Earth Information Day 2022

9 November 2022

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

28 February 2023

Introduction and overview

1. The Earth Information Day 2022 provided the opportunity for attendees to engage across the fields of science, policy, and society and explore key challenges, solutions and ways forward for Earth observations to support the Convention and the Paris Agreement. The information discussed is the best available science on the global climate observing system and the state of our climate. It is a cornerstone of work under the Convention, not just for negotiations during the sessions, but also for informing decision making on adaptation and mitigation at all scales.

2. Meetings of the SBSTA[1] Earth Information Day provide the opportunity to exchange information on the state of the global climate system and developments in systematic observation. It acts as a forum to convey findings, needs, and lessons learned from activities undertaken by regional and international research programmes and organizations relevant to and supporting the implementation of the Convention[2] and the Paris Agreement.[3] Meetings enable engagement between a wide range of experts from the earth observing community, Parties and non-Party stakeholders.

3. Systematic observation is considered annually at the second session of the Subsidiary Bodies under the Research and Systematic Observation agenda item of the SBSTA. The Earth Information Day is scheduled during sessions to allow Parties the opportunity to engage with experts to support the informal consultations on RSO.

4. Earth information Day 2022[4] was held during the Sharm el-Sheikh Climate Change Conference on November 9.[5] The dialogue was themed according to the submissions of Parties in response to the call issued by the SBSTA Chair and in consideration of the mandates and the wider context of ongoing work under the UNFCCC.[6] Earth Information Day 2022 explored three themes: **Updates on the state of the climate and the global climate observing system**; **Earth Observations for Mitigation**; and **Earth Observations for Adaptation and Early Warning Systems**.

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

6. This summary report provides an overview of the presentations and discussions of the dialogue session and the posters of the poster session. See the Earth Information Day webpage[4] for a full recording.

7. 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.

[1] See Abbreviations and acronyms, page 3.
[2] Available at https://unfccc.int/resource/docs/convkp/conveng.pdf.
[3] Available at https://unfccc.int/sites/default/files/english_paris_agreement.pdf.
[4] See https://unfccc.int/event/earth-information-day-2022.
[5] See https://unfccc.int/cop27.
[6] See https://www4.unfccc.int/sites/submissionsstaging/Pages/Home.aspx, search "Earth", tag SBSTA 57.

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Abbreviations and acronyms

AFOLU	Agriculture, Forestry and Other Land Use	**MRV**	Monitoring Reporting and Verification
AR6	IPCC Sixth Assessment Report	**NAP**	National Adaptation Plan
CMIP6	Coupled Model Intercomparison Project Phase 6	**NDC**	Nationally Determined Contribution
COP	Conference of Parties	**REDD+**	Reduce Emissions from Deforestation and forest Degradation in developing countries
CRD	Carbon Resilient Development	**RSO**	Research and Systematic Observation
ECV	Essential Climate Variable	**SBSTA**	Subsidiary Body for Science and Technological Advice
ENSO	El- Niño-Southern Oscillation	**SDGs**	Sustainable Development Goals
EWS	Early Warning System	**SIDS**	Small Island Developing States
GBON	Global Basic Observing Network	**SOFF**	Systematic Observation Financing Facility
GCOS (IP)	Global Climate Observing System (Implementation Plan)	**SSP**	Shared Socioeconomic Pathways
GEO	Group on Earth Observations	**TFI**	IPCC Task Force on National Greenhouse Gas Inventories
GOOS	Global Ocean Observing System	**UNFCCC**	United Nations Framework Convention on Climate Change
GHG	Greenhouse Gas	**UNDRR**	United Nations Office for Disaster Risk Reduction
GST	Global Stocktake	**UNSG**	United Nations Secretary General
IOC UNESCO	Intergovernmental Oceanographic Commission of the UN Educational, Scientific and Cultural Organization	**WG**	Working Group of the IPCC
IPCC	Intergovernmental Panel on Climate Change	**WMO**	World Meteorological Organisation

Key messages

- Atmospheric greenhouse gas concentrations in 2022 again reached record levels. Atmospheric and oceanic heat content continue to rise, leading to accelerating sea level rise and continued sea-ice melt.
- Earth observations, as well as their international exchange and use in modelling frameworks provides the basis for all current and future mitigation and adaptation action.
- Earth observations are the base of a value chain that informs all climate projections and services, including Early Warning Systems.
- The Global Climate Observation System sets a standard for global observations and provides a framework, the GCOS Implementation Plan, to enhance them.
- The GCOS ECVs Requirements details the Essential Climate Variables that must be monitored to guide global ambition, achieve climate targets and mobilise action.
- Both satellite and in-situ observations are necessary to sufficiently monitor the changes and interactions of coupled systems, including within the Earth system itself and between the human, climate and biodiversity systems.
- Despite progress, knowledge of the climate system and its components are incomplete, with information to answer key questions lacking, such as the risk of increased heavy precipitation in most of the Global South.
- Persistent observation gaps exist for many parts of the globe, with many ECVs unobserved. Many fragile systems with high importance to the global climate system are among these, such as the ocean and cryosphere.
- Developing countries' need for climate information is growing and further support is needed to develop observational coverage and capacity in these areas to close gaps and support adaptation and mitigation planning and action.
- Earth observations and observations capacity for informing risk assessment and assessing vulnerability is lacking or not in place in many regions.
- The observation system itself is fragile in places, with many components dependant on short term research funding. This puts both observational capacity and the data records collected by these systems at risk.
- New technologies are required to increase observations resolution and coverage.
- The systematic observation community is actively engaging with decision-makers to provide policy-relevant climate information and climate services, often via open-access online platforms.
- Parties, the private sector and the observing community must collaborate to target finance and maintain the systems needed to provide long-term observations data that support our understanding of the climate system and enable action on climate change.
- A global goal for observations would help to ensure adequate global observations coverage, strengthen and improve the resilience of existing observing systems and networks, and enhance support for climate services in line with the UN SG's Early Warnings for All initiative.
- The COP can add momentum to these efforts by deciding to encourage action on the GCOS IP and supporting a global goal on observation

I. Summary of the opening statements

8. Opening statements were provided by **Mr. Ovais Sarmad**, Deputy Executive Secretary of the UNFCCC Secretariat; **Mr. Petteri Taalas**, Secretary General of the World Meteorological Organisation (WMO); and **Mr. Vladimir Ryabinin**, Executive Secretary of the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO).

9. ***Mr. Ovais Sarmad***. Observations and their improvement are vital for all stakeholders as we push towards implementation to achieve the goals of the Paris Agreement. The Earth Information Day provides a unique platform for Parties to engage in an active dialogue on Earth information systems to inform the essential strengthening of observations across land, mountains, the ocean, cryosphere, and atmosphere.

10. Our planet is at a threshold of vulnerability and we need to act decisively today. Earth systems information should not only drive decision makers within the climate regime but inform all people around the world. Establishing long-term climate data records and generating and accessing reliable climate information will be essential to developing and implementing effective mitigation and adaptation action, as well as early warning systems. Once integrated into local and national planning processes, this information will be a powerful tool to guide resilient development trajectories and strengthen mitigation action.

11. ***Mr. Petteri Taalas***. Earth observations are the foundation of our work. These measurements feed into climate models, inform the climate research assessed by the IPCC, and provide the basis for weather, hydrological, and marine services. When considered together as insights into the entire Earth system, Earth observations provide the basis for a more comprehensive range of services and tools, such as multi-hazard early warning systems.

12. In 2021 we have again broken records for the concentrations of carbon dioxide, methane and nitrous oxide. The rate of growth of the concentration of methane was the highest since records began but the cause is uncertain. This highlights the urgent need to further strengthen observation systems.

13. Many observation networks rely on short-term research funding, and coverage provided by observing systems in some areas is still low, in particular for many developing countries and for the ocean and cryosphere. The COP can address this by encouraging government financing for long-term observation systems and promoting the establishment of the global greenhouse gas monitoring system.

14. Several initiatives support the development of observation systems globally. The Global Climate Observing System regularly assesses earth observations systems and provides guidance on improving observations. The Global Basic Observing Network establishes standards for the global meteorological observing systems. The Systematic Observation Financing Facility provides financial aid to countries to strengthen national observing systems. The WMO is collaborating with UNDRR and several other UN agencies to secure investment of 3.1 billion euros over five years to improve basic observing systems, build national capacities, and support the delivery of climate services.

15. ***Mr. Vladimir Ryabinin*.** The ocean is at the heart of climate change, absorbing more than 90% of excess heat and around 25% of annual carbon dioxide emissions. Changes in the ocean result in changing climate extremes, disruptions to ocean ecosystems, and impact all of society. Understanding how this will affect the trajectory of the climate and severity of future extremes requires further knowledge of the ocean's capacity to absorb heat and carbon. This vital knowledge is based on systematic observations performed by initiatives such the Global Ocean Observing System.

16. Through a network of partners across sectors and with many specialised instruments, GOOS observes much of the ocean that satellites cannot, including physical, chemical, biogeochemical and biological measurements to shed light on the Essential Climate Variables. All data collected is shared, but significant gaps in the data and the observing system remain.

17. Only 7% of the ocean surface is estimated to be covered by systematic monitoring of biological and ecological variables, with the largest gaps in the tropics. Disruptions in the maintenance of observing networks, such as during the COVID-19 pandemic, leave irreparable scars in the climate record. We must urgently commit to coordinated investment in long-term, resilient ocean observing as part of systematic climate monitoring. The GCOS Implementation Plan 2022 can guide this effort and the COP can raise the profile and encourage strengthening of all climate observations by adopting a global goal on observation.

18. UN Secretary General Guterres has said that we are on the roadway to hell but, thanks to the first two years of the UN Decade of Ocean Science for Sustainable Development, we are paving the way off that road toward a healthy ocean using climate-smart, science-based sustainable ocean management. Ocean action by the UN will not only benefit action on climate change, but also on biodiversity, for the economy, for the well-being of people, and for peace.

