Framework Convention on
Climate Change

Subsidiary Body for Scientific and Technological Advice 22 April 2021

Earth Information Day, 2020
30 November 2020

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 2020 provided updates on the state of the global climate and its observation in 2020, including impacts of the Covid-19 related lockdowns. It also provided updates on recent advances in Earth observation technology and data processing to support mitigation and adaptation.

This summary report provides an overview of the presentations, posters and discussions that took place virtually. Key messages from the discussions are also provided. Thirteen individual presentation were given during the dialogue. The poster session consisted of 31 posters.

Contents

		Page
	Key messages	3
I.	Introduction	5
II.	Summary of proceedings - presentations and discussions	5
	A. Theme 1. Updates on the state of the global climate and its observation	5
	B. Theme 2. Recent advances in Earth observation technology and data processing to support decision making	24
III.	Summary of proceedings - posters	36
	A. Theme 1. Updates on the state of the global climate and its observation	36
	B. Theme 2. Recent advances in Earth observation technology and data processing to support decision making	45

Key messages

I. Updates on the state of the global climate and its observation

Climate change drivers, indicators and impacts

- Greenhouse gas concentrations in the atmosphere reached record levels in 2019
- Ocean heat content reached a record level in 2019 with the rate of warming having increased particularly over the past two decades and across all observed depths
- Ocean acidification has been steadily increasing, with ocean pH decreasing from approximately 8.11 to 8.06 since 1985
- Sea ice extent has declined for every month of the year over the satellite record from 1979 to the present
- Regional differences are observed in temperature rise in 2020, with new highs in many regions
- Rising global temperatures have contributed to severe impacts around the world from weather and climate events compounded by COVID-19.

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

- The Earth Energy imbalance is the most important measure of understanding the future of continued global warming and climate change.
- During 2010-2018 the Earth Energy Imbalance was 0.87 ± 0.12 W/m^2
- The amount of CO2 in the atmosphere would need to be reduced from 410 ppm to 353 ppm to increase heat radiation to space by 0.87 W/m2, bringing Earth back towards energy balance
- The Earth Energy Imbalance should be a vital metric for the global stocktake

Closing the global carbon cycle and closing the emissions gap

- The impact of the Covid-19 associated lockdown on 2020 annual emissions is about 6-7% but the direct effect on atmospheric CO_2 is negligible.
- Government actions and economic incentives post COVID-19 crisis will likely influence the global CO_2 emissions path for decades to come.
- Current NDC pledges are not enough to limit global temperature rise to 2°C
- A low-carbon pandemic recovery could cut 25 per cent off GHG emissions expected in 2030, based on policies in place before COVID-19.

Covid-19 imprints on the short- and long-lived chemical species in the troposphere

- Primary (NO_2) and secondary (PM2.5) short-lived air pollution species showed large decreases over different parts of the globe in 2020 depending on the timing of lockdowns
- While the detection of mean concentration changes were challenging for the long-lived species CO_2 and CH_4, changes were detectable in the ratio of their synoptic variabilities
- High-quality long-term surface observations without data gaps are indispensable for accurately tracking emission mitigation policies.

10 New Insights in Climate Science

- Future Earth updated on preparation for their annual synthesis of ten fields within climate science where there have been significant advances in understanding.

The Status of the Global Climate Observing System: Plans and Progress

- Observation of essential climate variables and the archival and accessibility of data have improved but more support is needed
- GCOS are currently reviewing the essential climate variables and preparing the latest GCOS status report
- GCOS areas of work aim to strengthen Earth observation, its coordination, ECV and indicator requirements and their applications
- Significant action is still needed to improve and sustain observations, and address challenges and gaps in observation.

II. Recent advances in Earth observation technology and data processing to support decision making

Mitigation

- Top-down atmospheric inventories will be a useful complement for informing the bottom-up inventories being compiled to report progress on the Paris Agreement for emissions reductions, and for the global stocktake
- Ground-based, airborne, and space-based measurements are now being combined in atmosphere inverse models to provide high-resolution global maps of carbon dioxide and methane emissions and to understand how to integrate top-down methods with bottom-up inventories
- Copernicus is developing an integrated system approach, combining different information sources based on the latest science, to support Parties’ emissions reporting through the Enhanced Transparency Framework
- IG3IS provides a common framework for the provision of systematic services for stakeholder communities working to reduce their greenhouse gas emissions
- The GFOI is a model for how the systematic observation community supports the efforts of developing countries to provide information on GHG emissions and removals that can be used for reporting to the UNFCCC

Adaptation

- The WMO Global Framework for Climate Services is supporting the provision of climate services as both products and tools for adaptation and the NAP process
- GEOGLAM focuses on agriculture monitoring and aims to increase market transparency and improve food security by producing and disseminating relevant, timely, and actionable information on agriculture conditions and outlooks for production at national and global scales
- Improved agriculture monitoring and reporting are essential for designing the appropriate early warning systems and adaptation programmes
- GEO Blue planet aims to assist decision makers parse the information available on the ocean and coastal zone to support marine spatial planning, integrated coastal zone management, adaptation and the NAP process.

I. Introduction

1. The Earth Information Day 2020[1] was held on 30 November 2020 during the virtual UNFCCC Climate Change Dialogues,[2] 23 November–4 December 2020.

2. The Earth Information Day, mandated by the 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 the state of the global climate and its observation;

Theme 2. Recent advances in Earth observation technology and data processing to support decision making

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 2-and-a-half-hour dialogue as well as a virtual poster session. As part of the poster session, two 1-hour meetings were organized to allow participants to ask questions of the poster presenters.

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

7. This report provides a summary of the Earth Information Day 2020 proceedings with Section II providing the summary of presentations and discussion, with key messages highlighted, and Section III providing a summary of the posters.

8. I encourage 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

A. Theme 1. Updates on the state of the global climate and its observation

9. Presenters for Theme 1 included Mr. John Kennedy, WMO, Ms. Karina von Schuckmann, Mercator Ocean; Mr. Pierre Friedlingstein, Global Carbon Project (GCP); Ms. Anne Olhoff, UNEP; Mr. Prabir K. Patra, Japan Agency for Marine-Earth Science and Technology (JAMSTEC); Mr. Erik Pihl, Future Earth; and Mr. Anthony Rea, WMO/Global Carbon Observing System[6] (GCOS).

1. Climate change drivers, indicators and impacts

10. Mr. John Kennedy provided a brief update on some of the climate change drivers, global climate indicators, and impacts of extreme events, as detailed in the *WMO Greenhouse Gas Bulletin,*[7] released on 23 November 2020, and the *WMO Provisional Report on the State of the Global Climate 2020*,[8] released on 2 December 2020.

---

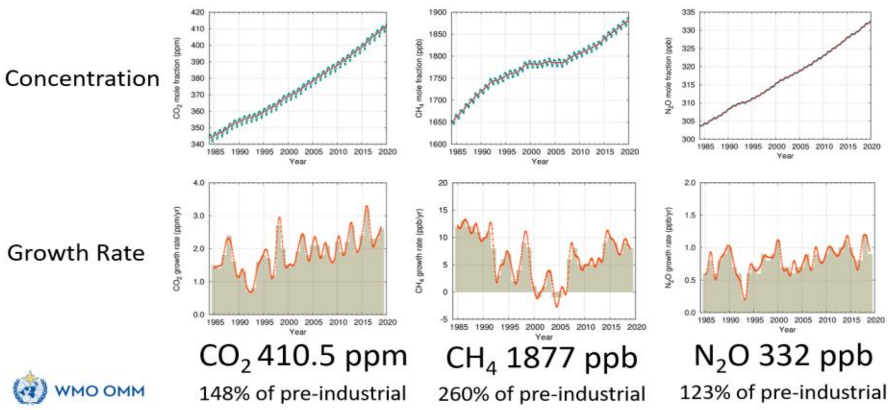
1 See https://unfccc.int/event/earth-information-day-2020.
2 See https://unfccc.int/cd2020.
3 FCCC/SBSTA/2019/2 para. 58.
4 Submissions were received from the Bhutan on behalf of the Least Developed Countries Group, Germany and the European Commission on behalf of the European Union and its Member States, and Japan. See: https://www4.unfccc.int/sites/submissionsstaging/Pages/Home.aspx.
5 Available at https://unfccc.int/sites/default/files/resource/EID2020%20Information%20note.pdf.
6 See https://gcos.wmo.int/en/home.
7 Available at https://public.wmo.int/en/resources/library/wmo-greenhouse-gas-bulletin-no16-november-2020.
8 Available at https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate.

11. The State of the global climate report collated information from 70 WMO members, 43 scientific experts and 7 UN agencies (UNEP, FAO, World Food Programme, High Commissioner for Refugees, International Organisation for Migration, Intergovernmental Oceanographic Commission of UNESCO and International Monetary Fund).

Greenhouse gas concentrations in the atmosphere reached record levels in 2019

12. The atmospheric concentrations of GHGs reflect a balance between emissions from human activities, sources and sinks. Increasing levels of greenhouse gases in the atmosphere due to human activities are a major driver of climate change. GHG concentrations in the atmosphere reached record levels in 2019, as shown in figure 1 for CO_2, methane, and nitrous oxide.

Figure 1. Concentration and growth rate time series of Carbon Dioxide, Methane, and Nitrous Oxide

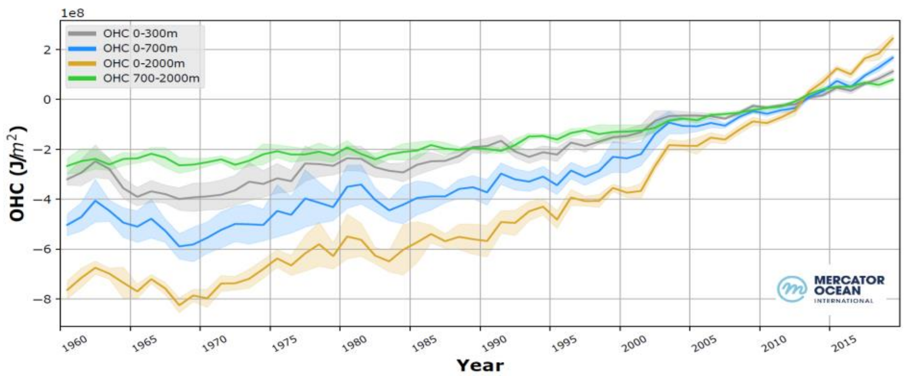


Source: Slide 3 of Mr. Kennedy's presentation; WMO Global Atmosphere Watch, WMO Greenhouse Gas Bulletin 25 November 2019 (2019)

Ocean heat content reached a record level in 2019 with the rate of warming having increased particularly over the past two decades and across all observed depths

13. Ocean heat content is a key indicator of climate change as ninety percent of the energy trapped by atmospheric GHGs goes into the ocean. Ocean heat content from 0 to 2000m depth increased between 1960 and the present, and especially in the past two decades relative to the earlier period (figure 2).

Figure 2. Global ocean heat content



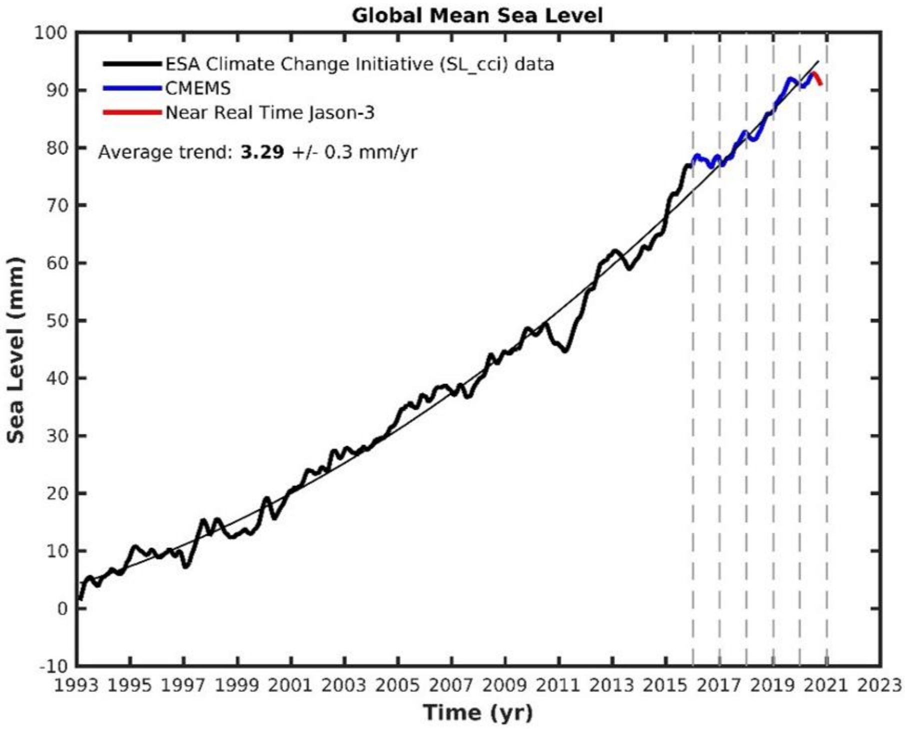
Source: Slide 5 of Mr. Kennedy's presentation

1960-2019 ensemble mean time series and ensemble standard deviation (2-sigma, shaded) of global ocean heat content (OHC) anomalies relative to the 2005-2017 climatology for the 0-300m (grey), 0-700m (blue), 0-2000m (yellow) and 700-2000m depth layer (green).

Sea level has risen throughout the altimeter record from 1993 to present with an accelerated rate of rise in the last 2 decades

14. There has been an acceleration in the rate of global sea level rise in the last 27 years partly due to increased rates of ice loss from Greenland and Antarctica. Variations around the trend (figure 3) are largely due to El Niño and La Niña, which can temporarily raise or lower sea level. As 2020 was a La Niña year, a small drop in sea level rise is likely due to shifting rainfall patterns which drop water onto land.

Figure 3. Global mean sea-level satellite altimeter records from 1993 to 2020



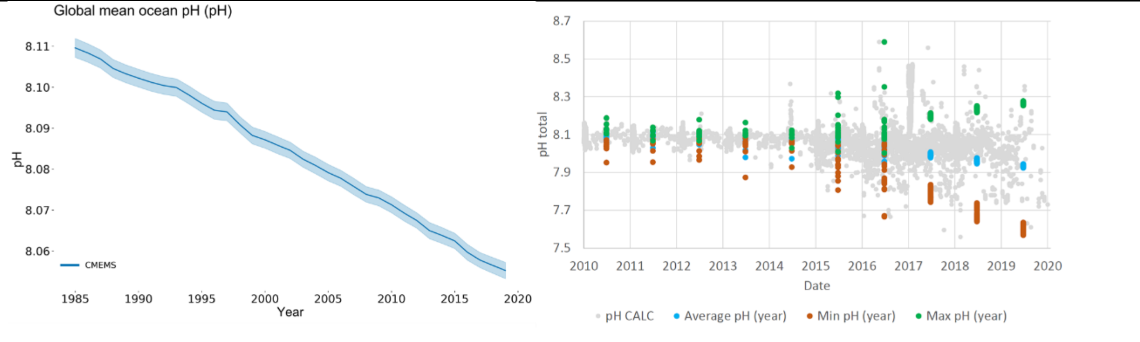
Source: Slide 5 of Mr. Kennedy's presentation; Cazenave,A et al, Observational Requirements for Long-Term Monitoring of the Global Mean Sea Level and Its Components Over the Altimetry Era, Frontiers in Marine Science (2019)

Ocean acidification has been steadily increasing, with ocean pH decreasing from approximately 8.11 to 8.06 since 1985

15. The ocean has absorbed around 23% of anthropogenic CO_2 emissions, decreasing ocean pH and causing ocean acidification. Ocean acidification affects many organisms and ecosystem services, threatening food security by endangering fisheries and aquaculture. From 1985 to 2019 global mean ocean pH declined from 8.11 to approximately 8.06 (figure 4).

16. Measurements indicate a high variability in pH from different monitoring sites showing the urgency for increased ocean monitoring to understand global trends, the combined effects of global and local variation, and the decreasing capacity of the ocean to absorb CO_2 from the atmosphere.

Figure 4. Ocean surface pH values



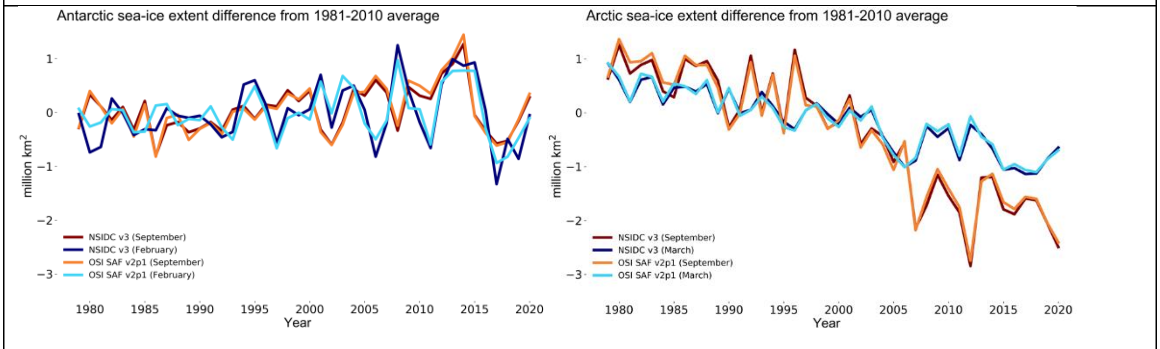
Source: Slide 7 of Mr. Kennedy's presentation

Surface pH values based on ocean acidification data submitted to the 14.3.1 data portal (http://oa.iode.org) for the time period from 1 January 2010 to 8 January 2020. Grey circles –calculated pH of data submissions (including all data sets with data for at least two carbonate parameters); blue circles –average annual pH (based on data sets with data for at least two carbonate parameters); red circles –annual minimum pH; green circles –annual maximum pH. Note that the number of stations is not constant with time (right). Global mean surface pH from E.U. Copernicus Marine Service Information (blue). The shaded area indicates the estimated uncertainty in each estimate

Sea ice extent has declined for every month of the year over the satellite record from 1979 to the present

17. Sea ice extent has declined for every month of the year over the satellite record from 1979 to the present. In the Arctic, the annual minimum sea-ice extent was the second lowest on record and record low sea-ice extents were observed in the months of July and October 2020. In the Antarctic, sea ice extent in 2020 remained close to the long-term average (figure 5).

Figure 5. Arctic and Antarctic sea ice extent difference from 1981-2010 average



Source: Slide 8 of Mr. Kennedy's presentation

Sea-ice extent difference from the 1981-2010 average in the Arctic (left) and Antarctic (right) for the months with maximum ice cover (Arctic: March, Antarctic: September) and minimum ice cover (Arctic: September, Antarctic: February).

Regional differences are observed in temperature rise in 2020, with new highs in many regions

18. Many regions experienced new temperature highs throughout 2020, with some variation due to La Niña (figure 6):

(a) Russia experienced record high average temperatures from January to August and in late June, a temperature of 38˚C was recorded in Siberia, provisionally the highest temperature ever measured north of the Arctic Circle;

(b) Parts of east Asia experienced heat waves between June and August. Hong Kong, for example, recorded several hot nights between 19th of June and 1st of July that broke records and Japan saw temperatures equalling the previous national record in August.

