHG and space-based AFOLU data to avoid gaps, enabling a more complete and transparent GST;
- Identifying best products and producing harmonized Earth observation datasets to facilitate adaptation planning by users on national and global levels;
- Developing global adaptation indicators;
- Providing free and open access to data and facilitating knowledge exchange to support the Enhanced Transparency Framework;
- Engaging with Parties to boost capacity building and facilitate the uptake of data streams.

I. Introduction

1. The Earth Information Day 2021[1] was held on 03 November 2021 during the Glasgow Climate Change Conference,[2] 31 October–13 November 2021.

2. The Earth Information Day, mandated by the Subsidiary Body for Scientific and Technological Advice (SBSTA), provides the opportunity for exchanging information on the state of the global climate system and developments in systematic observation.[3]

3. The themes and topics were guided by submissions,[4] and in consideration of the mandates and the wider context of ongoing work under the UNFCCC. The dialogue addressed two themes:

Theme 1. Updates on Earth observation of the climate system and climate change;

Theme 2. Interpreting Earth observations for implementing the Paris Agreement – developments, opportunities and challenges.

4. The SBSTA Chair prepared an information note[5] in advance of the event to provide an overview of the themes addressed and the guiding questions to help focus presentations and discussions.

5. The event consisted of a 3-hour dialogue as well as a 90-minute virtual poster session.

6. The event was chaired by the Vice-Chair of SBSTA, Mr. Kakhaberi Divani (Georgia).

7. The event was opened by Mr. Andrés Couve, Minister of science, technology, knowledge and innovation (Chile), and Mr. George Freeman, Minister of science, technology and innovation (United Kingdom of Great Britain and Northern Ireland).

8. This report provides a summary of the proceedings of Earth Information Day 2021 with Section II providing the summary of presentations and discussion and Section III providing a summary of the posters.

9. 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.

II. Summary of proceedings - presentations and discussions

10. **Minister Andrés Couve** highlighted the work of the IPCC in identifying and addressing knowledge and evidence gaps that make creating robust policies difficult. The work of researchers to address these gaps has impacted how we envision systems that provide information on climate change. The Earth Information Day is an opportunity to showcase advances in these information systems, to enhance our collective capacity to engage in research and observation under the Convention, and to promote knowledge and data sharing at regional and intergovernmental levels.

11. Chile covers a wide latitudinal range, and so offers a unique opportunity to develop a monitoring system to observe and understand climate change globally. A national climate change observatory[6] is being developed to build capacity for the integration, interoperability, standardisation and compliance of climate observation data. The aim of the initiative is to make use of information currently hosted on multiple isolated stakeholders from both the public and private sectors, and to promote robust and evidence-informed policies.

12. The integration of disparate sources of data and information is both a challenge and a great opportunity for observation systems, and Parties and organizations should enhance cooperation and collaboration schemes to share data openly. Science is not negotiable - globally relevant science and

[1] See https://unfccc.int/event/earth-information-day-2021.

[2] See https://unfccc.int/conference/glasgow-climate-change-conference-october-november-2021.

[3] FCCC/SBSTA/2019/2 para. 58.

[4] Submissions were received from Antigua and Barbuda on behalf of AOSIS, Chile, Slovenia and the European Commission on behalf of the European Union and its member states, Japan, Peru, Tanzania and the United States of America. See https://www4.unfccc.int/sites/submissionsstaging/Pages/Home.aspx.

[5] Available at https://unfccc.int/sites/default/files/resource/COP26_EarthInformationDay_Informationnote.pdf.

[6] See https://www.minciencia.gob.cl/occ/en/.

policymaking is based on global collaboration. Collective action on systematic observation at COP can drive global momentum to provide input for ambitious climate action.

13. Minister George Freeman emphasised the advances in Earth observation that reveal the state of urgency for action on climate change. Observations from space have been fundamental to developing our understanding and awareness of the importance of the global climate and the sensitivity of global ecosystems. These, combined with other remote sensing platforms, are essential for collecting information on climate change, understanding potential solutions and assessing the effectiveness of these solutions so that we may take effective climate action.

14. The UK Space Agency is developing their strategy to further Earth observations and building a supply chain from technology development to information to inform decisive climate action. The UK collaborates with Group on Earth Observations to ensure observation data is available and hosts the European Space Agency's (ESA) Climate Change Initiative, which contributes to the identification and monitoring of the Essential Climate Variables.

15. Creating effective global climate services requires stakeholders to work in partnership with organisations such as the ESA and the Copernicus Climate Change Programme using all available tools to provide trusted and calibrated data to decision makers and so enable decisive climate action. Earth observation therefore provide a tool to identify solutions to the global challenges of tackling climate change and assess the effectiveness of policies. It is therefore critical that we celebrate and support the science and technology behind them.

A. Theme 1. Updates on Earth observation of the climate system and climate change

16. Presenters for Theme 1 included **Ms. Valérie Masson-Delmotte** and **Mr. Panmao Zhai**, IPCC; **Mr. Anthony Rea**, WMO; **Mr. Vladimir Ryabinin**, IOC and **Ms. Anya Waite,** GOOS; **Mr. Albrecht von Bargen** and colleagues on behalf of CEOS/CGMS Working Group on Climate; **Ms. Sara Venturini**, GEO Secretariat; **Mr. Markus Woltran** on behalf of **Ms. Simonetta Di Pippo**, United Nations Office for Outer Space Affairs (UNOOSA); **Ms. Barbara Ryan**, World Geospatial Industry Council (WGIC); and **Mr. Carlos Garcia-Soto**, Group of Experts of the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects.

1. Insights from the IPCC AR6 WGI report: Earth observations, the current state of the climate system, constraints on possible climate futures

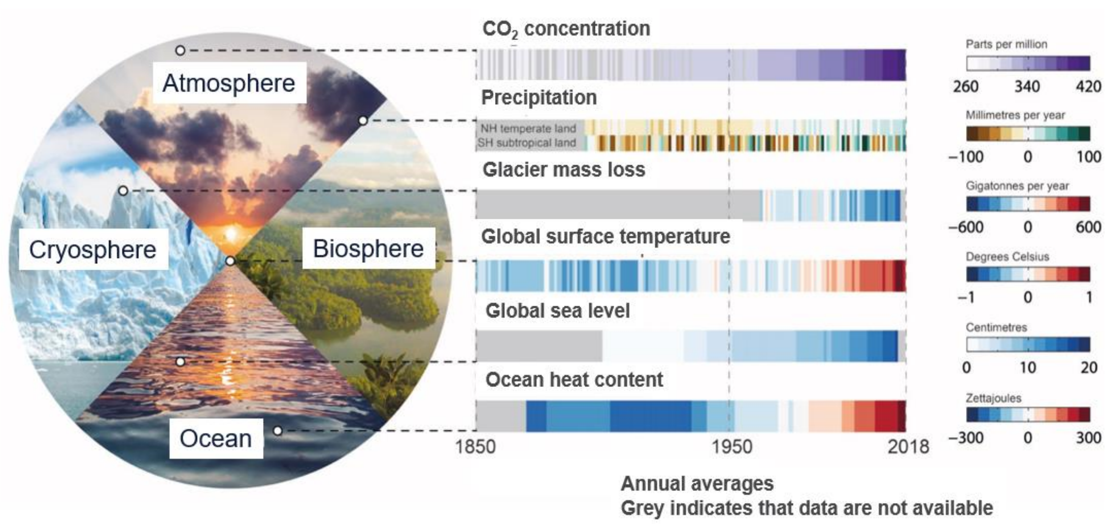
17. **Ms. Valérie Masson-Delmotte,** Working Group I Co-Chair, provided a summary of the key messages of the IPCC Working Group I contribution to the Sixth Assessment Report (AR6) - *Climate Change 2021: The Physical Science Basis*, finalised on 6 August 2021,[7] and the observation gaps evident from the assessment. This complemented the information provided at the SBSTA-IPCC special event on the Working Group 1 contribution to the AR6, 4 November 2021.[8]

18. Earth system observations are an essential driver of progress in our understanding of climate change, and observational capacities have continued to improve and expand since the Working Group I contribution to the IPCC Fifth Assessment Report (AR5) in 2013.

19. The Working Group I contribution to the AR6 combined multiple lines of evidence. The report assesses observations and insights from paleoclimate archives, revealing that the scale of the observed changes in the atmosphere, ocean, cryosphere, and biosphere and across the climate system is now unprecedented on the scale of hundreds to thousands of years. Observations show that recent changes in the climate are widespread, rapid and intensifying, (figure 1).

[7] See https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/.
[8] See https://unfccc.int/event/ar6wgi-special-event.

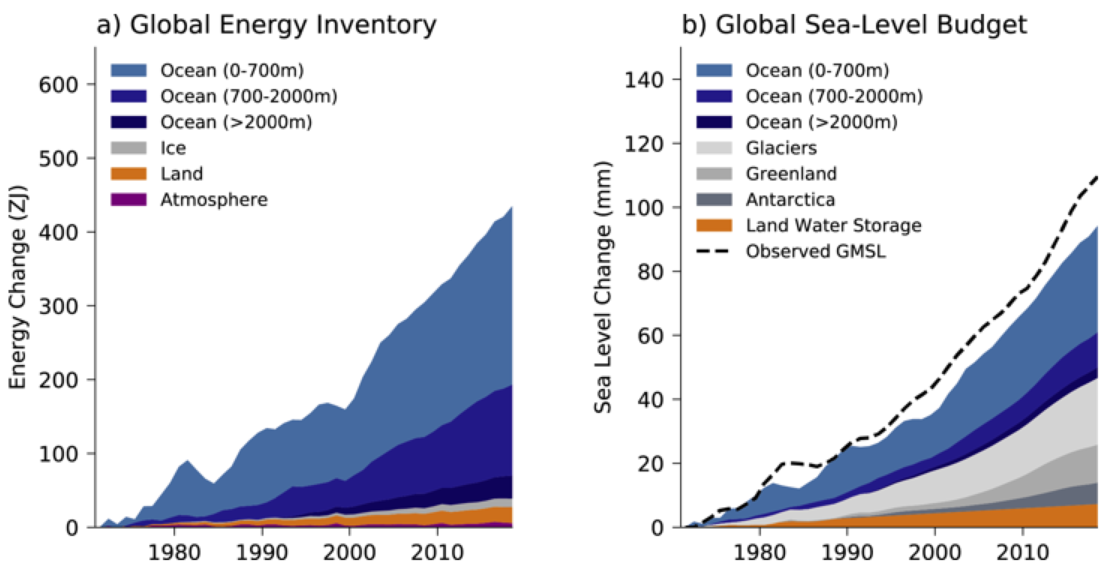
Figure 1. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred



Source: Slide 2 of Ms. Masson-Delmotte's presentation; IPCC, 2021, Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.[7] Cambridge University Press. In Press. Changes are occurring throughout the climate system. Left: Main realms of the climate system: atmosphere, biosphere, cryosphere, and ocean. Right: Six key indicators of ongoing changes since 1850, or the start of the observational or assessed record, through 2018. Each stripe indicates the global (except for precipitation which shows two latitude band means), annual mean anomaly for a single year, relative to a multi-year baseline (except for CO_2 concentration and glacier mass loss, which are absolute values). Grey indicates that data are not available. Datasets and baselines used are: (1) CO_2: Antarctic ice cores and direct air measurements; (2) precipitation: glacier mass loss; (4) global surface air temperature (GMST); (5) sea level change; (6) ocean heat content (model-observation hybrid). Further details on data sources and processing are available in the Table 1.SM.1 of Climate Change 2021: The Physical Science Basis.

21. Human induced climate change is now unequivocal and is increasingly affecting every region in multiple ways, making extreme climate events more frequent and severe including heat waves, heavy rainfall events, droughts, fire weather, and compound flooding. The attribution of climate change to human influence has been strengthened by assessing evidence from across the climate system and from understanding the Earth's energy imbalance (figure 2).

Figure 2. The Earth's energy imbalance causes increased heating of the climate system



Source: Slide 4 of Ms. Masson-Delmotte's presentation; IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.[7] Cambridge University Press. In Press. Left: Observed energy changes in zeta joules in the ocean, ice, land and atmosphere. Right: The contribution of reservoirs of water to sea level rise in mm via thermal expansion or influx of water to the ocean.

22. However, our understanding of extreme events is limited by the currently available observational records and spatial data gaps. Progress could be achieved by making past historical observations available and filling gaps in monitoring networks. Historical observations from the global South are particularly understudied within the event attribution framework.

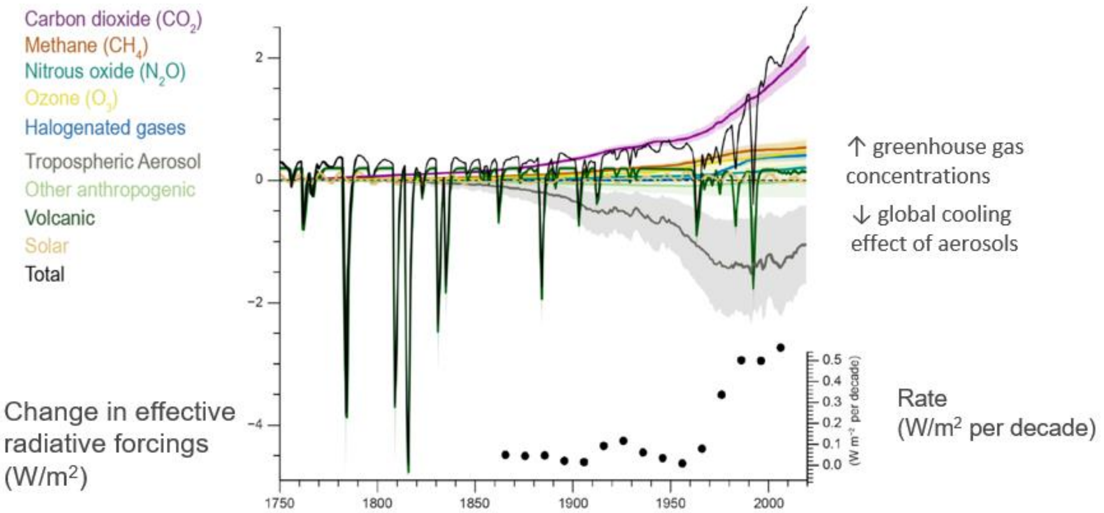
23. Observed increases in well mixed greenhouse gas concentrations in the atmosphere since the 1750s are unequivocally caused by human activities. Atmospheric CO_2 concentrations are unprecedented in more than 2 million years. CO_2 uptake by the land and ocean have also reached unprecedented levels, at 31% and 23% respectively.

24. Carbon flux monitoring shows that the proportion of CO_2 taken up by the ocean and land has been near constant over the past six decades, but some ocean carbon processes are starting to change. This is expected to contribute to a future weakening of the ocean sink if global CO_2 emissions remain close to current levels or increase in the coming decades. Furthermore, ocean acidification is increasing globally and affecting the ocean including into the deep ocean. Coastal monitoring needs to be improved to better understand the regional implications for coastal ecosystems of ocean acidification and changes in the carbon cycle.

25. The aerosol cooling effect on the atmosphere peaked in the late 20th century and has now declined with varying regional rates. The understanding of the effects of aerosols and greenhouse gases on respectively decreasing and increasing precipitation in monsoons has increased since the AR5. Major volcanic eruptions can also have a temporary cooling effect and at least one such eruption is likely to occur this century. Preparing for such eventualities must be included in climate risk management strategies.

26. Human caused radiative forcing in the atmosphere is estimated to have reached around 2.7 watts per square meters, around a 20% increase since 2013, driven by increased greenhouse gas concentrations and the reduced aerosol cooling effect (figure 3). The accumulation of the additional energy heating the climate system is caused by anthropogenic radiative forcing, partly reduced by the increased energy lost to space due to surface warming.

Figure 3. Human-caused radiative forcing is increasing



Source: Slide 3 of Ms. Masson-Delmotte's presentation; IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.7 Cambridge University Press. In Press. Top: The increase of radiative forcing due to the anthropogenic input of greenhouse gases to the atmosphere, the cooling effect of aerosols, and solar radiation in watts per metre squared. Bottom: The rate of change of radiative forcing in watts per metre squared per decade.

27. The rate of global heating has increased from around 0.5 watts per square meter between 1971 and 2006 to 0.8 watts per square meter in the last 20 years. Atmospheric warming accounts for 1% of the heating, ice loss for 3%, land warming for 5% and ocean warming for 91%.

28. Heating of the climate system has caused sea level rise through land ice loss and thermal expansion from ocean warming. The rate of ice sheet loss has increased by a factor of four since the 1990s and, as a result, the rate of sea level rise has accelerated from 1.3mm per year until the 1970s to 3.7mm per year now.

29. The quantification of ocean heating has been improved by measurements from thousands of autonomous floats while the quantification of land ice loss has been improved by ground measurements, coordinated field campaigns and remote sensing progress. Long term investment and sustainability of these ocean observations is critical both for understanding the global energy budget and the changes in global sea level.

30. Research assessed in AR6 shows that substantial progress has been made on combining new evidence of the Earth's climate sensitivity. These improvements are possible due to advances in the understanding and quantification of the Earth's energy imbalance, the instrumental record of global surface temperature change, insights on past climates from natural archives, climate feedbacks and their dependence on timescale and climate states. Furthermore, detailed remote sensing observations of clouds combined with theoretical advances have contributed to a better understanding of how clouds respond to climate change. Ms. Masson-Delmotte emphasised the importance of continuing progress in these research directions.

31. The broad agreement across the multiple lines of evidence supports the best estimate of climate sensitivity of 3 degrees C, with a likely range that is half of that assessed in 2013 in AR5. Best estimate of human caused global warming, which is now equal to the observed warming of 1.5 degrees Celsius, has been strengthened both using attribution studies and with radiative forcing and climate sensitivity studies. This updated knowledge is used in the WGI report to assess the climate response to a broad range of emission futures.

32. The range of the response of the climate to future emission scenarios has been narrowed using the multiple lines of evidence. For the first time in an IPCC report, the latest multimodal projections, observational constraints based on past warming, and the assessment of climate sensitivity have been combined to assess future changes in global surface temperature, ocean warming and sea level.