II. Summary of plenary presentations, discussions and posters on Theme 1: Updates on the state of the climate and the global climate observing system

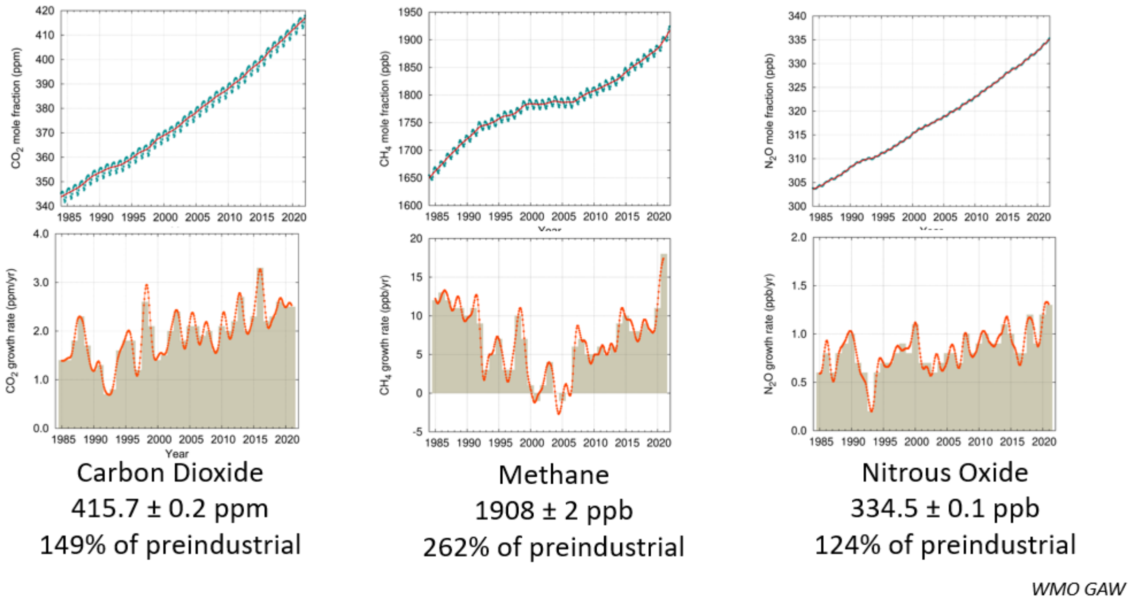
A. Summary of Presentations

19. Presenters speaking on theme 1 were Mr. Han Dolman, Global Climate Observing System (GCOS) Secretariat; and Mr. Stefan Rösner, Deutscher Wetterdienst & WMO. Anya Waite, Global Ocean Observing System (GOOS) and Ocean Frontier Institute, moderated the section.

Mr. Stefan Rösner. WMO State of the Global Climate 2022

20. **The concentration of atmospheric greenhouse gases continued to rise and again reached record levels** in 2021 *(fig. 1)*. The cause of a steep increase in methane concentrations has not yet been explained.

Figure 1: **New record levels of atmospheric greenhouse gas concentrations**



Atmospheric concentrations of carbon dioxide, methane and nitrous oxide from 1984 to 2021, top. Rate of growth of each, bottom. *Source*: Slide 3 of Ms. Rösner's presentation, WMO Global Atmosphere Watch.

21. **Global mean temperature continues to increase.** Despite the cooling effect of the 2021 la Niña, 2022 is likely to be fifth or sixth warmest year since 1850 at about 1.15° C above the 1850–1900 average temperature. Most of the globe was warmer than the average temperature from 1981–2010, despite la Niña contributing a cooling effect in the Pacific Ocean region, while severe floods and droughts were experienced in regions across the globe.

22. **Ocean heat content reached a record high in 2021**, causing further thermal expansion of water and further sea level rise, which in 2022 has also exceeded the previous record.

23. **The rate of sea-level rise is accelerating quickly** as glaciers continue to melt. Ice mass balance, a measure of whether more ice has been accrued or lost, was negative in 2022 for the 26th consecutive year in Greenland, while Switzerland saw the largest recorded percentage ice loss relative to the previous year, with a third of its glacier ice lost since 2021.

24. **Sea ice extent in the Arctic has continued to decline** despite an above average monthly minimum in September 2022, while Antarctic sea ice extent dropped to its lowest extent on record in February 2022 with an overall trend still proving difficult to discern.

25. Further information drawn from observations is available in the WMO Provisional State of the Global Climate Report 2022, with the final report to be released in April 2023.[7] The WMO Global Annual to Decadal Climate Update for 2011–2020 will be released prior to COP 28, and regional climate reports are available via the WMO library.[8]

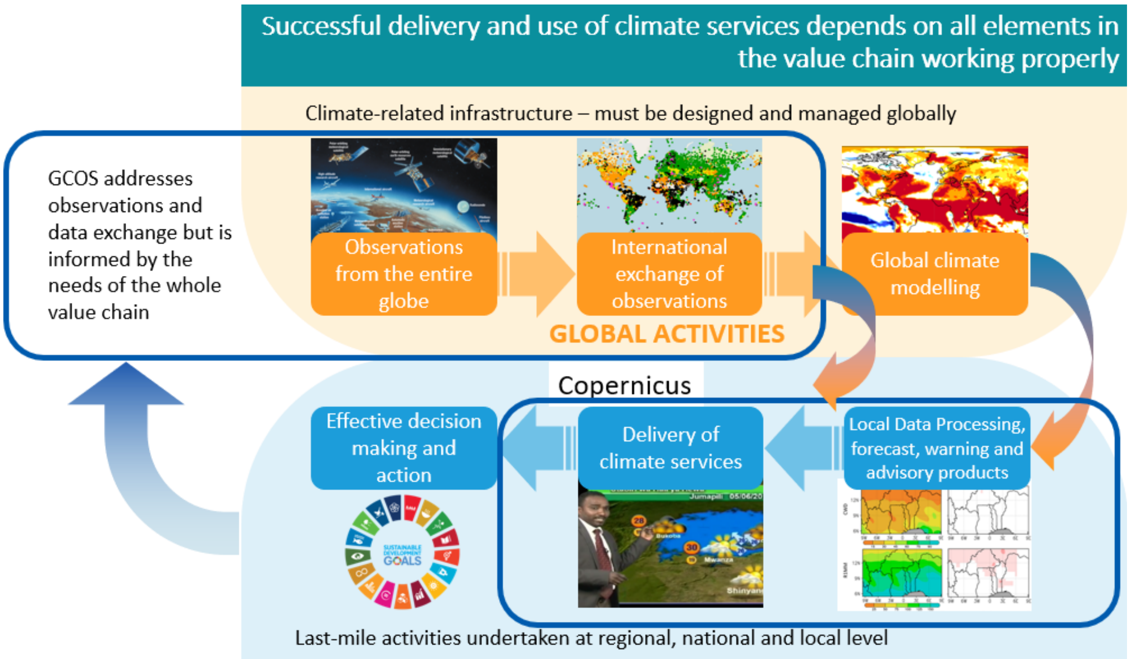
[7] See https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate

[8] See https://public.wmo.int/en/resources/library

<u>Mr. Han Dolman. Keeping Watch Over Our Climate: New Recommendations from the Global Climate Observing System</u>

26. **Earth observations are the basis of the climate services value chain** *(fig. 2)*. The successful delivery of these services depends on what can be measured and informs where enhanced observations are necessary. Effective mitigation and adaptation efforts are impossible without adequate climate observations.

Figure 2: **GCOS and Copernicus in the climate services value chain**



Source: Slide 2 of Mr. Dolman's presentation

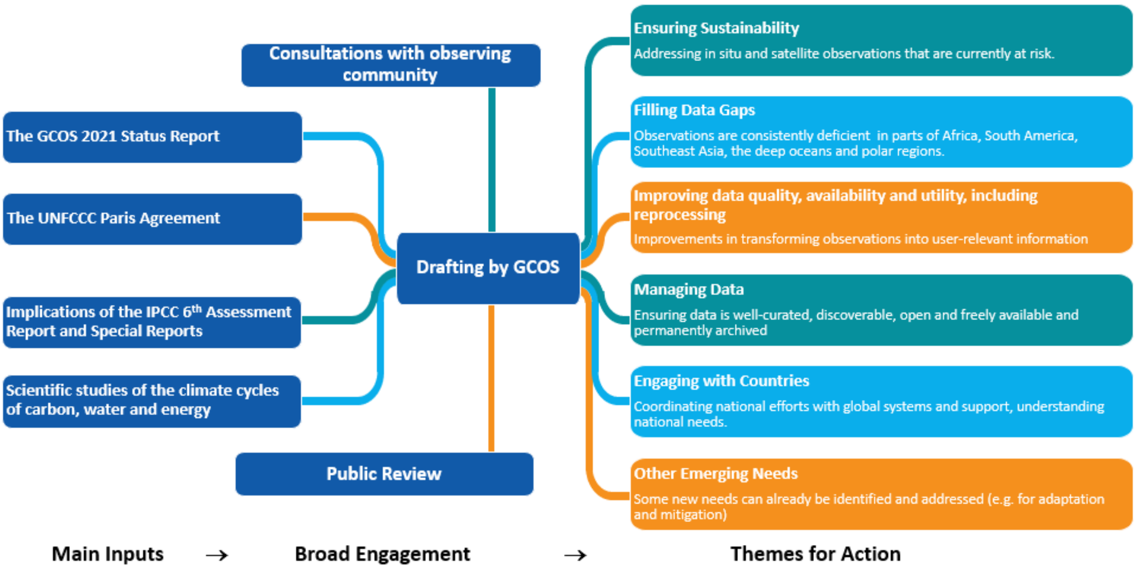
27. **The demand for climate data has expanded beyond the monitoring of the climate system** to include specific information to inform mitigation and adaptation action. These data are used, for example, to create effective mitigation plans, develop early warning systems, and enhance understanding of the basic processes of cycles of energy, water and carbon that are essential for calculating the remaining carbon budget.

28. **The 2020 GCOS Implementation Plan (IP) responds to these expanded demands.** In parallel, the 2022 GCOS ECVs Requirements details the individual climate variables and how they can be measured.

29. The GCOS IP assesses the system used to track climate change with publications every five to six years, as requested by the SBSTA. It provides a set of integrated recommendations to develop a fit for purpose, global climate observing system in response to the latest needs of Parties and provides a focused set of integrated actions, a means of assessment, and identifies the stakeholders who need to respond to and implement the recommended actions. The new IP considers the water, energy and carbon cycles in more depth than before and guides the development of a comprehensive system capable of closing observations gaps, such as the uncertainty over the cause of accelerated methane emissions.

30. The GCOS IP identifies six major themes *(fig 3)*. Among these, in-situ support of observation networks is crucial to ensuring their sustainability, particularly for the ocean and for land measurements with gaps in the satellite record. Data gaps such as the estimation of latent and sensible heat fluxes – evaporation data, are also in urgent need of attention to inform action, for example on the prediction of droughts. The IP also identifies emerging needs, such as on providing and improving the availability of high-resolution data and enhancing coverage over the ocean, cryosphere, and urban areas, and operationalising the Global GHG Monitoring System.

Figure 3: **Identification of themes in the GCOS Implementation Plan**



Source: Slide 5 of Ms. Dolman's presentation.

31. **The delivery of global observations must fit the contexts of local decision making** and physical, chemical and biological measurements of the climate system are need to be co-located to provide a complete picture at the observed point of the system.

32. **A global goal on observation under the United Nations could provide a long-term perspective for the implementation of a number of the IP's actions and guide an action-oriented framework for observation.**

Discussion

33. **CO2 emissions declined during the pandemic but the increasing trend in atmospheric CO2 concentration remains unaltered. Has this affected the overall lifetime of CO2 in the atmosphere?**

A: There is no sign that CO2 concentrations are levelling out or decreasing. While emissions decreased during the pandemic, the overall upward trajectory has remained the same as before now that emissions have resumed.

34. **Should policymakers prioritise the consideration of annual CO2 emissions or the cumulative emissions relative to the remaining carbon budget?**

From a scientific perspective, the primary consideration is the greenhouse gas concentration itself. Data is available in terms of current and cumulative emissions for the consideration of policymakers.