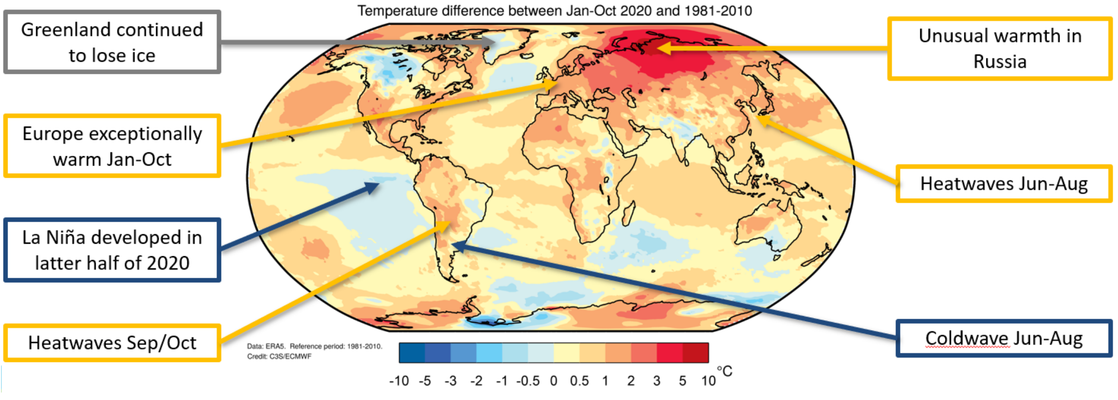
(c) Southern South America experienced record temperatures. Paraguay recorded new minimum temperatures for August, while farther north there were heat waves in September and October which caused record temperatures in some parts of Brazil.

(d) Europe was exceptionally warm from January through October, setting records for that period in 2020;

(e) Greenland continued to lose ice of about 152 gigatonnes in the 2019-2020 season despite approximately average temperatures at the surface;

(f) La Niña developed in the last half of 2020, causing below average annual temperatures in the eastern tropical Pacific. La Niña also typically leads to lower-than-average global temperatures.

Figure 6. Temperature difference between Jan-Oct 2020 and 1981-2010



Source: Slide 9 of Mr. Kennedy's presentation; Data from ERA5; Freja Vamborg, Copernicus Climate Change Service/ECMWF (2020)

Rising global temperatures have contributed to severe impacts around the world from weather and climate events compounded by COVID-19

19. Changing precipitation totals for January to September 2020 relative to the same period from 1951 to 2010 are shown in figure 7. Impacts in 2020 of these changes included:

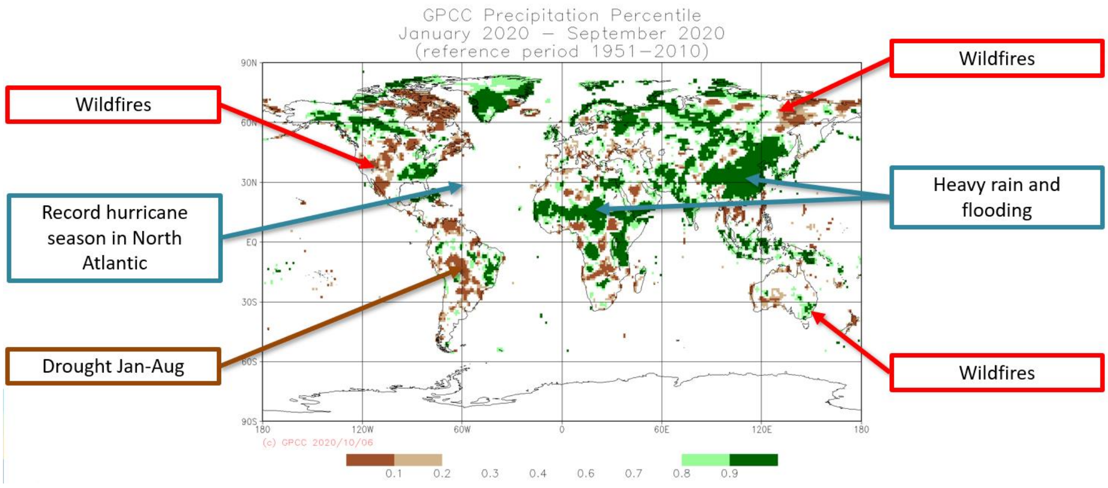
(a) Severe droughts in northern Argentina. Peru, Paraguay, and parts of Brazil, causing heavy agricultural losses;

(b) Extensive wildfires through many parts of northern Siberia, contributing to record high wildfire-related carbon emissions during the Arctic summer; the western US with California and Colorado experiencing their largest fires on record; and Australia in late 2019 and early 2020, before heavy rain in February helped to bring those fires under control;

(c) Heavy rain and flooding from the west coast of Africa, through the Sahel and to the greater horn of Africa; India had one of its two wettest monsoon seasons since 1994 and Pakistan recorded its wettest August on record. China saw heavy rainfall and floods of the Yangtze river basin, and other parts of Southeast Asia were also severely affected by heavy rain and floods;

(d) A record hurricane season in terms of the number of named storms forming in the North Atlantic. Out of the thirty of the hurricanes that formed, a record 12 made landfall in the US. The southeast of the US experienced unusually high rainfall totals due at least in part to some of those tropical storms.

Figure 7. Average precipitation from January to September 2020 relative to the same period of months from 1951 to 2010



Source: Slide 11 of Mr. Kennedy's presentation; Markus Ziese, Global Precipitation Climatology Centre, DWD (2020)

20. Information from UN agencies on impacts and risks associated with severe weather and climate events in 2020 show that impacts of extreme events were compounded by the COVID-19 pandemic which made disasters and responses to them even more difficult. For example:

(a) Data from the UNHCR and IOM shows that human displacement from 2010 to 2019 due to weather-related events triggered an estimated 23.1 million displacements each year. In the first half of 2020 alone, 9.8 million displacements occurred largely due to hydrometeorological hazards in South and Southeast Asia and the horn of Africa;

(b) The FAO and WFP reported that heavy rains on the Arabian Peninsula and in east Africa were associated with one of the largest desert locust outbreaks in 25 years across the horn of Africa. In Ethiopia alone, 200,000 hectares of cropland were damaged and over 356,000 tonnes of cereal were lost, leaving almost 1 million people food insecure.

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

21. Ms. Karina von Schuckmann presented on *The Earth Energy Imbalance: Where does the energy go?* – a study established by an international team of climate researchers from different institutions.[9] Further details were also provided in the poster (see paragraph 138 below).

22. All energy entering or leaving the Earth's climate system does so in the form of radiation at the top of the atmosphere. The difference between incoming solar radiation and outgoing radiation determines the net radiative flux at the top of the atmosphere.

23. Today the Earth climate system is out of balance, manifested as a positive Earth Energy Imbalance at the top of the atmosphere. This positive Earth Energy Imbalance can be directly attributed to the increases in carbon dioxide and other greenhouse gases in the atmosphere that originate from human activities.[10]

[9] Schuckmann, K. von, L. Cheng, M. D. Palmer, J. Hansen, C. Tassone, V. Aich, S. Adusumilli, et al. "Heat Stored in the Earth System: Where Does the Energy Go?" Earth System Science Data 12, no. 3 (2020): 2013–41. https://doi.org/10.5194/essd-12-2013-2020.

[10] IPCC. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by Core Writing Team, Rajendra K. Pachauri, and Leo A. Meyer. Geneva: IPCC, 2014. https://www.ipcc.ch/report/ar5/syr/.
IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways in the Context of Strengthening the Global

The Earth Energy imbalance is the most important measure of understanding the future of continued global warming and climate change.

24. The positive Earth Energy Imbalance is driving global warming and is responsible for the observed changes in the climate system, including ocean warming, ice loss, warming of the land, and warming of the atmosphere. The Earth Energy Imbalance is the portion of the forcing that the Earth has not yet responded to and provides a measure of how much heat is still in the pipeline. This makes the imbalance the most important measure of understanding the future of continued global warming and climate change.

During 2010-2018 the Earth Energy Imbalance was 0.87 ± 0.12 W/m^2

25. The global earth heat inventory has been established based on estimates of heat storage in the ocean, atmosphere, cryosphere and land (figure 8). The accumulation of heat in the earth system was found to amount to 358 +/- 37 zetajoules over the period from 1971 to 2018 resulting from an average positive energy imbalance of 0.47 +/- 0.1 w/m^2 (watts per metre squared) over the same period.

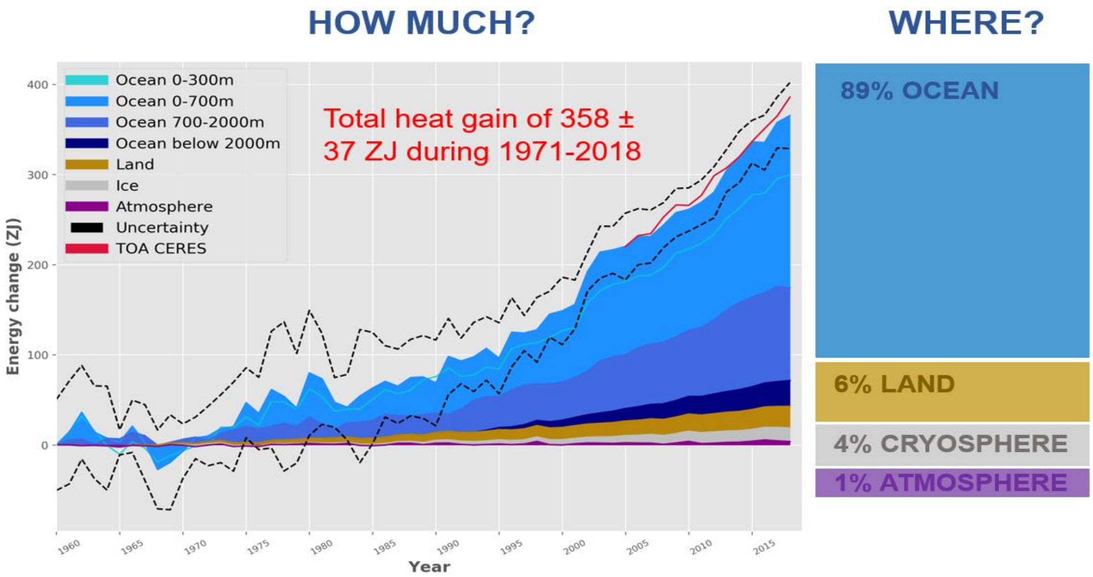
26. The global ocean stores 89% of the Earth Energy Imbalance, of which 52% is partitioned in the upper 700 metres, 28% at intermediate layers between 700 and 2000m depth and 9% in the deep ocean layer below 2000m depths. Atmospheric warming amounts to 1% of the Earth's heat inventory, the land heat gain was 6%, and the heat uptake by the cryosphere was 4%. These results show general agreement with previous estimates but are considerably higher for the cryosphere and land.

27. The link back to the Earth's energy imbalance can be obtained by calculating the rate of change of the Earth's heat inventory. Results show a positive Earth Energy Imbalance of 0.47 +/- 0.1 w/m^2 from 1971 to 2018 and 0.87 +/- 0.1 w/m^2 from 2010 to 2018.

28. Results from this study show that over the past decade, the Earth Energy Imbalance has continued at a comparable rate as reported during the Fifth IPCC assessment cycle.

29. Results also show that the Earth Energy Imbalance is not only continuing but increasing. It has doubled over the past decade.

Figure 8. Earth heat inventory (energy accumulation) in ZJ for the components of the Earth's climate system relative to 1960 and from 1960 to 2018.



Source: Slide 9 of Ms. von Schuckmann's presentation

1 ZJ =10^{21} J

Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty. Edited by V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, and J. Skea. Geneva: World Meteorological Organization, 2018. https://www.ipcc.ch/sr15/.

The amount of CO_2 in the atmosphere would need to be reduced from 410 ppm to 353 ppm to increase heat radiation to space by 0.87 W/m2, bringing Earth back towards energy balance

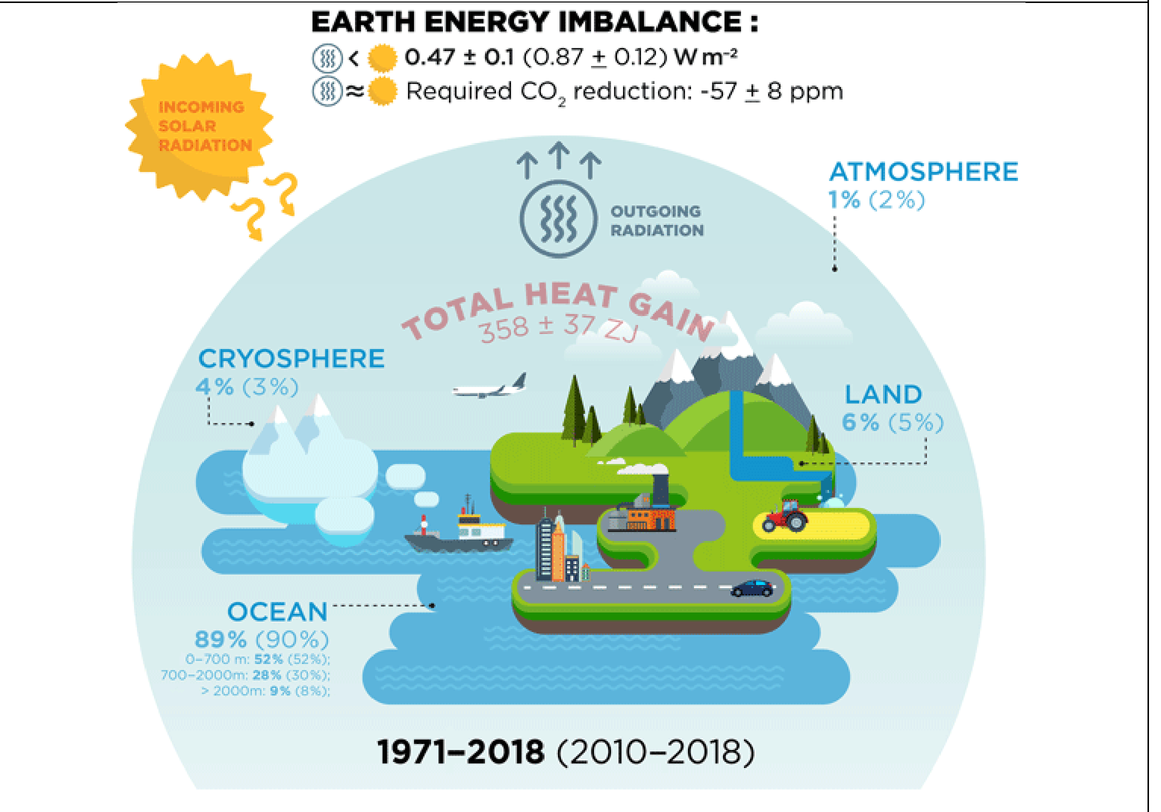
30. Stabilisation of the climate requires that the Earth Energy Imbalance be reduced to approximately 0 to achieve earth system quasi-equilibrium. The amount of CO_2 in the atmosphere would need to be reduced from 410 to 353 ppm to increase heat radiation to space by 0.87 w/m^2, bringing Earth back towards energy balance (figure 9).

31. Continued quantification and reducing uncertainties in the earth heat inventory can be best achieved through the maintenance of the current global climate observing system and its extension into areas with sampling gaps as well as establishing an international framework for concerted multidisciplinary research of the Earth heat inventory.

The Earth Energy Imbalance should be a vital metric for the global stocktake

32. The Earth Energy Imbalance is the most fundamental metric that the scientific community and the public must be aware of as it is a measure of humanity's success in controlling climate change. The research community working on the Earth Energy Imbalance call for inclusion of this metric in the global stocktake.

Figure 9. Earth Energy Imbalance



Source: Slide 12 of Ms. von Schuckmann's presentation

3. Closing the global carbon cycle and closing the emissions gap

33. Mr. Pierre Friedlingstein and Ms. Anne Olhoff presented on closing the global carbon cycle and closing the emissions gap.

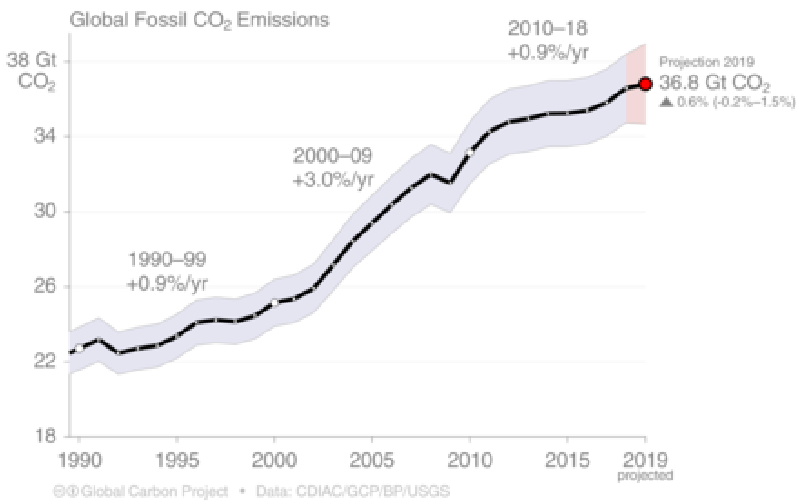
34. Mr. Friedlingstein outlined the latest information from the Global Carbon Project (GCP) which assesses the budget of the global carbon cycle every year[11]. The GCP is also developing regional carbon and GHG budgets through the Regional Carbon Cycle

[11] Available at https://www.globalcarbonproject.org/carbonbudget/index.htm.

Assessment and Processes study 2 (RECCAP2) for 10 different regions over land and five over the ocean for the last decade.

35. As mentioned above, CO_2 concentrations in the atmosphere have reached record levels (see paragraph 12). Atmospheric CO_2 concentrations have increased by 2.3 ppm per year over the last decade. Drivers of changes in the global carbon cycle are anthropogenic CO_2 emissions, primarily emissions from fossil fuel combustion with emissions from land use changes accounting for about 15% of the total. Fossil fuel emissions have been increasing each year over the last 30 years up to 2019, with exceptions such as the global financial crisis (figure 10).

Figure 10. Global annual carbon dioxide emissions 1990-2019



Source: Slide 3 of Mr. Friedlingstein's presentation

The impact of the Covid-19 associated lockdown on 2020 annual emissions is about 6-7% but the direct effect on atmospheric CO_2 is negligible.

36. Mr. Friedlingstein presented the outcomes from three different studies[12,13,14] examining the impact of the COVID-19 pandemic and associated lockdown on global emissions and the environment. For these studies, two sets of information were combined – time series of regions impacted by different severities of lockdowns, and proxy data showing the impact of lockdowns on different sectors. These data were then used to estimate global fossil fuel emissions.

37. For example, in April 2020 over 90% of fossil fuel emitting regions were in some form of lockdown. Aviation emissions decreased by 75%, surface transport by 50%, power generation by 15% and industrial sectors by approximately 35%. Emissions from residential buildings increased by 5%.

38. Data collected showed that daily emissions for the first part of 2020 decreased about 17%, reaching a CO_2 emission level that was last observed 15 years ago. Peak emission reductions for individual countries in spring 2020 reached 26%, with the surface transport sector being most affected on average.