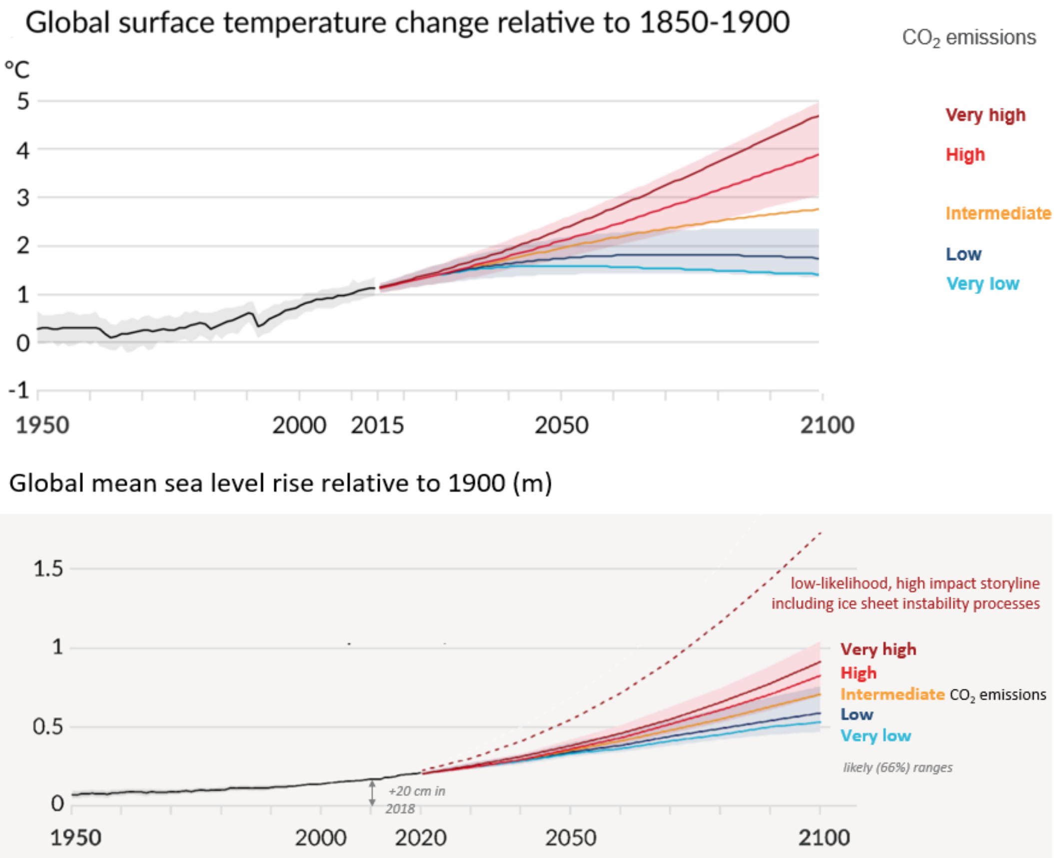
33. Global warming will reach 1.5 degrees C in the next 20 years on current emission trajectory (figure 4). If emissions remain near current levels before they slowly decreasing after some decades, global surface temperature would exceed two degrees by around 2050, and by 2100, the assessed range is 2.1 to 3.5 degrees Celsius. The last time the surface temperature was sustained at or above 2.5 degrees Celsius was over 3 million years ago. If deep reductions in CO_2 and other greenhouse gas emissions occur in the coming years and continue over decades, warming could stabilize to well below 2 degrees C in the second half of the century.

34. Glaciers are committed to continue to melt over the coming decades, while the timescale of the response of the deep ocean and ice sheets is measured in centuries to millennia. For the first time in an IPCC report the assessed future change in global mean sea level rise consistently combines climate, ice sheet, and glacier, simulations with the assessed climate sensitivity. This reveals how much the rate and magnitude of sea level rise depends on future greenhouse gas emissions. Estimates of sea level rise over the next 2000 years range from two to six meters if peak warming remains below two degrees, and higher for higher peak warming levels.

35. The chance of avoiding triggering irreversible instabilities in ice sheets that could substantially increase sea level rise is increased by lowering greenhouse gas emissions. Deep uncertainty remains concerning the processes of Antarctic ice sheet instability. With high emissions and large warming levels, the low probability outcome of rapid ice sheet loss cannot be ruled out. This could almost double the magnitude of sea level rise by the end of the century.

36. Trends in polar regions, including trends in the carbon cycle feedbacks associated with abrupt permafrost thaw, have global relevance. Improved monitoring systems in these remote regions are crucial to better understand the processes at play and improving our understanding of future climate change.

Figure 4. Global surface temerature change relative to 1850–1900 and global mean sea level rise relative to 1900



Source: Slide 6 and 7 of Ms. Masson-Delmotte's presentation; IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.[7] In Press. Top: Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining Coupled Model Intercomparison Project Phase 6 (CMIP6) model simulations with observational constraints based on past simulated warming, as well as an updated assessment of equilibrium climate sensitivity. Changes relative to 1850–1900 based on 20-year averaging periods are calculated by adding 0.85°C (the observed global surface temperature increase from 1850–1900 to 1995–2014) to simulated changes relative to 1995–2014. Very likely ranges are shown for SSP1-2.6 and SSP3-7.0. Bottom: Global mean sea level change at 2300 in metres relative to 1900. Only SSP1-2.6 and SSP5-8.5 are projected at 2300, as simulations that extend beyond 2100 for the other scenarios are too few for robust results. The 17th–83rd percentile ranges are shaded. The dashed arrow illustrates the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice-sheet processes that cannot be ruled out.

2. The State of the Global Climate and WMO's role in Coordinating the Global Observing System

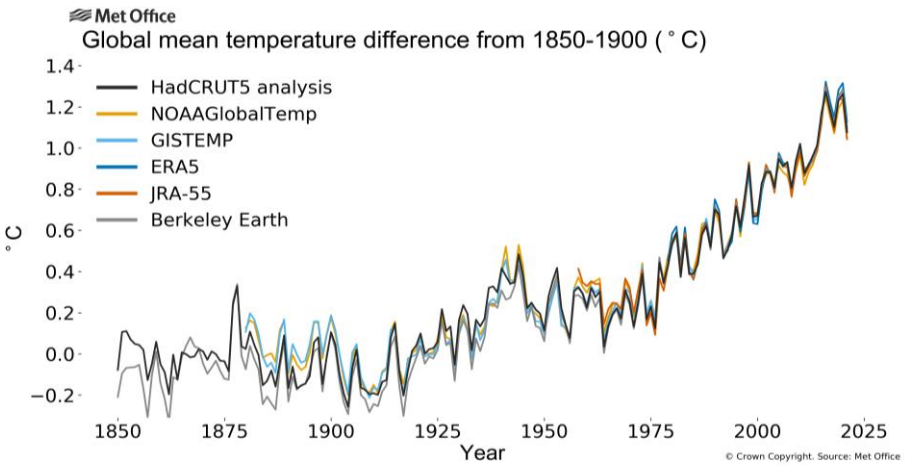
37. **Mr. Anthony Rea,** Director, GCOS Secretariat, provided an update on the provisional WMO *State of the Global Climate 2021* report and observation frameworks that underpin reporting on systematic observation for climate change.[9]

38. The *State of the Global Climate 2021: WMO Provisional report* highlights key events and looks at a range of specific climate indicators. It is a communication tool relevant to both policymakers and the general population that reinforces the messages coming from the IPCC. The WMO has also started producing regional state of the climate reports containing more locally relevant information. More information is also available in the WMO poster submission (see paragraph 158).

39. The State of the Climate report states that global temperature in 2021 is 1.08 degrees above that of the pre-industrial period and will likely be the fifth to the seventh warmest year on record. The last seven years will have been the hottest seven years on record, based on four different data sets and two reanalyses (figure 5).

[9] See https://library.wmo.int/index.php?lvl=notice_display&id=21982.

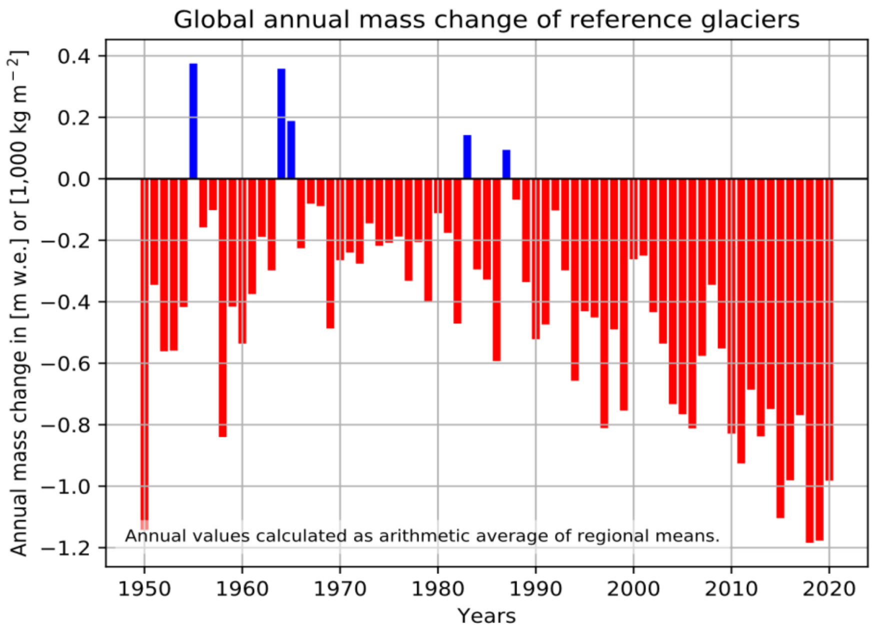
Figure 5. Provisional State of Global Climate 2021 - Temperature



Source: Slide 4 of Mr. Rea's presentation; WMO, 2021, State of the Global Climate 2021: WMO Provisional report, WMO Statement on the state of the Global Climate.[9] Global annual mean temperature difference from preindustrial conditions (1850–1900) for six global temperature data sets.

40. The World Glacier Monitoring Service[10] reports on glacier loss as measured by the mass balance of the reference glacier. This balance was negative for the 33rd consecutive year, with the average annual loss since 2015 now over 1 million tonnes per square meter. This is the fifth largest annual loss on record (figure 6).

Figure 6. Provisional State of Global Climate 2021 - Glaciers

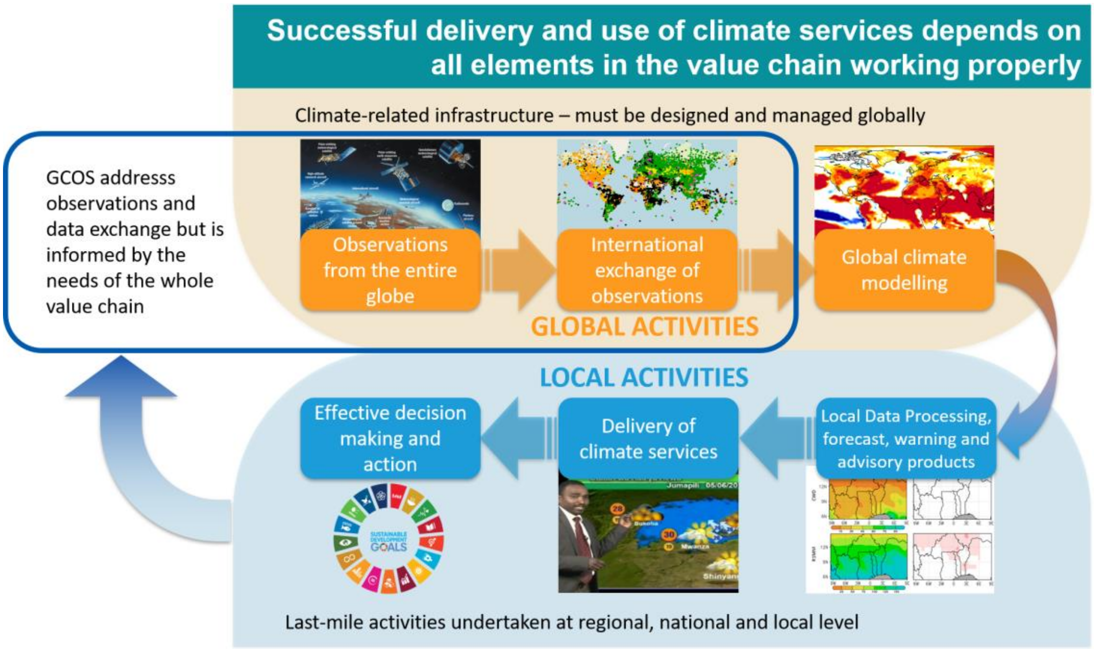


Source: Slide 5 of Mr. Rea's presentation; WMO, 2021, State of the Global Climate 2021: WMO Provisional report, WMO Statement on the state of the Global Climate.[9] Data curated by the World Glacier Monitoring Service.[10] Global glacier mass balance, 1950–2020, from a subset of around 40 global reference glaciers. Units are m w.e. – the depth of water that would be obtained from melting the lost ice and distributing it evenly across the glaciers.

[10] See http://www.wgms.ch/.

41. The Global Climate Observing System (GCOS) addresses observations and data exchange and is informed by the needs of the whole value chain (from observations to decision making) to deliver climate services including climate indicators. Climate services requires that all elements of this value chain work properly and that both climate and weather systems are understood in a global context (figure 7).

Figure 7. The value chain to deliver climate services



Source: Slide 7 of Mr. Rea's presentation.

42. The GCOS Status Report 2021 examines the state of global observation as outlined in the GCOS implementation plan 2016. Recent improvements to systematic observation include:

(a) Satellite observations, both in terms of spatial and temporal coverage, and in terms of observed variables. Much of this satellite data is curated and accessible;

(b) Establishment of GBON, a reference network for atmospheric and land surface observations;

(c) An expansion of the Argo programme to extend observations through the full water column and under the sea ice. The programme now also includes many biogeochemical variables;

(d) Technological innovations also contributed to expanding the ocean observing system and its capability.

43. The GCOS Status Report also identifies areas where improvements are needed, including for:

(a) Surface- based observations (figure 8);

(b) Sustainability of funding for many ocean, atmospheric, and terrestrial observing systems. Many of these systems rely on short-term funding;

(c) Gaps in geographical coverage in areas, particularly in the ocean and in terrestrial areas in Africa, South America and the Pacific;

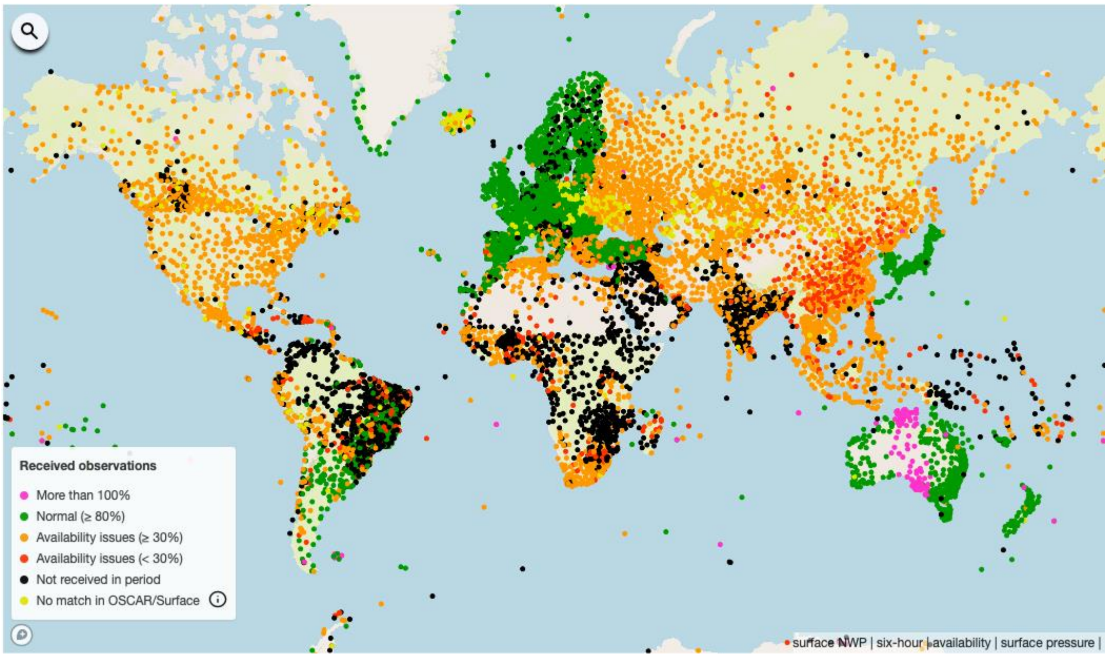
(d) Data stewardship, archiving and access, all of which also require sustained funding and effort.

44. The report underlines the need to support the Paris Agreement. GCOS is considering how it can support adaptation and mitigation efforts, with its next implementation plan due in mid-2022. GCOS is collecting contributions before the public review of the next implementation plan, and Mr. Rea encouraged interested Parties to contribute. Further information is provided in the poster on the GCOS status report (see paragraph 159).

45. Mr Rea identified decisions relevant to the UNFCCC taken by the most recent WMO Congress, in particular:

- The new WMO Unified Data Policy recognizes the interrelatedness of the of the total Earth system and brings together policies for weather, climate and water to create a combined data policy that addresses the entire Earth domain.
- The Global Basic Observing Network (GBON) which provides a set of rules outlining the observations countries need to take regarding surface and upper air observations. The GBON will increase the availability of observational data available for the atmosphere and lead to significant improvements in prediction, early warning systems. and climate analyses.
- The Systematic Observations Financing Facility (SOFF) will provide technical and financial support for the implementation of GBON, and address some of the previously mentioned financing gaps.

Figure 8. The WMO Integrated Global Observing System (WIGOS)



Source: Slide 14 of Mr. Rea's presentation. In many areas the exchange of surface-based observations has been declining in recent years while model resolutions have increased by factors of 1,000–10,000 since 1995. Especially in areas dominated by red or black, data quality will be relatively poor, and the possibility of verification will be limited.

3. Linking ocean carbon observation to effective climate targets

46. **Mr. Vladimir Ryabinin**, Executive Secretary of the Intergovernmental Oceanographic Commission of UNESCO, and **Ms. Anya Waite**, Co-Chair the Global Ocean Observing System (GOOS), presented on linking ocean carbon observation to effective climate targets.

47. Ocean observation and research, strengthened understanding of the ocean carbon cycle and options for ocean-based adaptation and mitigation are critically important to keep 1.5 alive. For example, ocean mitigation solutions can address 20% of the carbon gap to keep us within a 1.5 degrees scenario. Mr. Ryabinin highlighted the importance of scientific reporting on the ocean by the IPCC and initiatives that continue to move science forward such as the United Nations Decade on Ocean Science for Sustainable Development.[11]

48. One of the critical challenges of the Decade is the strengthening of understanding, decision-making and action at the ocean-climate nexus. The work of GOOS in understanding how ocean carbon factors into efforts to reduce emissions, store carbon, and provide solutions, is an important part of this work.

49. Ms. Waite stressed that ocean carbon must be accounted for in climate targets. The ocean controls the climate, holding 100 times more heat and 50% of the carbon of the atmosphere, more

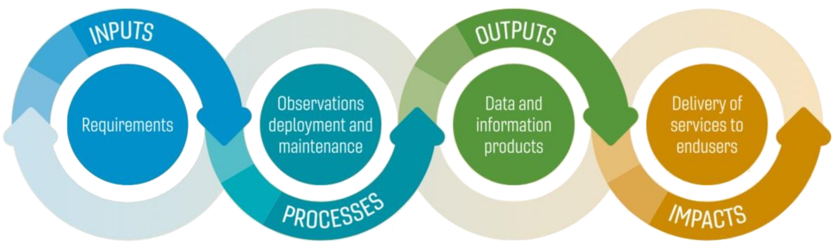
[11] See https://www.oceandecade.org/.

carbon than is contained in all land sinks. However, the ocean remains critically under-observed. The models of ocean, climate, and the data being collected in the ocean are now starting to diverge and make the application of models difficult. Ocean observation systems therefore require urgent international support.