35. **To what extent should the systematic observation community prioritise observations for mitigation or adaptation?**

The systematic observation community aims to respond to the needs and differing priorities of all Parties. Where mitigation is the focus, the community intends to help to ensure that climate change does not exceed our ability to adapt to it. Similarly, actions recommended by the GCOS IP to strengthen the global GHG monitoring system will not only inform mitigation action, but also contribute to projecting what conditions will need to be adapted to and fill adaptation data gaps. Observations for adaptation and mitigation are two sides of the same coin and the IP lists a wide range of actions beyond the GHG monitoring system that are critically important to filling data gaps for both mitigation and adaptation.

36. **What actions in the GCOS IP can contribute to explaining the accelerated rise in the concentration of methane?**

The 2022 GCOS IP and ECVs Requirements calls for a mix of long-term satellite and in-situ methane observations. Analysis of methane isotopes indicates that the acceleration in the increase of the methane concentration has a biological origin. This underlines the importance of using an integrated approach to strengthening observing systems, as isotope analysis is not generally available as part of the observation package.

37. **How do changes in the regional state of the climate and observed impacts compare to the global mean signals and impacts, particularly where relevant to small islands?**

The greatest warming signals are expected over land areas as the land heats faster than the oceans. Regions in the ocean have warmed slower, and in the Pacific the warming signal is also currently partially weakened by el Niño. Sea level rise is well known to be a major issue for small islands, but, beyond this, poor coverage over many areas including small islands limits how climate impacts can be projected. There are fewer measuring stations in the ocean and though reanalysis of the global models can fill observation gaps, those models are only as good as the observational data that feeds into them. A strengthening of the observation system in areas of low coverage is needed, and a global goal on observation could support this.

38. **Where are the largest gaps in land observations?**

Some of the largest gaps are in Africa, Siberia, and in the Amazon. Siberia and the Amazon are particularly important areas for understanding the biological feedback of the of the carbon cycle, and Africa in terms of the CO2 observing capability.

B. Posters

39. Ten posters were presented on Theme 1. Full author lists and all posters are available by following the hyperlinks below and on the Earth Information Day 2022 webpage.[4]

40. 2022 GCOS Implementation Plan

Anthony Rea, WMO, on behalf of the Global Climate Observing System;

GCOS supports the planning and development of the global climate observing system, formulating requirements for satellite and in-situ climate observations. GCOS addresses adaptation and mitigation observation needs such as those highlighted by Parties to the UNFCCC and IPCC assessments, advocates for free and open access to observation data, and works to ensure that observations are enhanced and continued. The 2022 GCOS Implementation Plan describes actions under six themes that can be taken to fill the observations gaps identified in the 2021 GCOS Status Report in the next 5–10 years.

41. State of the Global Climate 2022

Lars Peter Riishojgaard, WMO Secretariat on behalf of the WMO

The WMO State of the Global Climate Report is produced annually to report on the current state of the climate using key climate indicators and extreme events and their impacts.

Greenhouse gas concentrations continue to rise, again reaching record levels. The annual methane concentration increase was the fastest on record. 2022 is likely to be the 5th or 6th warmest recorded year.

Glacier ice and sea ice extents continue to be impacted. Sea level continues to rise and the ocean to heat. Impacts of climate change-exacerbated extreme weather and climate events were felt globally.

These changes to the global climate and gaps in the observation network are undermining global capacity to achieve sustainable development.

42. State of the Climate 2021: Africa

Lars Peter Riishojgaard, WMO Secretariat on behalf of the WMO

The State of the Climate in Africa Report 2020 is a collaborative effort involving the WMO, experts from Africa, other UN agencies and the African Union, as well as experts from partner international scientific and technical institutions. In 2021, the focus was on water-related indicators and impacts. The report describes changes in key climate indicators relevant to Africa, subsequent impacts of these changes, and suggestions for policy on climate action and to achieve the SDGs.

43. Earth Observation from space: Supporting the Parties in Implementing the Paris Agreement

Albrecht von Bargen (DLR), Jeff Privette (NOAA), Mark Dowell (EC), Frank Martin Seifert (ESA) on behalf of the Joint CEOS/CGMS Working Group on Climate

Space observations support key parts of the Paris Agreement, providing information on the state of the climate, supporting action on mitigation and adaptation, and enabling enhanced reporting, stocktaking, and climate services.

Space agencies develop the climate monitoring infrastructure, maintain long-term climate data records, and create the frameworks and roadmaps to further observations for climate action.

Through this, Parties' efforts to mitigate and track mitigation are enhanced, MRV is complemented, and Earth observations are integrated into value chains to support the end-users or services. The synthesis paper "The Role of Systematic Observations in the Global Stocktake" provides a starting point for further collaboration on assessing progress towards achieving the goals of the Paris Agreement.

44. The Met Office global climate dashboard – up-to-date information on key climate indicators

Nick A Rayner; John J Kennedy; Robert Dunn; Jonathan Winn; Presented by Tyrone Dunbar, UK Met Office Hadley Centre

The Met Office global climate dashboard provides up-to-date monthly information in between formal assessments, based on publicly available time series. It contains simple-to-use information of relevance to Parties and the Global Stocktake on greenhouse gas concentrations, global warming and other key climate indicators. Graphics are designed to be easily included in reports and slide sets. Data are transparent, acknowledged to source and provided in a simple common format.

45. Observing the ocean carbon cycle from space

Gemma Kulk, Plymouth Marine Laboratory & National Centre for Earth Observation

The ocean plays a key role in the Earth's carbon cycle, constituting its largest carbon store and mitigating a large fraction of anthropogenic CO2 emissions. Phytoplankton cycle a substantial amount of carbon through the biological carbon pump. The Ocean-Colour Climate Change Initiative produces high-quality products that provide a satellite-based carbon budget in the surface layer of the ocean. Further research is needed to fully ascribe changes in the oceanic carbon budget to climate change.

Ocean colour fluxes reveal an increase in primary productivity at the poles and lower productivity in the open ocean, implying knock on affects for fisheries and the need to further understanding to action adaptation efforts.

46. Enhanced Ocean Carbon Sinks Triggered by Climate Change Seen from the Space

Fang Shen; Xuerong Sun; Mengyu Li; GiHoon Hong, Integrated Marine Biosphere Research (IMBeR)

Phytoplankton, observed from space, can provide a proxy for the biological removal of atmospheric carbon-dioxide by the ocean. Phytoplankton size affects the rate at which it sinks, and therefore affects the ocean carbon cycle. Phytoplankton size was found to differ under different conditions, such as the ENSO.

Wildfire emissions, including those from fires exacerbated by climate change, transport nutrients to the ocean, providing a nutrient source for phytoplankton growth. Wildfires are therefore another factor to consider in the anthropogenic alteration of the ocean carbon cycle.

47. Integrated ocean-observation research by JAMSTEC

Masuda Shuhei, Research Institute for Global Change (RIGC), Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

JAMSTEC is involved in global ocean observation to understand global changes. High-precision observations using research vessels such as R/V Mirai, the deployment of autonomous observation platforms equipped with physical and biogeochemical sensors such as Argo and Biogeochemical (BGC) Argo, and moored buoy monitoring are carried out. By integrating available observation data through a data assimilation technique, a global ocean-state estimation is created.

This is applied to climate research, to particle drift simulations and observation-impact experiments such as optimizing the BGC Argo array. It also contributes to the systematic construction of global ocean-observation networks in conjunction with the digital twin oceans.

48. The Physical Climate at 2°C vs 4°C as seen in the UK Earth System Model (UKESM1)

Ranjini Swaminathan; Robert Parker, National Centre for Earth Observation (NCEO); Colin Jones, National Centre for Atmospheric Science; Richard Allan, NCEO; Tristan Quaife, NCEO; Doug Kelley, Centre for Ecology and Hydrology; Lee de Mora, Plymouth Marine Laboratory; Jeremy Walton, Met Office Hadley Centre; Richard Betts Met Office Hadley Centre, University of Exeter

Based on an analysis of global climate models to determine when the earth will warm to 2° C or 4° C compared to pre-industrial temperatures, the United Kingdom's UKESM1 model was used to identify regions of significant future climate change where this warming occurs and relate these changes to impacts on humans.

Results show that: a majority of CMIP6 models ran exceeded 2° C of global warming under SSP1–2.6 by 2075; warming in the Arctic may double the global average; Mediterranean summer precipitation will increase; and Indian monsoons will intensify.

49. Sustained and effective ocean observations for the Agulhas Current - A GOOS Co-Design Boundary Current Initiative

Tamaryn Morris, South African Weather Service; Ann-Christine Zinkann, National Oceanic and Atmospheric Administration

The Ocean Observing Co-Design Program is a flagship Programme for GOOS and the UN Ocean Decade and will develop a user-focused co-design process to create an integrated, responsive ocean observing system and close observation gaps.

Boundary currents occur where major ocean currents meet coastlines. The understudied Agulhas Current directly influences regional weather systems and impacts the fisheries and aquaculture of South Africa. Boundary currents around southern Africa contribute and significantly impact a multi-million-dollar fisheries industry.

The co-design initiative will follow lessons learned studying other boundary currents to engage stakeholders and funders and design an ocean observing system to form the base of a value chain from observations to climate services.

III. Summary of plenary presentations, discussions and posters on Theme 2: Earth Observations for Mitigation

A. Summary of Presentations

51. Presenters speaking on theme 2 were Ms. Karina von Schuckmann, Mercator Ocean; Mr. Carlo Buontempo, European Centre for Medium-Range Weather Forecasting (ECMWF); and Mr. Eduardo Calvo Buendia, IPCC Task Force on National Greenhouse Gas Inventories (TFI). Ms. Anya Waite and Mr. Lars Peter Riishojgaard, WMO, provided framing input. Mr. Riishojgaard moderated the section

Ms. Karina von Schuckmann. Further enhancing understanding of Earth climate cycles and observation gaps

52. **Systematic climate observations across all domains are the foundation for monitoring, understanding and predicting the Earth system cycles' natural rhythm and their underlying processes.** These observations must evolve to close knowledge gaps. The Earth is a complex, interrelated system driven by Earth system cycles. These cycles sustain life on Earth through the transfer, exchange and storage of heat, water, carbon, and other substances across the atmosphere, ocean, land, cryosphere, and biosphere. Interactions of these cycles are triggered by natural variations of the climate system that act to balance and maintain the natural rhythm of the cycles.

53. **The signal of anthropogenic climate change can be picked out and separated from the natural variation, affecting the rhythm of all cycles across all domains**. In the carbon and nitrogen cycles, the accumulation of greenhouse gases has been increased and is affecting land and ocean sink dynamics, lessening an important natural mitigation effect. In the energy cycle, surplus heat has accumulated across the ocean, land, atmosphere and cryosphere. The intensification of the water cycle is contributing to increasing variation in monsoons and increasing severity of wet and dry events.