39. For the latter part of 2020, the studies projected a 6 to 7% decrease of global CO_2 emissions relative to 2019. Although this decrease is unprecedented, it is insignificant compared to the CO_2 accumulation in the atmosphere. A reduction of 6 to 7% CO_2 roughly corresponds to one gigatonne of carbon. If this is compared to the accumulated emissions of

[12] Available at https://www.nature.com/articles/s41558-020-0797-x.
[13] Available at https://www.nature.com/articles/s41558-020-0883-0.
[14] Available at https://www.nature.com/articles/s41467-020-18922-7.

around 600 gigatonnes so far, the direct effect on atmospheric CO_2, on warming, and on the climate is negligible.

Government actions and economic incentives post COVID-19 crisis will likely influence the global CO_2 emissions path for decades to come.

40. The studies show the great opportunity in emissions reduction opportunities in the transport sector and greening of the electrical grid. Changes in active mobility in big cities in response to covid-19 crisis could partially become permanent with great benefits.

41. Therefore government actions and economic incentives post COVID-19 crisis will likely influence the global CO_2 emissions path (and hence warming) for decades to come. A "green deal" recovery route would lead to significant reduction in warming compared to returning to "business as usual."

42. Ms. Olhoff presented an outline of implications of global emission trends for the Paris Agreement, reporting from the 2019 emissions gap report[15], and looking ahead to the 2020 emissions gap report, which was published shortly after this event on 9 December 2020.[16]

43. The emissions gap is the difference between the global emission level which will result if countries implement their current mitigation pledges under the NDCs, and the levels that science tells us are required to limit global warming to below 2˚ or 1.5˚ C by the end of this century.

Current NDC pledges are not enough to limit global temperature rise to 2°C

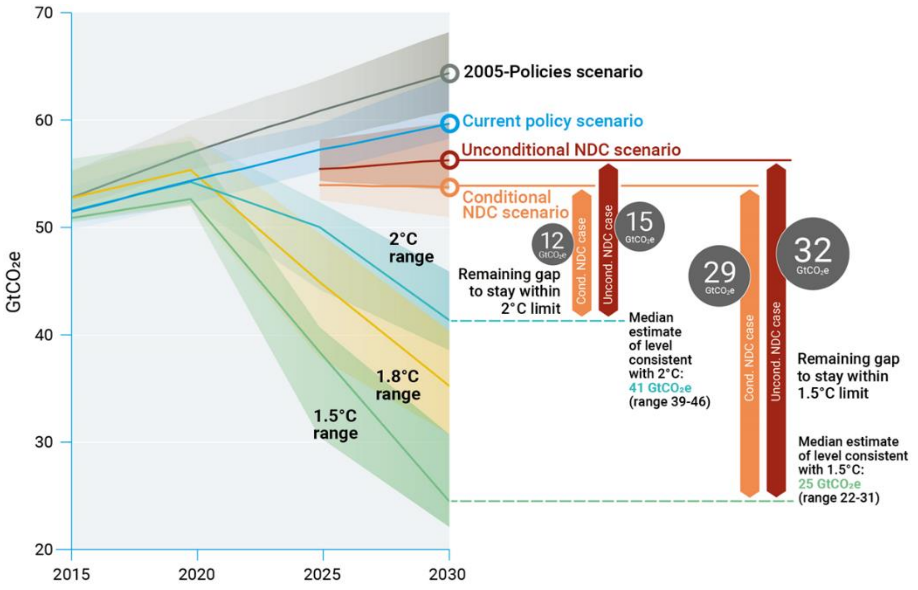
44. The UNEP assessment of the emissions gap and opportunities to bridge it has been published annually since 2010. Figure 11 shows the global GHG emissions under different policy scenarios, expected emissions reductions if unconditional and/or conditional NDCs were met, and the gap in emissions between those and pathways limiting global warming to below 2°C and 1.5°C. For example if NDC conditions are met, a further 12 - 15 Gt CO_2 equivalent decrease is required to limit warming to 2˚C, and 29-32 Gt CO_2 equivalent to limit warming to 1.5˚C.

45. Emission levels resulting from NDCs are 4 to 6 GtCO2e/yr lower than the current policy trajectory in 2030, but the remaining Gap is in the order of 12 to 15 GtCO2e/yr compared with 2 ˚C scenarios and 29 to 32 GtCO2e/yr compared with 1.5 ˚C

46. Implementing unconditional NDCs will likely result in a temperature increase of 3.2˚C by 2100, or 3˚C if the conditional NDCs are also implemented. Every year, postponed action would require deeper and faster cuts in emissions, jeopardizing the potential to achieve the goals of the Paris Agreement. Bridging the emissions gap will require that countries increase their NDC ambitions threefold to limit warming to 2°C and more than fivefold for the 1.5°C goal

[15] Available at https://www.unep.org/resources/emissions-gap-report-2019.
[16] Available at https://www.unep.org/emissions-gap-report-2020.

Figure 11. Global GHG emissions under different scenarios and the emissions gap by 2030



Source: Slide 5 of Ms. Olhoff's presentation

A low-carbon pandemic recovery could cut 25 per cent off GHG emissions expected in 2030, based on policies in place before COVID-19

47. Ms. Olhoff concluded by summarising some developments in 2020 and elements of the 2020 emissions gap report.

48. The COVID-19 pandemic-associated policy responses have implications not only for 2020 but also in terms of future levels of GHG emissions and the ability to bridge the gap. Due to slow progress in submission of updated NDCs, little analysis has been possible although less than 1% decrease in the expected global emissions by 2030 is identified from updated NDCs. The 2020 report highlighted the opportunities for GHG reduction if governments invest in a low-carbon pandemic recovery.

4. Covid-19 imprints on the short- and long-lived chemical species in the troposphere

49. Mr. Prabir Patra presented on COVID-19 imprints on the short- and long-lived chemical species in the troposphere during 2020.

Primary (NO_2) and secondary (PM2.5) short-lived air pollution species showed large decreases over different parts of the globe in 2020 depending on the timing of lockdowns

50. The COVID-19 pandemic caused a large impact on our lifestyles and industrial activity. Short-lived chemical air pollution species such as NO_2 (Nitrous Dioxide) and PM 2.5 (inhalable particulate matter of 2.5 micrometres and smaller), except for O_3 (ozone) as observed from satellites, showed large decreases over different parts of the globe corresponding with the timing of lockdowns. Time-series observations were analysed in New Delhi and its surroundings to understand the effects of lockdown on air pollution and the tropospheric radiation budget.

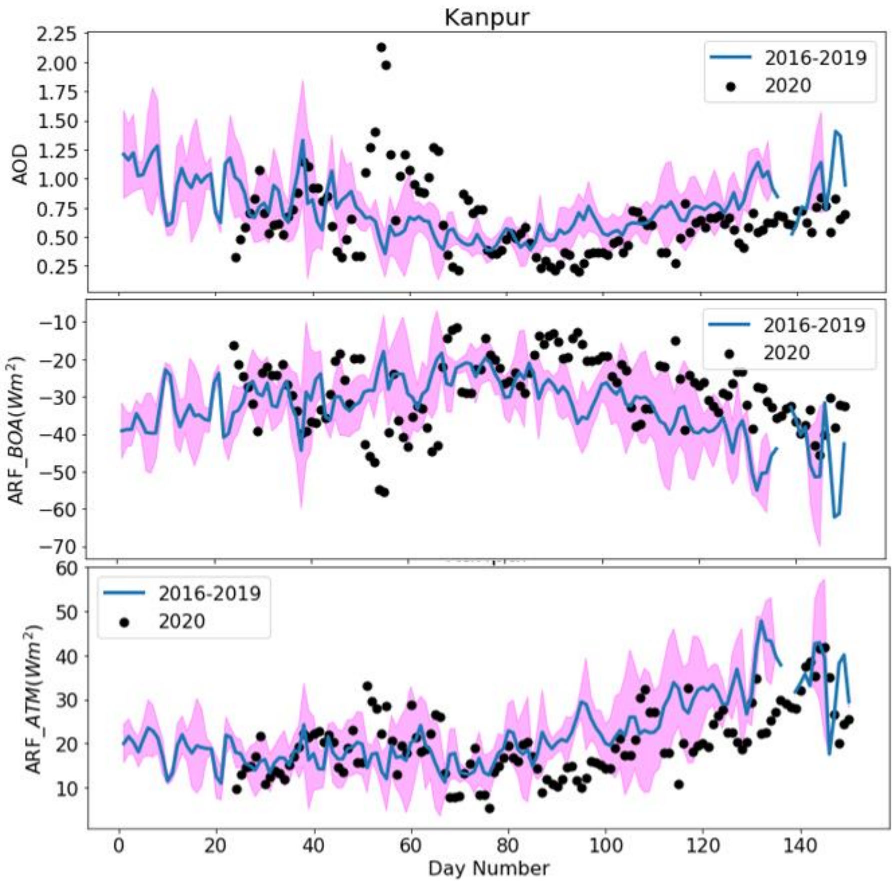
51. Time series from March to the middle of April showed a drop in the concentrations of PM 2.5, coinciding with the March lockdown. Daily variability of PM 2.5 also decreased during this period, suggesting an attributable effect of the lockdown on PM 2.5. Lower concentration of PM 2.5 relative to before the lockdown were also measured after the lockdown ended. Concentrations in all locations were still over the threshold set by international standards of air quality.

52. Using AERONET[17] data from the city of Kanpur, a time series of the daily mean aerosol optical depth at 440 nanometres was constructed (figure 12). The time series shows a decrease in aerosol optical depth over Kanpur in 2020 compared to the period from 2016 to 2019. These observations can also be used to calculate the bottom-up atmosphere aerosol radiative forcing, which revealed a higher radiative forcing in March of 2020 compared to the previous year. This also has a large impact on climate forcing, which may change atmospheric circulation and precipitation as aerosols have a strong forcing effect at the local and regional scale.

53. Air quality index data from several locations in India show that many sites exceeded air quality thresholds for national and WHO standards, even during lockdowns with implications for policymaking concerning the improvement of conditions in cities in developing nations.

[17] See https://aeronet.gsfc.nasa.gov/.

Figure 12. Time series: of daily mean aerosol optical depth (AOD) at 440nm (top); of 24 hours mean aerosol radiative forcing at the bottom of the atmosphere (BOA) (middle); and of 24 hours mean atmospheric forcing (bottom)



Source: Slide 4 of Mr. Patra's presentation; Khatri et al., Unpublished; Data from AERONET, IIT-Kanpur

While the detection of mean concentration changes were challenging for the long-live species CO_2 and CH_4, changes were detectable in the ratio of their synoptic variabilities

54. Carbon dioxide responds differently to small short-term changes in emissions compared to short-lived species. The global mean CO_2 growth rate is about 2 ppm per year with a large interannual variability (up to 70%) due to biospheric climate feedbacks. Therefore, detecting the COVID-19 effect on emissions using satellite and surface measurements is challenging. However, using inventory emission scenarios and model simulations, a 30% reduction in fossil fuel CO_2 emissions from China was detected during February to March 2020. (A 10% reduction of global fossil fuel emissions would result in a decrease of about 0.5ppm of the global average CO_2 growth rate.)

55. Observations were unlikely to detect the small signal caused by the change in CO_2 emissions during lockdown, so a model was used to simulate a 30% change in emissions over China and determine the impact of an emission decrease on daily variability. Results show approximately a 2ppm change in variability near the surface, but not at height.

56. Data from the Mauna Loa observatory was also used to simulate a 30% emission reduction in China and produced a >1 ppm XCO_2[18] change in background concentrations. This is a very small change in terms of the sensitivity of currently available instruments.

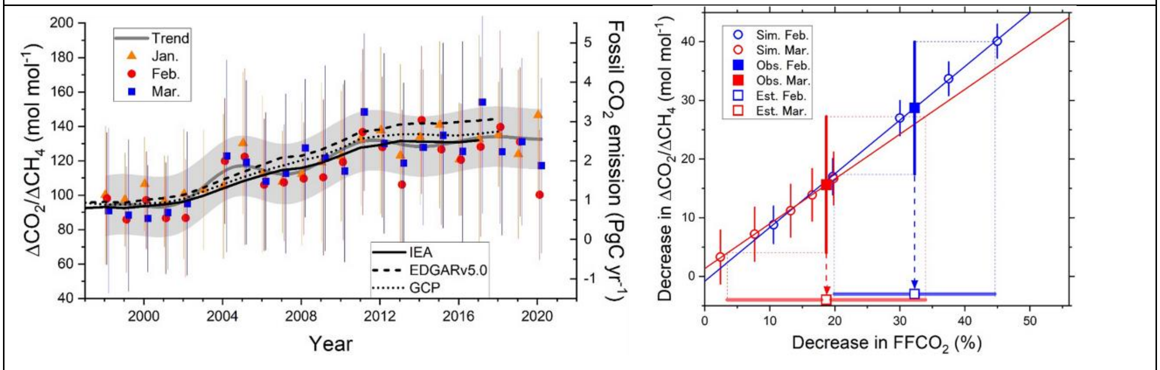
[18] The average value in ppm of CO_2 at heights in a column above a location, measured via satellite.

Some signals over 1 ppm would be present in satellite GOSAT[19] and OCO-2[20] data if the background could be defined.

57. Sub-hourly, continuous measurements of CO_2 and CH_4 have been made at Hateruma in Japan since 1996. This allowed us to look at the variability of the CO_2 concentration. In February and March of 2020 CO_2 variability was below that observed in 2019. Emissions of methane were not affected by the lockdown.

58. The data from CO_2 and CH_4 concentrations can be combined to remove the effect of transport and other effects on CO_2 concentration variability. This low variability allows the validation of observations from the last 20 years. This can be used as an input to model simulations that reveal the change in CO_2 emissions in China. In February, a decrease of 30 to 35 percent decrease in fossil fuel CO_2 emissions is estimated in China based on observations at Hateruma (figure 13).

Figure 13. Monthly average ΔCO2/ΔCH4 ratios and FF-CO2 for Jan-Feb-Mar to estimate 2020 emission reduction from China during lockdown



Source: Slide 8 of Mr. Patra's presentation

$FFCO_2$ = fossil fuel carbon dioxide

High-quality long-term surface observations without data gaps are indispensable for accurately tracking emission mitigation policies

59. Mr. Patra concluded that the impacts of the COVID-19 lockdown on short- and long-term species of gases near the earth's surface was shown to depend on their behaviour and the behaviour of sourcing sectors as driven by human activity. Short-lived air pollutants (except for ozone) showed immediate decreases in concentration following lockdown. These results help us to understand climate impacts on a local and regional scale although more modelling is required to understand this feedback in the system.

60. Analysis of CO_2 also highlights the importance of long time series without observation gaps for the development of mitigation strategies and accurately tracking mitigation policies.

5. 10 New Insights in Climate Science

Future Earth updated on preparation for their annual synthesis of ten fields within climate science where there have been significant advances in understanding

61. **Mr. Erik Pihl** provided a brief update on the key messages from the 2020 publication of ***"Ten new insights in climate science"*** report, which was published following the Earth Information Day on 27 January 2021.[21] The report highlights the advances in climate related research in 2020 and is written to be accessible to policymakers, with the ten insights covering the following points:

---

[19] Greenhouse gas Observing Satellite. See https://earth.esa.int/eogateway/missions/gosat.
[20] Orbiting Carbon Observatory 2. See https://www.nasa.gov/mission_pages/oco2/index.html.
[21] Available at: https://futureearth.org/2021/01/27/top-10-insights-in-climate-science-in-2020-selected-by-57-leading-global-researchers/.

(a) **Early warning flags have been raised concerning the Equilibrium Climate Sensitivity (ECS) to carbon dioxide**, with models results finding higher sensitivities. The report will detail this and the likely new higher ECS range.

(b) **'Abrupt thaw' processes related to permafrost thaw in a heating climate have not yet been included in global climate models.** While this phenomenon is not new, there have been recent advances in understanding the quantification of these processes that raise causes for concern.

(c) The ability of land ecosystems to take up carbon dioxide – the land sink, has been increasing steadily due to plant growth as atmospheric carbon dioxide increases and fertilizes planets. **The report will describe critical factors related to the enhancement of the land sink and climate feedbacks such as wildfires and aridification that affect the carbon balance in land ecosystems**.

(d) **Water crises are at risk of being worsened due to climate change, increasing water scarcity, drought, poor water quality, and flooding**. The report will detail some of the latest research on changes affecting precipitation and the socioeconomic drivers behind water crises, as well as the possible policy implications of these.

(e) **Recent research has shown that the impacts of climate change including sea-level rise, coastal erosion, extreme weather, and wildfires will also affect mental health.**

(f) The COVID-19 pandemic has directly impacted socioeconomic activity with resultant reductions in greenhouse gas and air pollution. **The report examines how much of the stimulus spending intended to revive economic post-pandemic activity is oriented towards green measures.**

(g) **There are also lessons to be learned from the COVID-19 pandemic in terms of governing transboundary risks**, how local governments have reacted to this event, and what approaches will be needed for effective governance in the future.

(h) **The report details the latest assessments of the societal costs of maintaining or transitioning away from existing fossil fuel fired infrastructure** and outlines **empirical evidence for decoupling global emissions from economic growth.**

(i) Cities are at the forefront of innovation and adaptation of technologies. **Sectors and actors driving urban electrification and the required system changes are discussed.**

(j) Finally, **the report describes an analysis on how rights-based climate litigation has been used to urge action**, examining the changes in who brings forth cases, the interests they represent, and the claims that they put forth.

6. The Status of the Global Climate Observing System: Plans and progress, indicators and impacts

62. Mr. Anthony Rea provided an update on the status of the Global Climate Observing System (GCOS). Further information was also provided in the poster on the Status of Global Climate Observations: Update from GCOS (see paragraph 146).

Observation of essential climate variables and the archival and accessibility of data have improved but more support is needed

63. Over the past year there have been significant improvements to the observation of Essential Climate Variables (ECVs), and in the archival and accessibility of data including:

(a) New satellite observations from Aeolus[22], measuring wind, and from TROPOMI[23], measuring atmospheric composition.

(b) Ocean data from Argo floats and drifters.

[22] See https://www.esa.int/Applications/Observing_the_Earth/Aeolus.
[23] See http://www.tropomi.eu/.

(c) The joint CEOS/CGMS ECV inventory, the Copernicus Climate Change (C3S) service and the NOAA National Centres for Environmental Information (NCEI).

(d) C3S and NOAA are also collaborating on a new database of all the meteorological surface parameters measured from standard meteorological stations.

64. The WMO has agreed to support the implementation of the GCOS surface reference network which will lead to improved accuracy of in-situ atmospheric observations. The WMO Global Baseline Observing System (GBON) is a new type of framework to support the exchange of core meteorological and climatological data by WMO members. If fully implemented, it would lead to significant improvements in short-term modelling, reanalysis, and hence climate modelling. GBON has been agreed by the WMO infrastructure and will go to WMO congress in 2021. WMO is spearheading an initiative to support the implementation of GBON through the Systematic Observing Financing Facility (SOFF).

65. There have also been successes in land surface observation. New methods have been developed to assess uncertainty and for quality assurance and control, particularly of satellite observations. Greenhouse gas fluxes derived from atmospheric composition measurements have been demonstrated globally, plans to improve observations of atmospheric composition to allow estimates of greenhouse gas fluxes have been made, and C3S is implementing their plan for CO_2 Monitoring, Verification, and Support (MVS) capacity. GCOS is considering climate cycles (combining energy balance, water and carbon cycles, and the biosphere) to integrate observations across domains while identifying gaps and improving climate data and understanding.