50. Land based emissions targets are now failing to recognise changes in ocean carbon absorption. 40% of our fossil fuel emissions have been taken up by the ocean, but, as reported by the IPCC WG1, the uptake of carbon by the ocean will decrease as anthropogenic emissions decrease. This has critical implications for efforts to limit warming to 1.5 degrees C. The IPCC was not able to fully report on the changes in ocean circulation and changes in how carbon is transported through the system however, as observations are not available at this resolution. Thus, further ocean observation and research is vital to understand changes in ocean circulation and the transport of carbon in ocean systems to inform climate targets.

51. GOOS aims to facilitate conversation through the ocean-climate value chain to the other, from requirements to services and stakeholders (figure 9). GOOS will coordinate with ocean observers to set up observations and deploy and maintain observation systems to produce long term and sustainable outputs and data information products that inform services. GOOS is working to strengthen engagement with stakeholders, particularly policymakers, to bring their needs back into the conversation and deliver services suited specifically to them. Ms. Waite emphasises that coordinating a long-term sustained ocean observing system will require nations to work together to support a step change in ocean observation.

Figure 9. The ocean-climate value chain



Source: Slide 4 of Ms. Waites' presentation.

52. The Integrated Ocean Carbon Research report[12] frames the needs for stakeholder engagement and enhanced ocean carbon observation. The Framework for Ocean Observation[13] collects insights from the global ocean observation system in a single framework. These documents together can show the way forward to address ocean observation and research needs.

53. The design of ocean observatories is essential to making good observations. Satellite observations have great potential to support ocean monitoring and our understanding of the carbon cycle but can only see the ocean surface. Therefore, enhanced in-situ observations are also urgently needed to achieve sustainability and narrow the range of uncertainties on the heat and carbon budgets to support and assess climate targets. If the ocean sink fails, current emission trajectories will fall far short of climate targets.

54. Ms. Waite underlined the urgent need for nations to support the ocean observing community in addressing these observation gaps, therefore ensuring that efforts to achieve climate targets are not based on incomplete information. Ms. Waite emphasised the preparedness and capability of the ocean community to design ocean observatories and the need for coordination and conversation between nations.

55. The ocean has not been adequately addressed in the conversation around climate change but is essential to achieving global net-zero. The ocean's role in the climate system was discussed at the 2021 meeting of the G7 and GOOS has been in conversation with policymakers, philanthropists, governments, and foundations. Establishing sustainable observation networks and taking effective action requires discourse and cooperation on a global level.

56. A good first step proposed by IOC is collaboration on a North Atlantic carbon observatory is one way to begin the process. The ocean in this area takes up 30% of all ocean carbon and nations

[12] See https://unesdoc.unesco.org/ark:/48223/pf0000376708.
[13] See https://www.goosocean.org/index.php?option=com_content&view=article&id=18&Itemid=118.

in the region could collaborate to create a globally applicable example of international ocean observation and data sharing.

57. With respect to carbon dioxide removal (CDR), a baseline is urgently needed to inform ocean-based CDR, for example to guide initiatives and technologies that sequester carbon into hard materials and store it in the ocean floor. Without a credible way to measure the impact of CDR, ocean industries cannot be adequately supported as innovation in the ocean is accelerated.

58. Ms. Waite concluded by emphasising that while climate change is a trillion-dollar problem, solutions to it can be much smaller. It is therefore critical that ocean observations are integrated into our climate targets and that the ocean is brought into the conversation on climate change to inform our efforts in identifying and actioning solutions.

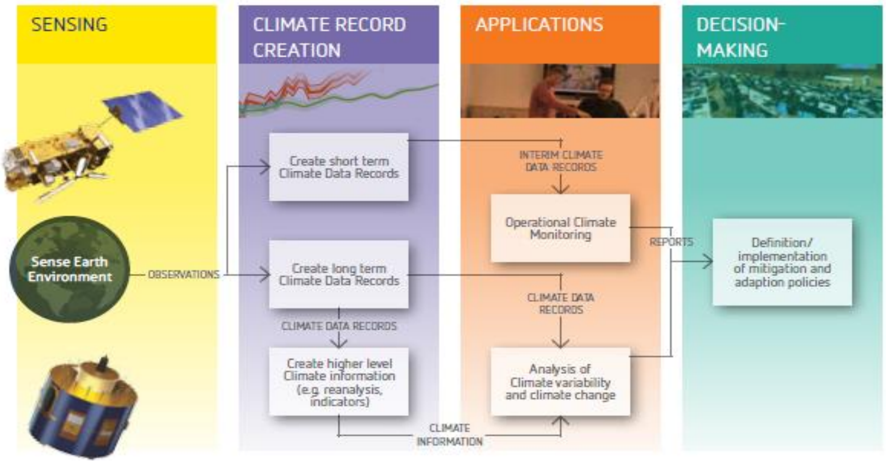
4. How space-based observations can support NDCs, national inventories and the global stocktake

59. **Mr. Albrecht von Bargen**, Chair, CEOS/CGMS Working Group on Climate, presented on how space-based observations can support NDCs, national inventories and the global stocktake on behalf of the CEOS/CGMS Working Group on Climate (WGClimate).

60. Based on the Paris Agreement, space agencies address the observational needs of Parties to the UNFCCC as facilitated by GCOS. GCOS coordinates with space agencies to define their needs for observations, and WGClimate provides a coordinated response to the GCOS implementation plan, reports back to GCOS on the status of space observations, and provides input to SBSTA and the COP.

61. The Architecture for Climate Monitoring from Space[14] developed by space agencies delivers a value chain for new technology in space to be applied to policy and decision making (figure 10). This incorporates the creation of climate data records and their applications, the conversion of space observation data into accessible information, and the translation of the observational uncertainty into confidence statements.

Figure 10. The Architecture for Climate Monitoring from Space



Source: Slide 3 of Mr. von Bargen's presentation. See the CEOS Strategy Towards an Architecture for Climate Monitoring from Space[14] for more information.

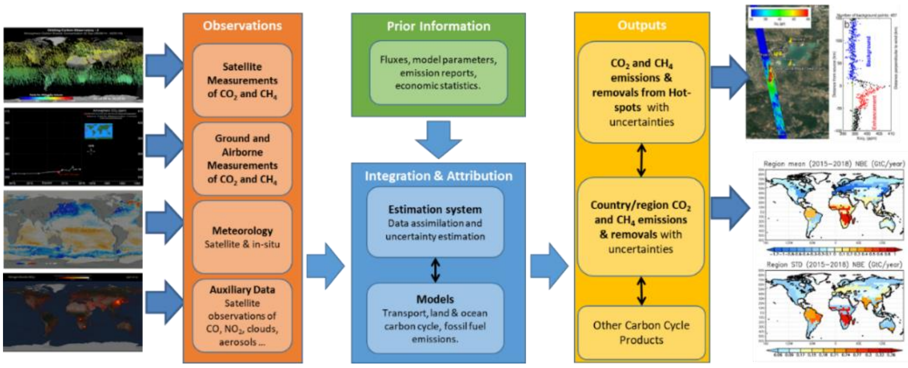
62. WGClimate is dedicated to providing information to the Global Stocktake. Space agencies and their partners are implementing a system for combining top-down CO_2 and CH_4 measurements from space with bottom-up approaches from the ground, and using data assimilation techniques and gas transport modelling. The freely available outputs of this system allow the identification of CO_2 and CH_4 emissions and removals at hotspots and regionally (figure 11). These results shall support the:

- Reduction of uncertainties in national emission inventory reports
- Identification of additional emission reduction opportunities

[14] See https://ceos.org/document_management/Meetings/COP-21/COP-21_2015/Strategy-Towards-Architecture-for-Climate-Monitoring-from-Space.pdf.

- Support to nations in formulating their NDCs
- Tracking of anthropogenic changes to the climate and the natural carbon cycle such as, deforestation, ecosystem degradation, and fire.

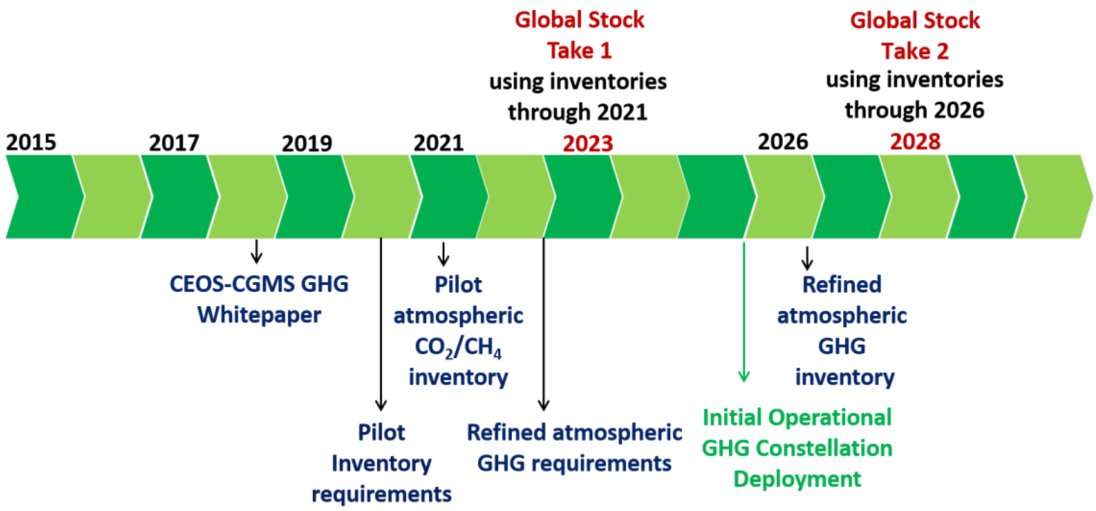
Figure 11. A Systems Approach to Deliver Atmospheric CO_2 and CH_4 Inventories



Source: Slide 5 of Mr. von Bargen's presentation.

63. The CEOS community is implementing new technology to strengthen GHG monitoring, as described in the CEOS Greenhouse Gas 2018 white paper[15] (figure 12). Pilot atmospheric CO_2 and CH_4 inventories are being developed and improved to provide input to the first GST. Initial greenhouse gas satellite constellations will be operational by 2026 and will lead to further refinement of atmospheric greenhouse gas inventories. By the second Global Stocktake, other systems such as the Copernicus CO2M mission[16] and GOSAT 2[17] will also be operational, allowing an initial operational GHG constellation deployment.

Figure 12. Timeline for Supporting the Global Stocktakes with Earth Observations



Source: Slide 6 of Mr. von Bargen's presentation.

64. The success of these systems depends on engagement with external stakeholders including Parties to the UNFCCC. Feedback from the GHG emission inventory community is crucial to continuing engagement with international policy frameworks. WGClimate also continues to work closely with international technical entities such as the WMO's Integrated Global Greenhouse Gas Information System (IG3IS) programme and other joint programs supporting the UNFCCC such as GCOS and the modelling community.

65. Another type of tailored information produced by WGClimate focuses on sustaining space capabilities for climate including the Essential Climate Variable (ECV) inventory. Additional ECVs

[15] See https://ceos.org/document_management/Virtual_Constellations/ACC/Documents/CEOS_AC-VC_GHG_White_Paper_Version_1_20181009.pdf.
[16] See https://www.esa.int/ESA_Multimedia/Images/2021/02/CO2M.
[17] See https://global.jaxa.jp/projects/sat/gosat2/.

were recently added to inform the Global Stocktake, such as above ground biomass and permafrost. An updated gap analysis dedicated to the GST will be published in 2022 and additional support to the GST will be provided by satellite observations of relevant areas such as mangroves and agriculture. The ECV inventory is also a data source for further climate applications and services.

66. Further information was provided in the four posters presented by WGClimate (see paras 161-164).

67. Mr. von Bargen concluded with some key messages:

- Space-based observations of documented quality can support the Global stocktake;
- The greenhouse gas constellation architectures follow a systematic approach, bringing together top-down and bottom-up emission estimates for carbon dioxide and methane for use by Parties to support the development of their national inventories;
- Space agencies provide long-term observations for 35 of the 37 GCOS ECVs using satellite observation;
- Data records from observations are 98% open-access;
- The Global Stocktake will lead to an extension of the ECV inventories portfolio beyond the current GCOS ECV using the available space borne observation capabilities.

5. GEO: Updates on Earth Observation applications across key sectors

68. **Ms. Sara Venturini** Climate Coordinator of the Group on Earth Observations provided updates on the applications of Earth Observations across key sectors.

69. GEO sits at the interface between earth observation and climate services in the value chain. The group assists governments to access and use Earth Observations data from both public and private providers. GEO collaborates with a diverse range of users, including regional and national decision makers and local communities, to develop applications and trusted knowledge products that integrate Earth observations with statistical, economic, demographic and other social information to support climate action.

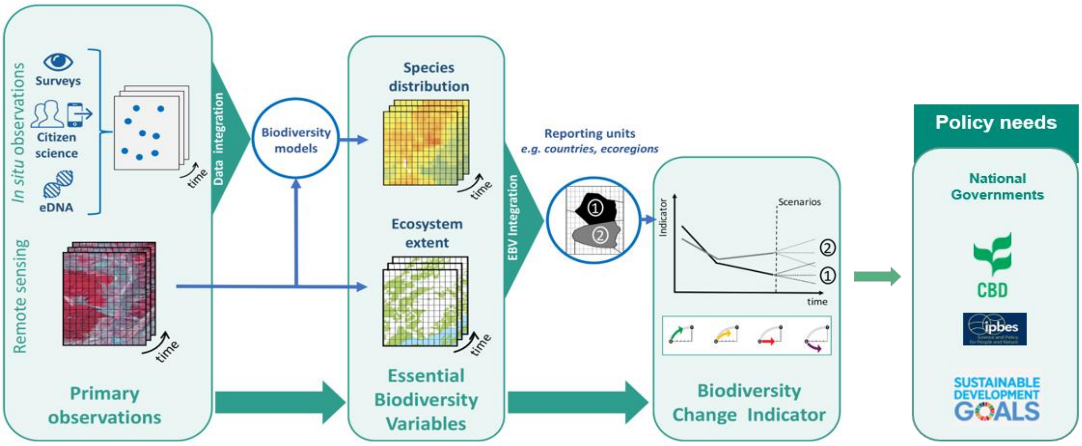
70. The GEO work programme[18] supports the UNFCCC and the IPCC with over 60 activities and 4 flagship initiatives that cover key sectors. Biosphere observations of the ocean and land are key areas of the work programme. Ms. Venturini provided several examples in the presentation as well as via the GEO posters (see paragraphs 171, 176, 180, 186).

71. The GEO Global Agricultural Monitoring Initiative[19] (GEOGLAM) has worked with the government of Uganda to predict crop failure and drought, which triggered a disaster risk financing facility that saved millions lives from food insecurity and averted financial losses in 2017. Based on this successful model of collaboration, GEOGLAM is developing supplementary technical guidance that will serve as a blueprint, especially for developing countries, to integrate remote sensing and ground-based observations for crop monitoring into National Adaptation Plans.

72. The GEO Biodiversity Observation Network[20] (GEO BON) use standardised biodiversity observations and new technology to calculate Essential Biodiversity Variables (EBVs) and biodiversity change indicators which in turn inform national reporting and decision making for Parties to the Convention on Biological Diversity (figure 13). GEO BON is currently working to create several analytical tools and online platforms that are important for the establishment of national and regional monitoring networks and for providing training to Parties of the CBD on biodiversity indicators. This could serve as an entry point for developing indicators to track the progress of adaptation action under the Paris Agreement and the Global Stocktake as well as implementing nature-based solutions and linking the work of the CBD with the UNFCCC.

[18] See https://earthobservations.org/geoss_wp.php.
[19] See https://www.earthobservations.org/geoglam.php.
[20] See https://geobon.org/.

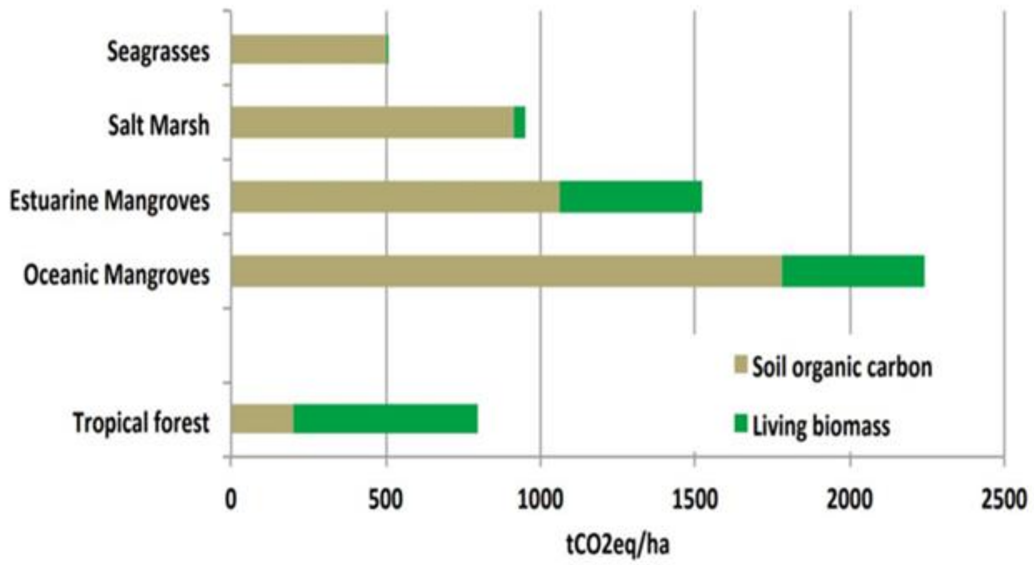
Figure 13. Biodiversity observations to inform national reporting and climate-relevant decisionmaking for Parties to the Convention on Biological Diversity



Source: Slide 5 of Ms. Venturini's presentation. Navarro, L.M. et al, 2017, Monitoring biodiversity change through effective global coordination, Current Opinion in Environmental Sustainability, Volume 29, pp 158–169, https://doi.org/10.1016/j.cosust.2018.02.005.

73. GEO Blue Planet[21] is GEO's ocean and coastal initiative which aims to work with the UNFCCC to use Earth observations to inform national adaptation plans on issues related to coastal erosion, saltwater intrusion, changes in species distributions, ocean acidification, storm surge risk and other coastal issues. GEO Blue Planet also intends to support work on mapping blue carbon ecosystems to set LMDC targets. Ms. Venturini emphasises the vital role that seagrasses, mangroves, salt marshes, and corals play in carbon sequestration as well as in protecting coastal communities from storm surges, erosion and other climate impacts (figure 14).