54. **Understanding how climate change drives feedback mechanisms that amplify processes and alter cycles is essential to the understanding of climate trajectories**. The ocean heat-carbon nexus is one such process whose variation has knock-on effects throughout the Earth system. The land and ocean carbon sinks determine the uptake of carbon, and therefore how much carbon stays in the atmosphere – the airborne fraction, that affects radiative forcing. The ocean determines the thermal response, by taking up and mixing heat from the atmosphere. The warmer the ocean becomes, the less carbon it can absorb, increasing the airborne fraction and radiative forcing, and leading to further warming.

55. ***Ms. Anya Waite.*** The ocean stores 80% of Earth's total carbon but observations of ocean carbon make up only a small percentage of Earth observations overall. 'Deep blue carbon', the world's largest carbon store and 90% of all ocean carbon, is stored outside of Exclusive Economic Zones (EEZs) and is therefore not often highlighted as a national priority for observation. Considering this and with increasing attention on ocean carbon CO2 reduction, a framework to enhance observations and close gaps is urgently needed to inform decisions within and beyond EEZs.

56. **GCOS, the Global Climate Project, and others provide tools to action science for policy and support the climate services value chain**, such as updates on Earth cycles, changes in heat and carbon inventories, and calculations of the remaining carbon budget. Enhancing these tools, and all climate services, requires sustained, long-term measurements to support decision-making on climate change, climate action, and sustainable development.

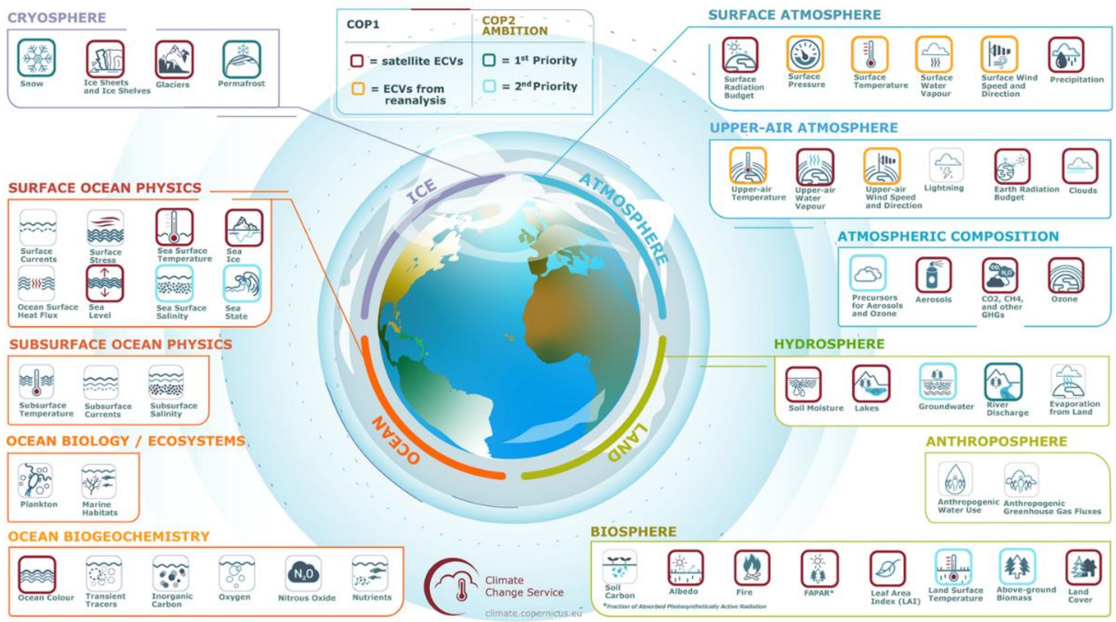
57. **The most critical element of a robust climate policy regime with credible targets is the accuracy of the climate trajectories, as informed by understanding the Earth system cycles.** These are the most robust indicators in informing the state and evolution of climate change, and both the natural cycle and anthropogenic perturbation of the cycles need to be considered together to accurately monitor, understand, and predict climate trajectories.

58. **There is an urgent need to fill observational and knowledge gaps** to further understanding of system cycles and achieve net-zero targets. The systematic observation community is ready to engage with decision-makers to synthesise and communicate information on capacities and gaps, assess progress in responding to multilateral agreements, and continues to improve monitoring, understanding, and prediction for regional climate change and impacts in support of mitigation and adaptation strategies.

Mr. Carlo Buontempo. Enhancing observations to inform mitigation planning

59. **Of the 54 Essential Climate Variables, only 22 are observed by satellites, with a further 6 described by reanalysis** *(fig. 4)*. The remaining ECVs are not observed with the required accuracy or precision or do not have available records. However, satellite measurements of atmospheric CO2 and methane are now well established and are producing increasingly high resolution and precise measurements of GHG concentrations.

Figure 4: **The Essential Climate Variables and their observation status**



. *Source*: Slide 1 of Mr. Buontempo's presentation; Copernicus.

60. **Mature meteorological technologies, modelling, data simulation and AI are being used to invert GHG fluxes and meet the high demand for emission flux estimates.**[9] This has contributed substantially to discerning the signal of anthropogenically heightened concentrations from the noise of high background atmospheric CO2. This process is a slower but more accurate method of estimation than using

[9] See https://www.ecmwf.int/en/forecasts/dataset/cams-greenhouse-gas-ghg-flux-inversions.

proxy data. Services based on these methods will be available by the end of 2026 to provide global, high resolution GHG estimates.

61. ***Mr. Lars Peter Riishojgaard.*** Constructing mitigation strategy based on the total concentration of greenhouse gases in the atmosphere at any given time requires enhanced monitoring and understanding of all greenhouse gas fluxes, including anthropogenic and natural sources and sinks. While the overall budget of atmospheric GHGs is well understood, natural sinks and emissions from land use and land use change remain uncertain. Understanding future GHG concentrations and projecting climate feedbacks depends on resolving the uncertainties in these less understood areas.

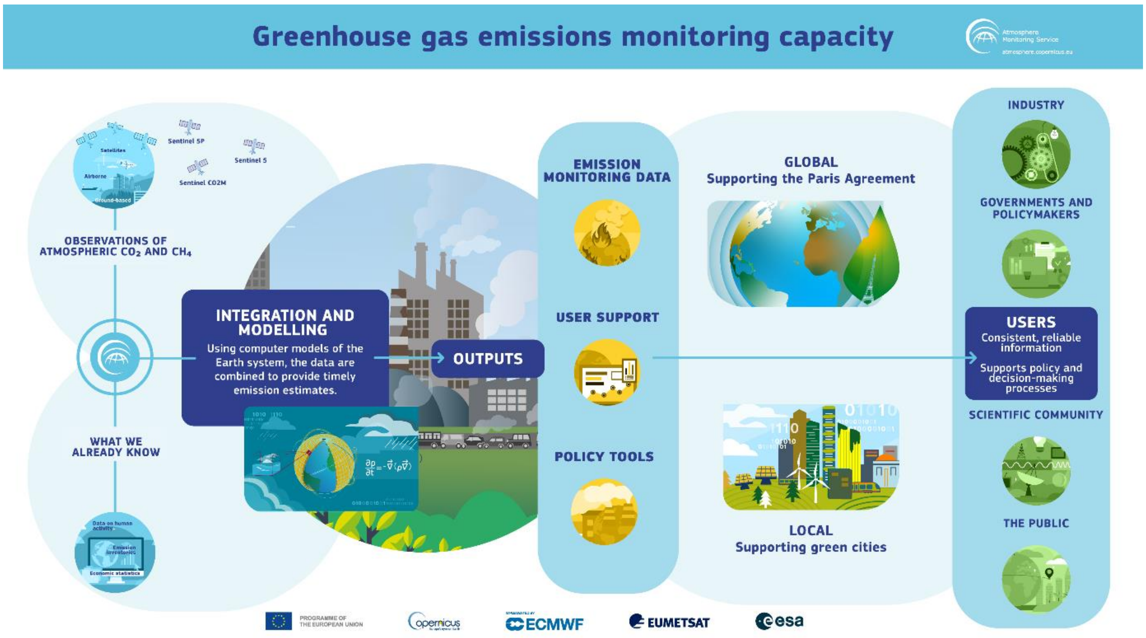
62. The WMO and a group of international stakeholders are collaborating on a framework for a multi-model system to deliver top-down, monthly estimates of net GHG fluxes at a 100km squared resolution. This system will provide open-access, authoritative and verifiable data developed transparently to inform processes under the UNFCCC and more localised national, regional, and sub-national applications to track emissions and enhance mitigation action.

63. **Observations are increasingly used to plan renewable energy and contribute to the societal transition to a low carbon economy.** For example, the International Renewable Energy Agency (IRENA) has produced a map of locations in Africa that would be suitable for siting solar and wind energy facilities.[10] These locations account for both the climate data that allow these technologies to function, and also the access to energy networks to distribute power.

64. **Managing the renewable fraction of energy networks requires a knowledge of the risks and opportunities posed by climate variability.** Copernicus' European State of the Climate Report looks at some of the events that have characterized the climate of the continent, such as the 2021 'wind drought' in western Europe.[11]

65. **Enhancing observing capabilities will provide greater and more precise data for decisionmakers** *(fig.5)*. As described in the 2022 GCOS IP, observations are key to understanding the climate system and its variations and are playing a growing role in informing adaptation and mitigation options. Enhancing observation capability from satellite missions and in-situ analyses, combined with the use of complementary modelling, will produce a major advancement of our ability to monitor global carbon emissions.

Figure 5: **Greenhouse gas emissions monitoring in the value chain for climate services**



. *Source*: Slide 2 of Mr. Buontempo's presentation; Copernicus Atmosphere Monitoring Service (CAMS).

[10] See https://www.irena.org/Search?contentType=4e1a7711-45d0-4b90-8671-729e3c913378&orderBy=Date&query=africa&tagRegions=26326c42-a110-45f7-8148-5b4eaba79824.
[11] See https://climate.copernicus.eu/ESOTC.

Mr. Eduardo Calvo Buendia. Earth Observations for National Greenhouse Gas Inventories

66. **National greenhouse gas inventories are a key component of the Paris Agreement's transparency framework.** The emissions estimates that make up these inventories are based on both activity data and emission factors associated with levels of human activities. These estimates are the basis of NDCs and provide a means of tracking NDC progress and implementation.

67. **Earth observations and inverse modelling data can be of great use to inventory compilers**, particularly when reporting GHG fluxes from the atmosphere, land and biosphere. Observations and modelling can also support the verification of national GHG inventories and the tracking of mitigation action. To support this, the IPCC TFI has produced the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[12] and recently a report following the recent meeting on the use of atmospheric observation data in emissions inventories.[13] **Greater dialogue and interaction between earth observation researchers and inventory compilers is critical to enhance the estimations in national inventories.**

68. **The 2019 Refinement offers elaborated guidance on the use of inventories with atmospheric measurements** and describes several successful examples. Difficulties in comparing inventories and observations exist, and differ depending on the gas, sector and region, but work is underway to enhance the use of observations as tools for inventory compilers by accounting for the strengths and weakness in measuring different gases, leveraging different measurement techniques for different purposes, and continuing dialogue between the communities *(fig. 6)*. These efforts are expected to assist users to use observations for inventory verification and support policymakers with greater data for mitigation planning and action.