66. Ocean observation has been furthered in particular by biogeochemical Argo[24]. This builds on the strength of the existing Argo float network while expanding the range of parameters that are measured, including six essential biogeochemical and bio-optical parameters. The sensor network is the current best method of collecting temporally and vertically resolved observations of biogeochemical properties throughout the entire ocean. All data from the network is freely available from within 24-hours of transmission. Several commitments and programs will increase the network of floats soon.

GCOS are currently reviewing the essential climate variables and preparing the latest GCOS status report

67. GCOS are undergoing an internal review of the Essential Climate Variables which includes a public consultation. Results will be included in the next GCOS implementation plan.

68. The latest GCOS status report reviewing the adequacy of observations of each ECV and the progress of the GCOS implementation plan 2016 is being drafted. The report should be published in summer 2021.

69. **The GCOS-WCRP[25] Climate Observations Conference, scheduled for 12 to 14 October 2021** in Darmstadt, Germany, aims to assess how well the current global climate observing system supports the current and near-term user needs for climate information. The GCOS implementation plan will be drafted in 2021 based on the GCOS status report, GCOS-WCRP Climate Observations Conference and IPCC findings. There will be a public review in early 2022 for the revised implementation plan, which will be published in May 2022.

GCOS areas of work aim to strengthen Earth observation, its coordination, ECV and indicator requirements and their applications

70. Mr. Rea highlights significant ongoing areas of work within GCOS.

(a) Inputting climate needs into the WMO GBON to further integrate activities and align work processes;

(b) Improving data on lightning and thunder days to monitor changes in convection;

[24] See https://biogeochemical-argo.org/.
[25] World Climate Research Programme, see https://www.wcrp-climate.org/.

(c) Establishing reference networks to improve understanding of uncertainty and network operation. For example, the GCOS surface reference network (GSRN), which will initially cover atmospheric and terrestrial variables;

(d) Improving data centres and data accessibility;

(e) Considering which globally made observations are useful for adaptation and mitigation and how well the existing ECV requirements meet these needs, especially for monitoring extremes;

(f) Identifying indicators at the global level that monitor systematic changes occurring in the biosphere;

(g) Ongoing work to improve network coordination and operation, especially in the GCOS atmospheric networks and Global Terrestrial Networks.

Significant action is still needed to improve and sustain observations, and address challenges and gaps in observation

71. Challenges in GCOS' work include:

(a) Improving the sparse observations across some areas such as Africa, South America, Southeast Asia, the Pacific and Southern oceans, and Antarctica;

(b) The need for enhanced data rescue projects to ensure that historic archives are freely available;

(c) Strengthening the fragile observing systems in many areas of the world;

(d) Sustainability and long-term continuity of some satellite missions such as AURA[26] and Aeolus. These satellites are subject to continuation of research funding, making them and their cloud radar and lidar vulnerable;

(e) Sustainability of many ocean observation and some terrestrial observation projects due to their reliability on continued research funding rather than sustained operational budgets. Some global data centres do not have long-term funding, and these are essential to establish long-term time series and quality assurance for some ECVs, as well as for constructing data sets from different sources;

(f) Open-access to all relevant observation data so that it is freely exchanged and freely available;

(g) Assurance of the long-term viability of some global data archives of in-situ data, particularly those based in research settings.

72. Gaps and sustainability in ocean observations are particularly significant. Research and development funders tend to fund science for solutions rather than for monitoring and understanding the climate issue. This creates a tension between the desire to do new science and the need to sustain ongoing observations programs that are essential to understand and predict the ocean and climate systems across scales, assess risks, develop adaptation measures, and track the effect of mitigation.

73. A recent report by C3S and the EEA found that ocean observing systems are up to 70% funded by short-term research grants, with direct implications for sustaining ocean observations. This is an issue to some extent also in atmospheric composition and terrestrial observations, and an issue that must be addressed as a global community.

Summary of Discussions

74. **EEI is not a familiar metric for the public, what communication challenges are envisioned in using this as a key reporting metric on the state of the climate system?**

Ms. von Schuckmann: There is a general challenge on how to communicate observation science and data to the wider public. There are other experts working in different

[26] See https://earth.esa.int/web/eoportal/satellite-missions/a/aura.

channels in order to further communication. The Earth Information Day is a great opportunity to bring the message forward.

75. **Which are the most at-risk observations** underpinning **the information presented in the WMO State of the Climate Report?**

Mr. Kennedy: There are some observations that need to be developed, for example there are large gaps in the measurements of ocean pH and precipitation relative to the scales of these phenomena. The WMO State of the Climate in Africa[27] report highlighted some areas in the continent where precipitation measurements are needed.

76. **How is heat of transformation or latent heat** included **in calculations of the EEI, particularly for the cryosphere?**

Ms. von Schuckmann: Within each component of the cryosphere, energy uptake is dominated by that associated with melting; including both the latent heat uptake and the warming of the ice to its freezing point. As a result, the energy uptake by each component is directly proportional to its mass loss. For consistency with previous estimates,[28] we used a constant latent heat of fusion of $3.34x10^5$ J/kg, a specific heat capacity of $2.01x10^3$ J/kg C and an ice density of 920 kg/m^3.

Mr. Kennedy: The record of mass loss from Greenland can be estimated using the GRACE and GRACE-FO satellites. Gaps in records like this, and problems with individual satellites as was experienced with GRACE lately, indicate the "fragility" of sustaining long term data records and the value of these records which are ultimately based on only a small number of satellite instruments.

77. **Do we have robust measurements of snow cover change?**

Mr. Kennedy: We have satellite-based records of snow cover. The longest extend back to the late 1960s. As to their robustness, I am not sure. The ESA CCI snow project validates their product (covering a more recent period) using a variety of methods.

Snow cover has been reported previously in the WMO statement on the state of the global climate previously and in the IPCC reports. The key climate indicators section of the WMO statement is based on the selection of these seven indicators made by GCOS. Snow extent is a "secondary" indicator under this scheme, and is definitely something that is considered.

78. **What are the largest uncertainties in the** GCP's **work? Would improvements in observational data help to reduce uncertainties here?**

Mr. Friedlingstein: Our main uncertainty is in the absence of very recent data, "near real time" estimates of CO_2 emissions for most countries across the world. At best we have estimates with 3 months lag, but usually it's a one-year lag.

79. **What is the effect of the heat that is being stored in the Earth via the energy imbalance and how is this related to the 2°C limit of the Paris Agreement?**

Ms. von Schuckmann: The Earth Energy Imbalance represents the difference between the applied radiative forcing and Earth's radiative response through climate feedbacks associated with surface temperature rise. Thus, the EEI and surface temperature rise are intrinsically linked. For pathways of CO_2 reduction, and implications on different pathways, this is outlined in the IPCC special report on 1.5.[29]

80. **Are you aware of Earth Observations-based studies** that **validate the 6-7% drop in atmospheric CO_2 estimated for 2020 from activity data? What is your view on the observations requirement to permit this?**

Mr. Friedlingstein: A reduction of 6-7% will be hard to detect in atmospheric CO_2. The natural variability of the carbon cycle (such as 2020 being a La Niña year) has a large impact on atmospheric CO_2, which will largely mask the direct effect of the observed reductions in emissions. Long term monitoring of atmospheric CO_2 and other components

[27] Available at https://library.wmo.int/index.php?lvl=notice_display&id=21778.
[28] See https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter06_FINAL.pdf.
[29] Available at https://www.ipcc.ch/sr15/.

(for example, ocean photosynthetic CO_2 and ocean interior CO_2) are key to help separate natural variability from long term changes in CO_2 emissions. In parallel, monitoring of other gases such as NO_2 and CO will help to understand changes in emissions.

81. **Is the UK House of Commons Science and Technology Committee correct in saying that "In the long-term, widespread personal vehicle ownership does not appear to be compatible with significant decarbonisation."?**

Mr. Friedlingstein: I would say that it is largely correct. Large scale zero carbon public transport will be more energy efficient than individual vehicles (even electric ones).

82. **Do we have adequate monitoring in place to track abrupt landscape changes, such as permafrost thaw, over the large Arctic region?**

Mr. Rea: Monitoring is not adequate enough although there are laudable efforts in some countries. More details are available from the Global Terrestrial Network for Permafrost website.[30]

83. **What can be done to improve observations in areas where** data **is scarce?**

Mr. Rea: We can make greater use of satellites. but in situ observations require significant resources and this can only come from governments.

[30] Available at https://gtnp.arcticportal.org/resources/maps/12-resources/37-maps-boreholes.

B. Theme 2. Recent advances in Earth observation technology and data processing to support decision making

84. Presenters for Theme 2 included Mr. **David Crisp**, Joint CEOS/CGMS WGClimate[31] GHG Task Team; Mr. **Richard Engelen**, Copernicus Climate Change Service[32] (C3S); Mr. **Phil DeCola**, Science Team Chair, Integrated Global Greenhouse Gas Information System[33] (IG3IS), WMO; Ms.**María José Sanz Sánchez**, Global Forest Observations Initiative[34] (GFOI), GEO; Ms. **Mariane Diop Kane**, Programme Officer, Regional Office for Africa, WMO / Global Framework for Climate Services[35] (GFCS); Ms. **Catherine Nakalembe**, Group on Earth Observations Global Agricultural Monitoring[36] (GEOGLAM); and Mr. **Louis Celliers,** Group on Earth Observations (GEO) Blue Planet[37].

1. Recent advances in Earth observation technology and data processing to support decision making on mitigation

85. Mr. David Crisp presented on recent advances in Earth observation technology and the opportunities provided by combining bottom-up and top-down inventory methods.

Top-down atmospheric inventories will be a useful complement for informing the bottom-up inventories being compiled to report progress on the Paris Agreement for emissions reductions, and for the global stocktake

86. Bottom-up statistical inventories, used by the Global Carbon Project and the IPCC, estimate greenhouse gas emissions from the number of tons of coal or barrels of oil consumed by specific sectors such as commercial, residential, industrial or transportation sectors. They estimate emissions from the land using statistics such as the number of acres converted from forest to agriculture or lost to desertification or flooding. These techniques usually provide accurate estimates for fossil fuel emissions, but are somewhat less reliable for tracking changes in emissions from other sectors. They also sometimes miss emissions changes associated with rapid changes in the natural carbon cycle due to severe weather or climate change.

87. Top-down atmospheric inventories complement bottom-up statistical inventories by providing an integral constraint on emissions. They directly measure the carbon dioxide or methane concentrations in the atmosphere at high spatial and temporal resolution, and then use an inverse modeling system to derive the emissions distribution needed to maintain the observed concentrations in the presence of the winds.

88. Top-down inventories are less source specific than bottom-up statistical inventories, but are ideal for identifying emerging emission hot spots and rapid changes in large emission sources. For example, the COVID-19 related reductions in carbon dioxide emissions have now been detected by the Orbiting Carbon Observatory 2 and Japan's GOSAT. They also track changes in emissions from the natural carbon cycle resulting from human activities or climate change such as deforestation or severe weather and climate change.

89. Scientists believe that top-down atmospheric inventories will be useful for informing the bottom-up inventories being compiled to track nationally-determined contributions (NDCs) for emissions reductions and more generally for the global stocktake.

90. To implement top-down inventories we need accurate measures of carbon dioxide, methane, and other greenhouse gases at high spatial resolution around the globe. Ground-based and airborne measurements from the WMO’s Global Atmosphere Watch programme (GAW)[38] and its partners provide the most accurate estimate of greenhouse gas

[31] See https://ceos.org/ourwork/workinggroups/climate/.
[32] See https://climate.copernicus.eu/.
[33] See https://ig3is.wmo.int/en/welcome.
[34] See http://www.fao.org/gfoi.
[35] See https://gfcs.wmo.int/.
[36] See https://earthobservations.org/geoglam.php.
[37] See https://geoblueplanet.org/.
[38] See https://community.wmo.int/activity-areas/gaw.

concentrations and their trends on global scales. The capabilities of these measurement systems are improving as they incorporate new measurement technologies and as the networks expand, but the resolution and coverage required to track emissions inventories on national and smaller scales has not yet been achieved.

91. Space-based measurements of carbon dioxide and methane are being collected from a growing fleet of satellite sensors. These space-based measurements are less precise and accurate than their ground-based counterparts but complement those systems with higher resolution and greater coverage of the globe. Space-based systems are expected to expand rapidly in the future as new satellites come online such as the Japanese GOSAT-GW expected in early 2024, and the Copernicus CO2M constellation in 2026.

Ground-based, airborne, and space-based measurements are now being combined in atmosphere inverse models to provide high-resolution global maps of carbon dioxide and methane emissions and to understand how to integrate top-down methods with bottom-up inventories

92. Ground-based, airborne, and space-based measurements are now being combined in atmosphere inverse models to provide high-resolution global maps of carbon dioxide and methane emissions and to understand how to integrate top-down methods with bottom-up inventories. The CEOS/CGMS WGClimate Greenhouse Gas Task Team is coordinating efforts among member agencies to:

(a) Work with the atmospheric CO2 measurement and modeling communities, stakeholders and national inventory compilers to define requirements and plans for atmospheric flux inventories;

(b) Produce pilot atmospheric CO_2 and CH_4 flux inventories by the end of 2021, in time to inform the 2023 global stocktake (GST);

(c) Use lessons learned from this prototype flux product to refine requirements needed to implement a purpose-built, operational, atmospheric inventory systems for use in future stocktakes.

93. Mr. Richard Engelen presented on the integrated system approach for monitoring anthropogenic emission being developed by the European Commission Copernicus service as a contribution to the enhanced transparency framework. He highlighted the huge potential for Earth observations from both satellite- and ground-based instruments to contribute to more comprehensive outlooks on anthropogenic emissions and mitigation actions.

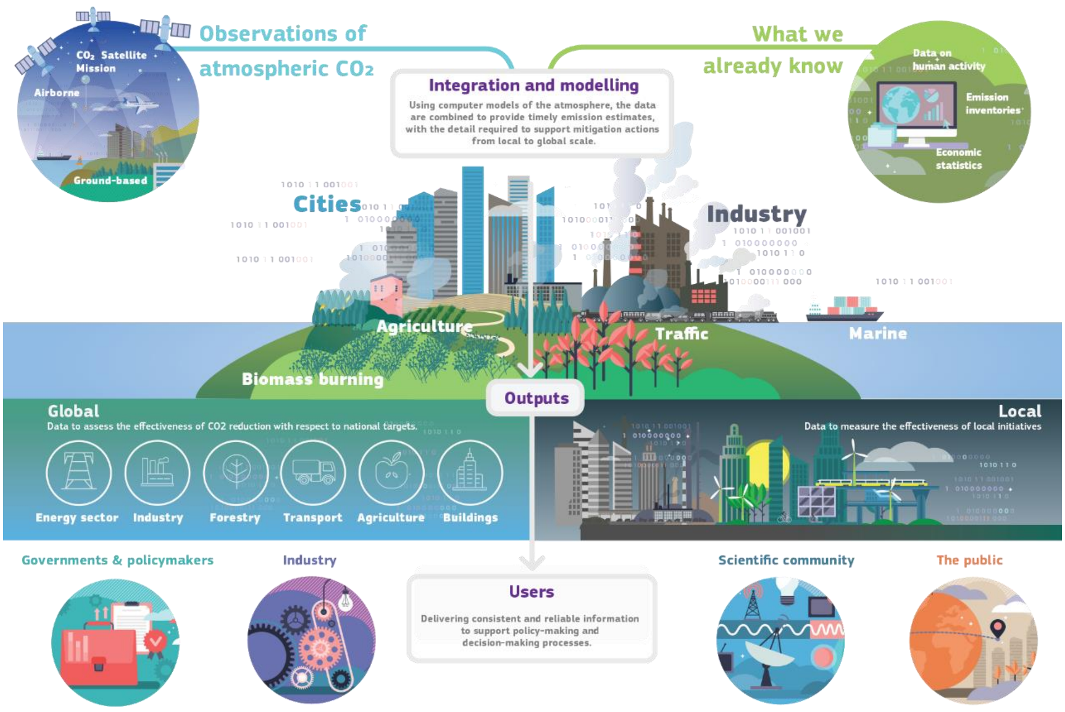
Copernicus is developing an integrated system approach, combining different information sources based on the latest science, to support Parties' emissions reporting through the Enhanced Transparency Framework

94. He noted that observations generally do not measure emissions directly. Observations measure atmospheric CO_2 and methane concentrations which result from emissions, but which are strongly affected by natural fluxes.

95. The European Commission is combining observations with state-of-the-art modelling in an Integrated System approach to provide added value in terms of timeliness, spatial and temporal detail global consistency, as is done in weather forecasting and climate reanalysis (figure 14). This will be implemented through the Copernicus atmosphere monitoring service and will also directly link to monitoring other pollutants such as NO_2 and carbon monoxide, which are co-emitted with CO_2 and sometimes with methane. This service integrates closely with other relevant work and is intended to support a wide range of user communities from local to global scales.

96. This new Copernicus programme will also include the development and launch of new dedicated satellite sensors, the CO_2 monitoring mission (CO2M), which will support the strengthening of CO_2 networks and expanding the modelling, simulation, and user interface capabilities to convert observations to actionable information.

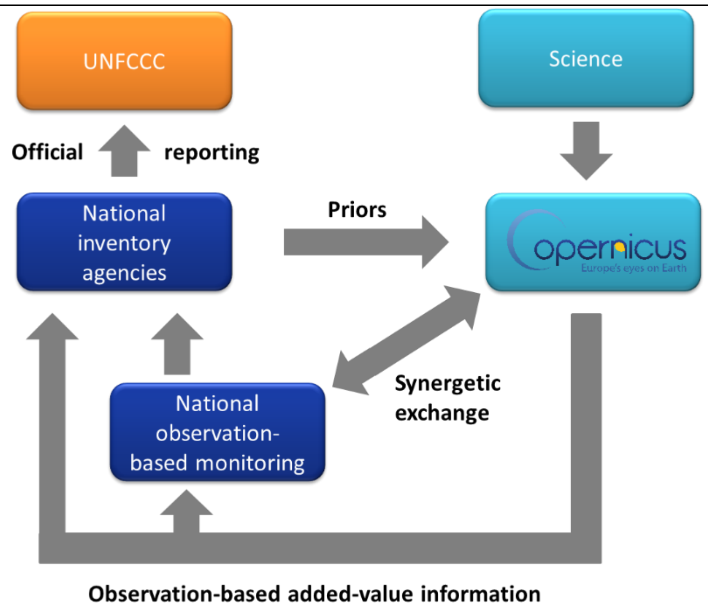
Figure 14. Copernicus anthropogenic CO_2 emissions monitoring capacity



Source: Slide 2 of Mr. Engelen's presentation; Atmospheric Monitoring Service, Copernicus Climate Change Service[39]

97. Parts of the integrated system already exist as prototypes which will be integrated in the coming years. The service is intended to add value and support existing practice rather than replacing or duplicating existing processes (figure 15). Therefore, an active interaction with Parties is required to ensure fit-for-purpose services. Copernicus can convert science to operational services to support countries around the world with free and open data while working closely with international partners such as GEO, GCOS, CEOS, the WMO, and others to add value to Earth observation services for the global community.

Figure 15. Copernicus support for Parties' emissions reporting



Source: Slide 4 of Mr. Engelen's presentation

[39] See https://atmosphere.copernicus.eu/.

98. Mr. Phil DeCola presented on the work of the WMO Integrated Global Greenhouse Gas Information System (IG3IS) in translating scientific advances into mitigation services.