Figure 14. Marine and coastal carbon storage in comparison to tropical rainforests



Source: Slide 6 of Ms. Venturini's presentation. Murray B.C., Pendleton L. et al., 2011, Green Payments for Blue Carbon: Economic Incentives for Protecting Threatened Coastal Habitats, NC: Nicholas Institute for Environmental Policy Solutions, Duke University. Total carbon sequestered per hectare habitat.

74. GEO Mountains[22] is a network of existing specialized observations whose experts provide Earth observation information on the environment, ecology, societal systems and their changes in mountain regions globally. GEO Mountains' work informs climate research, models and services that help local governments to make decisions on adaptation.

[21] See https://geoblueplanet.org/.
[22] See https://www.geomountains.org/.

75. GEO also has regional foci. Digital Earth Africa,[23] for example, provides open access, and ready to use Earth observation datasets for the African continent that can be used to detect changes such as in water supply, crop coverage, coastlines and land cover to make informed decisions on mitigation and adaptation. Digital Earth Africa also provides a cloud computing platform, open source algorithms and methods, and online training to support capacity development in African countries.

76. The GEO Indigenous Alliance[24] shares and supports indigenous led innovations in Earth observation data, science and technology for climate action and food security. The Alliance also addresses indigenous data sovereignty and data management, the empowerment of women, and education in support of local indigenous communities.

77. GEO has started to engage new stakeholders such as the sustainable finance sector. A new workstream was launched at the GEO climate policy and finance workshop in September 2021 to further promote the use of Earth observations in financial investment decisions by banks and businesses and to strengthen the evidence base of project proposals for adaptation and mitigation investment in developing countries, for example, by the Green Climate Fund.

78. The *GHG Monitoring from Space* report[25] is the outcome of a public-private collaboration brokered by GEO, ClimateTRACE and the Word Geospatial Industry Council. The report maps government, commercial, and joint satellite missions that detect and measure greenhouse gases. Over 30 missions are detailed that are currently in orbit or in development and provides information on the types of gases monitored and the scale of application across global, national and point-source levels. These complementary satellite missions allow the development of more accurate greenhouse gas inventories that can serve as aggregate input to the Global Stocktake.

79. Ms. Venturini emphasised that building governments' trust in the use of satellite greenhouse gas data for reporting is essential for the GST and the UNFCCC process. The seven key policy messages in the report call for action for continued cooperation between the public and private Earth observation data providers to support policymakers in developing robust and measurable mitigation policies at all levels (figure 15).

Figure 15. Key Policy Messages from the *GHG Monitoring from Space* report

Source: Slide 11 of Ms. Venturini's presentation. GEO, ClimateTRACE, WGIC, 2021, GHG Monitoring from Space: A mapping of capabilities across public, private, and hybrid satellite missions.

6. Markus Woltran on behalf of Simonetta Di Pippo, United Nations Office for Outer Space Affairs (UNOOSA)

80. **Mr. Markus Woltran,** Programme Officer at the United Nations Office for Outer Space Affairs (UNOOSA) provided a statement on behalf of **Ms. Simonetta Di Pippo**, Director of UNOOSA.

[23] See https://www.digitalearthafrica.org/.
[24] See https://www.earthobservations.org/geo_indigenous_alliance.php#book/.
[25] See https://earthobservations.org/documents/articles_ext/GHG%20Monitoring%20from%20Space_report%20final_Nov2021.pdf.

81. The *Space for Net Zero*[26] report by the World Economic Forum emphasizes the critical role of space technologies in understanding our changing environment and reacting accordingly. This report, along with the WEF's Global Future Council on Space, emphasised the need for global collaboration and the consolidation of efforts around the research and measurements of Earth System Variables. The report strongly recommends the establishment of an Earth Operations Centre that leverages space data and expertise to conduct global interdisciplinary sustainability science. Through the consolidation of global climate science, understanding of global climate change can be furthered and translated into physical visualization and earth information to support international decision-making.

82. Integrated data management and the interoperability of systems, as well as a multilateral collaborative environment, are paramount for collaborations to succeed. Promoting these efforts is at the core of the work of UNOOSA. The Office is also involved in the further development of the Space Climate Observatory (SCO), an informal group of space agencies and international organizations that addresses the need to step up international coordination for accurate assessment and monitoring of the consequences of climate change. By conceiving methodologies that combine various data sources to provide scenarios for action, the SCO aims to become an important tool for decision-making on preparedness, adaptation and resilience to the impacts of climate change at the local level.

83. UNOOSA also works to strengthen and deliver targeted capacity-building and technical advisory activities, facilitate multi-stakeholder collaboration, and promote efforts to encourage the use of space for sustainable development. The UN/Austria World Space Forum on Space4Climate Action[27] aims to close the capabilities gap and support a more inclusive and diverse environment in order to maximise both direct and indirect contributions from the space sector.

84. Mr. Woltran emphasised that political commitments to strengthen collaboration and system interoperability will greatly further the global understanding of climate change and our capability to act on it. UNOOSA looks forward to further engaging with and to facilitating access to and usage of space data for Earth Information and evidence-based decision making

7. Barbara Ryan, World Geospatial Industry Council (WGIC)

85. **Ms. Barbara Ryan**, Executive Director of the WGIC spoke on the engagement of the private sector on Earth observations and partnerships between the private and other sectors.

86. The *GHG Monitoring from Space* report which is the first systematic assessment of greenhouse gas monitoring capabilities from space across public, private and hybrid missions.

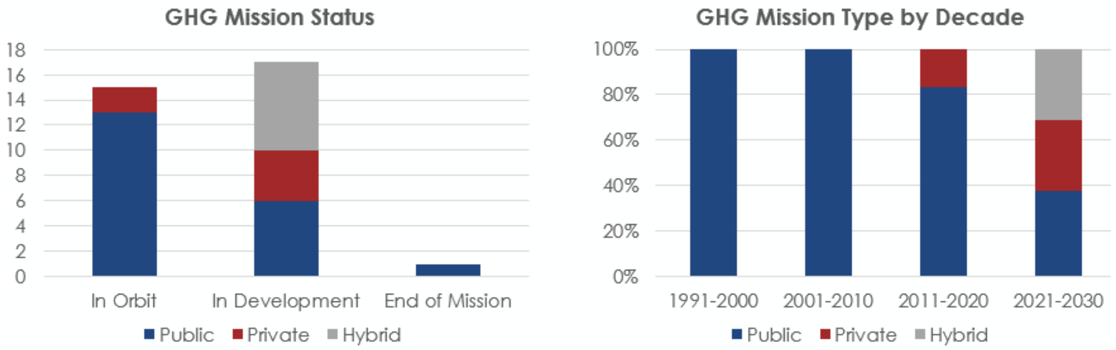
87. In the early 1990s to the 2000s earth observation satellite missions were carried out only by the public sector. From 2011 to 2020 private sector missions started to emerge (figure 16). For example, GHGSAT is currently operational and Orbital Sidekick will start delivering data soon. From 2021 to 2030, hybrid missions started to emerge in some combination of public, private or philanthropic funding.

88. Private sector and hybrid missions, important for GHG and other climate monitoring, are building on decades of work by the public sector with increased spatial, spectral and temporal resolution. Both public and private sector entities need continued financing to continue to bring the data and information from complementary capabilities to tackle local, regional and global issues. Ms. Ryan underlined the importance of collaborative activities between agencies such as CEOS and CGMS, companies through WGIC, and organizations like GEO, WGIC and Climate Trace. Assets from these organisations and collaborations are all available to be leveraged by Parties.

[26] See https://www.weforum.org/whitepapers/space-for-net-zero.

[27] See https://sustainabledevelopment.un.org/content/documents/28749Space_concept_note_and_programme.pdf.

Figure 16. Greenhouse Gas missions by sector from the *GHG Monitoring from Space* report



Source: Slide 3 of Ms. Ryan's presentation. Data from GEO, ClimateTRACE, WGIC, 2021, GHG Monitoring from Space: A mapping of capabilities across public, private, and hybrid satellite missions. Left: In orbit, in development, and ended missions by sector. Right: Percentage of each sector running GHG satellite missions per decade.

8. Carlos Garcia-Soto, Group of Experts of the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects

89. **Mr. Carlos Garcia-Soto**, Joint Coordinator of the Group of Experts of the UN Regular Process presented the Process and its contributions on climate change and earth observations reported in the World Ocean Assessment II.[28]

90. The objective of the Regular Process is to assess the state of the marine environment including socioeconomic aspects and to provide the best available scientific information to strengthen decision making. The First World Ocean Assessment, WOA 1, was published in 2016, and WOA 2[28] in April 2021. The Regular Process has initiated its third cycle from 2021 to 2025, which will conclude with WOA 3.[29]

91. In addition to WOA 1 and 2, the Regular Process publishes scientific briefs and technical abstracts summarising the information of the World Ocean Assessments relevant to key topics, including climate change. The first Technical Abstract on Ocean Climate Change was published in 2017 and the Regular Process will publish a second brief presenting the climate change information contained in WOA 2 in 2022.

92. The climate change brief includes the following sections: physical and chemical impacts, changes in extreme events, impacts in the marine ecosystems, impacts and adaptation measurements in marine coastal communities, knowledge gaps and capacity development needs, and potential interactions of the Regular Process with other ocean-related intergovernmental bodies and panels, such as the UNFCCC and IPCC.

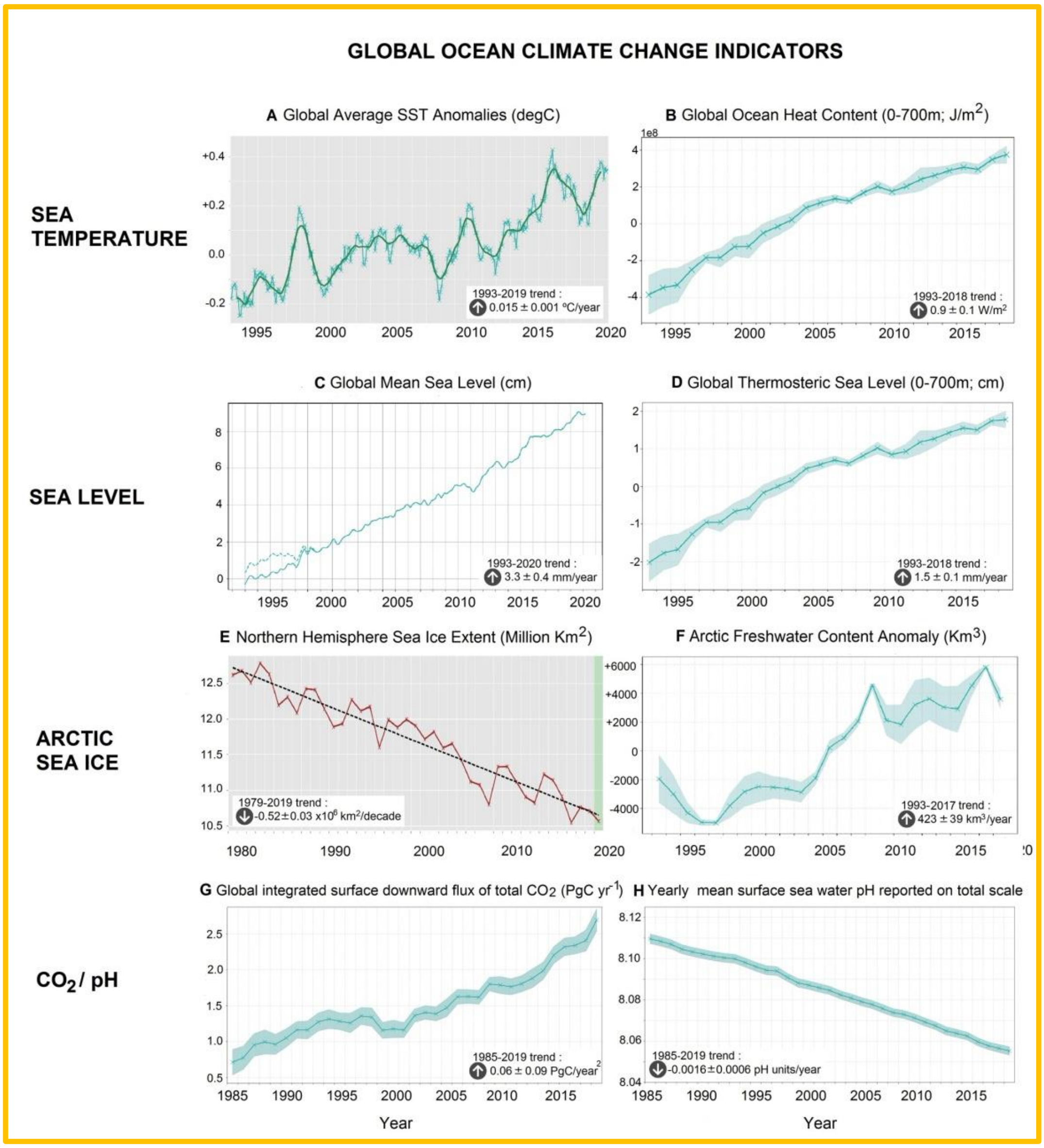
93. The human society section of the brief highlights the need to develop marine citizen science approaches through the use of user friendly sensors and the deployment of sensors in non-scientific ships to expand the ocean observations and for early ocean warning of climate change-related marine hazards.

94. The findings on Earth Observation are included in Chapter 5 of the World Ocean Assessment 2 and have been updated by the writing team in a recent publication (figure 17). A visual summary highlights the global trends during the last decades (from 1993 to 2019/2020) of key global climate change indicators: sea surface temperature, ocean heat content, sea level, northern hemisphere sea ice extent, Arctic freshwater content, surface downward flux of carbon dioxide and global ocean acidification.

95. The Regular Process works in collaboration with all interested UN bodies on issues related to the ocean, including ocean climate change, and aims to provide information that allows for decisive and urgently needed decision-making at all levels.

[28] See https://www.un.org/regularprocess/woa2launch.
[29] See https://www.frontiersin.org/article/10.3389/fmars.2021.642372.

Figure 17. Visual Summary of Global Ocean Climate Change Indicators



Source: Slide 2 of Mr. Garcia-Soto's presentation. Garcia-Soto, C. et al., 2021, An Overview of Ocean Climate Change Indicators: Sea Surface Temperature, Ocean Heat Content, Ocean pH, Dissolved Oxygen Concentration, Arctic Sea Ice Extent, Thickness and Volume, Sea Level and Strength of the AMOC (Atlantic Meridional Overturning Circulation), Frontiers in Marine Science, 8, pp1266, doi:10.3389/fmars.2021.642372. (A) Global Sea Surface Temperature (SST) anomalies (°C) during the period January 1993–December 2019. The anomalies are relative to the climatological period 1993–2014. Blue crosses (monthly mean values) and green thick line (filtered values). (B) Global Ocean Heat Content (OHC; 0–700 m; J/m^2) for the period January 1993–December 2018. 60°N–60°S. Spread indicated with shade. (C) Global Mean Sea Level (cm) during the period January 1993–October 2019. Daily altimetric measurements. The time-series are low-pass filtered, the annual and semi-annual periodic signals adjusted and the curve corrected for the Glacial Isostatic Adjustment (GIA; Peltier, 2004). The dashed line indicates an estimate of the global mean sea level corrected for the drift of the TOPEX-A instrument during 1993–1998 (Ablain et al., 2017). (D) Global thermosteric sea level (0–700 m; cm) for the period January 1993–December 2018. (E) Northern Hemisphere sea ice extent (millions of Km^2) during the period January 1979–December 2019 (40 years). Based on satellite passive microwave data (SMMR, SSM/I, SSMIS). Sea Ice Extent is defined as the area covered by sea ice, or area having more than 15% sea ice concentration. All northern hemisphere sea ice is included, except for lake or river ice. (F) Arctic ocean freshwater content annual anomalies (Km3) during the years 1993–2017. The regional domain is the Arctic Ocean basin with a depth > 500 m. (G) Global area integrated annual surface downward flux of total CO_2 (PgC/year) during the period January 1985–December 2019. (H) Annual global mean surface sea water pH over the period January 1985–December 2019 using a reconstruction methodology. Individual figures credited to EU Copernicus Marine Service (CMS).

Summary of Discussions

96. **What is the best strategy to ensure systematic observations for monitoring physical processes that contribute to the potential collapse of the Antarctic marine ice-sheet?**

Mr. Anthony Rea: Making in-situ observations of the Antarctic and Greenland ice sheets is difficult due to the cost, technological challenges, and difficulty in transporting data back. Both a space-based component and a surface-based component are required to validate these observations. Mr. Rea encouraged Parties to expand their service-based in-situ observation programmes to better understand the phenomenon of ice-sheet collapse and the risks and responses associated with such an event.

Ms. Helene Hewitt, IPCC: The assessment of the Antarctic ice-sheet has benefited enormously from the continued satellite observations and in situ observations that have facilitated the continuation of the Ice Sheet Mass Balance Inter-comparison Exercise (IMBIE) products. There have also been advances in the monitoring of Southern Ocean temperatures with the expanded Argo Network. Satellite monitoring and in-situ observations of these regions must be continued to enhance our understanding of accumulation over the Antarctic continent, measurements on the ice shelves, and under ice shelf observations from robotic floats.

97. **To what extent did the limited coverage of systematic observations in LDCs affect the IPCC's assessment of these regions in the Working Group I report?**

Ms. Sonia Seneviratne, IPCC: Data gaps are considered in the assessment and therefore do not affect the conclusion of the WGI report. There are still regions where data are missing, but substantially more information is available now compared to during the Fifth Assessment Report, for example evidence on observed changes of extremes such as heat waves, heavy precipitation, droughts, tropical cyclones, and in particular, the attribution to human influences.

98. **What is the current state of knowledge and understanding for projecting wind, storms, and cyclones, both in terms of strength and direction, for the different regions in the world?**

Mr. Anthony Rea: Comprehensive observation systems are vital for monitoring, predicting and reacting to systems as they evolve. In a warming climate, the intensity and the frequency of severe events will increase. The WMO is developing the Global Basic Observing Network (GBON), and the Systematic Observations Financing Facility (SOFF) to support the GBON and ensure that numerical weather predictions and climate analyses are based on the best available information.

99. **How long are the satellite data records that are available for performing climate analyses, and how accurate are these data when validated against observations from station data?**

Mr. Albrecht von Bargen: Data records exist for several ECVs that are between 25 and 40 years long. Some greenhouse gases do not have records for some years as satellite observations were not yet available.

100. The ECV inventory is built up by a certain structure of around 75 criteria which are considered before data records are included in the inventory. This includes information on validation and accuracy for each individual climate data record. Some data records may be more or less accurate than others, and this is accounted for by the criteria.

101. The CO2M mission is a good example of future accuracy requirements. The mission is required to achieve a specific accuracy window for its CO_2 and CH_4 measurements. This results in slight changes regarding the absolute contribution, for example with a concentration of 410 parts per million CO_2 the change is around 2 parts per million, with similar accuracy for CH_4. Validation against independent observations, including station data, is key for the success of a satellite mission.