69. **The Refinement also provides guidance on using observations to estimate fluxes from the land and biosphere.** Challenges include a lack of consistent time series for activity data and emission factors, land use and land cover change, gaps in observations, and a low capacity to access and use the data in some developing countries. These challenges can be addressed by promoting cooperation with the remote sensing community to enhance the use of land biosphere observation, improving the estimates of fluxes from AFOLU, and creating tools to enhance land management.

[12] See https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/.
[13] See https://www.ipcc-nggip.iges.or.jp/public/mtdocs/2209_AtmObs.html.

Figure 6: **Strengths, problems and prospects of using atmospheric measurements for verification of GHG emissions**

TABLE 6.2 (NEW)
STRENGTHS, PROBLEMS AND PROSPECTS OF USING ATMOSPHERIC MEASUREMENTS FOR VERIFICATION OF GHG EMISSIONS

Gas	Strengths/Successes[13]	Problems/Weaknesses	Future Development/Possibilities
CO_2	Large number of observations, although historically focusing on natural fluxes.	With sparse observing networks, uncertainties of models may be significantly higher than those of national anthropogenic CO_2 emission inventories.	Need more CO_2 observations targeting anthropogenic emissions, complemented by APO and radiocarbon observations.
CO_2 city-scale	City-scale studies show some degree of success. Inventory uncertainties are relatively larger than at national scale.	Even with dense observation networks, errors in emission estimates are large, due to interference from strong vegetation fluxes. Not used in national reporting.	Large efforts are ongoing to develop observation networks, pilot projects for tracking urban emissions, trends. Radiocarbon, APO, satellite observations also expected to contribute.
CH_4	Large anthropogenic emission fraction. National reporting[14]: UK, Switzerland. National-scale emission estimates[15]: EU-28, USA, India, China and others.	Few countries have observations, transport and inverse models have uncertainties, interference from natural emissions (wetlands) cited.	Regional observation networks and satellite observations are expanding.
N_2O	National reporting: UK National-scale emission estimates: EU-28, US, and others.	Observation sites are few, gridded inventories are simplified, large contribution from natural sources.	Expansion of surface networks will contribute to better model estimates.
HFCs, SF_6	Dominant anthropogenic emission fraction. National reporting: UK, Switzerland, Australia. National-scale emission estimates: China, US, EU. Revised EFs: Australia, UK.	Measurements are sophisticated and expensive. Observation sites are few, gridded inventories are simplified.	Expanding the monitoring network depends on funding.

Source: Slide 3 of Mr. Buendia's presentation; IPCC 2019; 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 6, Table 6.2.

Discussion

70. Experts supporting the discussions on theme 2 included the presenting experts and Anya Waite; Frank Martin Seifert, European Space Agency (ESA); Albrecht von Bargen, Coordination Group of Meteorological Satellites / Committee for Earth Observation Satellites Working Group on Climate (CEOS/CGMS WGClimate); and Lucia Perugini, Euro-Mediterranean Center on Climate Change (CMCC).

71. **What further information can the experts provide on estimates and near real time scenarios of greenhouse gas emissions over different regions, gases, and sectors?**

We can measure the global GHG concentrations and have an understanding of regional concentrations. These are updated several times a year, which is close to real time in terms of concentrations. Emissions are more difficult, but Copernicus and others are working on products with near real time emissions estimates based on satellite observation CO2, methane and other GHGs.

72. **What further information can the experts provide on the key variables selected to observe the climate system and support enhanced ambition for mitigation and adaptation?**

GCOS has identified 54 essential climate variables with differing importance depending on the course of action. Monitoring CO2 is essential for atmospheric measurements for example, and we need higher resolution and more measurements to fill gaps. Gaps also exist in land surface temperature monitoring, vegetation monitoring and gaps with respect to the cryosphere in terms of polar ice and snow topography.

Proposals have been made to fill these gaps with enhancements to the current Sentinel satellite mission, which is providing free, open-access data.

73. **Has there been or is there collaboration or data exchange between experts working with the data presented here and the Climate TRACE initiative?**

Climate TRACE is developing emissions verification and emissions documentation, whereas the WMO and partners are creating an internationally coordinated, transparent, global greenhouse gas monitoring system that considers both natural and anthropogenic fluxes. Experts working on systematic observation to support the Convention and the Paris Agreement are in touch with experts working on Climate TRACE on possible ways to collaborate.

74. **How can uncertainties in the measurements of GHGs using satellites be reduced?**

The best way to reduce the uncertainty of satellite data is to improve and increase measurements on the ground, both from permanent sampling sites and from inventories. A challenge here however is how to integrate these data and from them elaborate the satellite data. Guidance already exists for some sectors, for example the Global Forest Observation Initiative of the Group on Earth Observations provides guidelines for REDD+ on the integration of remote sensing data and ground observation.

Several systems approaches are being developed, incorporating top-down GHG monitoring systems and also maturing bottom-up approaches focussing on AFOLU. Different systems approaches to estimate GHG emissions will suit the circumstances of different Parties, depending on both how well uncertainty is known and managed in different parts of the system and how much is known about the different parts of the anthropogenic contributions and the natural variability. These latter parts are a very active area of study for the systematic observation community.

Uncertainties in satellite measurements are being overcome in the same way that modelling and data assimilation have been used for weather prediction. Satellite data and data from surface based observing systems are input into global models and produce estimates that have an accuracy greater than any of the individual original observations. Remote sensing data also provides the quantified data on uncertainty that the inventory community uses in its reporting. Even if uncertainties cannot always be eliminated, a clear understanding of the degree of uncertainty is vital.

B. Poster Session

75. Ten posters were presented on Theme 2. Full author lists and all posters are available by following the hyperlinks below and on the Earth Information Day 2022 webpage.[4]

76. Systematic Observations Required for Mitigation

Albrecht von Bargen, DLR; Jeff Privette, NOAA; Mark Dowell, EC; Frank Martin Seifert, ESA; on behalf of the Joint CEOS/CGMS Working Group on Climate

Space- and ground-based measurements of atmospheric carbon dioxide and methane are analyzed with atmospheric transport models to estimate greenhouse gas emissions and removals from human activities and the natural land and ocean.

Bottom-up greenhouse gas inventories can be complemented by top-down estimates to produce a more complete and transparent input to the Global Stocktakes.

The Earth Observation community is supporting the Global Stocktakes by developing space-based observation capabilities, working to operationalize research on observations by the second global Stocktake, and sustain observation systems to provide a seamless flow of reliable information to national stakeholders.

77. Strengthening Observation-Modelling Interface to Support Climate Action

European Space Agency Climate Change Initiative (ESA CCI)

Satellite observation data is used in climate models help us to better understand past, present and future climate changes. They are used to make predictions, which help guide actions to reduce carbon emissions and adapt to climate change. The ESA supports several initiatives to enhance data provision and modeling and provide analytical tools for users.

Urgent collective action required to enhance observation support to the UNFCCC process includes developing climate observation networks, maintaining sustainable climate data records, ensuring open access to data, and enhancing the values chain to supply climate data for decision-making.

78. RECCAP-2 Attribution: Balancing the global land carbon budget and elucidating its regional drivers

Philippe Ciais, Ana Bastos, Stephen Sitch, Marielle Saunois, Xin Lin, Frederic Chevallier, Jean-Pierre Wigneron, Catherine Prigent, Luiz Aragão, Philippe Aires, Carlos Jimenez, Dominic Fawcett, REgional Carbon Cycle Assessment and Processes project, Phase 2

One goal of the RECCAP-2 project is to enable the scientific community to make significant steps forward in the attribution of the global land carbon sink to land use change, fire and harvest disturbances & recovery, as well as climate effects using ECV data from ESA CCI, and attribution of the global CH4 budget to natural and anthropogenic sources.

Applications include the assessment of national GHG inventories to support to the GST, improving estimates of carbon fluxes from changes in biomass, identifying regional hotspots and driving processes of biomass change, and reducing uncertainties of the global CH4 budget.

79. Near-real-time estimates of greenhouse gas budgets

Philippe Ciais, Ana Bastos, Stephen J. Davis, Zhu Deng, Sassan Saatchi, Benjamin Poulter, Frederic Chevallier, Giacomo Grassi, Zhu Liu, Ron L. Thompson, Gallen A. McKinley, Nicolas Gruber, Jean-Pierre Wigneron, Stephen Sitch, Marielle Saunois, Alexandre d'Aspremont, Thomas Lauvaux, Grégoire Broquet, James T. Randerson, Clément Albergel, Lesley Ott, and David Crisp, REgional Carbon Cycle Assessment and Processes project, Phase 2

More frequent observation-based assessments of national greenhouse gas budgets are needed to enable users to assess progress toward emission reduction pledges and support national inventories. Complementary knowledge of natural fluxes is also required to reconcile the reductions of anthropogenic emissions with the observed growth rates of GHGs in the atmosphere and assess the risk of missing climate targets if natural sinks weaken.

Both national inventories and scientific assessments, such as the Global Carbon Budget, enable long term tracking of emissions from sectors, but can both be improved by near real time information. Components of such a system are already available and can be integrated to form a near real time global GHG budget.

80. Global megacity stories: GHG emissions and CO2 uptake by surrounding forests and farmlands utilizing satellite technology

Suto Hiroshi, Japan Aerospace Exploration Agency (JAXA)

JAXA has developed a space-based Greenhouse Gas Emissions (GEI) Index to help cities to identify their emission sources and track their changes at key national levels. The GEI is based on the difference between upper and lower tropospheric CO2. Reducing emission from megacities are essential to achieve net-zero. Observational analysis of the functionality and impact of forests and agricultural lands around megacities applying JAXA's satellite data was used to estimate mega cities' emissions and removals. Data from the GOSAT indicates how CO2 fluxes from farmland, such as around Cairo, changed based on combustion and solar-induced chlorophyll fluorescence (SIF) levels.

81. In situ observations support the Methane Pledge: The Nord Stream leaks case study

Sindu Raj Parampil, Integrated Carbon Observation System (ICOS); Michel Ramonet, French National Center for Scientific Research (CNRS)/Laboratoire des sciences du climat et de l'environnement (LSCE); Anna Agusti-Panareda, Copernicus Atmosphere Monitoring Service (CAMS), European Centre for Medium-range weather Forecasts (ECMWF); Philippe Ciais, CNRS/LSCE; Elena Saltikoff; Werner L Kutsch, ICOS

ICOS stations detected CH4 leaks from the Nord Stream pipeline in real-time. CH4 monitoring overseas is difficult as water absorbs most of the light needed for measuring CH4, limiting the use of satellites to monitor the leak. Different models simulated the leaks and movement of the CH4 plume in order to estimate the amount of CH4 lost. ICOS in-situ data supported the models.

The Nord Stream leaks emphasize the need for an integrated observation system comprising ground-based stations, satellites and models, for the monitoring and mitigation of GHGs. The system will support Parties to verify emission reductions, detect unreported methane fluxes such as leakages, and support local efforts in cities and hot spots.