IG3IS provides a common framework for the provision of systematic services for stakeholder communities working to reduce their greenhouse gas emissions

99. Although progress is being made in observation to support mitigation services, increased granularity and accuracy to identify opportunities and measure progress is needed. IG3IS provides a common framework for the provision of systematic services for stakeholder communities working to reduce their greenhouse gas emissions.

100. Working examples of positive support of emissions monitoring with standard GHG reporting include:

(a) In UK and Switzerland, HFC 134a inventory compilers used a top-down inversion model to reanalyse previously reported bottom-up measurements and produce new data in closer alignment with the atmospheric and bottom-up data. There are plans to reassess emission factors to see if even greater agreement can be achieved.

(b) In New Zealand combining atmospheric measurements with the radiocarbon CO_2 measurements revealed a greater variability, a much larger land sink of CO_2, and increased granularity to assist management.

101. IG3IS is recognized by the SBSTA[40] and promotes and supports the use of atmospheric concentration data to target mitigation opportunities, improve emission estimates and track progress. IG3IS works from the industrial facility to the global scale, providing good practice methodologies and guidelines to enable stocktaking exercises and quality control.

102. The IPCC Task Force on National Greenhouse Gas Inventories have updated their protocols to reflect the progress made by IG3IS and others in the implementation of science related to using and promoting the use of observations for enhanced constraints and guidance on how progress can be made at different scales.

103. Ms. María José Sanz Sánchez presented on the work of the Global Forest Observations Initiative (GFOI) in assisting developing countries in improving national forest information and reporting. GFOI provides an already working example of how the observation community is providing bottom-up support to Parties in their GHG reporting. Further information was also provided in the GFOI poster (see paragraph 159)

The GFOI is a model for how the systematic observation community supports the efforts of developing countries to provide information on GHG emissions and removals that can be used for reporting to the UNFCCC

104. Forests can play an important role in mitigating global climate change, in sustainable development, biodiversity protection, and in many other functions that are essential to society. Better forest management is underpinned by better forest monitoring. Many countries are developing National Forest Monitoring Systems (NFMS) and associated procedures for monitoring reporting and verification (MRV). This informs their decision-making, policy development, and reporting to international initiatives, and their action on forests and climate.

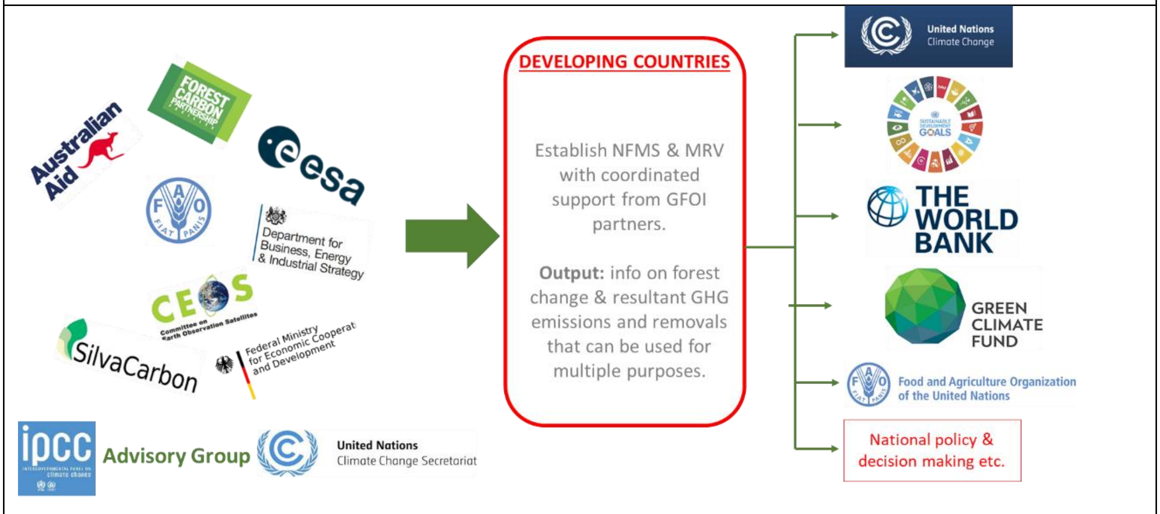
105. The GFOI has fundamentally contributed to the efforts of these developing countries to produce information and access resources related to REDD+[41]. There has been an increased demand for forest information coupled with a boom in the supply of data, tools, and other forms of international support.

106. The GFOI brings together all the major players working in the forest monitoring sector and aims to organise their support to developing countries in a globally coherent manner. The GFOI helps countries to establish NFMS and MRV to provide information on forest change

[40] Available at https://unfccc.int/documents/199148.
[41] See https://redd.unfccc.int/.

and the resultant GHG emissions and removals that can be used for multiple purposes, including reporting to the UNFCCC. These partnerships also work with and are advised by the IPCC Task Force on National Greenhouse Gas Inventories and the UNFCCC Secretariat as part of an advisory group on methods and guidance. This supports countries and informs national policy and decision making (figure 16).

Figure 16. Global partnership for coordinating international support to help developing countries address their international and national information needs on forest monitoring and greenhouse gas (GHG) accounting for REDD+ and related climate reporting and activities



Source: Slide 3 of Ms. Sanz's presentation

107. The GFOI is successful as it was able to provide **four urgently required needs**.

(a) Capacity building to deliver direct assistance to developing countries;

(b) Method and Guidance Documentation to complement the existing guidance and produce new guidance to allow countries to personalise methods of creating national forest inventories and greenhouse gas inventories. Fifty countries currently use this documentation in its third phase;

(c) Research and Development to explore how new research and technologies can be operationalised in the context of routine monitoring or NFMS;

(d) Data Coordination to provide support on how to use data and tools in a cost-effective manner.

108. Operationalising new methodologies in the national monitoring schemes of countries is a major challenge. The GFOI works with developing countries to make use of new research and understand the processes and evolution of emissions and removals from forests. Cooperation and integration with countries that need the information to make decisions is critical to make progress in this area.

109. To date, as well as working with partners to build capacity in over 60 developing countries across the three major forested regions – Asia, Africa and Latin America, the GFOI has:

(a) Developed and disseminated a comprehensive user-friendly methodological guidance document (MDG Guidance) in compliance with the IPCC and to meet UNFCCC reporting and transparency requirements. Such guidance was incorporated in the IPCC 2019 Refinement;

(b) Contributed to best scientific practices and research, addressed knowledge gaps, and progressed new approaches that are incorporated into the MDG document. The document is periodically updated and dynamically incorporates new guidance through frequently asked questions or temporary models;

(c) Contributed to an inventory of activities, information exchange and other structured communications between major partners;

(d) Fostered a strong global network of experts and practitioners;

(e) Ensured annual comprehensive coverage of the world's forested regions with remote sensing data in support of reporting by countries;

(f) Developed structured coordination mechanisms to make it easier for partners to participate in and extract net benefits from international cooperation.

2. Recent advances in Earth observation technology and data processing to support decision making on adaptation

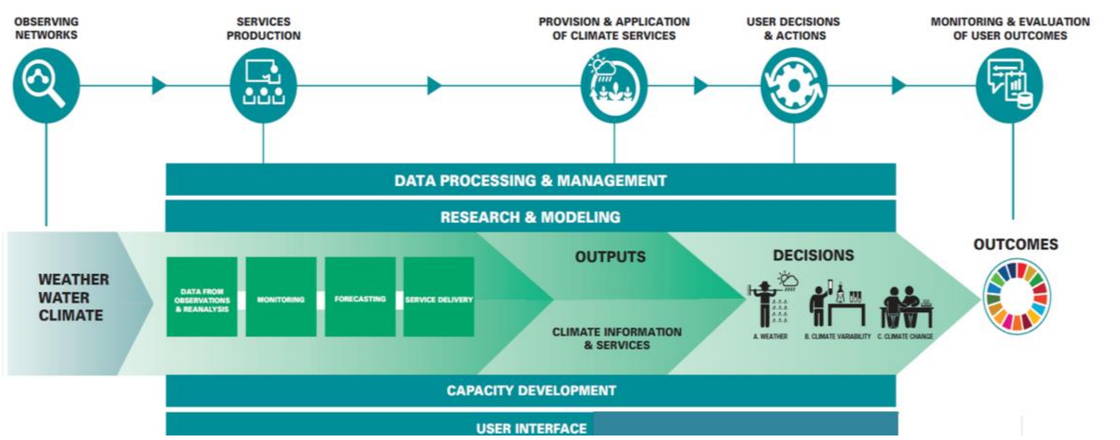
110. Ms. Mariane Diop Kane presented on climate service for adaptation and identified that climate services should be seen as products and tools for adaptation. These services need to process many data inputs from different models and information sources and this can be facilitated through the Global Framework for Climate Services (GFCS).

The WMO Global Framework for Climate Services is supporting the provision of climate services as both products and tools for adaptation and the NAP process

111. Climate services for adaptation are realised via a value chain (figure 17), starting with operational hydrometeorological systems, observing networks, data and databases, and climate monitoring and forecasting, and ending with products to support climate decision-making. These services are applied in climate sensitive sectors such as agriculture, food and water resource management, health, energy, disaster risk reduction, and others to improve socioeconomic benefits. The infrastructure required to generate tailored products includes data processing and management, research and development, modelling, expertise for capacity development, a user interface, and a platform where users and product generators can discuss and define their needs.

112. The climate information system that supports adaptation action is implemented on a sub-regional scale through processes at the global, regional, and national levels. At the national level, meteorological services observe and store data, implement quality control, generate products, and transmit data to the regional level. At the regional level, data is checked for coherence and inputs are monitored before data proceeds to the global level. Data and information are also input to the regional level from global processes, where it is optimised for regional use with multi-model ensembles and verification or is passed directly to the national level to produce adaptation services.

Figure 17. The data chain for climate services



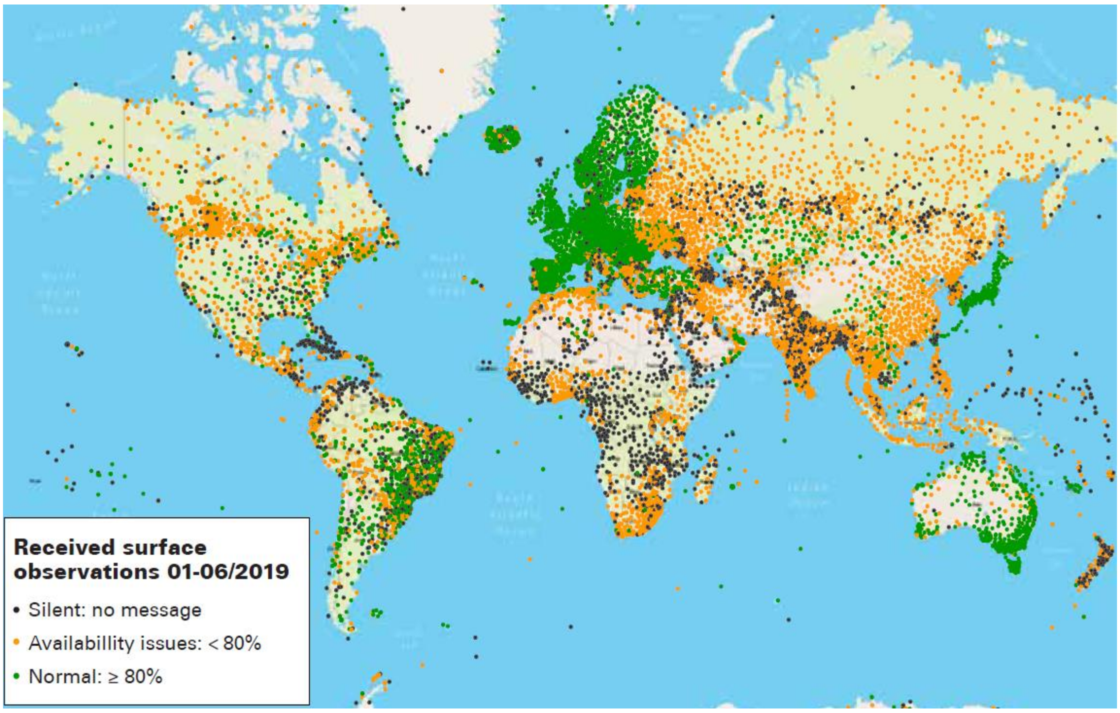
Source: Slide 3 of Ms. Kane's presentation; Global Framework for Climate Services, 2019 State of Climate Services, WMO (2019)

113. For example, the Global Surface Station Network is one of the most fundamental components of the climate services value chain. However, the density of reporting is inadequate in Africa and many small developing islands (figure 18). The GBON system will hopefully address some of these inadequacies.

114. The World Hydrological Cycle Observing System (WHYCOS) provides basic hydrological observations and fosters river basin-wide, regional, and international cooperation to promote the free exchange of hydrological data.

115. Data rescue is also an important part of the value chain and data rescue initiatives are ongoing in many countries worldwide, such as the Copernicus Climate Change Data Rescue Service, but more investment is urgently needed

Figure 18. The Global Surface Station Network. Black dots are substations that do not report at all. Orange dots show stations that report below 80% of the time and green dots show stations that report more than 80% and compliant with the WMO



Source: Slide 6 of Ms. Kane's presentation; Global Framework for Climate Services, 2020 State of Climate Services: Risk Information and Early Warning Systems, WMO (2020); Data from WIGOS Data Quality Monitoring System[42]

116. WMO coordinates provision of climate service information systems through the Regional Climate Outlook Forums[43]. These forums have achieved nearly global coverage since starting in Africa. They meet two to three times per year with the participation of national meteorological services, subregional climate scientists, and representatives of key user constituents.

117. Due to the proliferation of observing systems, the WMO has led an initiative to create a single open-source system that can be updated by the WMO community. At the invitation of the COP, the WMO and partners have prepared annual reports on the state of climate services for adaptation. These reports have indicated that small developing islands and Africa are particularly in need.

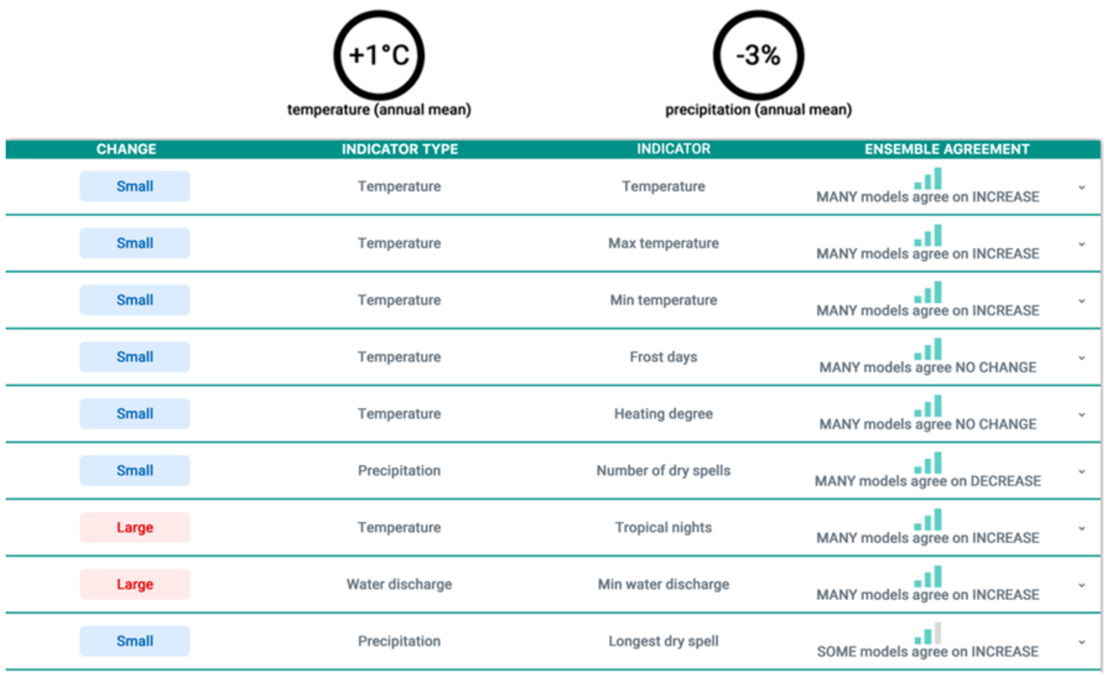
118. The 2020 WMO State of climate services report[44] reported that the Multi-Hazard Early Warning System (MHEWS) covers only 40% of people in Africa, where preparedness and monitoring are particularly weak, and warning, dissemination, and communication capabilities are also lacking. For example, currently, only South Africa has a floods and early warning system, with a western African system delayed due to the COVID-19 pandemic.

119. The WMO has recently partnered with the Green Climate Fund to provide methods and tools to ensure climate action is well underpinned by the best available climate change

[42] See https://wdqms.wmo.int/.
[43] See https://public.wmo.int/en/our-mandate/climate/regional-climate-outlook-products.
[44] Available at https://public.wmo.int/en/our-mandate/climate/state-of-climate-services-report.

science. A climate information platform[45] implemented by the Swedish Meteorological and Hydrological Institute through this collaboration has made available climate projections of a variety of key climate indicators such as temperature, dry spells, and soil moisture at 50 km resolution. This information can be used to formulate National Adaptation Plans and adaptation and mitigation projects. Figure 19 shows the projected changes, and degree of confidence in the projections for Praia, Cabo Verde that were generated through this collaboration.

Figure 19. Main climate indicators from climate projections for Praia over the period 2041-2070 for the RCP 4.5 emissions scenario



CHANGE	INDICATOR TYPE	INDICATOR	ENSEMBLE AGREEMENT
Small	Temperature	Temperature	MANY models agree on INCREASE
Small	Temperature	Max temperature	MANY models agree on INCREASE
Small	Temperature	Min temperature	MANY models agree on INCREASE
Small	Temperature	Frost days	MANY models agree NO CHANGE
Small	Temperature	Heating degree	MANY models agree NO CHANGE
Small	Precipitation	Number of dry spells	MANY models agree on DECREASE
Large	Temperature	Tropical nights	MANY models agree on INCREASE
Large	Water discharge	Min water discharge	MANY models agree on INCREASE
Small	Precipitation	Longest dry spell	SOME models agree on INCREASE

Source: Slide 12 of Ms. Kane's presentation; Data from https://climateinformation.org/

120. The WMO and the African Union have recently launched the regional state of the climate Report in Africa.[46] This report is the first of a set of planned regional reports to provide information such as multi-model average forecasts of near surface temperature and precipitation for the five-year period 2020–2024. Data shows elevated probabilities of temperatures of an increase of 1˚ C above pre-industrial levels across northern Africa over the next five years, and likely increased precipitation across the Sahel and Eastern Africa with continuing dry conditions across much of Southern Africa.

121. WMO is also supporting national Frameworks for Climate Services to bring together stakeholders at national and regional levels, to identify priorities, formulate plans and projects, and monitor associated outcomes to support adaptation decision making and the NAP process. In Africa, many countries have launched frameworks, but operationalisation is slow.

122. Ms. Catherine Nakalembe presented on the Group on Earth Observations Global Agriculture Initiative[47] (GEOGLAM). GEOGLAM works to strengthen the capacity of the international community to use Earth observations for agricultural monitoring.

GEOGLAM focuses on agriculture monitoring and aims to increase market transparency and improve food security by producing and disseminating relevant, timely, and actionable information on agriculture conditions and outlooks for production at national and global scales

[45] See https://climateinformation.org/.
[46] Available at https://library.wmo.int/index.php?lvl=notice_display&id=21778.
[47] See https://earthobservations.org/geoglam.php.