102. **What insights are there on the role of regional Earth observation in the latest IPCC report particularly with regards to Small Island Developing States?**

Ms. Valérie Masson-Delmotte: About a third of the WGI report is focused on these issues, including the specific aspects in the Regional Atlas chapter. This chapter details the status of the assessment regarding in-situ observations and the use of reanalyses with a specific paragraph on small islands.

Mr. Peter Thorne: Small Island States are well addressed in the regional chapters of the WGI report and in the Atlas, which has benefited greatly from observations that have made available in those regions. Those data are also very valuable to informing global assessments. The new WMO Unified Data Policy mandates historical data sharing and Parties are strongly recommended to contribute data that will help to fill further data gaps in historical observations.

B. Theme 2. Interpreting Earth observations for implementing the Paris Agreement – developments, opportunities and challenges

103. Presenters for Theme 2 included **Mr**. **Frank-Martin Seifert**, on behalf of the Earth observation community; **Mr**. **Kenel Delusca,** Least Developed Countries Expert Group Chair; **Ms**. **Adelle Thomas**, Climate Analytics & University of The Bahamas; **Ms**. **Virginia Marshall**, Australian National University; **Great Grandmother Mary Lyons**, Ojibwe Nation; **Mr**. **Arry Simon**, Antigua and Barbuda on behalf of AOSIS; **Mr. Gabriel Kpaka**, Sierre Leone on behalf of the LDCs; **Ms**. **Yongxiang Zhang**, National Climate Centre, China Meteorological Administration, China; **Ms**. **Sheylla Sulca Paredes**, National Weather and Hydrology Service of Peru; and **Mr**. **Vincent-Henri Peuch** on behalf of **Ms**. **Samantha Burgess**, EU Copernicus Programme.

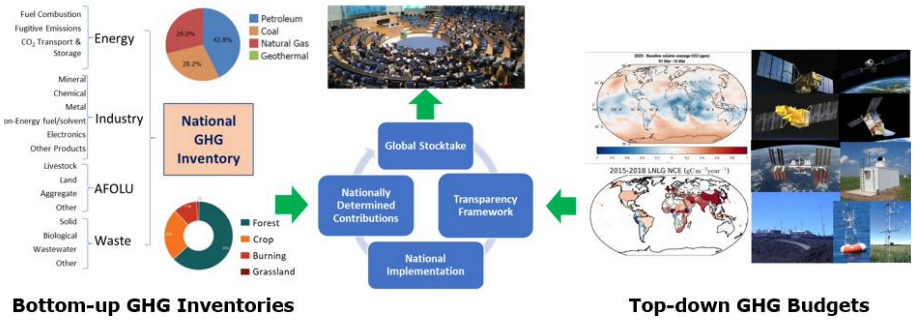
1. Systematic Observations Supporting the Global Stocktake

104. **Mr. Frank Martin Seifert,** European Space Agency, presented on behalf of the systematic observation community on systematic observations to support the Global Stocktake.

105. As mentioned above, global systematic observation includes space-based and ground-based observations. Ground based and airborne data provide accurate estimates of weather, climate, air quality, greenhouse gases, forestry and agriculture on local scales worldwide. Space-based measurements from a growing fleet of satellites provide high spatial and temporal resolution and greater, more frequent, coverage of the globe. The combination of these observations forms a more complete image of our planet to support decision making on climate change.

106. With respect to mitigation, bottom-up national greenhouse gas inventories are being combined with top-down atmospheric greenhouse gas budgets to produce a more complete and transparent input to the Global Stocktake (figure 18). Observation can also support national action and greenhouse gas inventories.

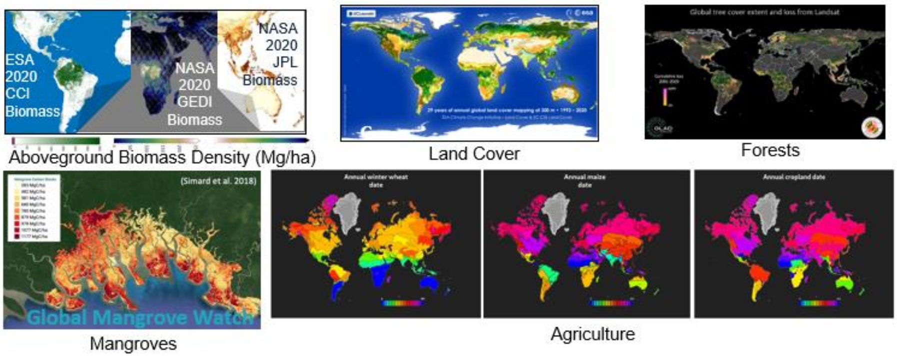
Figure 18. Bottom-up national GHG inventories can be combined with top-down atmospheric GHG budgets to produce a more complete and transparent input to Global Stocktake



Source: Slide 4 of Mr. Seifert's presentation. Left: Bottom up inventories considering GHG emissions from various sectors. Right: Top down measurements of atmospheric greenhouse gases by satellites. Middle: Both top-down and bottom-up approaches complement each other to factor into the Global Stocktake and enhance its transparency.

107. The observation community is strongly supporting measurements of emissions from the AFOLU sector, the primary source of emissions in many developing countries (figure 19). Several decades of observations of land cover are available from various resources such as from the Copernicus Climate Change Programme, of forests such as from the University of Maryland's LANDSAT data analysis, of mangroves, and of agricultural areas.

Figure 19. Earth Observations for monitoring emissions from the AFOLU sector



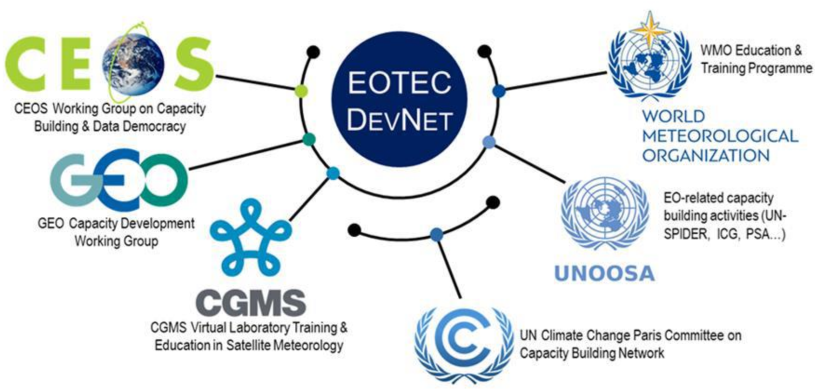
Source: Slide 6 of Mr. Seifert's presentation. Over 40 years of global land monitoring datasets are available. Data is generated by satellite missions from a variety of providers such as the ESA CCI, and the NASA GEDI and JPL Biomass missions.

108. With respect to adaptation, efforts may be guided by multiple Earth observation datasets of varying spatial scales, as well as demographic, economic, and social data. The systematic observation community is contributing to the Global Stocktake by assessing the aggregate progress countries have made on adaptation related to agriculture and food security, water supply, coastal vulnerability, energy, biodiversity, health and other areas. Earth observation-based adaptation indicators are being developed in key areas to further guide adaptation efforts, and the community is working to integrate multiple data sets into models to support countries in their adaptation efforts, including additional technical guidelines for National Adaptation Plans.

109. Earth Observation are underpinning climate services including the Global Framework for Climate Services;[30] GEO-developed Earth observation-based indicators, applications, and services for a diverse range of users; and Copernicus Climate Change Services.[31]

110. The systematic observation community is coordinating efforts to enhance the effectiveness of the 54 ECVs and implement interfaces between organisations and users, and action technology transfer and capacity-building. Examples of this include the WMO's capacity building strategy, the GEO Knowledge Hub, and the GFOI's method and guidance documentation on national forest monitoring systems. EOTEC DevNet[32] is an attempt to coordinate the capacity building efforts of various organisations to make them more effective (figure 20).

Figure 20. EOTEC DevNet



Source: Slide 10 of Mr. Seifert's presentation. EOTEC DevNet aims to coordinate the capacity building efforts of the systematic observations community. https://ceos.org/ourwork/other-ceos-activities/eotec-devnet/.

111. Earth observations are increasingly supporting investment decisions around climate resilience and nature-based solutions, and the systematic observation community is expanding related collaborations with the sustainable finance sector. When co-developed with and for

30 See https://gfcs.wmo.int/.
31 See https://climate.copernicus.eu/.
32 See https://ceos.org/ourwork/other-ceos-activities/eotec-devnet/.

indigenous peoples, Earth Observation data and tools can promote a "people-centred" and indigenous knowledge-driven approach to climate action.

112. Earth observations are also relevant to loss and damage associated with hydrometeorological hazards. For example, the *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes*[33] includes a record of the distribution of economic losses by hazard type and by decade globally. The two main hazards identified are storms and flooding. Damage from these hazards has increased significantly over the last two decades, costing approximately 3.6 trillion US dollars.

113. In summary, the systematic observation community provides the observations that underpin climate science and services and can support the GST by:

- Providing atmospheric GHG and space-based AFOLU data to avoid gaps, enabling a more complete and transparent GST;
- Identifying best products and producing harmonized Earth observation datasets to facilitate adaptation planning by users on national and global levels;
- Developing global adaptation indicators;
- Providing free and open access to data and facilitating knowledge exchange to support the Enhanced Transparency Framework;
- Engaging with Parties to boost capacity building and facilitate the uptake of data streams.

2. Adding value to National Adaptation Plans

114. **Mr. Kenel Delusca**, Chair of the Least Developed Countries (LDCs) Experts Group presented on Earth observations for adding value to National Adaptation Plans (NAPs).

115. The process of formulating NAPS identifies the medium - and long-term adaptation needs of a country, as well as planning the implementation of programmes and action to address the identified needs. The NAPs are based on 10 guiding principles and two are particularly relevant to systematic observation. NAPS must be “guided by the best available science” and “supported by comprehensive monitoring and review”.

116. The second stage of NAP formulation concerns preparatory elements, in which countries seek to base their decisions on the best available science as they identify evidence to support the NAP formulation and implementation process.

117. In its role in providing technical guidance and support to the NAPs, one of the modalities of the LEG relates to collaboration with other bodies and organizations, specifically the Climate Service Centre Germany (GERICS) and the Group on Earth Observations Global Agricultural Monitoring Initiative (GEOGLAM).

118. GERICS provides technical guidance to support NAP formulation and implementation by developing climate factsheets. GERICS works to address an identified series of gaps and needs**:**

- Training to access, use and generate climate data and climate change scenarios;
- Support for climate information services and early warning systems;
- Accessible methodology and tools for adaptation assessment by countries;
- Training on NAPs using Integrative and system approaches;
- Peer-reviewed publications of country case studies on NAPs.

119. GEOGLAM works to fight food insecurity by supporting the production and dissemination of relevant and accurate projections of agricultural production at national, regional, and global scales. GEOGLAM supports LDCs in formulating and implementing NAPs by providing tools and information products on near real-time status and changes in agricultural production at national and global scales and through the development of early warning systems for agriculture.

120. As of November 2021, 129 of 154 developing countries are formulating or implementing NAPS, 61 of which countries are supported in this process by the GCF. 30 countries, 9 of which are LDCs, have completed and submitted their NAPs on NAP Central. 60 countries, 7 of which are

[33] See https://library.wmo.int/index.php?lvl=notice_display&id=21930.

LDCs, have submitted one project concept note to the GCF for implementing the priority actions identified in the NAPs. 13 countries have received approval to access funding from the GCF for implementing 16 of the 32 proposals for priority projects.

3. Risk Assessments to Inform Adaptation and Loss and Damage

121. **Ms. Adelle Thomas,** Caribbean Science Lead at Climate Analytics and Senior Fellow with the University of The Bahamas presented on risk assessments to inform adaptation and loss and damage.

122. Risk assessments help to characterize risks to inform risk management decisions and actions. They are a foundational component of comprehensive risk management, along with risk reduction, risk transfer and risk retention. Comprehensive risk management is recognized as a framework to avert, minimize and address loss and damage as well as to identify priorities for planned adaptation responses.

123. Earth observations inform risk assessments by providing a better understanding of current and projected hazards. It is equally important to advance the understanding of current and projected exposure and vulnerability to gain a comprehensive picture of how physical aspects of climate change are experienced differently in different places and by different groups, particularly vulnerable people and ecosystems. Ms. Thomas emphasises that vulnerability needs to be incorporated in risk assessments to understand how adaptation measures such as policies, actions and socioeconomic change can reduce risk.

124. Ms. Thomas underlined the importance of further research to understand projected levels of exposure and vulnerability, and multidisciplinary approaches to risk assessments so as to bring together the physical and social sciences for a comprehensive picture of climate change risk.

125. Ms. Thomas relates the process of a risk assessment carried out in Grenada by a multidisciplinary team which focused on communities at risk.[34] A series of quantitative and compound indicators were developed to represent a range of hazards, exposure, and vulnerability, which were then used to spatially map varying levels of risk for the country (figure 21). A parallel vulnerability assessment identified factors such as demographics, education levels, and insurance coverage to better influence different levels of risk. These studies were used to identify potential adaptation strategies and related technology needs, as well as to support the development of GCF concept notes to access finance to implement measures to avert the identified risks.

126. There are a number of gaps and challenges that limit the widespread use of risk assessments for risk management that must be addressed:

- Data on hazards, vulnerability and exposure is an essential input for risk assessments, but often not available at fine resolution or is fragmented. This is especially true in developing countries, where obtaining data and developing capacities to use it is expensive in terms of both resources and scientific capacities. The IPCC has highlighted data gaps such as these between the global north and south in recent reports.

- Risk assessments may result in outputs that do not effectively inform the needs of users. Assessments must provide policy relevant information that prioritizes risks and shows how differential action may be needed for highly vulnerable groups. For example, risk assessments can show gender-based differences in risk, and this can then inform gender sensitive adaptation measures.

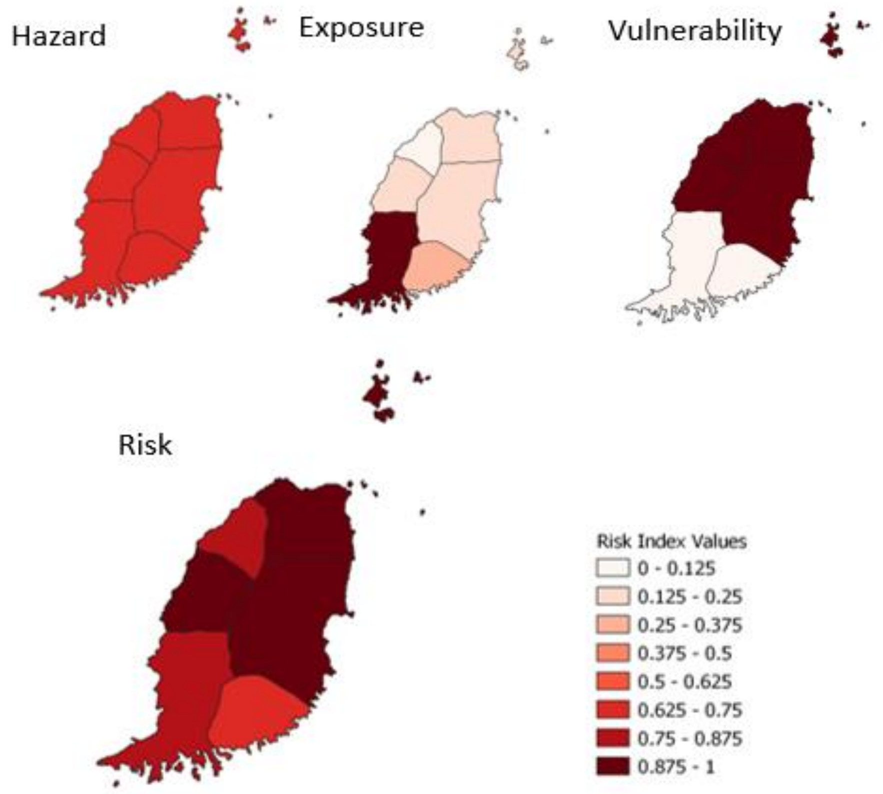
- It is difficult to assess cascading, compound and interacting risks where, for example, a series of extreme events occurs that may overwhelm adaptive capacities. It is also difficult to incorporate unexpected factors such as the COVID-19 pandemic, as well as tipping points that limit the effectiveness of adaptation and risk assessments.

127. Some opportunities and best practices for performing risk assessments have been identified. Freely available risk assessment tools offer a resource to increase capacities for risk assessment and to help link them to broader planning processes, including NAPs, disaster risk reduction strategies, and Nationally Determined Contributions. The use of a combination of quantitative and qualitative methods can aid in identifying and addressing economic and non-economic loss and damage. The combination of these methods also helps to ensure that the output of the assessment is more inclusive and relevant to a wide range of stakeholders.

[34] See Climate Analytics, 2021. Grenada, Carriacou, and Petite Martinique Climate Change Risk Assessment.

128. Ms. Thomas highlighted resources of the Warsaw International Mechanism for Loss and Damage Executive Committee Technical Expert Group on comprehensive risk management in the updated plan of action. Ms. Thomas also highlighted the upcoming expert meeting on risk assessment and adaptation.

Figure 21. Hazards, exposure, and vulnerability mapping during a climate risk assessment of Grenada



Source: Slide 4 of Ms. Thomas' presentation; Grenada, Carriacou, and Petite Martinique Climate Change Risk Assessment, March 2021.

4. Contributions and feedback between scientific and indigenous knowledge

129. **Ms. Virginia Marshall**, Wiradjiri Nyemba and Inaugural Indigenous Postdoctoral Fellow with the Australian National University, and **Great Grandmother Mary Lyons** of the Ojibwe Nation presented on contributions and feedbacks between scientific and indigenous knowledge.

130. Loss and damage and the effects of climate change, such as rising sea levels, are known of and observed daily by the Aboriginal peoples and Torres Strait Islander peoples in Australia. These observations and traditional knowledge are passed down by traditional knowledge holders to young people.

131. Ms. Marshall highlighted the importance of caring for country, including its biodiversity, water resources, and cultural heritage. Ms. Marshall emphasised the importance of indigenous peoples' ownership of land and resources that allows the care of that land, as well as funding to carry out this care.

132. Elders in Australia observe seasonal indicators of climate change, such as unseasonal extreme weather and changes in the flowering times of some species of plants. These experiences echo those in other countries, such as in the fire seasons of Greece and California. Australian knowledge holders have collaborated with knowledge holders in America and Canada to assist in the revitalization of indigenous science and knowledge.

133. Indigenous science and knowledge are essential for the protection of biodiversity. Creating partnerships between knowledge-holders transfers theoretical and practical knowledge of climate change. Transferring knowledge in an accessible and understandable form is vital, and the importance of co-design and free, prior, and informed consent is emphasised at every stage of a project.

5. Arry Simon, Antigua and Barbuda on behalf of AOSIS

134. **Mr. Arry Simon** of Antigua and Barbuda spoke on behalf of AOSIS to present the perspective of small island states.