82. Consistent Monitoring of Greenhouse Gas Emissions: Current Status of the Copernicus CO2MVS Prototype Systems

Nicolas Bousserez, European Centre for Medium-Range Weather Forecasts (ECMWF); Frederic Chevallier, Laboratoire des Sciences du Climat et de l'Environnement (LSCE); Panagiotis Kountouris; Joe

McNorton, ECMWF; Hugo Denier van der Gon, TNO; Greet Maenhout, Joint Research Centre; Anna Agusti-Panareda, ECMWF; Wouter Peters, Wageningen University; Dominik Brunner, EMPA; Gregoire Broquet, LSCE; Marko Scholze, Lund University; Sander Houweling VU Amsterdam, Werner Kutsch, Integrated Carbon Observation System (ICOS); Julia Marshall, Max Planck Institute for BioGeoChemistry; Han Dolman, VU Amsterdam; Glen Peters, Center for International Climate Research; Thomas Kaminski, iLab; Audrey Fortems-Cheiney, LSCE; and Richard Engelen, ECMWF on behalf of the CoCO2 Team

The CoCO2 project aims to deliver prototype systems for the Copernicus anthropogenic CO2 emissions monitoring and verification support (CO2MVS) system. The project will combine earth observations with modelling to build a portfolio of information products to support and inform the operational implementation of a Copernicus CO2MVS by 2026.

CO2MVS will provide a long-term perspective with continuous monitoring and re-processing to increase the accuracy of observation-based information. The service will be applicable on scales ranging from facilities and cities to regional and global. It will provide evaluation, quality control and user support functions with specific support to scale up key European in-situ observations as part of the ICOS research infrastructure.

83. Global Carbon Budget

Pierre Friedlingstein and Alissa Haward, Global Carbon Project & University of Exeter

The Global Carbon Budget provides annual updates on the global carbon budget and trends. The 2022 installment highlights the decline and rebound of atmospheric CO2 associated with measures put in place to manage the COVID-19 pandemic, global CO2 emissions from land-use changes, the estimated time period before 1.5° C of global warming is reached, and trends required to hold global warming below this threshold.

84. Ocean Observing System Report Card 2022

Global Ocean Observing System Observations Coordination Group

GOOS' Ocean Observing Report Cards provide updates on the status of the global ocean observing system, assesses the networks' progress, and identifies challenges to improving the system.

The ocean observing network is returning to normal following the COVID-19 pandemic. Automation is improving data delivery, but increased resources are needed to ensure information delivery on current and future changes in the ocean, and how they can be mitigated or adapted to.

GOOS continues to increase inclusion and engagement of partners across sectors and society, including via the UN Ocean Decade Odyssey. The development of user capacities and ocean literacy will connect people to the ocean, improve the observing system's fitness for purpose, and enhance ocean data collection.

85. Sustained, Coordinated, & Integrated Southern Ocean Observations to support climate change mitigation & adaptation

Sian Henley, University of Edinburgh, UK; Eileen Hofmann, Old Dominion University, USA; Sebastien Moreau, Norwegian Polar Institute, Norway; Irene Schloss, Instituto Antartico Argentino, Argentina; Alyce Hancock, University of Tasmania, Australia; Julia Bach, University of Tasmania, Australia.

The Southern Ocean has absorbed more anthropogenic heat than any other part of the ocean, with knock on effects for Antarctic ice-sheet stability, carbon storage, and Antarctic ecosystem integrity. The Southern Ocean is the world's largest carbon store but is insufficiently observed to monitor changes.

SOOS has identified five themes corresponding to observations that must be enhanced to advance understanding of the Southern Ocean and to address critical societal challenges. A coordinated, multidisciplinary program is envisioned to integrate autonomous platforms and novel approaches with traditional observing techniques in order to deliver essential data to stakeholders, including real-time information.

IV. Summary of plenary presentations, discussions and posters on Theme 3: Earth Observations for Adaptation and Early Warning Systems

A. Summary of presentations

86. Presenters speaking on theme 3 were Mr. Hans-Otto Pörtner, IPCC Working Group II; and Ms. Aïda Diongue-Niang, IPCC Working Group I and the National Agency of Civil Aviation and Meteorology of Senegal (ANACIM); and Ms. Lucy Mtilatila, Department of Climate Change and Meteorological Services, Malawi. Anya Waite moderated the section.

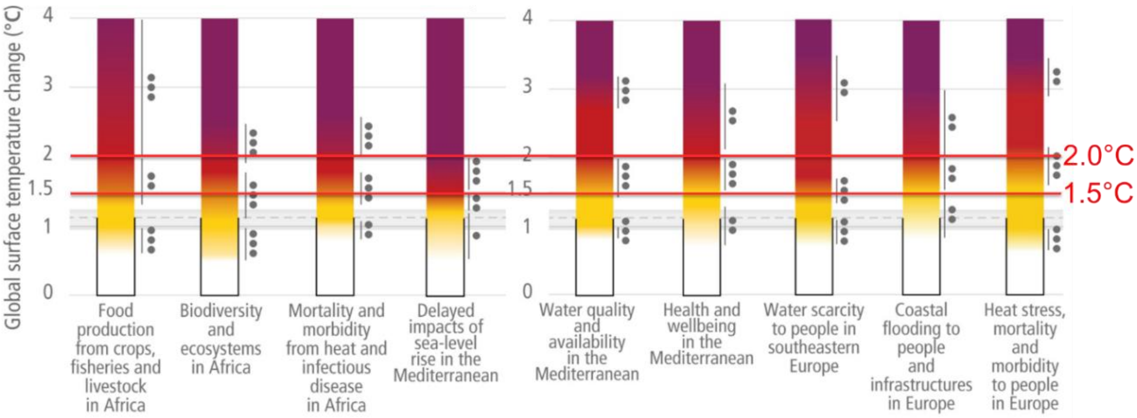
Mr. Hans-Otto Pörtner. Earth observations for impacts, risks, and adaptation progress

87. **The IPCC Working Group II on Impacts, Adaptation and Vulnerability considers several sets of indicators** during its assessment. These indicators provide information on complex processes involving living systems that can be integrated into the assessment of higher-level characters, for example, vulnerability, biodiversity and risk, and over different spatial patterns.

88. **Indicators are monitored for change to provide a basis for mobilising action.** Greater understanding helps to guide ambition and evaluate the progress of adaptation and mitigation, sets guardrails for climate action, shows criteria for possible futures, informs early warning systems, and assesses human and environmental liveability in line with Climate Resilient Development.

89. **Risk assessments can guide global ambition.** Risk can be assessed and visualised using the burning ember diagrams *(fig. 7)*, here showing that limiting global warming to 1.5° C or below would prevent the transitioning of risk levels from moderate to high for many systems and highlighting areas where adaptation action can reduce risk.

Figure 7: **Risk assessment visualisation via a 'burning ember' diagram**



Dots indicate low (fewer) to high (greater) confidence levels. Undetectable risks are coded white. Moderate, high, and very high risks are coded tallow, red and purple respectively. *Source*: Slide 3 of Mr. Pörtner's presentation; IPCC, 2022: Summary for Policymakers. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

90. **The systems for analysing key indicators for vulnerability are not in place**, or cannot provide enough data, in many regions. Vulnerability must be considered in a societal and spatial context with a high enough resolution to aid decision-making and assess the effectiveness of adaptation efforts. Key indicators to assess vulnerability include poverty, equity and inclusivity; the availability of basic services; security aspects; social, political and economic stability; and transparency.

91. **Biodiversity and human and other species habitat ranges will be increasingly impacted with increasing climate change, especially in low latitudes and in the ocean.** The spatial resolution required to observe related indicators in many areas is insufficient, but progress has been made in tracking indicators with the WGII Atlas. Key indicators for biodiversity and habitat change include species inventories; population densities; geographical ranges; phenological indicators; metagenomics; resilience; and non-climatic stressors in the background that may act to enhance vulnerability.

92. **Treating climate, biodiversity, and human society as coupled systems is key to successful climate and conservation outcomes.** With sufficient resolution of these sets of indicators, spatial planning can be enhanced. The mosaic approach conceptualises how protected spaces and sustainably or intensively used spaces could be arranged in a way that is mutually supportive and conserves 30-50% of land and ocean ecosystems.

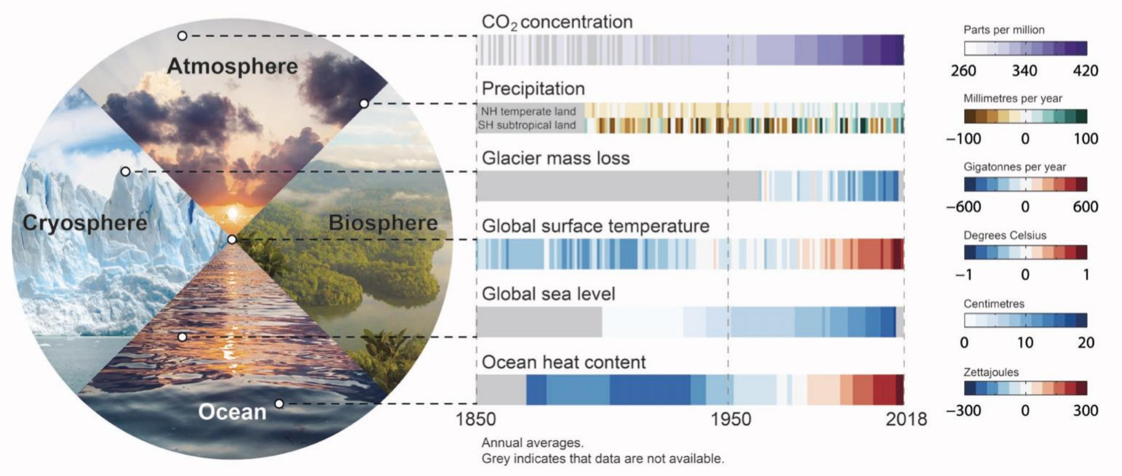
93. **Systematic observation is key to monitoring systems and indicators.** Linking earth observation with statistical data from bottom-up sources will enhance understanding of rapid and slow-onset events, exposure to climate hazards over time, and the vulnerability of humans and ecosystems. The imbalances caused by anthropogenic GHGs and human impacts can only be addressed through a holistic approach that considers climate variables and the responses of living systems.

Ms. Aïda Diongue-Niang. Earth observations for Adaptation and Early Warning Systems

94. **The IPCC WGI contribution to the AR6 reports widespread and rapid changes** in the atmosphere, ocean, cryosphere and biosphere *(fig. 8)*. Human activities are causing climate change, making extreme climate events, including heat waves, heavy rainfall, and droughts, more frequent and severe

95. **Earth observations reveal changes in the climate systems and allow us to project future changes** at global, regional and local levels to assess risk and determine attribution. The IPCC WGI report summarises advances and challenges regarding observation for climate change assessment. Since the AR5 more and longer datasets of historical data are available, as well as more granular and detailed satellite measurements, an expansion of in-situ observing stations in the ocean, and enhanced data reanalyses for multiple uses and filling multiple gaps.