123. In order to leverage Earth observation data for decision making, it needs to be modified or adapted for specific needs such as for early warning systems for drought or floods and the subsequent impacts on agricultural production. The combined data of satellites from, for example ESA, NASA, and JAXA, make it feasible to provide timely, objective, repeatable data at the global scale for monitoring diverse landscapes. Where data coverage is sparse, satellite date provides a low-cost alternative to traditional agriculture monitoring that can inform lifesaving decisions related to floods and droughts.

124. An immense amount of Earth observation data is becoming available at high resolution. Though some countries lack the computing infrastructure to leverage this data themselves, machine learning is providing insights that enable the production of, for example seasonal crop production forecasts. Different application programming interfaces are used to allow the combination of rainfall, temperature, crop conditions, and crop masks to understand the health of specific crops.

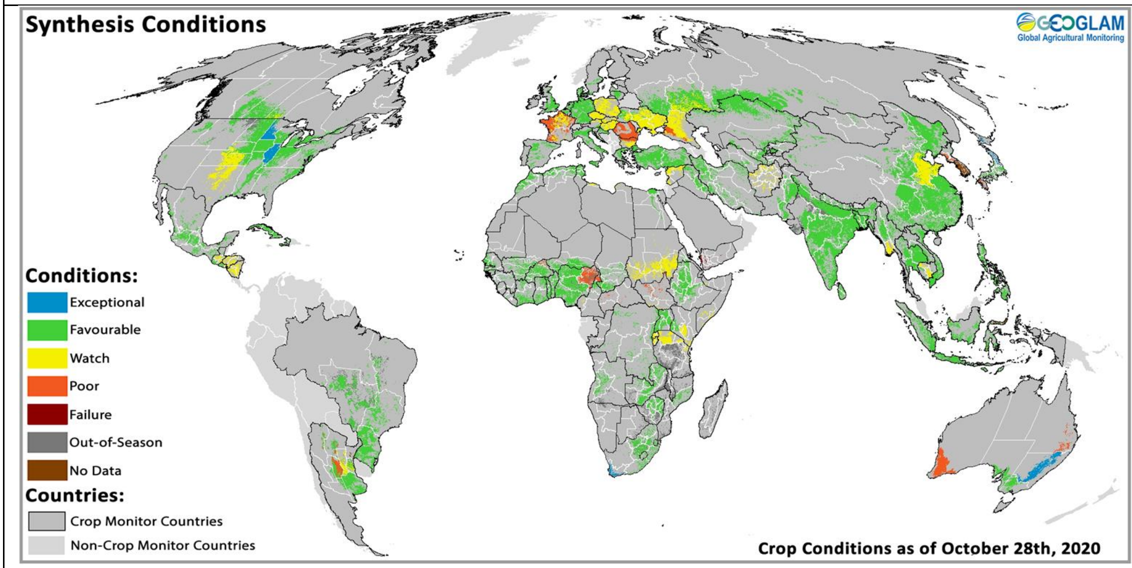
125. Even with these advances, many countries face enormous events that significantly impact farmers. For example, in 2019, sub-Saharan Africa experienced floods, droughts, landslides, crop failures and a one-in-25-year desert locust invasion. Though these events were tracked from a global perspective with a lot of information available, that information may not trickle down from institutions to the communities that rely on their decisions.

126. To partially address this local information deficit, GEOGLAM developed the crop monitor initiative (figure 20), made possible by the increased accessibility of Earth observation data, satellite data and systems.[48] Crop monitors were originally designed as an open public good to provide timely science-driven information on crop conditions and support market transparency. The first crop monitor initiative was for the Agricultural Market Information System[49], focusing on countries producing crops important to food security such as soy, wheat, rice, and corn and providing critical information that reflects an international multi-source consensus of growing conditions across the globe.

127. Crop monitor has also been adapted to be used for early warning and is used in several different contexts. Machine learning combined with high-resolution data has made it possible to monitor agriculture at different scales in a timely and accurate way. This data can be used by national institutions with the relevant capacities to inform the production of reports and policies and, if done within a broader framework of goals and objectives can produce impactful outcomes. For example, the crop monitor initiative is used by the IGAD Climate Prediction and Application Centre[50] (ICPAC), which runs the Climate Outlook Forum for Eastern Africa. The ICPAC uses the crop monitoring system in Kenya, Uganda, and Tanzania, with more systems in development for Mali and Rwanda.

[48] See https://cropmonitor.org/.
[49] See http://www.amis-outlook.org/amis-monitoring/crop-monitor/overview/en/.
[50] See https://www.icpac.net/.

Figure 20. An example of crop monitor output

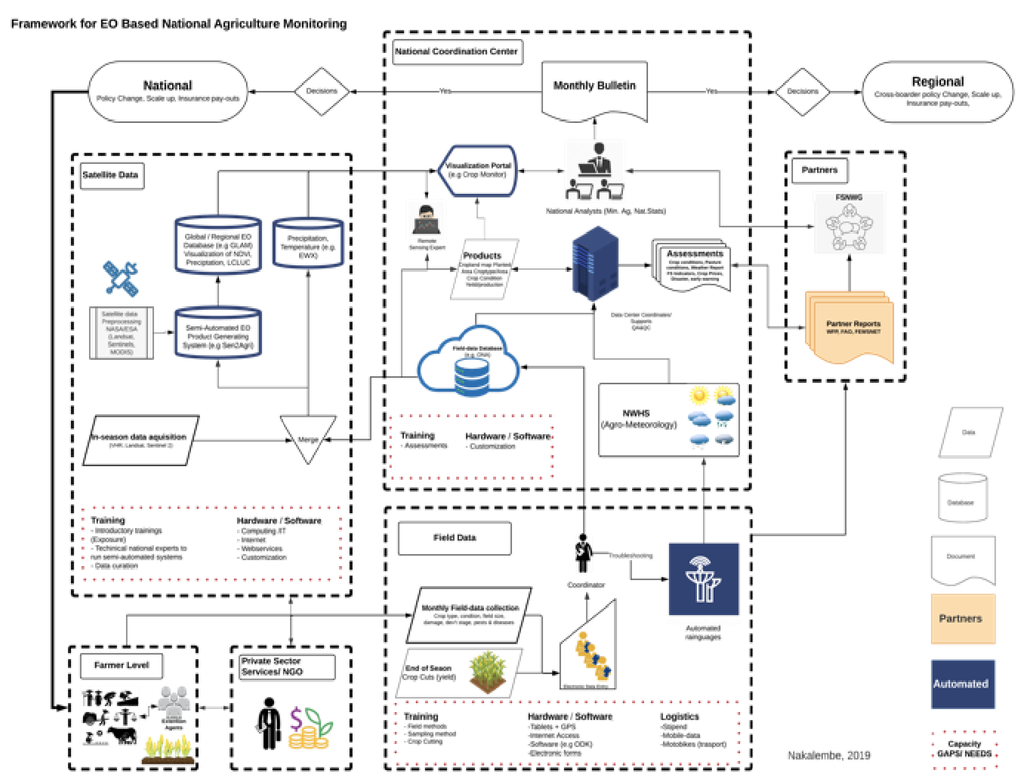


Source: Slide 5 of Ms. Nakalembe's presentation

Improved agriculture monitoring and reporting are essential for designing the appropriate early warning systems and adaptation programmes

128. GEOGLAM aims to guide frameworks at a national level to source data, assess it, and assess systems to use it for reporting and decision-making via national infrastructure and institutions with the required capacity (figure 20). This capacity should not be focused only on training but also on the capacity to use newer tools. newer systems, and ground networks.

Figure 21. Framework for Earth observation-based national agriculture monitoring



Source: Slide 8 of Ms. Nakalembe's presentation; Nakalembe, Leveraging Earth Observation for agriculture monitoring in Eastern Africa, American Geophysical Union (2019)

129. Ms. Nakalembe concuded that in many places the lack of reporting systems compromises agriculture monitoring capacity at the desired scale. These systems are essential to designing early warning systems or designing adaptation programmes that require leveraging satellite data. Once these systems are operational, they could then be transitioned into specific programmes that ensure their long-term funding and maintenance.

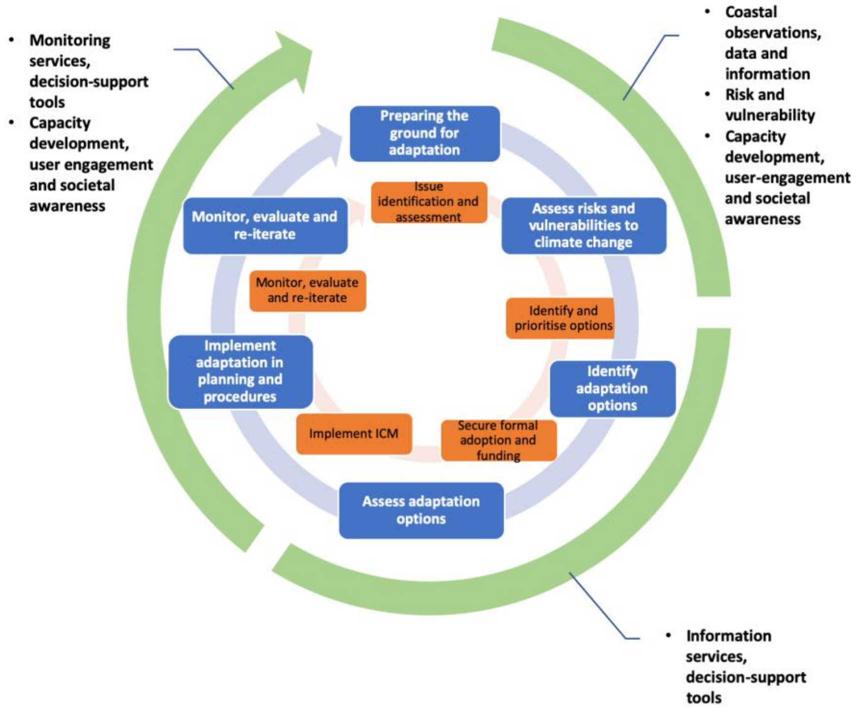
130. **Mr. Louis Celliers** presented on coastal and ocean observations for climate adaptation. He outlined the work of **GEO Blue Planet,**[51] a network of ocean and coastal observers, social scientists, and end-user representatives from a variety of stakeholder groups across a variety of sectors.

GEO Blue planet aims to assist decision makers parse the information available on the ocean and coastal zone to support marine spatial planning, integrated coastal zone management, adaptation and the NAP process

131. GEO Blue Planet aims to advance and exploit synergies amongst ocean and coastal observation programmes, improve engagement with a variety of users to enhance the timelines, quality, and range of services delivered for adaptation, and raise awareness of the societal benefits of ocean and coastal observations at the public and policy levels. It aims to assist adaptation decision makers parse the large amounts of data available.

132. There are numerous examples of how ocean and coastal observations support integrated coastal management, Marine Spatial Planning (MSP), and blue economy implementation using a similar, potentially mutually supportive, policy implementation pathway to climate change adaptation. Earth observation data and information services can support the NAP process (figure 22) as it also applies to coastal climate change adaptation, Integrated Coastal Management (ICM) as a sector and policy implementation.

Figure 22. Earth observation data and information (green) supporting the UNFCCC NAP process (blue) and policy implementation cycle (orange)



Source: Slide 4 of Mr. Celliers' presentation;

133. GEO Blue Planet can provide a range of information on coastal and ocean observations to support the development of the NAPs including on preparedness for and

[51] See https://geoblueplanet.org/.

management of disasters, observing trends in adaptation success, monitoring the impact of adaptation over time, assessing climate vulnerabilities, and identifying adaptation options at sub-national, national, and other levels (figure 23).

Figure 23. Adaptation options enabled by different ocean and coastal zone observations

Observation Application	Links to Adaptation Options
Optical water types for coastal water quality monitoring	• Food security, nutrition, sustainable agriculture • Management of water, quality and quantity • Sustainable use of ocean resources
Species niche habitat distribution mapping	• Food security, nutrition, sustainable agriculture • Sustainable consumption • Sustainable use of ocean resources
Complementary multi-platform coastal bathymetry	• Conserve and sustainably use the oceans, seas and marine resources for sustainable development
Coastal inundation mapping and prediction, and storm surge risk assessment	• Reduce risk to communities • Maintain infrastructure
Extreme event monitoring	• Drought and flooding management

Source: Slide 5 of Mr. Celliers' presentation; Politi, E. et al, Earth observation applications for coastal sustainability: potential and challenges for implementation, Anthropocene Coasts (2019); Benveniste, J. et al, Earth Observations for Coastal Hazards Monitoring and International Services: A European Perspective, Surveys in Geophysics (2020)

134. Examples of GEO Blue Planet activities include:

(a) For example, the Oceanscape[52] initiative, jointly managed by Blue Planet and Pogo[53], identifies organizations, projects, programmes, and other structures working on the ocean, clarifies connections between them, and identifies opportunities to make connections where none already exist. This search network can be used by scientists, NGOs, the private sector, governments, and funding agencies to gain a clearer understanding of organisations working on the ocean and coastal zones.

(b) Supporting the development of an oil spill information system to help countries in the wider Caribbean monitor and respond to oil spills.

(c) Along with NOAA[54], the USGS[55], and Deltares[56], GEO Blue Planet are supporting WaveFoRCE[57], which aims to provide forecasts of wave driven flood events.

(d) GEO Blue Planet collaborates in the Sargassum Information Hub[58] with AtlantOS[59], IOCAIRBE[60], the AIR Centre[61] and other partners, and with the ESRI[62] to

[52] See https://oceanscape.org/.
[53] See https://pogo-ocean.org/.
[54] See https://www.noaa.gov/.
[55] See https://www.usgs.gov/.
[56] See https://www.deltares.nl/en/.
[57] See https://waveforce.online/.
[58] See https://geoblueplanet.org/blue-planet-activities/sargassum-information-hub/.
[59] See https://www.atlantos-h2020.eu/events/setting-observing-targets-for-biogeochemical-observing-system-in-the-atlantic/.
[60] See http://iocaribe.ioc-unesco.org/.
[61] See https://www.aircentre.org/netfridays-sargassum/.
[62] See https://www.esri.com.

produce statistics for global indicators for eutrophication for inclusion in the 2020 SDG report.[63]

Discussion

135. **Has there been interest from the private** sector **in IG3IS to improve understanding of industrial emissions?**

Mr. DeCola: Yes, there has been interest and buy in especially with regards to methane emissions from the oil and gas sector, national and urban waste management sectors, and from agriculture and the dairy industry.

136. **Can the Crop Monitor system be used to** calculate **damage and loss?**

Ms. Nakalembe: Yes, Crop Monitor is a system of systems that can be used to do assessments of damage following events. Examples of special reports can be found on the webpage.[64]

III. Summary of proceedings - posters

A. Theme 1. Updates on the state of the global climate and its observation

137. Sixteen posters were provided to support the information presented during the dialogue on Theme 1. Updates on the state of the global climate and its observation and are summarised below. Each poster can be viewed with accompanying audio commentary,[65] as well as directly by a hyperlink in the title below.

1. Updates on the state of the global climate - global

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

Karina von Schuckmann, et al, Mercator Ocean, on behalf of GCOS

Human-induced changes in the composition of the atmosphere cause a positive radiative imbalance at the top-of-atmosphere. This is known as the Earth Energy Imbalance (EEI). The EEI is driving global warming.

Over the period 1970-2018, the Earth's system has gained 358 ± 37 Zetajoules (ZJ) of heat at a rate of 0.47 ± 0.1 W/m^2 (Watts per metre squared), which constitutes the EEI). The majority of heat gain is reported in the global ocean with 89%, 6% over land, 4% in the melting of grounded and floating ice, and 1% for atmospheric warming.

The EEI has increased by 0.87 ± 0.12 W/m^2 during 2010-2018 and continues to do so. Stabilisation of the climate requires that the EEI be reduced to approximately zero to achieve the Earth's system quasi-equilibrium. The amount of CO_2 in the atmosphere would need to be reduced from 410 ppm to 353 ppm to increase heat radiation to space by 0.87 W/m^2, bringing Earth back towards energy balance.

EEI is the most fundamental metric that the scientific community and public must be aware of, as the measure of how well the world is doing in the task of bringing climate change under control. The EEI should be incorporated into the global stocktake based on the best available science.

139. **Observation of Greenhouse gas emmisions from Space during COVID-19 pandemic**

Hiroshi Suto, Japan Aerospace Exploration Agency (JAXA)

The Japanese Greenhouse gases Observing SATellite (GOSAT) monitors the global CO_2 distribution every 3 days, and has continuously monitored CO_2 concentration changes for

63 Available at https://unstats.un.org/sdgs/report/2020/.
64 Available at https://cropmonitor.org/index.php/cmreports/reports-archive/.
65 See https://unfccc.int/event/earth-information-day-2020 or https://unfccc.padlet.org/unfccc/EarthInformationDay2020.

more than 11 years. GOSAT data shows that the global and local CO_2 concentration is increasing annually with clear latitudinal differences.

GOSAT data can be used to estimate emissions from megacities. To monitor this on the regional and local scale, GOSAT data was analysed for 50 large cities over a decade. Research found that the largest changes in economic activity associated with the COVID 19 pandemic have been in large urban areas. Average monthly CO_2 concentrations were calculated for Beijing, Shanghai, Tokyo, New York, Mumbai, Delhi, and Dhaka for the months of January to April from 2016 to 2020.

Background CO_2 concentrations were generated by averaging monthly CO_2 concentrations from 2016 to 2019 over the city. Comparing this to the data from April 2020 showed reduced CO_2 concentrations compared to 2019. This is consistent with pandemic related decreases in emissions, but the data also contains signals from the land biosphere.

JAXA continues to collaborate with the ESA and NASA to track the effects of the COVID 19 pandemic on fossil fuel emissions and air quality.

2. Updates on the state of the global climate – land and atmosphere

140. **Terrestrial satellite data records for essential climate variables – ESA Climate Change Initiative (CCI)**

Emilio Chuvieco, Alcala University / ESA Climate Change Initiative

The ESA Climate Change Initiative includes seven terrestrial satellite data records. Updates to Terrestrial ECVs include new global maps of above ground biomass, high resolution land cover, lakes, whilst global products for land surface temperature are under development. Continued R&D is improving the climate-quality records for soil moisture, land cover, and fire disturbance.

The CCI land cover project team have generated annual land cover maps from 1992-2019 at a 300m resolution using. These land cover products have been linked to newer high-resolution land cover maps that use Copernicus Sentinel-2 at 10-30m resolution. One of the latest developments of these land cover products has been the adaptation of land cover to land functional types enabling the data to be used directly by the climate modelling community.

The CCI soil moisture project team generates information from passive microwave sensors. Spanning 1978-2019, the CCI soil moisture dataset represents one of the longest satellite-derived climate records available. This dataset registers annual and five yearly anomalies. These annual soil moisture anomalies have been regularly included in Bulletin of the American Meteorological Society State of the Climate reports.

In relation to fire, burned area products have been developed to generate medium resolution global datasets. Higher resolution continental datasets using Copernicus Sentinel-2 data have also been generated. Higher resolution maps covering Africa have been generated and incorporate small fires (<100ha) to provide a much more detailed analysis of the impact of fires. This is particularly relevant to Africa, where more than 90% of small fires contribute to the continent’s total fire-related emissions.