135. Earth observations are essential for the implementation of the Paris Agreement, particularly for supporting the assessment of loss and damage, and Global Stocktake. Systematic earth system observations to provide timely updates on the emissions of greenhouse gases and the state of our climate system are of critical importance to support urgent climate action required this decade.

136. Small island states are regions of high vulnerability to climate impacts. Addressing these challenges requires data and modelling at the local level at high resolutions, and this same data is also important for attribution studies of anthropogenic influences on climate change.

137. Mr. Simon highlights the regional information reported by the IPCC WGI contribution to the AR6. The climate Atlas reveals, for example, trends in maximum temperature per decade in the Caribbean region.

138. Substantial observational challenges remain, however, such as limitations of observational networks and regional downscaling. Mr. Simon emphasised the importance of additional regional research, enhanced capacity building and the need to overcome sustainability issues. Observation systems need to be maintained and improved so that they can contribute to long-term continuous data exchange and inform both national services and international systems. Achieving this will require additional staff capacity and training, as well as funding.

139. The WMO has contributed to addressing these needs through its regional workshops. Continued research facilitated through the WMO and other initiatives is essential to ensure that small islands have adequate information available on the devastating changes taking place in their regions.

6. Gabriel Kpaka, Sierra Leone on behalf of the LDCs

140. **Mr. Gabriel Kpaka** of Sierra Leone spoke on behalf of the LDCs on the gaps and needs for research on adaptation and mitigation.

141. The impacts of climate change are globally visible at the current level of warming of approximately 1.1 degrees Celsius higher than pre industrial levels, and warming beyond 1.5 degrees will expose millions more people to extreme events such as droughts, landslides, heat waves and floods, as well as biodiversity loss, the melting of glaciers, ocean warming, and sea level rise. Though these are global impacts, the Least Developed Countries will be affected first and affected more due to lower levels of resilience and higher vulnerability.

142. Building on recent advances, additional efforts are required to improve the quality of observations over the LDC countries. The IPCC WGI report has shown that information on certain variables is not available over most LDC countries, preventing the determination of the impact of certain extreme events and associated risks. This hinders the national ambition planning and restricts the country's ability to engage in policy discussions. The lack of sufficient data also impacts the development of documents, such as NDCs and NAPs, and other programmes.

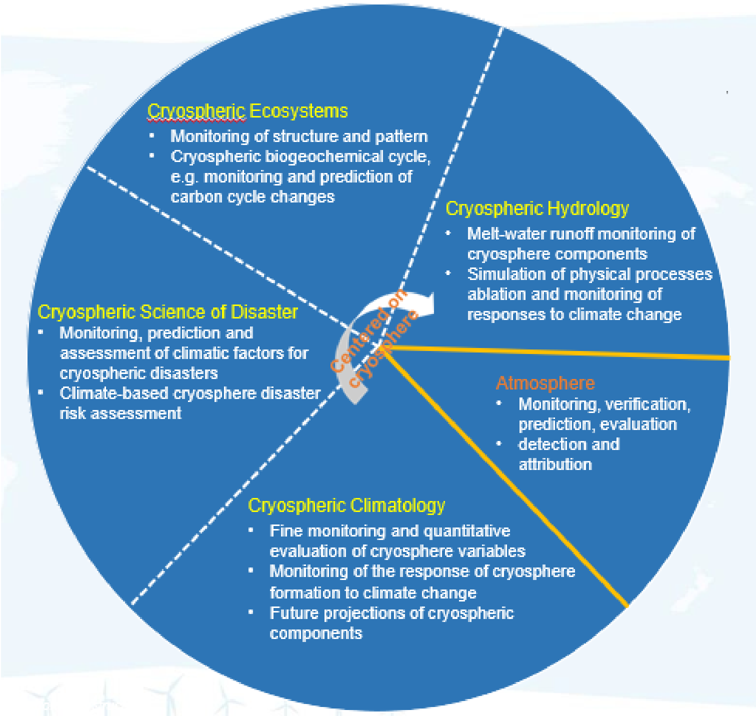
7. Yongxiang Zhang, National Climate Centre, China Meteorological Administration, China

143. **Ms. Yongxiang Zhang** of the China Meteorological Administration (CMA), presented on delivering climate information for regional sustainable development.

144. China continues to work with a systematic observation system that informs action on climate change and the development of climate strategies, producing the Green Book on Tackling Climate Change since 2009. Efforts are underway to build capacity to adapt to climate change in vulnerable regions such as high mountain areas.

145. The CMA and the WMO have signed a letter of intent to provide meteorological support for the Belt and Road construction and to further work on disaster risk reduction, climate services, integrated observations, research, and capacity development, such as through the Third Pole Regional Climate Centre Network (TPRCC-Network). A result of this partnership is a cryosphere observation system that has been developed to monitor ecosystems, hydrology, climatological factors, disasters and other aspects of high mountain environments (figure 22).

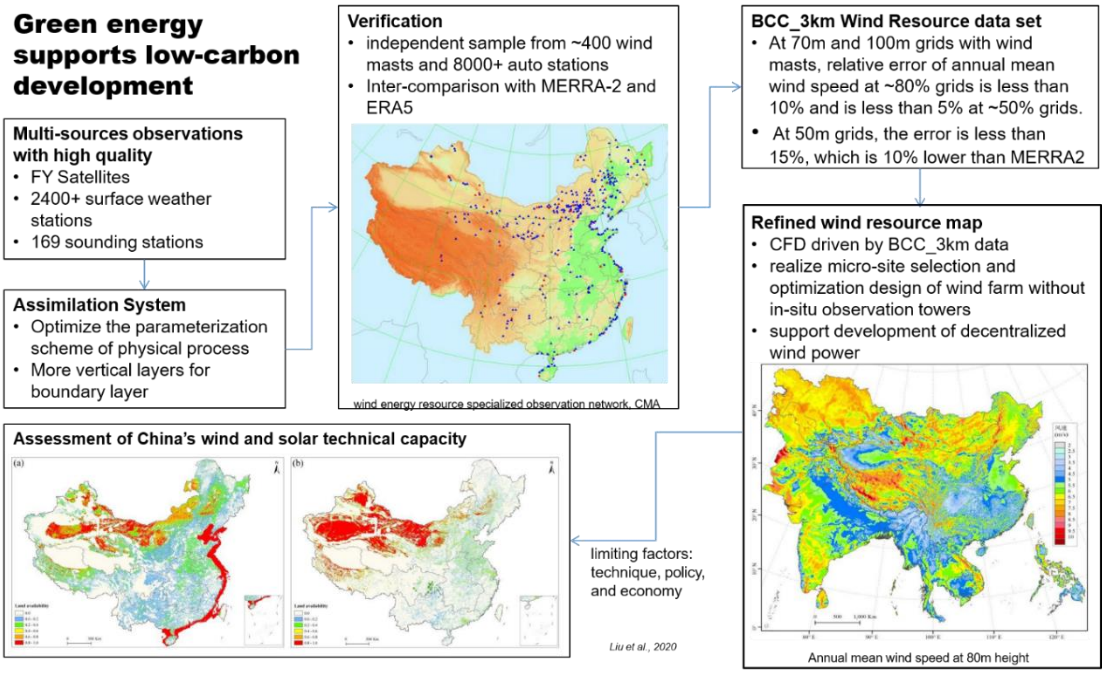
Figure 22. Regional Climate Service to meet challenges in High Mountain Asia



Source: Slide 4 of Ms. Zhang's presentation; A cryosphere observation system has been developed to monitor ecosystems, hydrology, climatological factors, disasters and other aspects of high mountain environments through the Third Pole Regional Climate Centre Network (TPRCC-Network) in association with the China Meteorological Administration.

146. To support green energy projects, data produced by high quality observation systems and independently verified by national weather stations can be used as input to models to produce high-accuracy wind resource datasets. These refined datasets can then inform the design and location of decentralised wind farms without in-situ observation towers. Both wind and solar capacity can be assessed in this way, and further research is underway to overcome limiting factors in technique, policy and the economy (figure 23). This assessment is then provided to the department of energy.

Figure 23. Green energy to support low-carbon development in China



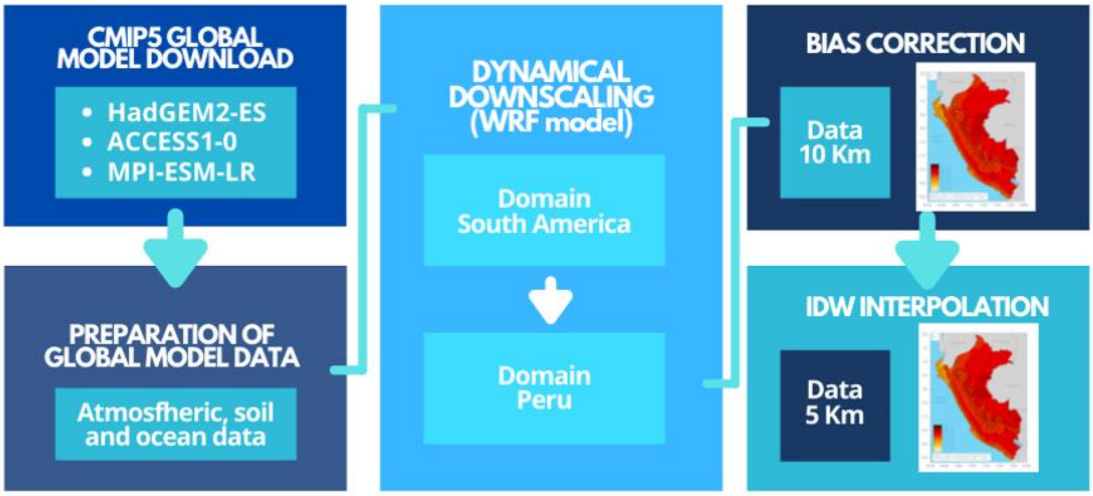
Source: Slide 5 of Ms. Zhang's presentation; Liu et al. 2020, Earth Observations to assess wind and solar capacity in China.

8. Sheylla Sulca Paredes, National Weather and Hydrology Service of Peru

147. **Ms. Sheylla Sulca Paredes** of the National Weather and Hydrology Service of Peru gave a video presentation on using climate scenarios to support adaptation planning.

148. Peru is one of the most vulnerable countries to climate change. The National Weather and Hydrology service of Peru has generated climate scenarios through dynamic downscaling using the Weather Research and Forecasting model to better represent the regional climatic conditions of Peru. Bias correction and spatial interpolation of these data produced a dataset at 5km resolution (figure 24).

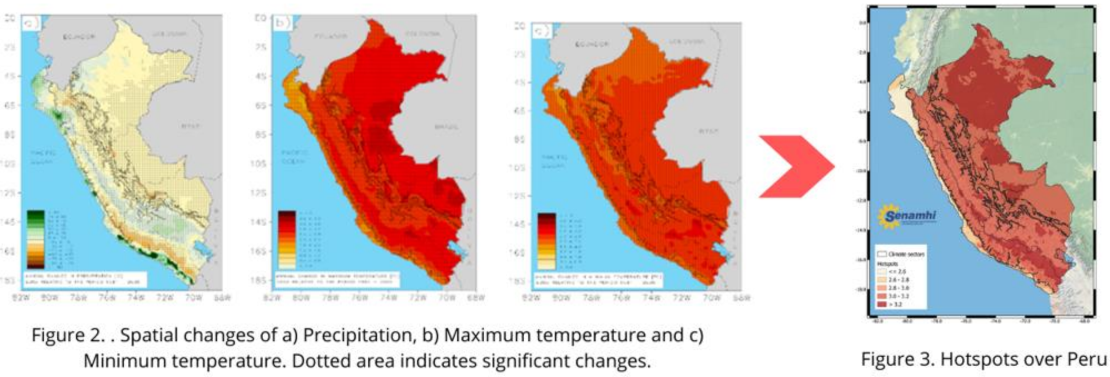
Figure 24. Methodology for generating climate scenarios in Peru



Source: Slide 1 of Ms. Sulca Paredes's presentation; The process of creating a downscaled dataset from CMIP5 data for use in national climate scenarios.

149. The data shows that in 2050 under a high emission scenario the greatest temperature changes are projected to occur in the Amazon. Rainfall is projected be reduced in most parts of the Amazon and the south-western Andes and increased over the eastern Andes and on the south coast. Climate change hotspots with large projected changes in both rainfall and average temperature were identified in the northern Amazon and south western Andes (figure 25).

Figure 25. Identifying climate change hotspots in Peru



Source: Slide 2 of Ms. Sulca Paredes's presentation; Ministerio del Ambiente Gobierno del Perú, 2021, Plan Nacional de Adaptación al Cambio Climático del Perú: un insumo para la actualización de la Estrategia Nacional ante el Cambio Climático, https://www4.unfccc.int/sites/NAPC/Documents/Parties/Per%c3%ba_NAP_Spanish.pdf. Right: Spatial changes of precipitation, and maximum and minimum temperatures. These combined data identify hotspots for the effects of climate change in Peru.

150. This information was a critical input for Peru's NAP, guiding the national adaptation to climate change through clear priorities focussed on reducing exposure and vulnerability, increasing adaptive capacity and taking advantage of opportunities for improvement.

151. Generating reliable and high-quality climate information remains challenging. Ms. Sulca Paredes highlights the importance of strengthening national scientific capacities and research on regional climate models to improve the representation of climate patterns in the future.

9. Vincent-Henri Peuch and Samantha Burgess, EU Copernicus Programme

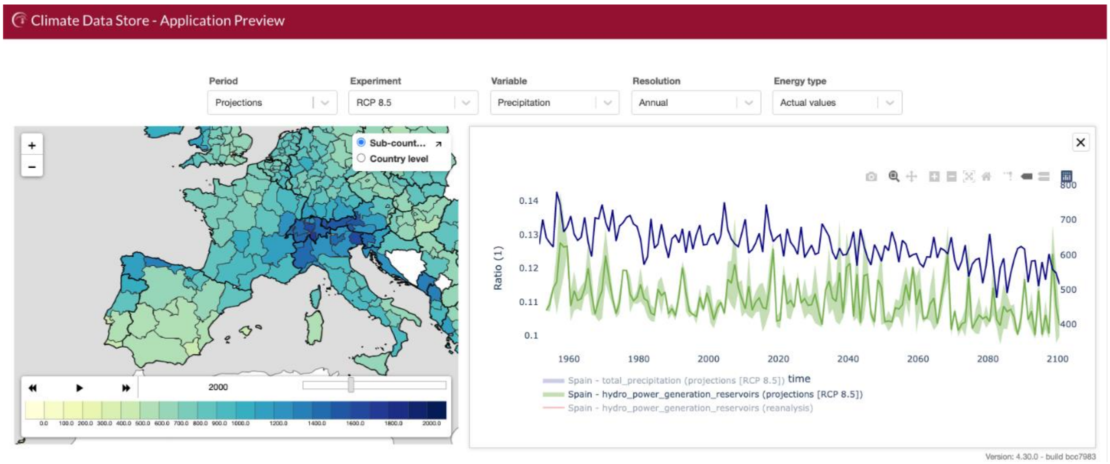
152. **Mr. Vincent-Henri Peuch**, Deputy Director of the Copernicus Department at the European Centre for Medium-Range Weather Forecasts presented on behalf of **Ms. Samantha Burgess**, Deputy Director of Copernicus Climate Change Services.

153. The Copernicus Climate Change Service (C3S) is a part of the European Union's Copernicus programme and counts the Climate Data Store[35] as one of its main achievements. It is both a platform to democratise access to vast amounts of freely available data and information about the past, the present and the future climate, and also a tool to support applications that provide access to information that is directly relevant for society. The Data Store serves over one hundred thousand users and contains more than one hundred datasets.

154. C3S' flagship dataset is its global reanalysis. The latest dataset, ERA5, integrates several satellite and non-satellite datasets to provide a gridded dataset of the weather of the last 70 years in the form of "maps with no gaps" for several Essential Climate Variables.

155. The Climate Data Store enables users to run applications that exploit datasets without the need to download the data (figure 26). One example of datasets is the calculation of monthly anomalies using ERA5, which is also used by C3S to issue regular climate update bulletins in short timespans. Another application is the C3S European energy and climate data explorer which enables users to view past and future trends for different renewable energy sources.

Figure 26. Data viewed in the Copernicus Data Store



Source: Slide 3 of Mr. Peuch's presentation; C3S Climate Data Store. Projections of precipitation and hydropower generation reservoirs in Spain under RCP 8.5, viewed using the Climate Data Store[35] data viewer.

Further information on the Climate Data Store is available via the below QR codes

Source: Slide 4 of Mr. Peuch's presentation.

[35] See cds.climate.copernicus.eu.

III. Summary of proceedings - posters

A. Theme 1. Updates on Earth observation of the climate system and climate change

156. Fifteen posters were provided to support the information presented during the dialogue on Theme 1 and are summarised below. Each poster can be viewed directly by a hyperlink in the title below. Some posters have accompanying audio or video where specified.

157. State of the Global Climate

John Kennedy, UK Met Office

The provisional WMO State of the Global Climate 2021 is a summary of key climate indicators and the weather and climate events of the year. It draws on inputs from over 80 WMO Members and 60 domain experts to provide an authoritative review of the year. The report is split into three parts. The first presents updates of key global climate indicators – including greenhouse gas concentrations, global mean temperature, ocean heat content, global mean sea level, ocean pH, sea-ice extent, glacier mass change and ice sheet mass change – and summarizes key drivers of short-term variability. The second part details high-impact events that occurred during the year informed by contributions from WMO Members. These include heatwaves and wildfires, cold spells and snow, floods, droughts, tropical cyclones and severe storms. The third part, supported by other UN agencies, highlights the socioeconomic risks and impacts of weather and climate events.

158. State of the Global Climate Observing System: GCOS Status Report 2021

Han Dolman, Royal NIOZ

The poster reviews the state of the global climate observing system described in the recently published GCOS Status Report 2021, progress accomplished in the last 5 years and challenges ahead.

Since 2015, satellite observations have improved, allowing near-global coverage of many variables and providing open access to the data. There also have been many improvements to surface-based observations of individual ECVs across the atmospheric, ocean and terrestrial domains, with new technologies and approaches being developed, especially in the oceans. Archiving and online access to the observations and derived information has improved.

There are four principal areas that require improvements:

- Ensuring the sustainability of observations;
- Addressing gaps in the system;
- Ensuring permanent, free and unrestricted access to the observations;
- Increasing support for policies driven by the UNFCCC Paris Agreement.

GCOS is preparing its 2022 Implementation Plan, which will include prioritised actions addressing the needs identified in the GCOS Status Report. Both the GCOS Status Report and Implementation Plan are submitted to the UNFCCC for consideration at COP.

159. GBON and SOFF: Filling the gaps in global weather and climate data coverage

Lars Peter Riishojgaard, **Lorena Santamaria-Rojas**, WMO

Weather and climate services depend on a functioning meteorological value chain, starting with a robust exchange of observational data from all areas of the globe. The lack of adequate observational data coverage is negatively impacting the quality of climate analysis products, especially locally, where observations are missing. Implementation of the Paris Agreement must be carried out based on the best available science (Article 4); without observations, no science.