Figure 8: **Changes across domains in the Earth system**



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 CO2 concentration and glacier mass loss, which are absolute values). Grey indicates that data are not available. *Source*: Slide 2 of Ms. Diongue-Niang'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.

96. **Early Warning Systems can be used to predict extreme and slow-onset events.** According to the UNISDR, they are a "set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss". Risk knowledge; monitoring and warning services; dissemination and communication; and response capabilities are pillars of EWSs, with systematic observation an essential component of monitoring.

97. **Hazards in the AR6 have been assessed to occur with greater magnitude, increased frequency, in new locations, with different timings, and as compound events.** IPCC WG I and II have adopted a common risk framework in the AR6. This allows climate risk drivers such as hazards to be linked with social and ecosystem vulnerability and exposure, as well as the consequences of responses to climate change.

98. **Warning systems rely on observations** to inform numerical predications from the timescales of minutes to decades. While much progress has been made, more is still necessary, especially in developing countries.

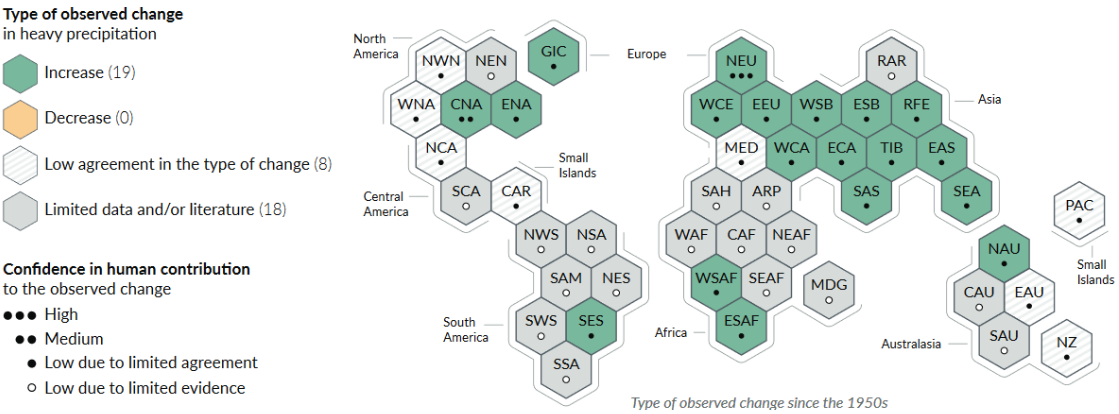
- Major advances have been made in the production and use of satellite data and data products, though some areas need greater data-processing capacity and more in-situ data for calibration.
- Global numerical weather prediction requires a representative baseline informed by real-time data assimilation and data exchange.

- Gaps in the surface and upper-network coverage and in data exchange, especially in Africa, the South-West Pacific, South America and Antarctica, are limiting its accuracy. Urban coverage in many regions is not optimal.
- Climate models require further input of non-atmospheric components to more accurately represent the climate system as a whole and approach the concept of Seamless Earth system models.
- Early Warning Services require greater sub-regional collaboration and financing support to feed into national EWS, and services need to be integrated into disaster risk reduction, climate services, and adaptation strategies to allow effective, early, and coordinated national action.

99. **Challenges are exacerbated in regions with limited data or data access, and by the loss of historical weather archives, the loss of natural climate archives, and disruptions during the COVID-19 pandemic.** Building on the advances already made since the AR5, these challenges can be overcome by expanding global in-situ observation networks such as tide gauges, expanding international data rescue programmes, and coordinating efforts to rescue and record vulnerable paleoclimate archives. The WMO is working towards addressing these challenges via the GBON[14] and the SOFF[15].

100. **Enhanced Earth observations enhance climate risk EWSs**, for example via the MISVA collaboration project where observations of precipitable water is used to predict active phases of the West African monsoon. Some regions, in particular Africa and South America, have insufficient data to assess the trend and attribution of changes in heavy precipitation *(fig.9)*. Precipitable water, the column of water able to condensate, is tightly linked to, and more predictable, than precipitation, enhancing the accuracy of forecasts and EWSs. A limited and declining amount of atmospheric measurements from radiosonde is decreasing this capacity by providing less data to compare against datasets from global analysis centres.

Figure 9: **Synthesis of assessment of observed change in heavy precipitation and confidence in human contribution to the observed changes in the world's regions**



Different region are shown as polygons. In many regions, there is limited data or access to data or literature to perform trend analyses for heavy precipitation increases. *Source*: Slide 6 of Ms. Diongue-Niang'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.

Ms. Lucy Mtilatila. Earth observation capabilities to enhance early warning systems and climate services in Malawi

101. **Malawi has established a network of stakeholders who collaborate to support EWS**, including the Department of Disaster Management Affairs (DoDMA), the Department of Water Resources, and the Department of Climate Change and Meteorological Services.

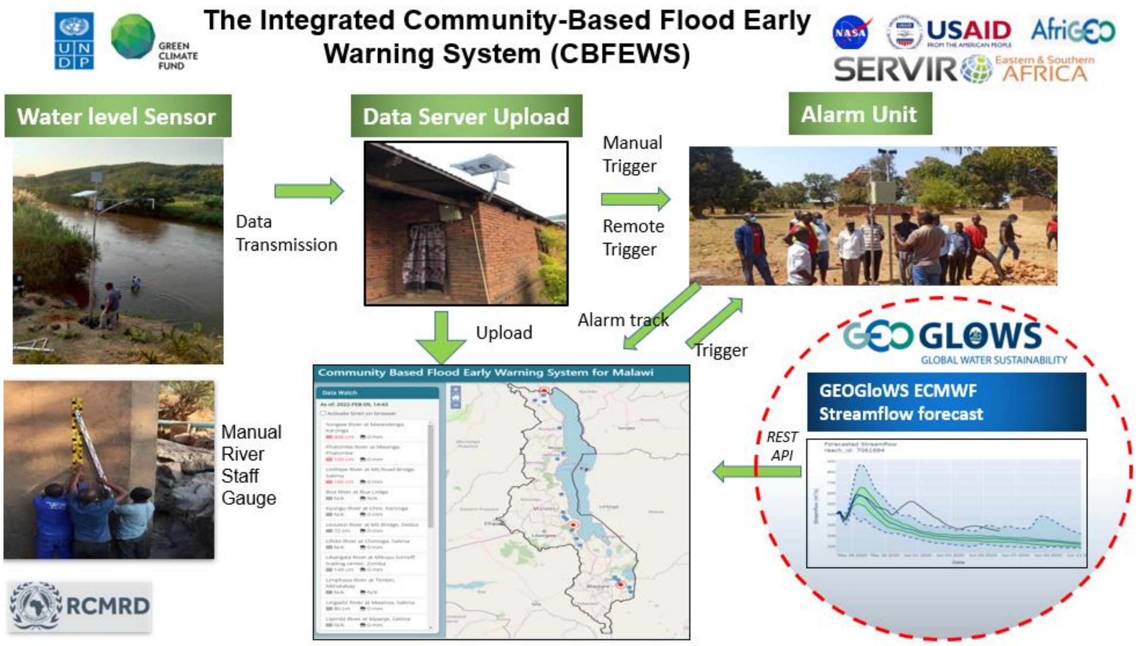
102. **Several types of EWS have been implemented in Malawi with the goal of communicating warnings as quickly and as widely as possible.** The most extreme and extensive hazards affecting Malawi are floods and droughts, standing out against pests, disease and extreme wind. Vulnerability of some communities in Malawi compounds the effects of extreme events.

103. **Community based EWSs use instruments installed in-situ in communities** *(fig. 10)*. The Community-Based Flood Early Warning System (CBFEWS) was implemented in 8 flood-prone districts. CBFEWS uses input from upstream water sensors and downstream caretakers to assess flood risk and trigger SMS based warnings for the relevant communities. This manual system improves the lead time for

[14] See https://community.wmo.int/en/activity-areas/wigos/gbon.
[15] See https://public.wmo.int/en/resources/library/soff-establishing-systematic-observations-financing-facility.

communities to evacuate and establish emergency centres by several hours. In parallel, the Department of Climate Change and Meteorological Services runs numerical weather predictions that are used in the hydrological models of the Department of Water Resources to inform national to community level EWS.

Figure 10: **Integration of community-based and national Early Warning Systems**



Source: Slide 3 of Ms. Mtilatila's presentation.

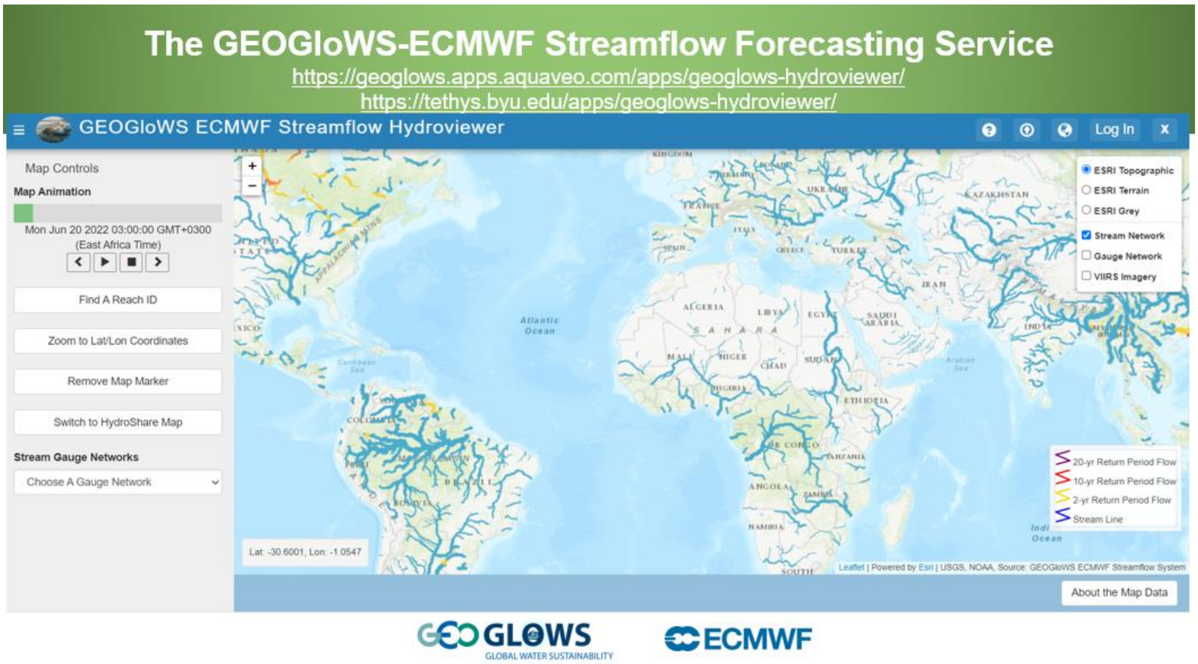
104. **Challenges for these EWSs include issues of time and scale.** For example, water gauges that measure flow over time may trigger a warning too late for communities to react to. Numerical weather predictions may not be of sufficient resolution to accurately forecast events, and hydrological models are not available for all waterways and river basins.