141. **Atmosphere satellite data records for essential climate variables – ESA Climate Change Initiative**

Michel van Roozendael, BIRA / ESA Climate Change Initiative

Atmosphere ECVs measured with support from satellite-derived climate data include aerosol, cloud, ozone, greenhouse gases and water vapour. Atmospheric.

Aerosols and clouds are mutually related and together they represent one of the main uncertainties in the estimation of global climate forcing. Feedback mechanisms between clouds, particles and other climate variables are complex and are not generally well understood. The CCI Cloud research project team found that regions characterised by low sea ice content were correlated with the presence of more clouds of low altitude[66]. The

[66] See https://doi.org/10.1175/JCLI-D-19-0895.1.

identification of this feedback mechanism is important as it contributes to the melting of sea ice in Arctic regions.

Measurement of greenhouse gas emissions and sinks, in particular carbon dioxide and methane, is crucial and increasingly possible with the new generations of high-resolution atmospheric sensors. A recent study by the CCI greenhouse gas project team using Copernicus Sentinel-5P data quantified the amount of methane emissions in oil and gas production fields due to leakages[67].

Ozone studies provide evidence for changing ozone that points to recent modification of atmospheric circulation, possibly due to climate change. Understanding such effects is important to improve our predictions of ozone recovery[68].

Continued monitoring of the Earth system using satellite instrumentation is essential as they provide the long term global data to understand and address our changing climate.

3. Updates on the state of the global climate – ocean

142. **Ocean satellite data records for essential climate variable – ESA Climate Change Initiative (CCI)**

Shubha Sathyendranath, PML / ESA Climate Change Initiative

The ECVs within the ocean domain include ocean colour, sea surface temperature, sea level, sea surface salinity, sea state, and sea ice. These products are being used to identify trends and inform decision pathways to meet the goals of the Paris agreement and are providing important observation-based information on how climate change is impacting our oceans.

A new coastal sea level dataset for 2002-2018 brings observations to within 3-4 km of the coast, where impacts are felt most keenly.

CCI data detail the spatial and temporal change in sea surface temperature over the last four decades. The regions of strongest warming include the Arctic sea ice boundary, the Mediterranean, and the Black sea.

Ocean colour data provided by the CCI are underpinning studies of pools and fluxes of carbon in the ocean, which in turn are related to ocean biodiversity and fisheries.

143. **Monitoring and assessment of ocean acidification by Japan Agency for Marine-Earth Science and Technology (JAMSTEC)**

Akihiko Murata, Katsunori Kimopy, and Masahide Wakita, RIGC/JAMSTEC

JAMSTEC measured oceanic pH in the western subarctic region of the North Pacific Ocean. In the winter mixed layer, the CO_2 concentrations have increased at a slower rate (1.3 ppm/yr) in the ocean than in the atmosphere (2.1 ppm/yr). The pH in the mixed layer has decreased at a rate of 0.0012/yr, which is slower than the rate observed at other oceanic time-series stations.[69]

However, at intermediate depths, the pH has decreased faster than the rates of decrease at comparable depths at stations outside this ocean region[70]. The faster decline has been caused by greater release of CO_2 from organic matter, which is reflected by a decreasing trend of dissolved oxygen concentrations. The rate of decrease of the annual mean pH, 0.0025/yr, has been primarily a response to oceanic uptake of anthropogenic CO_2.

Annual mean pH decreased considerably at all depths in the eastern Tsugaru Strait at rates of 0.0030–0.0051/yr and 0.017–0.036/yr, respectively, during 2012–2019, exceeding the rates observed in the Sea of Japan and the North Pacific. The acceleration of ocean acidification can be attributed to a more rapid increase of dissolved inorganic carbon concentrations caused by enhanced mixing of the upper and deep-water column in the Sea of Japan.

---

[67] See https://doi.org/10.5194/acp-2020-274.
[68] See https://doi.org/10.5194/acp-20-7035-2020.
[69] See Wakita et al., 2017, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017JC013002.
[70] See Wakita et al., 2013, https://bg.copernicus.org/articles/10/7817/2013/.

Results show that ocean acidification is a basin-scale phenomenon in the open ocean. In 2021, the researchers will conduct continued hydrographic observations and expect that progression of ocean acidification on a basin scale will be detectable.

4. Updates on the state of the global climate – cryosphere

144. Cryosphere satellite data records for essential climate variable – ESA Climate Change Initiative

Thomas Nagler, ENVEO / ESA Climate Change Initiative

Satellite-derived climate data records demonstrate how the cryosphere has been changing over the satellite era with serious implications for society around the world.

As the cryosphere shrinks, better understanding is needed of how each component will interact with the climate system. Observations are crucial for identifying climate trends and constraining the climate models used to help explain the cause of observed variability and change as well as predictions of future climate change. Satellite observations are especially important to monitor the Earth on a global scale.

The ESA CCI monitors glaciers, ice sheets, sea ice, seasonal snow, and permafrost from space. Long-term systematic observations of these key aspects of the climate, referred to as Essential Climate Variables, have shown that:

- Glaciers worldwide have lost more than 9,600 gigatons of ice since the 1960s.
- The arctic sea ice minimum extent in September continues to decrease at a rate of 12.2% per decade since the 1970s.
- The annual snow mass maximum for the Northern hemisphere in March has been narrowed down to around 3,000 gigatons using satellite information dating back to the 1980s.
- The combined rate of ice sheet mass loss of Antarctica and Greenland has sped up six-fold since the 1990s, tracking the IPPC worst case scenario.
- Our ability to integrate satellite-derived climate data records into models is allowing us to monitor permafrost temperature and distribution across the northern hemisphere.

145. Tackling Rapid Warming and Environmental Changes in the Third Pole: from Observation to Climate Information Services

Qingchen Chao, Lijuan Ma, Pengling Wang, National Climate Centre, China Meteorological Administration

The Tibetan Plateau and its surrounding mountains, the ‘Third Pole’ has been experiencing dramatic climatic and environmental changes. Climate records retrieved from four ice cores in the Third Pole disclosed that, during the past two millennia, rapid warming began in the 1960s, and reached its highest levels in the last 30 years. During the past 30-40 years, observed warming over the Third Pole was significant and of greater magnitude than the global mean or areas of the same latitude.

Glacier mass balance has decreased significantly, and the active layer thickness and the bottom temperature of the active layer increased dramatically. Runoff from the Third pole provides up to 45% of the total river flow of many international Asian rivers. Glacier fed lakes make up around75% of the total area of ice lakes in western China. This region is estimated to reach peak water between 2030 and 2050 due to climate warming, subsequently affecting water availability for 1.7 billion people.

The changing climate has also led to an increase in the frequency of disasters such as ice avalanches and glacier lake outburst flooding (GLOF). Risk assessments reveal a high-risk level of GLOF and snow disaster, which is valuable for policymakers in risk management.

Newly established observing networks and scientific experiments aim to extend observations in multiple dimensions. For example, the Third Tibetan Plateau Atmospheric Scientific Experiment extends observations horizontally and vertically as well as enriching the observed elements and variables.

Many stations have been established inside and outside of China under the umbrella of the Second Tibetan Plateau Scientific Expedition and Research. This forms two observation transects along the plateau monsoon region and the westerlies. Other extensions of the observing network in western China are planned by the China Meteorological Administration, but, as observations and scientific studies are conducted by different organizations, it is necessary to integrate resources and create synergies to provide fit-for-purpose climate services in the Third Pole.

The Third Pole Regional Climate Center Network was formally endorsed in 2018 combining resources from multiple organizations from China, India, and Pakistan, as well as the Global Cryosphere Watch program of WMO, the Third Pole Environment program, and other potential partners. It will address gaps in data and information, aiming to provide user-oriented and fit-for-purpose climate and cryosphere services to end users.

5. Updates on the state of global climate observation

146. **Status of Global Climate Observations: Update from GCOS**

Simon Eggleston, GCOS

The 2016 GCOS Implementation Plan established long-term targets for observing the major components of the climate system, integrating across all the ECVs. GCOS is preparing the next GCOS Status Report to be published in 2021 and will update its Implementation plan in 2022.

The GCOS Science Panels have been assessing how well ECVs are observed; the status of observations of each ECV; and the outcome of the actions identified in the 2016 Implementation Plan.

Regional workshops have identified local issues with monitoring such as funding, capacity, and planning for sustainability and regional collaboration. The WMO’s Global Basic Observing Network and the proposed Systematic Observations Financing Facility (SOFF) have been developed to address these issues.

GCOS is funded by a trust fund that supports the scientific secretariat staff, meetings, and travel for participants. Additional support is needed, especially to support the broadest possible participation in GCOS and its reviews.

GCOS is now looking at the main climate cycle encouraging scientific review papers on the energy, carbon, and water cycles and on the state of biomass. Looking at the cycles across the atmospheric, ocean and terrestrial domains in a holistic way, ensures consistency and identifies gaps in the observing system. Monitoring can both support the development of plans for adaptation and mitigation as well as monitoring its implementation. GCOS has established a Task Team that is exploring how a global observing system can support and monitor local adaptation and mitigation.

GCOS is preparing the next GCOS Status Report to be published in 2021 and will update its Implementation plan in 2022.

147. **Supporting UNFCCC Objectives Through International Coordination of Long-term Satellite Records**

Jeffrey L. Privette, NOAA; Joerg Schulz, EUMETSAT; Alexandra Nunes, Hamtec Consulting Ltd; Albrecht von Bargen, Deutsches Zentrum für Luft- und Raumfahrt e.V.; Wenying Su, NASA; on behalf of 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), 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[71]. The Inventory contains information on more than

[71] See http://climatemonitoring.info/ecvinventory.

1300 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. They will also 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 evolution of urban areas, enabling statements about disaster impacts leading to loss & damage. The sustained monitoring of the climate system from space also enables monitoring change due to mitigation and adaptation measures applied by UNFCCC Parties.

148. **VERIFY: Observation-based system for monitoring and verification of greenhouse gas fluxes**

Philippe Peylin, LSCE - CNRS, et al

The aim of the EU EC funded VERIFY project is to build an observation system for monitoring and verifying greenhouse gas fluxes at the National scale for Europe. The project's key annual objective is to derive syntheses comparing observation-based flux estimates with the national inventory reported to the UNFCCC.

The project provided an annual map of fossil fuel emissions at high resolution over Europe to be used in atmospheric inversions. One key message is that the atmospheric inversion and the bottom-up model provide a much larger year to year flux variation than the national inventory estimates. The inversion implies a much larger sink than these inventory estimates with a large range.

Regional CH_4 and N2O emissions were also calculated using bottom-up models and regional atmospheric inversions. Bottom-up estimates for CH_4 provide larger flux emissions than the national inventories due to the energy and waste sectors. The CH_4 atmospheric regional inversion also provides a larger flux estimate, with the differences in this case possibly partially due to natural factors. Bottom-up estimates for N2O are in good agreement with National Inventories but show a slightly different trend. Inversions provide larger emissions than the national inversion inventory, though these inventories have a large uncertainty.

149. **Creating a Global Atmospheric CO_2 Inventory to Support the Global Stocktake**

David Crisp, JPL/Caltech; Mark Dowell, JRC; Albrecht von Bargen, DLR; on behalf of the Joint CEOS/CGMS Working Group on Climate GHG Task Team (WG Climate)

Top-down atmospheric inventories will be useful for informing the bottom-up inventories being compiled to track Nationally Determined Contributions (NDCs) for emissions reductions and more generally for the Global Stocktake.

A three-step process for constructing a global, top-down atmospheric inventory for carbon dioxide is outlined.

- Emerging capabilities and requirements are defined.

  The Committee on Earth Observation Satellites (CEOS) and the Coordination group on Meteorological Satellites (CGMS) recently endorsed a white paper reviewing the capabilities and near-term plans for atmospheric GHG measurement and modelling systems. Space-based measurements of CO_2 and CH_4 are now being collected from a growing fleet of satellite sensors operated by CEOS and CGMS agencies. Greenhouse gas flux maps are now being generated on policy-relevant spatial and temporal scales, spanning large urban areas to national scales.

- A pilot inventory product is developed to illustrate the information contained in an atmospheric inventory. This will be generated using a system-level approach that integrates ground-based, airborne and space-based measurements of greenhouse gases. Two products will be derived: global, gridded maps of natural and anthropogenic CO_2

emissions and uptake with their uncertainties; and emissions estimates from a selected series of hot spots including large urban areas and large power plants.

- The utility of these products will be maximised by working with stakeholders and end users, including the UNFCCC, the IPCC and policy makers, to determine how to best exploit atmospheric inventories in the national inventory development process and in the Global Stocktake.

Lessons learned from this exercise will be used to refine the requirements for future top-down atmospheric inventories.

150. **The Ocean Observing System Report Card 2020**

Toste Tanhua and Anya Waite, Global Ocean Observing System (GOOS)

The poster presents the annually published report card by OceanOPS, an operational and meta-data tracking unit within GOOS. The report card summarizes the status of the ocean observing system, including a focus in the 2020 report on the animal-borne ocean sensors (AniBOS) network alongside increased commercial and private involvement in ocean observations. This report supplements and summarises this information regularly updated on the OceanOPS website.

- 9,349 in situ platforms and 170 satellites continuously monitor the global ocean and atmosphere. The system is assessed on implementation status, real-time, archived and meta data availability, and the availability of documented best practice.
- One of the Ocean Decade challenges is to ensure a sustainable ocean observing system that delivers timely data and information accessible to all users on the state of the ocean across all ocean basins. GOOS will play an important role in achieving this goal over the next decade.
- The Animal Borne Ocean Sensors (AniBOS) network provides cost-effective and complementary observing capability. 500,000 profiles from animal-borne instruments have been obtained in high latitudes, coastal shelves and tropical areas, which are currently poorly covered by traditional observing platforms.

  These measurements enhance studies of climate variability, ecological research and management applications, while also providing data on animal movements and behaviour essential to developing evidence-based sustainable management policies.
- Ships observations sustain and maintain GOOS at sea and research ships take the high-precision, multi-parameter full ocean depth observations that are the foundations of climate analyses and vital for the calibration of autonomous instruments. Commercial shipping and private initiatives are getting more involved in cost effective and innovative met-ocean data collection projects.

The current global ocean observing system must grow and it is critical that governments and the private sector work together to increase support for ocean observing and meet the increasing need for ocean knowledge.

151. **Impact of the Covid-19 pandemic on the Global Ocean Observing System**

Toste Tanhua and Anya Waite, GOOS

The impact of the pandemic was strongly felt on the ocean observing system, notably in the case of research vessels being called back to port, the re-seeding of surface drifters and Argo floats. The ships of opportunity program and glider operations were almost completely halted. Many coastal biological sampling missions were cancelled, causing a gap in data collection.

Some of the impacts were mitigated in the second half of the year as restrictions eased and the observing community learned to operate under the new conditions. Autonomous observing components continued to send data and operators worked from home to ensure data flow.

The pandemic was a stress test for the ocean observing system, and its resilience is now better understood. GOOS plans to:

- Increase the use of charter vessels and autonomous platforms to make its approach more flexible.
- Communicate critical nature sustained observations for services and highlight the maintenance needs deep sea moorings. The operation of the sustained observing system would benefit from being classified as critical to operate under difficult (lock-down) conditions.
- Increase connections with research vessel community.

The amount of data 'lost' and the impact on climate services will be assessed. Operational services dependent ocean data such as Harmful Algal Blooms (HABs), weather, shipping, port operations, tsunamis, and seasonal forecasts, have not reported major issues.

152. **RACE – Earth Observations to understand the environmental impact of changes in patterns of life during the 2020 pandemic**

Anca Anghelea, Simonetta Cheli, Yves-Louis Desnos, ESA; Elisabeth Hamdouch, Julien Turpin, EC

The Rapid Action Coronavirus Earth observation dashboard (RACE) demonstrates how the use of Earth observation data can help shed new light on societal and economic changes currently taking place due to the coronavirus pandemic. Across all European countries and ESA member states, the dashboard showcases examples of how different analyses over a wide range of Earth observation data coming from the Copernicus Sentinels and Third-Party Missions can illustrate these socio-economic and environmental changes.

The dashboard utilises the European Cloud infrastructure for Earth observation data access, data processing, information discovery and analytics[72,73], and is delivered as an Open Source solution[74] that allows for the monitoring of key environmental parameters such as air and water quality changes, economic and human activities including industry, shipping, construction, traffic, as well as agricultural productivity.

One of the platform's features allows for the tracking of air pollution worldwide. Using data from the Copernicus Sentinel-5P satellite, the map shows the averaged nitrogen dioxide concentrations over major cities and regions across the world.

The analysis of how changing patterns of human activity caused by the pandemic visibly impact our planet was scaled up globally with international partners NASA and JAXA into a twin platform 'COVID-19 Earth Observation Dashboard'[75]. For example, air quality analyses have been extended with monitoring of greenhouse gases, primarily carbon dioxide.

153. **ANDEX – A new South American initiative to develop a regional hydroclimate project in the Andean region**

René Darío Garreaud, Peter van Oevelen, GEWEX

The Andes mountain range encompasses a rich variety of mountain climates, from very humid conditions near the equator and over western Patagonia to the hyper arid conditions in the subtropics. The Andes produces sharply contrasting climate conditions along the eastern and western slopes and adjacent lowlands.

ANDEX, is a hydroclimate research program for the Andes, under the auspices of the Global Energy and Water Exchanges Program of the World Climate Research Program. Climatologists, meteorologists and hydrologists, stakeholders and representative from most Andean countries (Colombia, Ecuador, Peru, Bolivia, Chile and Argentina), are working together to better understand, model and predict the dynamics of the water and energy cycles over the Andes, at a wide range of temporal and spatial scales, and their linkages with the surrounding oceans, land surface and major river basins.

[72] See https://eurodatacube.com/.
[73] See https://www.copernicus.eu/en/access-data/dias.
[74] See https://race.esa.int.
[75] Available at https://eodashboard.org.

Substantial advances have been made and the quantity of researchers has expanded, but research has mostly been focused in specific regions and suffered from a substantial lack of coherent regional integral perspective. This has led to a lack of relevant in-situ observations and hindered the study of some basic features. Only 5 radiosonde stations make routine (daily) launches along the 7000km long Andes mountain chain and only two are over the Andes. A modest increase in such observations could have tremendous impact on prediction and forecasting skills.

ANDEX is establishing a research and practice community to tackle research questions and applications of interest to Andean countries. Key targets for ANDEX are to:

- Improve the regions' observational capacity, by upgrading and extending existing operational networks, especially in mountainous regions.
- Support high resolution (less than 4km) continental scale modelling to account for complex topography and develop local capacity and capabilities to do this.
- Support sustainable development through informed and targeted investments.

B. Theme 2. Recent advances in Earth observation technology and data processing to support decision making

154. Fifteen posters were provided to support the information presented during the dialogue on Theme 2: Recent advances in Earth observation technology and data processing to support decision making. Each poster can be viewed with accompanying audio commentary,[76] as well directly via a hyperlink in each title below.

1. GHG monitoring and assessment

155. **Climate data records in action: Use cases of Earth observations aiding decision-making**

Wenying Su, NASA; Werner Balogh, WMO; on behalf of the Joint CEOS/CGMS Working Group on Climate and WMO

The joint CEOS/CGMS Working Group on Climate together with the WMO is soliciting use cases that demonstrate the value of Earth Observation satellites for climate monitoring and for related policy- and decision making[77]. 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, etc. 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 fit for purpose and tailored for application and decision-making needs.

Use cases can also optimise the use of CDRs in climate service relevant applications. This activity could also support capacity building by providing use cases for training activities. Several use cases have already been received, covering agricultural applications, coastal risk information services, food security, and wildfire management.