WMO's recent approval of the GBON represents a binding commitment of all 193 WMO Member states and territories to the international exchange of basic weather and climate observations. These observations inform climate analysis products that are used as a basis for climate monitoring and climate prediction, providing detailed local observations via downscaling. Without high-quality climate prediction, it will be impossible to take meaningful climate adaptation measures.

Many countries with few resources relative to the size of the area they have to observe will have difficulties implementing GBON, especially many SIDS and LDCs. The Systematic Observations Financing Facility (SOFF) is a dedicated mechanism providing long-term grants and technical assistance to support the sustained operation of GBON in developing countries. SOFF focuses exclusively on the initial links of the meteorological value chain, working in partnership with other development initiatives that focus on other links in the chain. SOFF will deploy a global approach, using sustained international data exchange as its measure of success. It will provide innovative finance for sustainable GBON compliance and enhance technical competency and coordination.

160. International Coordination of Long-term Satellite Climate Data Records

Jeffrey L. Privette, NOAA; **Jörg Schulz**, EUMETSAT; **Alexandra Nunes**, Hamtec Consulting Ltd; **Albrecht von Bargen**, Deutsches Zentrum für Luft- und Raumfahrt; and **Wenying Su**, NASA; for the Joint CEOS/CGMS Working Group on Climate

Operational satellite observations of Earth now extend beyond 40 years in length. Using these, scientists have developed consistent time-series Climate Data Records (CDRs) useful for monitoring climate change and variability, supporting climate modelling, and analysing key climate processes.

The CEOS-CGMS Joint Working Group on Climate (WGClimate) maintains the world's only global compendium of satellite CDRs.[36] The Inventory contains information on 1,137 current and future CDRs that address the GCOS Essential Climate Variables and user requirements. The CDRs will provide unique information to support the forthcoming Global Stocktakes and will help to provide evidence for the success of the implementation of the Paris Agreement. For example, greenhouse gas monitoring helps to provide global and regional constraints on GHG sources and sinks supporting improved National Determined Contributions.

CDRs support other UNFCCC objectives by monitoring sea level rise, storms, extreme precipitation, floods, drought, (de)forestation, and the evolution of urban areas, enabling statements about disaster impacts leading to loss and damage. The sustained monitoring of the climate system from space also enables the monitoring of change due to mitigation and adaptation measures applied by UNFCCC Parties.

161. Climate data record in action: Use cases of Earth observations aiding decision-making

Wenying Su, NASA; **Guangxin He**, WMO; **Jeff Privette**, NOAA; **Ken Holmlund**, WMO; **Jörg Schulz**, EUMETSAT; **Albrecht von Bargen**, DLR; for the Joint CEOS/CGMS Working Group on Climate

The joint CEOS/CGMS Working Group on Climate together with the World Meteorological Organization (WMO) is soliciting use cases that demonstrate the value of Earth Observation satellites for climate monitoring and for related policy- and decision-making.[37] A collection of use cases will enhance awareness about the user uptake of space-based climate monitoring and will help expand the user community.

One of the main objectives of this activity is to demonstrate the value of Climate Data Records (CDRs) for decision making, including agriculture, coastal/flood management, food security, mitigation/adaptation, disaster risk reduction, energy, and protocol monitoring, among others. Through this activity, a better understanding of the application needs shall be achieved which can provide feedback towards the application specific GCOS ECV requirement setting process. Use case collection will also provide an opportunity to examine the architecture for climate monitoring from space to ensure the observing system is designed for purpose and is tailored for the application and decision-making needs. Similarly, use cases can also optimize the use of CDRs in the climate service-relevant applications and support capacity building by providing use cases for training activities and receiving use cases from them through CEOS/CGMS capacity building activities.

To date, 18 use cases have been submitted by multiple space agencies, covering a wide range of application areas such as food security, wildfire monitoring, climate extremes, coastal environment, insurance and the global stocktake.

[36] See http://climatemonitoring.info/ecvinventory.
[37] See https://climatemonitoring.info/use-cases.

162. Pilot, Country-scale Top-down Budgets of CO_2 Emissions and Removals Associated with Terrestrial Carbon Stock Changes

Brendan Byrne, NASA/JPL; **David Baker**, Colorado State University; and **David Crisp**, NASA/JPL; for the Committee on Earth Observation Satellites (CEOS) Atmospheric Composition – Virtual Constellation Greenhouse Gas Team and the OCO-2 Flux Multi-model Intercomparison Project (OCO-2 MIP)

Greenhouse gas inventories to support the global stocktake use bottom-up methods to estimate annual net emissions and removals of CO_2 from the sectors specified in the IPCC Guidelines for National Greenhouse Gas Inventories. CO_2 emissions and removals can also be estimated using inverse modelling of atmospheric CO_2 concentrations, which provide a constraint on CO_2 fluxes and track emission changes from in the ocean and biosphere. These complementary methods result in a more comprehensive measure of progress towards carbon neutrality.

Advances in CO_2 measurement and modelling capabilities have substantially enhanced the value of top-down methods for both inventory development and assessment applications. The WGClimate Greenhouse Gas Task Team is working with the inverse modelling community to compile pilot top-down budgets of CO_2 emissions and removals for 2015–2020. The aim is to start a conversation with stakeholders and users to establish the utility and best practices for combining bottom-up and top-down methods to enable more complete, transparent Global Stocktakes.

Pilot products are developed using national-scale CO_2 flux estimates derived from ground-based and airborne CO_2 measurements[38] and estimates of column-averaged CO_2 dry air mole fraction from the NASA Orbiting Carbon Observatory-2 (OCO-2).$CO_2CO_2CO_2$.

After analysis and corrections, the resulting country-level CO_2 budgets generally show robust signals for large extratropical countries. Larger uncertainties are seen for much smaller countries due to limitations in the resolution and coverage of the existing observing system. Results also show anomalously large CO_2 emissions over tropical land, though these results are difficult verify due to the limited availability of independent ground-based and airborne in situ CO_2 measurements. For future stocktakes, these limitations will be addressed with expanded ground-based, airborne and space-based atmospheric CO_2 observing systems and improved inverse modelling systems. These systems are expected to provide a more complete and accurate description of CO_2 emissions and removals for future Global Stocktakes.

163. Pilot Top-down Methane Emissions Estimates by Sector and Country to Support the Global Stocktakes

164. **John Worden** and **David Crisp**, NASA/JPL; for the Committee on Earth Observation Satellites (CEOS) Atmospheric Composition – Virtual Constellation (AC-VC) Greenhouse Gas Team and the NASA Carbon Monitoring System Flux (CMS-Flux) Team

Greenhouse gas inventories of methane (CH_4) emissions to support the global stocktake use bottom-up methods that estimate annual CH_4 emissions from the sectors specified in the IPCC Guidelines for National Greenhouse Gas Inventories. This approach is challenging as CH_4 is emitted by a broad range of natural and human processes. Inverse modelling of measurements of atmospheric CH_4 concentrations. provide a constraint on emissions and track emission changes in the biosphere. Advances in CH_4 measurement and modeling capabilities have substantially enhanced the value of top-down methods for both inventory development and assessment applications.

The CEOS AC-VC Greenhouse Gas team collaborated with the NASA Carbon Monitoring System Flux (CMS-Flux) team to produce national-scale CH_4 emission budgets derived from analysis of remote sensing observations of CH_4 from Japan's Greenhouse gases Observing SATellite (GOSAT). CH_4After emissions were optimised and projected onto each country, robust estimates of total CH_4 emissions were obtained for about 58 of the 242 countries. Like the bottom-up inventories, they show that the top five emitting countries (China, India, Brazil, US, Russia) are responsible for about half of the global anthropogenic CH_4 emission budget. These experiments also identified areas needing more investigation, such as the process of reconciling top-down CH_4 emissions estimates with the larger fossil fuel emissions inferred from recent ground-based in-situ isotopic measurements. These top-down estimates also indicate that CH_4 emissions from agricultural, waste and fires are larger than those derived in earlier inventories.

[38] See https://gml.noaa.gov/ccgg/obspack.

While top-down atmospheric CH_4 estimates provide significant insights into the largest sources of emissions and their response to human activity and climate change, pilot products should be interpreted with caution given limitations of the current atmospheric measurement and analysis systems. While this system does not yet completely meet the requirements for a CH_4 MVS system, ongoing advances in measurements of CH_4, combined with progress in atmospheric inverse methods, are yielding substantial improvements in precision, accuracy, resolution and coverage.

165. ESA Climate Change Initiative: new insights and global datasets for climate monitoring

Claire MacIntosh, on behalf of the ESA Climate Office

The ESA Climate Change Initiative (CCI) has used several decades of satellite data to produce 23 climate-quality datasets of cryospheric, atmospheric, oceanic and terrestrial Essential Climate Variables (ECVs). These contribute to the evidence base required by the UNFCCC to understand climate change and inform international action.

Each ECV dataset is the result of collaboration between an international team of scientists, overseen by a lead scientist and the ESA Climate Office. Several satellites and sensors are used for each dataset, enabling global coverage where it applies, and timeseries duration that stretches beyond the lifespan of individual satellites, with data currently spanning four decades. The data products are error characterised and updated regularly to incorporate new mission data. They are validated with in-situ measurements and key documents support their use. CCI supports over 450 scientists working in 178 institutions across ESA Member States to carry out research and development to generate these long-term, global data records.

The ECV datasets are an invaluable tool for climate action, producing new scientific insights and a growing body of records. The CCI Open Data Portal provides free access to these data, as well as tools to support their analysis and interrogation for a variety of users. These records can be used by researchers and policymakers in a wide variety of applications for essential environmental monitoring and prediction.

166. SLCF’s emission tracker: from field observations to data assimilation/inversions assisting inventory methodology development and efficient emission reductions

Yugo Kanaya, Earth Surface System Research Center (ESS), Research Institute for Global Change (RIGC), for the Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

The latest IPCC AR6 WG1 summary for policymakers (SPM) highlighted the roles of short-lived climate forcers (SLCFs) in the future climate change, mainly driven by inevitable reductions in cooling caused by aerosols and a potential counterbalance via stringent methane emission reductions. Depending on future SLCF emission scenarios, a warming of up to 0.9°C in 2100 relative to 2019 could be avoided, and air quality could be improved. Therefore, a globally unified system tracking SLCF emissions and atmospheric changes is highly demanded.

Meanwhile, the IPCC Taskforce on Inventories initiated expert meetings to develop a methodology for SLCF emission inventories (in addition to GHGs) during the IPCC seventh assessment cycle, and a path to such a system has been approved. However, the planned SLCF bottom-up inventories often encounter extreme uncertainties, for example, up to 200% for black carbon. These constraints on top-down observational systems are therefore essential. JAMSTEC undertakes activities relevant to such top-down SLCF tracking systems, consisting of in-situ observations in key regions, satellite observations and data assimilation/inversion based on numerical model simulations, and providing best estimates of emissions and their changes. A global synthesis is required of such initiatives for multiple SLCF species such as NO_X gases, black carbon and carbon monoxide.

167. Global Ocean Acidification Observations – connecting climate and SDG indicators

Kirsten Isensee and **Katherina Schoo**, IOC-UNESCO

The ocean absorbs around 23% of the annual emissions of anthropogenic CO_2 to the atmosphere, helping to alleviate the effects of climate change on the planet. The related costs to the ocean are high. The CO_2 reacts with seawater and changes the acidity of the ocean, a process known as ocean acidification. This threatens organisms and ecosystem services, including food security, by endangering fisheries and aquaculture. Coastal areas in particular are subject to a range of factors affecting CO_2 levels in seawater, such as freshwater influx, ice-melting, nutrient input, biological activity, temperature change and large ocean oscillations.

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. Global trends of ocean acidification as presented in the reports of the IPCC and the annual Statement of the State of the Global Climate show the overall downward trend of ocean pH. However, national datasets of ocean acidification observations submitted on Sustainable Development Goal (SDG) 14.3 and the associated SDG Indicator 14.3.1 highlight the need for sustained, repeated observation and measurement of ocean acidification along the coastlines and in the open ocean to improve understanding of its consequences, enable modelling and predictions of change and variability.

The Global Ocean Acidification Observing Network's (GOA-ON) programme "Ocean Acidification Research for Sustainability" (OARS), endorsed as an Ocean Decade Action (2021–2030), will address Sustainable Development Goal indicator 14.3.1 and help to improve the availability of site-specific information, suitable for mitigation and adaptation strategies addressing local conditions.

168. Heat stored in the Earth system: Where does the energy go?

Karina von Schuckmann and colleagues, for the GCOS Earth heat inventory team

The three pillars of sustainable development - environment, society, and economy - depend upon the health, services, and vitality of the ocean. Declining ocean health necessitates the coordination of integrated, knowledge-based ocean governance systems to preserve the ocean and its life-ensuring services. The Copernicus Marine Service monitors and forecasts the global ocean, which is necessary for ocean management on state and international levels. Due to the complexity of the ocean, international ocean management informed by science and data is essential for sustainable ocean stewardship.

The annual Copernicus Ocean State Report (OSR) covers the state of the ocean, natural variations, and changes in line with climate changes and draws on the Copernicus Marine Ocean Monitoring Indicator framework. The fifth edition covers the value chain of ocean data to ocean governance from the world ocean observation systems through the subsequent layers of research and development, expertise, and knowledge transfer, to sustainable ocean governance and stewardship. The OSR5 examines examples of tools and technologies to support climate mitigation and adaptation such as alert systems, forecasting technologies, and real-time monitoring programs. These help to protect marine environments and human communities, to provide early warning systems, to safeguard economic infrastructure, and to plan for and manage extreme ocean events. The OSR5 provides insight into the design and functioning of three of these downstream tools, with each benefitting the Blue (physical), White (sea ice) or Green (biogeochemical) ocean.

169. National Inventory of Glaciers and Lagoons of Peru

Gladis Celmi Henostroza, National Institute for Research on Glaciers and Mountain Ecosystems, Peru

The objective of the national inventory of glaciers and lagoons is to know the situation of glaciers and lagoons of glacial origin, in order to provide updated information on these resources and, at the same time, it can serve as an instrument for decision-making regarding its conservation, use and management by the competent authorities and the population in the context of climate change.

170. Measuring and addressing global and local climate change impacts on biodiversity through Earth Observations

Adriana Radulovici, GEO BON; **María Cecilia Londoño**, Instituto Humboldt, Colombia; **Andrew Gonzalez**, GEO BON; **Gary Geller**, NASA/JPL, USA; **Maria Kavanaugh**, Oregon State University, USA

Climate change is a direct and indirect driver of biodiversity and ecosystem change. It can drive population extinction, rates of adaptation, and migration, and thus alter distribution of plants, animals and microbes. Climate change can act indirectly via the effects on other drivers, such as land-use change, pollution and invasive alien species. Climate change impacts can now be measured (and predicted) through Earth observations (EO), provided that EO are conducted in a standardised manner through long-term monitoring.

The Group on Earth Observations Biodiversity Observation Network (GEO BON) offers a standardized framework for linking essential climate and essential biodiversity variables to assess and predict impact of climate change on biodiversity and ecosystem processes. The network uses biodiversity observations (remote sensing and in situ) collected in a standardised manner to calculate essential biodiversity variables which in turn are used to calculate various biodiversity indicators included in national reporting.

171. From data to action – the International Methane Emissions Observatory

Manfredi Caltagirone, UNEP

According to the IPCC methane emissions must be reduced significantly in the next decade to meet the 1.5°C target. The International Methane Emissions Observatory (IMEO) was launched to catalyse global mitigation action through data, with an initial focus on the oil and gas sector. The IMEO's core function is to change the methane emission data landscape by creating a global public dataset with verified and reliable data at an increasing level of accuracy and granularity. This is done by collecting and reconciling data from various sources including satellites, science studies, national inventories and company reporting through the Oil and Gas Methane Partnership 2.0, the methane reporting framework recognized by the European Commission as "the best existing vehicle for improving measurement, reporting and verification capability in the energy sector".

The IMEO works with governments and companies around the world to connect data to effective mitigation actions and seeks to extend the scientific understanding of methane emissions by funding peer-reviewed measurement studies around the world and assessing new and emerging methodologies and technologies that can measure emissions at scale. The IMEO will play an important role in creating a sound scientific basis for methane emissions calculations that will be crucial to deliver the Global Methane Pledge, which has now been signed by 111 countries.

The IMEO's first annual report is now available.[39]

172. Evidence for Abrupt Changes, Tipping Points and Cascading Impacts in the Earth System

Hannah Liddy, AIMES, for Future Earth

The geological record shows that warming temperatures can lead to disintegration of ice sheets, permafrost thaw, slowdown of ocean circulation, forest dieback, and ocean deoxygenation. These abrupt changes can occur on timescales short enough to challenge society's capacity to adapt. Geologic archives like ice and sediment cores provide a test-bed for understanding abrupt changes or tipping points in the past 20,000 years. Paleo-records can be synthesised to illustrate the cascading impacts of abrupt change in cryosphere-ocean interactions and hydroclimate variability on ecological and societal systems. These slow forcing processes can produce rapid responses.

Significant destabilisation of several key climate tipping elements is already observed today. The dominant driver of destabilization in many cases is global warming, but human influence on land cover change, such as deforestation and forest degradation, can play an equal or even greater role. Some tipping elements influence each other, for example melting ice sheets and changes to ocean currents. Interactions between tipping elements can ultimately cause shifts to happen at lower levels of global warming than anticipated.

Abrupt changes over the last 20,000 years show how tipping points, preceded by early warning signals, could occur in future. It is essential to continue to improve our knowledge of the precursors of abrupt change, for example, through thorough analysis of paleo-environmental records of improved precision, resolution, spatial coverage and reproducibility.

B. Theme 2. Interpreting Earth observations for implementing the Paris Agreement – developments, opportunities and challenges

173. Fifteen posters were provided to support the information presented during the dialogue on Theme 2. Each poster can be viewed directly by a hyperlink in the title below. Some posters have accompanying audio or video where specified.

174. Pilot space-based products and harmonization efforts on Agriculture, Forestry and Other Land Use (AFOLU) to support the Global Stocktakes

Frank-Martin Seifert, ESA; and **Osamu Ochiai**, JAXA; for the CEOS Land Surface Imaging Virtual Constellation Forest and Biomass Subgroup

Earth observation (EO) satellites have been acquiring global data on the state and dynamics of the global landscape for over 40 years and the role of these observations has been increasingly recognized. The recent update of the IPCC guidelines on Agriculture Forestry and Other Land Use

[39] See https://www.unep.org/resources/report/eye-methane-international-methane-emissions-observatory-2021-report.

(2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories on AFOLU) referred to the significant advancement of the use of EO data for monitoring land use and land change. CEOS is developing a roadmap to identify the substantive benefits of using Earth observation data, for providing satellite products for use by the policy community, and for understanding potential barriers to the effective use of EO for supporting the Paris Agreement.