105. **Other climate services can complement and fill gaps in EWSs.** The GEOGloWS-ECMWF Steamflow Model provides almost global coverage and increases the accuracy and extends the advance time of early warnings by around 15 days *(fig. 11)*.[16] This combination of systems is in its second year of pilot testing in Malawi and since their implementation in 2021 have already been shown to enhance EWSs and reduce the vulnerability of communities to some of the impacts of extreme events. Populations of districts in which the joint systems were implemented experienced fewer deaths, and much reduced economic losses and recovery costs. With support from the World Bank, DoDMA plans to upscale the integrated CBFEWS into 10 flood prone districts frequently impacted by cyclones in the Southern part of Malawi, targeting additional 40 river systems.

106. **Interest has been expressed outside Malawi, and work is underway to replicate the integrated CBFEWS and increase the institutional capacity in other countries through the USAID SERVIR Program.** To support these and global WESs GEOGloWS will develop supplementary guidance to the UNFCCC NAP Technical Guidelines to include the GEOGloWS-ECMWF service in other countries.

[16] See https://geoglows.ecmwf.int/.

Figure 11: **The GEOGloWS-ECMWF Streamflow Forecasting Service**



Source: Slide 4 of Ms. Mtilatila's presentation; GEOGloWS.

Discussion

107. Experts supporting the discussions on theme 3 included the presenting experts and Anthony Rea, WMO; Sara Venturini, Group on Earth Observations (GEO); Toste Tanhua, GOOS; Tabea Lissner and Chandni Singh, IPCC Working Group II; and Annett Bartsch, b.geos.

108. **What are key challenges for the observation of the cryosphere?**

The Special Report on the Ocean and Cryosphere in a Changing Climate provides some assessment of current observation capacity and further needs for the cryosphere. More observations in these regions are needed to enhance certainty and improve projections of some currently less well understood processes, such as ice-cliff instability, and their knock-on effects.

Observations at the poles often face challenges. Satellite observations are limited by cloud cover, and ships and other systems are affected by severe weather. Autonomous underwater vehicles and Argo floats are filling gaps, but more comprehensive observations are still lacking in these regions where the climate is rapidly changing.

It is crucial to monitor the components of the cryosphere to gain a greater understanding of global climate tipping points. Satellite data already shows how close we are to tipping points in some systems, but there is insufficient data to facilitate early warning systems in others. Thresholds of systems in the ocean and cryosphere are among those that require more innovation in the use of satellite data and more in-situ observation systems to assess how close we are to the associated tipping points.

109. **What is the role of systematic observations for attribution science and loss and damage? How can gaps in vulnerable regions be addressed?**

Observations of different parts of the climate system are needed to determine attribution of global change. For extreme events, precise observations of the event are needed on all scales from global to local to feed into the statistical modelling tools that inform attribution assessments.

WGI findings report a large improvement in studies on attributing the intensity and occurrence of extreme events to climate change. Further understanding of impacts, as assessed by WGII and including extreme events, are also contributing to advances in attribution science.

Attribution studies requires an understanding of the previous climate and changes, making data rescue projects to secure and make available long term-climate data records imperative for these types of studies.

Attribution studies for loss and damage are not currently well supported by the networks of observation stations and attribution studies. While WGII does account for these studies in its assessment, high resolution data is not always available in some areas, such as in many small island states.

GEO works with space agencies, national authorities, and experts to provide capabilities that enhance meteorological services. For example, combining satellite information and ground data has improved the lead time and accuracy of early warning systems, giving governments more time to prepare and respond to crises and alleviating subsequent losses and damages. These data are open, free, and provided in accessible online platforms. Software is also in place to allow developing countries to run models through freely available cloud-based platforms.[17] GEO is also responding to Parties' needs for seed funding and capacity development to implement national Earth observation-based monitoring systems for different sectors, such as agriculture, health and disaster risk preparedness.

B. Poster Session

110. Nine posters were presented on theme 3. Full author lists and all posters are available by following the hyperlinks below and on the Earth Information Day 2022 webpage.[4]

111. Global Framework for Climate Services

Global Framework for Climate Services (GFCS), WMO

The GFCS is a global partnership of governments and organizations that produce and use climate information and services.

The framework supports climate services in a cycle that describes their implementation, quality management, and support to climate policy, and in turn highlights priorities for enhanced services. The GFCS therefore supports the implementation of the Paris Agreement while identifying and aligning investments, supporting the establishment of national frameworks for climate services, and supporting national meteorological and hydrological services' input to service development.

112. Ocean acidification observation and research – latest advancements and new technologies

Kirsten Isensee; Katherina Schoo, IOC-UNESCO, Helen Findlay, Plymouth Marine Laboratory, UK (PML); Janet Newton, University of Washington, USA; Stephen Widdicombe, PML

The ocean takes up 25% of annual CO2 emissions, causing ocean acidification (OA) that affects marine ecosystems and fisheries, and limits the ocean's capacity to act as a carbon sink.

The UN Ocean Decade Ocean Acidification Research for Sustainability (OARS) programme fosters the co-development of ocean acidification science in support of SDG target 14.3 and aims to improve observations of inorganic carbon, an ECV, supporting the work of the UNFCCC and IPCC.

Advances in OA measurement and data collection include satellite remote sensing capabilities to fill gaps in traditional OA observation and the SDG 14.3.1 Data Portal for the submission, collection, validation, storage and sharing of ocean acidification data and metadata.

113. Marine Flood Forecasting: A tool to help build resilience against climate change for communities along reef-lined coasts

William Skirving, NOAA; Curt Storlazzi, US Geological Survey; Robert McCall; Ap van Dongeren, Deltares; Emily Smail, GEO Blue Planet; Derek Manzello, NOAA, Presenter: Isa Elegbede, Lagos State University, Nigeria & GEO Blue Planet & GEO BON.

WaveFoRCE is a Marine flood forecasting system with the capability to provide ten-day advance forecasts for points at every 200m along every reef-lined coast in the world. The system covers 90% of SIDS and quarter of LDCs. With marine flooding becoming increasingly severe for most low-lying coasts, historic data and forecasts provided by WaveFoRCE build resilience against loss of life, damage to infrastructure and loss of livelihoods, and loss of freshwater reserves.

Historic flood data also informs countries climate change adaptation planning and National Adaptation Plans under the UNFCCC.

114. Antarctic Ice-shelf basal melting as a possible tipping element

[17] See https://www.earthobservations.org/aws.php.

Kusahara Kazuya, Research Center for Environmental Modeling and Application, Japan Agency for Marine-Earth Science and Technology (JAMSTEC).

Fresh water stored in the Antarctic ice sheet is a potentially dominant contributor to future sea level rise. In the Japanese climate change projection programs, TOUGOU and SENTAN, numerical experiments using an ocean-sea ice model with an ice-shelf component are used to estimate Antarctic ice-shelf basal melting under the warming climate. The model projects a nonlinear response of basal melting to different future scenarios. In an extreme-warming scenario, a combination of enhanced warm water intrusions and summertime surface temperature rise can cause such a response, crossing a tipping point and contributing to global sea level rise.

115. Continued Climate-Induced Changes in the Cryosphere Will Cause Irreversible Impacts Across the Globe

International Cryosphere Climate Initiative

Higher levels of CO2 emissions and warming (including 2°C) will substantially increase the risk of irreversibly crossing thresholds in the cryosphere. Lower levels of emissions and warming will in turn substantially decrease this risk. Changes in the cryosphere have their greatest human and ecosystem impacts outside of mountain and polar regions, stemming from permafrost carbon emissions and sea-level rise from the melting of mountain glaciers and polar ice sheets.

The threats to mountain glaciers, snow and polar ecosystems, and their dependent communities rise with each increment of warming. The global impacts of crossing thresholds in these systems are irreversible on human timescales.

116. GEOGloWS: In support of Malawi's Community-Based Flood Early Warning System (CBFEWS) for Effective Disaster Preparedness & Recovery

Samuel J. Gama, Office of the President and Cabinet & Department of Disaster Management Affairs, Malawi; Fedson Chikuse, Office of the President and Cabinet & Department of Disaster Management Affairs, Malawi; Calvince Wara, Regional Centre for Mapping of Resources for Development, Kenya; Jim Nelson, Brigham Young University, USA; Angelica L. Gutierrez, National Oceanic and Atmospheric Administration (NOAA); Sara Venturini, GEO Secretariat.

The CBFEWS combines manual and automated, local and national components to increase the advance time of warnings to communities. It is complemented by the GEOGloWS ECMWF Streamflow Forecast, a global hydrological model providing river discharge data to producing open-access a 15-day ensemble forecasts and a deterministic historical simulation from January 1980 to near real time.

Malawi plans to scale-up the CBFEWS project into ten flood-prone districts frequently impacted by cyclones in the Southern part of Malawi, targeting 40 river systems.

117. GEO Global Agricultural Monitoring Agriculture and Food Security

Esther Makabe; Ian Jarvis GEO Global Agricultural Monitoring (GEOGLAM), Presenter: Steven Ramage, GEO Secretariat.

The GEO Global Agricultural Monitoring Initiative (GEOGLAM) aims to increase market transparency and improve food security by producing and disseminating relevant, timely, and actionable information on agricultural conditions and outlooks of production at national, regional, and global scales.

GEOGLAM collaborates with international agencies such as the UNFCCC and UNDRR to develop approaches to address climate change mitigation and adaptation, as well as disaster risk reduction.

GEOGLAM maintains initiatives such as Crop Monitor, that provides a monthly report informed by Earth observations focusing on primary commodity crops and their sensitivity to factors such as climate and conflict.

118. Integrating Earth Observations into the Formulation and Implementation of National Adaptation Plans: Agriculture and Food Security

Esther Makabe; Ian Jarvis, GEOGLAM, Presenter: Sara Venturini, GEO Secretariat

Climate change, increased disaster risk, and unsustainable practices have huge implications on food security, particularly in low- and middle-income regions. NAPs provide a means for countries to identify and implement adaptation measures, including in agriculture.

Earth Observations support agriculture adaptation with timely and accurate information for food security programs and policies. The 2022 GEO Supplement to the UNFCCC NAP Technical Guidelines provides practical approaches to drive the implementation of NAPs based on the work of the GEOGLAM initiative.

A National Agriculture Monitoring System based on Earth Observations would establish an institutional and a technical framework to support the co-development of capacity and access financial support for the implementation of NAPs.

119. Halting Amazon deforestation may not stop forest degradation

David Lapola, UNICAMP; AIMES; Future Earth

The Amazon rainforest is subject to multiple processes of forest degradation, including drought, fire, logging, and edge effects. Earth observations show that 5.5% of the total forest area affected by these processes, with 38% affected when including extreme drought. Projections indicate that degradation will remain a dominant source of carbon emissions in the Amazon independent of deforestation rates.

Curbing degradation will require interventions beyond policies focused on deforestation, such as operationalizing the monitoring of the different types of disturbances and refining the REDD+ framework. The combination of spaceborne LiDAR with optical imagery is a promising avenue for operationalizing the monitoring of disturbances linked to degradation.