156. **The CO2 Human Emissions (CHE) project – moving towards a European capacity to Monitor Anthropogenic CO_2 Emissions**

Gianpaolo Balsamo et al, CHE

The CO_2 Human Emissions (CHE) project has been successfully coordinating efforts of its 22 consortium partners, to advance the development of a European CO_2 monitoring and verification support (CO_2MVS) capacity for anthropogenic CO_2 emissions. The CHE project has enhanced global, regional, and local CO_2 simulations capabilities, with focus on anthropogenic sources representation. The project has achieved advances towards a CO_2 global inversion capability at high resolution to connect atmospheric concentration to surface emissions. Results demonstrated the use of Earth observations (satellite and ground-based) as well as proxy human activity data to constrain uncertainties and to enhance the CO_2 monitoring timeliness.

The CHE Horizon 2020 project, which ran from October 2017 until December 2020, transfers all ongoing developments to a new project that will target the Copernicus CO_2 Service (CoCO_2) from January 2021 until December 2023.This follow-on project has a particular focus on supporting the 1st Global Stocktake of the Paris Agreement and advancing the implementation and readiness of both the monitoring prototype and the information products portfolio that can support an operational phase. This will be done in close coordination with the European Commission, the United Nations, and National and International stakeholders.

157. **Towards an International standard for Urban GHG Monitoring and assessment**

[76] See https://unfccc.int/event/earth-information-day-2020 or https://unfccc.padlet.org/unfccc/EarthInformationDay2020.
[77] See https://climatemonitoring.info/use-cases/.

Oksana Tarasova, Jocelyn Turnbull, Phil DeCola, Mario Peiró and the Integrated Global Greenhouse Gas Information System (IG3 IS) Urban Authors; IG^{3}IS

The WMO sponsored IG^{3}IS initiative aims to coordinate an integrated global greenhouse gas information system, linking inventory and flux model-based emissions information with atmospheric observations and modelling of greenhouse gasses. Together these provide the best possible estimates of greenhouse gas emissions at the national and urban scales. Linkages to stakeholders and policy outcomes are a critical component of IG^{3}IS.

Urban areas are of special interest, as most human-produced greenhouse gasses are emitted from cities, and mitigation policies are often driven by city and local governments. Urban emissions are less well quantified than at the national scale, and detailed information about source sectors and temporal changes, as well as whole-city emissions, are essential to support policy actions.

IG^{3}IS is developing Guidelines for Urban Greenhouse Gas Emission Observation and Monitoring Best Research Practices. This document is being authored by researchers across a range of countries and cities working on a variety of different emission quantification techniques. It documents the current state-of-the-art methodologies, recommendations for application of these methodologies, as well as known challenges and limitations. These guidelines are aimed to the research community developing these emerging methods and are the first step towards documentary standards that can be implemented in operational situations.

158. **User requirements in the Integrated Global Greenhouse Gas Information System**

Oksana Tarasova, Jocelyn Turnbull, Phil DeCola, and Mario Peiró; IG^{3}IS

The WMO Integrated Global Greenhouse Gas Information System (IG^{3}IS) makes user requirements a cornerstone of its activities. IG^{3}IS serves as an international framework to ensure the quality and consistency of provided information (emissions reduction options and efficiency) across different spatial scales and economic sectors.

To ensure that user requirements are known and met, the IG^{3}IS Steering Committee has undertaken several steps including creation of a dedicated stakeholder group and organization of regular user consultations. The goal of the consultations is to give a floor to the representatives of different user groups, from national emission compilers to sectoral representative from oil and gas, waste management and agricultural sector to representatives of mayoral offices, to articulate the needs for greenhouse gas emissions information.

Technical solutions (for example those delivered through successful IG^{3}IS demonstration projects) are also shared with the stakeholders to demonstrate existing capabilities and potential solutions for their individual cases. IG^{3}IS presents a summary of the stakeholder needs collected at the first and second consultations and some examples of how those needs can be addressed.

2. Climate services provision

159. **Global Forest Observation Initiative: A partnership for tracking forests for climate action**

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.

160. **Copernicus Climate Change Service (C3S): a data value chain to support adaptation plans**

Stijn Vermoote, Chiara Cagnazzo, Andre Obregon & the C3S team, Copernicus Climate Change Service

To support national adaptation plans, consistent climate information at different scales is needed. The Copernicus Climate Change Service (C3S) provides consistent estimates of multiple Essential Climate Variables (ECVs), reprocessed Climate Data Records, a near-real-time climate monitoring facility, multi-model seasonal forecast datasets, climate projections at global and regional scales, and climate indicators aimed at supporting adaptation and mitigation policies in specific economic sectors.

Two examples of these information services are:

- Benchmark data for international climate funds to support investment decisions on adaptation. C3S reanalysis data (ERA5) is used by IISD and the GEF via the Special Climate Change Fund (SCCF) to support investors and government officials in considering nature-based solutions when making infrastructure spending decisions with the aim of scaling up action on nature-based solutions for adaptation.
- Enhancing European resilience to climate change through support to the EC DG CLIMA (European Directorate General on Climate Action) on the formulation and implementation of the new EU strategy on Climate Change Adaptation as part of the European Green Deal. This is achieved by feeding the Climate-ADAPT platform (EEA) with C3S data, stimulating the use of C3S data and tools and local data and information as benchmarks for better informed decision-making, and developing user driven applications on adaptation in key vulnerable sectors such as agriculture, infrastructure, water, and energy.

  It is important to not only provide consistent and standardized data but also to ensure that it reaches adaptation practitioners. C3S links with adaptation portals to accomplish this.

161. **Copernicus Climate Change Service (C3S): from raw data to users; making sense of the data**

Joaquín Muñoz-Sabater, Freja Vamborg, Andre Obregon & the C3S team, Copernicus Climate Change Service

C3S is actively involved in R&D and provides data services through the climate data store such as leaf area index, soil moisture, and sea level data. The climate data store also provides users options to directly use this data. The evaluation and quality control framework ensures transparency and traceability, provides certainty quantification, and ensures fitness for purpose. C3S also provides a framework to aid users to find the right data set and aid them with technical challenges.

A use of this data relevant to the Paris Agreement, the UNFCCC process, and the ECVs include its input to the European State of the Climate 2018 report. The report included data on the prolonged warm and dry conditions in the spring / summer of 2018. As well as including typical climate variables such as temperature and precipitation, the report also included anomalies related to soil moisture and leaf area index, increasing the relevance of monitoring products to specific users.

Another use of this data using C3S' own consistent Climate Data Record is seal level data for the production of e a global ocean monitoring indicator to support WMO monitoring activities and the UNFCCC.

162. **WMO Methodology for Cataloguing Hazardous Weather, Climate, Water and Space Weather Events**

Jim Douris, WMO

The WMO Methodology for Cataloguing Hazardous Weather, Climate, Water and Space Weather Events, developed in 2017 and adopted by WMO Congress (Cg-18) in February 2018, supports loss and damage stakeholders through implementation of a methodology to catalogue hazardous weather, climate, water, and space weather events. This supports the work of the Warsaw International Mechanism for Loss and Damage, the Paris Agreement, and the Sendai Framework for Disaster Risk Reduction.

The methodology includes a typology of different hazards, including, but not limited to, drought, floods, heat waves, cold waves, tropical cyclones, and hail. Each event is recorded in detail and added to an event database which interlinks with a loss and damage community database.

Next steps include:

- The development of an implementation plan (subject to WMO Congress approval).
- Leveraging experiences in countries.
- Strengthening the data partnership between the national loss and damage stakeholders and the National Meteorological and Hydrological Services.
- Developing national / regional process for recording, post processing and quality control.
- Implementation is expected in all WMO regions from 2021 through 2025.

163. **Ocean science, data, and services for the UN 2030 Sustainable Development Goals**

Karina von Schuckmann, Mercator Ocean; Elisabeth Holland University of South Pacific, Fiji; Peter Haugan, Institute of Marine Research, Bergen & University of Bergen; & Peter Thomson, United Nations Secretary General's Special Envoy for the Ocean, Fiji

A holistic approach that embraces sustainable Ocean stewardship informed by science, data and services to support society and the economy is required to create the 'Future We Want'. The UN Decade of Ocean Science for Sustainable Development is an essential foundation to achieve this objective.

The Ocean-climate nexus and efforts for integrated ocean management creates a complex array of diverse opportunities, contradictions, mandates and goals in the science-policy 'oceanscape'. This is all facilitated through the provision of ocean related data, science, and services.

The added-value chain is the core of ocean and climate services and connects raw products and oceanographic science knowledge to high-quality data products, and indicators. These added-value products can provide the evidence basis for agencies and reporting bodies, decision makers, other stakeholders and the public, yielding societal and economic benefit. Global partnerships under SDG 17 at the science policy and science/private interface support the optimized use of information in the marine environment through the added-value chain. Illustration of a science, data and services informed pathway towards sustainable fisheries to achieve SDGs 1, 2, & 8.

The combined use of environmental essential variables can support a holistic ecosystem approach to substantially improve fisheries management and support the development of sustainable fisheries. In this example, the environmental variables are key to inform the sustainable stewardship required to meet the SDG targets. Sustainable fisheries will support a sustainable blue economy that simultaneously embraces environmental stewardship to support society and sustainable economy.

Five of seven of the WMO's climate indicators derive from ocean variables. New Ocean essential variables and ocean climate variables, if observed with sufficient density and frequency, will allow us to describe the state of the ocean, develop predictions of the ocean and provide further services for humanity from the oceans. Sustained and accessible ocean observations and model systems interwoven with local, indigenous and cultural knowledge systems are required to monitor ocean dimensions from physics to ecosystems and from global to local scales. Capacities need to be secured and entered into operational services. Policy management and governance instruments require sustainable ocean stewardship, informed by the best available ocean science, data and services.

164. **Updates on regional and national climate services frameworks and funding**

Veronica F. Grasso, Global Framework for Climate Services (GFCS), WMO

National Framework(s) for Climate Services (NFCS) are multi-stakeholder user interface platforms enabling the development and delivery of climate services at a national level. NFCSs help improve the co-production, tailoring, delivery and use of science-based climate predictions and services in socio-economic sectors such as agriculture and food security, energy, health, water, and disaster risk reduction sectors. There are currently 54 NFCS globally, a 17% increase since 2019.

NFCSs support the Paris Agreement by ensuring the availability of science-based research and systematic observations needed for implementing the Nationally Determined Contributions. NFCSs also complement National Adaptation Plans (NAPs) by providing climate services that help in assessing climate vulnerabilities, identifying adaptation options, developing products that help improve the understanding of climate and its impacts, and enhancing the adaptation planning and implementing capacity of climate-sensitive sectors.

Climate finance has reached record levels, crossing the US$ half-trillion mark annually for the first time over the 2017-18 period. Action still falls far short of what is needed under a 1.5˚C scenario, however.

Adaptation finance is only 5% of the total climate finance. Moreover, the amount that is invested in climate services is a small percentage of the adaptation amount, despite the socio-economic benefits that can be derived from the use of climate services.

While climate services funding has substantially increased over the past decade, more and better investments are still needed to ensure the provision of high-quality climate information and services for climate-resilient action.

3. Risk assessment and adaptation

165. **Applications of Integrated Earth Information in achieving SDGs and promoting Ecological Civilization Construction in China**

Qingchen Chao, National Climate Centre (NCC), China Meteorological Administration (CMA); Caiying Wei, National Satellite Meteorological Center, CMA; Changxing Li, Meteorological Observation Center, CMA; Pengling Wang and Lijuan Ma, NCC, CMA, Xiuzhen Han, National Satellite Meteorological Center, CMA; Fa Tao, Meteorological Observation Center, CMA

Three cases are presented on the use of Earth information to provide services within the framework of the China Meteorological Administration. These services are designed to prevent and reduce disasters, improve the living environment, and boost economic development.

- Satellite resources can be used to prevent extreme floods. In summer of 2020, precipitation in the Yangtze River Basin was the highest recorded since 1961. During the flood season, products made from the FengYun, Gaofen, and Sentinel-1 satellites provided observation data on the major rivers and lakes in the area to both the government and the public to enable flood prevention.

  There were no catastrophes in a year of extreme flood risk. This demonstrates the success of China's flood prevention and disaster relief system through joint consultation, and accurate warning, monitoring, and sharing of early warning information among meteorological, hydrological, and other departments.

- Modern atmosphere monitoring techniques were used to translate Earth information on megacities for policymakers, supporting regional efforts in the governance of the atmospheric environment. The newly established integrated observation system in the Pearl River Delta region consists of a variety of remote sensing devices that detect atmospheric temperature, humidity, wind, and aerosols, among others.

  By understanding the previously studied mechanisms of haze generation and growth, an atmospheric environmental governance strategy was developed and resulted in a reduced the number of haze days in the Pearl River Delta region.

- The "National Climate Indication" was established at national level using Earth information. This protects the climate ecology, taps climate value, meets the people's growing needs for a better life, helps to build a Wild China, and promotes economic and social development. Climate cities are awarded this brand through a scientific assessment and review process based on the designed climatic index fit for different types of National Climatic Indications.

  Statistics shows that the awarded National Climatic Indications promoted local economic growth and enabled local people to enjoy the ecological dividends. The campaign also improves societal awareness of the climate, scientific understanding, reasonable use of climate resources, adaptation to climate change, and climate protection efforts.

166. **Combining Earth observation and policy to put ecosystems at the heart of resilient development in Costa Rica**

Rafael Monge Vargas, Ministry of Environment and Energy of Costa Rica; Becky Chaplin-Kramer, Stanford University, et al

Rapid improvements in spatial data, computation and visualization present new opportunities for biodiversity and ecosystem service monitoring and modelling, especially in terms of its integration with Earth observations (EO) from satellite remote sensing.

Costa Rica is making strides in the use of geospatial information to enhance conservation policies and promote a sustainable and resilient development for everyone. In 2020, two initiatives led by the Ministry of Environment and Energy, in partnership with UNDP and The Natural Capital Project, have presented preliminary results that show great potential to generate and integrate timely, high-quality information that will increase the country's capacity to safeguard and sustainably manage its natural systems.

The Mapping Nature for People and Planet Partnership brings together scientists and policy experts to harness Earth observations in the identification of essential life support areas (or ELSAs), which are areas where nature-based actions can most effectively deliver on multisectoral development priorities, including building climate resilience. Initially piloted in Costa Rica, the partnership is now evolving in Colombia, Kazakhstan, Peru, and Uganda.

Planning is in place to evolve this approach in 2021 for marine planning, as well as for the agro-environmental agenda and territorial planning. The next iteration of the ELSA map will be refined with inputs from the ecosystem service models developed with The Natural Capital Project.

The National Land Use, Land Cover and Ecosystems Monitoring System (SIMOCUTE) framework links biodiversity and ecosystem services to support decisions on the conservation of biodiversity, climate adaptation, and sustainable development. The framework will continue to generate analyses for use in the publication of Ecosystemic Accounts, identifying and managing Essential Life Support Areas, reporting on the quality and trends of the State of the Environment, designing new mechanisms to expand the national Payment for Environmental Services Program, and in the implementation of the National Decarbonization Plan and the National Climate Adaptation Policy. Together these activities help put ecosystems at the heart of resilient development in Costa Rica.

167. **Monitoring and understanding the ongoing evolution of global mountain systems: Hotspots of snow cover change and other examples**

Claudia Notarnicola, Ruth Sonnenschein, James Thornton, Elisa Palazzi, Carolina Adler, GEO Mountains Initiative

Little consensus exists regarding which variables should be considered absolute observation priorities – Essential Climate Variables, for monitoring and understanding the drivers, responses, and impacts of ongoing change in global mountains. As a first step, a workshop of several mountain experts was convened, and 25 key processes were identified and ranked over 80 corresponding variables according to their perceived importance.

Defining corresponding observation requirements in mountain areas is an important task that requires further work. Establishing better mountain observatories, making use of DataCube technologies, and integrating in situ and remotely sensed data alongside numerical models may further improve observations.

A new project is underway to use Artificial Intelligence to validate and downscale ecosystem-related Essential Biodiversity Variables in mountain environments. The project will derive accurate, high-resolution maps of mountain ecosystem extents by exploiting the advanced feature extraction capabilities provided by AI-based algorithms and the computational power of cloud-based platforms.

Two study regions – the Central European Alps and the Himalaya, will be used to assess the accuracy of the World Terrestrial Ecosystems (WTE) map and explore whether Earth observation data can be used to improve its spatial resolution and thematic content by integrating the latest Earth observations data.

168. **The influence of climate change on global snow cover distribution: Using the DLR Global SnowPack to identify snow cover trends and extreme events**

Andreas Dietz, Sebastian Rößler, Claudia Künzer; German Aerospace Center (DLR), German Remote Sensing Data Center (DFD), Department Land Surface Dynamics

DLR uses daily snow cover products from MODIS between 2000 and 2020 as the basis for the calculation of snow cover statistics. The MODIS products contain values for the Normalised Difference Snow Index (NDSI), which can be classified into presence or absence of snow based on additional information such as underlying land cover, topography, and seasonality.

To reduce the effect of cloud cover and polar darkness on the time series of snow cover information, the DLR Global Snow Pack processing chain contains several interpolation steps that sequentially remove all existing data gaps. These steps include combination of all available data for each calendar day, temporal interpolations, snow line detection and propagation, and the combination with available Snow Water Equivalent products which are independent from clouds.

Two application of this data are:

- Monitoring the variability of the annual snow cover by comparing the cumulative days with snow cover of a year with the long-term mean to identify trends and extremes. The winter of 2019/2020, for example, was characterised by a lack of snow in most of Europe, with the reverse situation in northern Scandinavia.
- The investigation of extreme hydrological events. Snow in Lapland in winter 2019/2020 led to floods in many places. In a current study, the relationship between the snow situation (duration and beginning of melting) and the risk of flooding is being investigated with the aid of hydrological and meteorological data.

169. **The future of Arctic sea-ice biogeochemistry and ice-associated ecosystems**

Delphine Lannuzel, University of Tasmania; Letizia Tedesco, Maria van Leeuwe, Karley Campbell, Hauke Flores, Bruno Delille, Lisa Miller, Jacqueline Stefels and the Biogeochemical Exchange Processes at the Sea-Ice Interfaces (BEPSII) community

Sea ice influences the climate system, provides food, and supports businesses. Arctic sea ice is becoming thinner, younger, warmer, and more ephemeral. The effects on biological productivity and the emission and capture of greenhouse gases was investigated in the Western Arctic (perennial sea ice), Central Basin (seasonal and perennial sea ice), and Eastern Arctic (seasonal sea ice).

The variables studied were environmental conditions (light, habitat, nutrients), biota (algal communities, microbial loop, metazoan, higher trophic levels, and biological pump of carbon), and climate-active gases (CO_2, dimethyl sulphate (DMS), CH_4 and halogens). Physical observations recorded changes in sea-ice coverage (horizontal changes) and sea-ice properties (vertical changes).

Key results of the study are:

- Marine primary productivity will increase and capture more CO_2, but the most successful algal species will also be smaller and transport less carbon to the ocean floor.
- There will be a greater dominance of zooplankton species with lower nutritional value for fish, leading to a decline in species like the Arctic cod.
- Sea-ice dependent predators like ringed seals, beluga whales and polar bears could face local and regional scale extinctions.

There is an urgent need for the establishment of long-term observing platforms in climate-sensitive sea-ice regions