The primary expected outcome of the CEOS AFOLU efforts is an enhanced uptake of EO satellite data sets in support of the first GST in 2023 on a global and country level. A comprehensive overview of the capabilities of CEOS and its constituent space agencies to contribute to information on Agriculture, Forests and Other Land Uses is required. EO satellite sensors operating in different modes either singularly or in combination provide information on agriculture, forests and vegetation biomass. Pilot data sets for the first GST have been produced with existing capabilities and using 2021 as a reference year.

175. GHG Monitoring from Space: A mapping of capabilities across public, private, and hybrid missions

Veronika Neumeier, GEO; **Aaron Davitt**, WattTime/Climate TRACE; **Sara Venturini**, GEO Secretariat; **Harsha Vardhan Madiraj** and **Barbara Ryan** (WGIC) for GEO; WattTime/Climate TRACE; WGIC

The GHG Monitoring from Space report maps the current and emerging capabilities of space-based monitoring of GHGs around the world and lays the groundwork for enhanced contributions to the Global Stocktake under the Paris Agreement. The report includes a database of in-orbit and planned satellite missions funded by public, private, and not-for-profit entities. These missions have the potential to contribute to climate mitigation policies and reporting, including National GHG Inventories and the GST, focusing on the three major gases listed under the Paris Agreement – carbon dioxide, methane, and nitrous oxide.

Satellite observations reduce uncertainty in GHG emission monitoring by providing data across a range of spatial, temporal, and spectral resolutions or scales. Government space agencies have the capability to collect national and global baseline data for all relevant GHGs in a sustained manner with measurement availability ranging into the 2040s. Private sector companies are speedily entering the market and bringing additional point-source emissions monitoring capabilities for specific GHGs.

Hybrid models are increasingly emerging and leveraging respective strengths. Collaboration, innovation, and financing are key levers for GHG monitoring from space. Open data, open science and open knowledge are essential to drive on-the-ground solutions, and new opportunities are arising for analysing secondary remote sensing measurements with frontier IT technologies which call for transparency and capacity development.

176. Moving towards a European capacity to monitor anthropogenic CO_2 emissions – the CoCO2 and VERIFY projects

Richard Engelen, ECMWF; **Gianpaolo Balsamo**, ECMWF; and **Philippe Peylin**, LSCE; for the CoCO2 and VERIFY consortia

The European Commission has initiated the design and development of a new observation-based operational anthropogenic CO_2 emissions Monitoring and Verification Support capacity (CO2MVS) as part of the Copernicus Atmosphere Monitoring Service. This system will use Earth observations and Earth-system modelling to target the monitoring of anthropogenic CO_2 and CH_4 emissions, supporting the Global Stocktake and countries' efforts to limit GHG emissions through Nationally Determined Contributions (NDCs).

This European CO2MVS is developed through several research projects which are transforming the current scientific state of the art into policy relevant services.

- The CoCO2 project builds the prototype systems for the Copernicus CO2MVS by bringing together expertise, existing capacities and innovative ideas from a wide range of European and international players. A mature and credible monitoring system for anthropogenic CO_2 emissions requires the integration of all available information streams through an integrated system approach, which is a complex undertaking and requires careful consideration of all components and interfaces.
- The VERIFY project has focused specifically on Europe using the existing observation infrastructure and made the first attempt to compare the GHG budget for the EU and for

individual countries from National Inventories to both observation-based atmospheric inversions and bottom-up process-based or data-driven models. Outputs are provided in country fact sheets that summarise the information in a user-friendly manner.

177. Earth observations in support of the Paris Agreement

Simon Pinnock, ESA on behalf of **Michaela Hegglin**

Earth Observations (EO) help to quantify the climate change and can be used to indirectly measure progress and achievements towards the UNFCCC Paris Agreement's overarching goals to combat climate change at both the national level via the enhanced transparency framework and at the global level via the Global Stocktake.

Translating EO variables to actionable information for policymakers is not always straightforward. A new ESA study offers case studies on mitigation, maintaining sinks & reservoirs, adaptation, and loss and damage, to showcase opportunities for EO to support the Paris Agreement.

Co-development of EO-derived information is key to using EO's full potential to guide global action on climate change. Collaboration on this is required across communities in research, industry, and governments, and both nationally and internationally, with specific focus on capacity building. A new conceptual framework has been developed for the EO community to leverage the EO value chain to deliver actionable information useful for decision-making.

178. Recent progress and future development in terrestrial GHG flux observations as an essential climate variable

Werner L Kutsch, ICOS; **Roland Baatz**, eLTER, Fz- Jülich; **Jaana Bäck**, eLTER, University of Helsinki; **Ankur Desai**, University of Wisconsin; **Gregor Feig**, EFTEON/SAEON; **Martyn Futter**, eLTER, University of Uppsala; **Mark Grant**, TERN; **Trevor Keenan**, AMERIFLUX, University of California, Berkeley; **Michael Mirtl**, eLTER, UFZ, Leipzig; **Beryl Morris**, TERN; **Dario Papale**, ICOS, University of Tuscia; **Johan Pauw**, EFTEON/SAEON; **Margaret Torn**, AMERIFLUX, Berkeley Biomet Lab; on behalf of ICOS

The systematic observation of greenhouse gas fluxes between terrestrial ecosystems and the atmosphere is a crucial part of the research on the global carbon cycle. Observational data is needed to evaluate natural carbon sinks and climate neutrality at country and global levels, and to better understand the impact of climate change on the ecosystem function. The Global Ecosystem Research Infrastructure (GERI) convenes regional Research Infrastructures (RIs) to address this challenge in a coordinated global effort. The global data initiative FLUXNET aims to compile global data sets. These combined activities are of great important to the systematic observation of terrestrial fluxes.

The 6th IPCC Assessment Report recognises that FLUXNET provides long-term eddy covariance data that contribute to the knowledge on land/atmosphere fluxes and improves IPCC projections. FLUXNET data allow ecological responses to climate change to be studies and map GHG exchanges and balances worldwide. A recently launched coordination project will strengthen international collaboration and support training and exchange opportunities, as well as the development of common tools and protocols.

GERI aims to improve the comprehension of the ecosystem function and its changes in indicator biomes across the globe. GERI supports researchers with critical data ranging over continents, decades, and ecological disciplines to advance process understanding, simulate and predict ecosystem fluxes and vulnerabilities, and inform decision-makers at various levels.

Both initiatives collaboratively aim to contribute to the work of the Global Climate Observing System (GCOS) to create and sustain climate observatories, the production of accurate, free and open climate data. The main objective is to establish land fluxes as an essential climate variable in the next GCOS implementation plan, which will maximise the scientific and societal impacts of observations and inform the Parties to the Paris Agreement on the state of the global carbon cycle.

179. How can ocean and coastal observations inform National Adaptation Plans?

James Fitton, **Emily Smail**, **Jong SeoYim**, **Hee-Jung Choi**, **Sung-JinCho**, **Louis Celliers**, **Laura David**, **Keith VanGraafeiland**, **Ana Carolina Ruiz Fernández**, **Samy Djavidnia**, **Jeremy Gault,** and **Audrey Hasson**, for GEO Blue Planet

Data gathered from ocean and coastal observations play a vital role for informed decision-making by governments, civil society and the private sector about sustainable development, ecosystem management, food security, ocean-resource utilization and natural disasters.

Ocean and coastal observations are required for adaptation planning for many coastal challenges related to climate change including coastal erosion, saltwater intrusion and ocean acidification. These observations can support assessments of risks and vulnerabilities, identify and assess options, and inform the development and success of National Adaptation Plans.

Two examples of ocean and coastal observations for National Adaptation Plans are South Korea's coastal adaptation plan and the mapping of the intertidal zone across the United Kingdom and the Republic of Ireland.

180. Let the ocean breathe again – Responding to ever-increasing need to protect and sustainably manage ocean services by fully harnessing the expanding volumes of ocean oxygen data

Marilaure Grégroire, **Veronique Garçon**, **Andreas Oschlies**, **Maciej Telszewski** and **Kirsten Isensee**, IOC-UNESCO

Oxygen dissolved in seawater supports the largest ecosystems on the planet. The ocean is losing oxygen, termed ocean deoxygenation, at a rapid rate. The Global Ocean Oxygen Decade (GOOD) will raise global awareness about ocean deoxygenation, provide knowledge for action, and develop mitigation and adaptation strategies and solutions to minimize impacts on the ocean economy through local, regional, and global efforts, including transdisciplinary research, innovative outreach, and ocean literacy.

The global ocean observing system continues to expand to meet the need to protect and sustainably manage ocean services. In order to harness the increasing volumes of O2 data, especially from autonomous platforms in the open ocean and coastal areas, roadmap for the Global Ocean Oxygen Data Atlas (GO2DAT) has been developed. GO2DAT will support the development of climate and ocean health indicators, facilitating knowledge-based decision-making processes aimed at sustaining a healthy, productive and resilient ocean as prioritised by international policies and initiatives.

181. Estimating and predicting global ocean and terrestrial carbon uptakes in a decadal time scale

Michio Watanabe, Research Center for Environmental Modeling and Application, JAMSTEC

CO_2 uptake at ocean and land surfaces is a fundamental process in the global carbon cycle and fluctuates in response to inherent climate variabilities. The implementation of the Global Stocktake increases the need to estimate and predict variations in atmospheric CO_2 concentration over a decadal time scale further the visualisation of emission-reduction efforts and aid sophisticated estimates of carbon budgets.

Earth system models reproduce the global carbon cycle and inherent climate variabilities. By assimilating observed climate data into Earth system models, the historical variability of global ocean and terrestrial carbon uptakes can be estimated, and decadal-scale predictions can be made. The Japanese climate model development program (TOUGOU) uses this approach to reproduce the variations in global ocean and terrestrial carbon uptakes. The carbon uptake of the world's oceans is found to be predictable for about six years into the future.

182. An overview of the state of risk and EWS from the GFCS State of Climate Services reports 2020 and 2021

Veronica F. Grasso, **Maxx Dilley**, **Nakiete K. Msemo**, WMO

Weather and climate services are vital for sustainable development and climate change adaptation. The benefits of investment greatly outweigh the cost.

Many actors and interactions are involved in the climate services value chain from observations to outcomes. While the production and service-delivery elements are important components of the process, the roles of communication, perception and interpretation, decision-making behaviour, and actions taken by users must be appreciated. These activities lead to outcomes and ultimately value.

Risks associated with climate change are increasing. Between 1970 and 2019, 11,072 disasters have been attributed to weather, climate and water related hazards, involving 2.06 million deaths and US$ 3.6 trillion in economic losses. Since 1970, 44% of weather, water and climate-related disasters and 31% of economic losses have been associated with floods, the majority of which have occurred in Asia.

Flood-related disasters have increased by 134% since 2000 compared with the two previous decades, and drought claimed the lives of over 700,000 people, with most deaths recorded in Africa. The number and duration of droughts also increased by 29% in the same period.

Data show that the number of WMO Members that report being able to provide warnings to the population at risk is insufficient. Only 40% of WMO Members have indicated having a Multi-Hazard Early Warning System in place, and one person in three is still not adequately covered by these systems.

On average, 60% of WMO Members lack the full capacity needed to provide climate services for water. Inadequate interaction with information users is experienced in 43% of WMO Members.

The Climate Science Information for Climate Action methodology can be used to address these challenges. On the completion of the four steps of the methodology, regular assessments and learnings should be carried out to determine whether actions are achieving their expected outcomes.

183. Climate reanalysis to support sustainable agriculture: Biosuccess

Samantha Burgess, Copernicus Climate Change Services

Research has shown that pest and diseases are responsible for up to 40% of small-holder crop losses worldwide. To date, synthetic chemical pesticides are the primary means of pest and disease control, but concern regarding over-reliance on these products is increasing due to issues such as environment toxicity, worker and consumer exposure, and insect resistance.

Biopesticides are emerging as safer, effective alternatives to chemical pesticides. As a living organism, the efficacy of a biopesticide is controlled in part by environmental conditions such as temperature. In addition, biopesticides require time to take effect and hence users need guidance on when to expect results from their spraying campaign.

The BioSuccess tool is an interactive web-based application providing a mapped historical analysis of an area over relevant climate datasets, current analysis of the results of biopesticide efficacy in combination with locust development, a mode to determine the latest date by which to apply biopesticides, and a user feedback utility.

The key objective for BioSuccess is to assist the agriculture industry in moving away from the use of synthetic chemical pest control to the use of more sustainable biopesticide pro-ducts.

184. WMO Integrated Global Greenhouse Gas Information System: targeting and tracking climate actions

Phil DeCola, University of Maryland; **Jocelyn Turnbull**, GNS Science; **Riley Duren**, University of Arizona; **Shuangxi Fang**, Zhejiang University of Technology; **Trinh Thang Long**, INBAR; **Oksana Tarasova**, WMO; for IG3IS, WMO

The Integrated Global Greenhouse Gas Information System (IG3IS) is a WMO spearheaded initiative that develops common practices and approaches towards measurement-based estimates of greenhouse gas emissions. The methodologies developed through IG3IS provide a common framework that ensures consistency of the emission estimates across spatial scales from national level to facilities, and across different sectors.

IG3IS considers the establishment and addressal of user requirements as a prerequisite for the development of services. IG3IS implements a value chain from observations to provision of data and insights in order to target significant and rapidly achievable emission reduction actions, tracks the effectiveness of these actions, and reports on them in a transparent way. The IG3IS community undertakes activities such as providing information services for implementing city climate action plans, targeting super-emissions of methane from waste management, agriculture and oil and gas operations, and providing regional attribution for the 60% of global HFC emissions currently unreported.

Two highlighted IG3IS initiatives are the Quadrature Foundation project on the evaluation of carbon uptake by the bamboo forest and the release of the review draft of the Urban GHG Emission Monitoring Guidelines.

185. The Global Forest Observations Initiative: A Partnership for Tracking Forests for Climate Action

Frank-Martin Seifert, ESA for the GFOI

Better forest management is underpinned by better forest monitoring. Recent advances in technology and the increased availability of data have allowed many developing countries to begin establishing National Forest Monitoring Systems (NFMS) and associated emissions Measurement, Reporting and Verification (MRV) procedures.

The GFOI is a flagship of the Group on Earth Observations (GEO). The GFOI Office with the FAO provides secretariat services. GFOI is a global partnership coordinating international support in forest monitoring to help developing countries address their international reporting requirements and national information needs.

Key results of the GFOI include:

- Coordinating partners' work in more than 60 developing countries across the three major forested regions – Asia, Africa, and Latin America to significantly advance forest monitoring and MRV capacity.
- Working with space agencies to help make available and expand wall-to-wall coverage of the world's forests from multiple satellite sensors.
- Improving the ability of countries to access and use space data through training on tools and platforms such as Collect Earth, SEPAL, and many others.
- User-friendly methods and guidance which comply with the IPCC published and are disseminated widely.

186. Climate Information for Regional Sustainable Development: Support Ecological Civilization Construction

Lijuan Ma, **Pengling Wang**, **Yang Wang**, **Qingchen Chao**, **Yongxiang Zhang**, National Climate Centre, China Meteorological Administration, China

The IPCC AR6 WGI report tells us that all regions are projected to experience changes in at least 5 Climatic Impact-Drivers (CIDs), with most regions projected to experience changes in at least 10. There is wide regional variation for many CIDs, underling the need for Earth observations. Efforts are also necessary to improve the accuracy of information extracted from observations to support both international and domestic action on climate change.

The National Climate Centre (NCC) of CMA has published the Blue Book and the Green Book of Climate Change to deliver key climate information for scientists and decision makers. The Blue Book provides observation data on changes of the climate system at global to sub-regional scales using in-situ and satellite observations, as well as reanalysis datasets. The Green Book transmits and interprets information on the international response to climate change and domestic actions on tackling climate change, assesses the status of green development in China And showcases relevant case studies.

High-mountain regions, where the cryosphere is a prominent feature, experience dramatic effects of climate change with low ability to adapt to or monitor these changes. High Mountain Asia is one of these affected regions, where effects are impacting natural ecosystems and socio-economic development.

The CMA and WMO have signed a LOI to provide meteorological support for the Belt and Road construction and conduct work in disaster risk reduction, climate services, integrated observation, and research and capacity development. Under this umbrella, the CMA is leading the development of the Third Pole Regional Climate Center Network by providing regional information and services to National Meteorological and Hydrological Services to improve their capacity to address climate change at national levels.

For example, the NCC is supporting green and low-carbon development in China and High Mountain Asia. Observation data was used to create high quality, 3km resolution wind resource maps that help to identify micro-sites and optimise wind farm design without in-situ observation towers, supporting the development of decentralised wind power. This enabled the assessment of China's wind technical capacity. A similar process is used to assess solar capacity.

187. Monitoring the cryosphere in the Hindu Kush Himalaya – measurements, analysis and dissemination

Miriam Jackson, International Centre for Integrated Mountain Development (ICIMOD)

The Hindu Kush Himalaya (HKH) contains the largest expanse of snow, glaciers, and permafrost outside of the polar regions. This vast accumulation of snow and glaciers acts as a natural water reserve, contributing significantly to the flows of the 10 major Asian river systems. ICMOD works with regional experts and partners to improve understanding of changes in the cryosphere across the HKH and the impact on water resources.

These cryosphere monitoring activities are carried out under three main components: field-based observations and monitoring; remote-sensing based observations and monitoring; and modelling of cryosphere and related processes. These three components are complemented by regular capacity building activities and the HKH CryoHub, a collaborative knowledge platform that brings partners and stakeholders together.

The Yala and Rikha Samba glaciers in Nepal are presently shrinking and follow the general trend of glaciers in the Himalayas. ICIMOD monitors and analyses snowmelt, which is a major contributor to streamflow during the non-monsoon seasons when rain is sparse. Glacier lake outburst floods are a changing hazard that can have a huge impact on downstream communities. In recent work, 47 potentially dangerous glacial lakes within the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India were identified using high-resolution satellite imagery.

Capacity building is an important part of ICIMOD's work. Over 1,500 professionals and young researchers have been trained in monitoring cryosphere change using the latest Earth observation tools and techniques.

188. Asian High Mountain Observations

Mandira Shrestha, ICIMOD and the Mountain Research Initiative

The Asia-Pacific region accounts for 57 percent of global fatalities and 87 percent of the global population affected by natural disasters. The intensity and frequency of disasters in the region is increasing. Climate observation networks in the region are inadequate, with limited sharing of data, varying capacities, and a lack of tailored climate services that are actionable and gender responsive.

GEO Mountains, the Third Pole Regional Climate Centre (TPRCC) Network, and ICIMOD are providing online tools and services to address observational challenges in the Asia-pacific region. Opportunities exist to harmonise climate data and information and standardise risk assessment methodologies. Advances in earth system prediction can contribute to reducing the impacts caused by extreme events. Furthering observation networks can result in increased demand for climate services and greater interest of partners for capacity building on EO to improve adaptive capacity to climate change.