# Earth Information Day 2019

# 3 December 2019, Madrid, Spain

## Summary report by the Chair of the SBSTA

*30 April 2020*


### *Summary*

This report contains a summary of the Earth Information Day 2019, held 3 December 2019 in conjunction with SBSTA 51 during the Climate Change Conference, Madrid 2019.

During a plenary discussion session and a poster session, the event focussed on three themes: (a) Updates on the State of the global climate; (b) Updates on implementing Earth observation: for region and country support, and needs; and (c) Earth observation for science, policy and practice: retooling global cooperation to respond to future climate risk.

**State of the Climate**

- The state of the global climate is a matter of concern, as shown by all climate indicators.
- People around the world are being increasingly impacted by climate change-related events, including 7 million people through displacement as a direct result of hazard events; exposure to extreme heat and heatwaves; increasing global hunger with climate change being a compounding driver in 26 out of 33 countries affected by food crises in 2019.
- Climate change will exacerbate and increase future risk, food security is already at high risk.

**Implementing observation**

- Systematic observation, in-situ and space-based, is the foundation for knowledge of the Earth – climate monitoring, information for GCOS essential climate variables (land, atmosphere and ocean) and climate indicators. It feeds into such products as the WMO statement on the state of the global climate and all climate services.
- Space agencies have developed the Constellation Architecture for Monitoring Carbon Dioxide and Methane from Space providing a system approach for emission estimates for carbon dioxide and methane.
- Sharing and exchanging data leads to benefits in all countries – it is a global good.
- There is not yet an optimal global observation system. Existing significant gaps lead to poor forecasts and climate projections.
- Data is lacking, including: in countries in Africa, Pacific Islands, some parts of South America, especially many mountainous areas; in the ocean particularly the Southern Ocean; for biological variables to monitor marine and terrestrial ecosystems.
- The global GHG monitoring network cannot yet enable complete understanding of the carbon cycle and carbon budget, including fluxes to the atmosphere, changes in the biosphere and intake of carbon to oceans and to vegetation.
- Observations for many key ocean variables do not yet have global coverage or have not reached the required density or accuracy for detection of change, for example ocean currents, surface heat fluxes, oxygen, inorganic carbon, subsurface salinity, phytolankton biomass and diversity.

**Retooling global cooperation**

- Global cooperation needs to be retooled to respond to future climate risk using synergies to strengthen interactions between different users and usages.
- The systematic observation community must work in collaboration with the modelling community, data and re-analysis providers to monitor emissions.
- There needs to be a move from open data to open science – and to share data, algorithms, tools and co-produce knowledge.
- The continuity of observations is vital to help develop and improve Earth system models and other climate models, with local observation data needed to verify models. Gaps in model information can only be identified through observations, in situ as well as remote sensing.
- Mechanisms are needed for putting together impacts information, and modelling and analysis to attribute events and to provide better and regular communication for all.
- Developing countries, particularly SIDS and LDCs need greater access to high-resolution data with appropriate temporal and spatial resolution as well as regional models.
- Global models need local data and local people need to be engaged to use the services as well as identify needs – to co-produce solutions.
- With the increase in the volume of data produced, new ways are needed of exploiting the big data being provided from satellite observations, climate models and climate reanalysis. The past methodology of downloading data and examining it is now over as there is just too much data. The data must be used and mined in a more intelligent way.

# Table of Contents

# I. Objective

1. Earth Information Day 2019 was held in conjunction with the fifty-first session of The Subsidiary Body for Scientific and Technological Advice (SBSTA 51), 2–9 December 2019, Madrid, Spain.[1]

2. The Earth Information Day provided an up–to–date picture of the global observing system for climate and its implementation needs, the state of the climate, and an outlook on systematic observation developments, opportunities and knowledge gaps to support decision making on risk assessment, adaptation and mitigation.

3. It presented the opportunity to optimize engagement and connect information and requirements between the science community, Party and non-Party stakeholders and link Earth observation with the global response to climate change to support the Convention and Paris Agreement implementation.

## A. Background and Mandates

4. The Convention[2] calls on Parties to promote and cooperate in research and systematic observation of the climate system and the development of data archives, including through exchange of information to further the understanding and to reduce or eliminate the remaining uncertainties regarding the causes, effects, magnitude and timing of climate change and the economic and social consequences of various response strategies.[3]

5. The Paris Agreement clearly identifies the need for an effective and progressive response to the urgent threat of climate change on the basis of the best available scientific knowledge.[4] Article 7.7(c) states that Parties should strengthen scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making.

6. The first Earth Information Day took place on 8 November 2016 at COP 22.[5] Subsequently, the SBSTA invited submissions from Parties to consider inviting the secretariat to organise similar events,[6] as mandated at SBSTA 50 (June 2019).

7. The information presented and discussions held at Earth Information Day 2019 provided useful input into the negotiations under agenda item 7(b) during SBSTA 51.[7]

8. In the conclusions, the SBSTA expressed its appreciation to the secretariat for organizing Earth Information Day 2019 and to Parties and all participating organizations and programmes and their representatives for their contributions. The SBSTA welcomed the diverse and informative presentations, posters and dialogue, and the value of the rich exchange of information during the Day. The SBSTA requested its Chair to prepare a summary report on Earth Information Day 2019, including on reported knowledge gaps on systematic observation, to be made available prior to SBSTA 52 (June 2020). This summary report is provided in response to that mandate.

## B. Approach

9. The Earth Information Day 2019 provided the opportunity to present an up-to-date picture of the current status of the climate, information gaps and the future outlook. It was an opportunity to optimise engagement and connect information and requirements between the science community, Parties and all stakeholders at the UN Climate Change Conference, December 2019. Its organisation was guided by previous mandates and submissions.[8]

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[1] See https://unfccc.int/topics/science/events-meetings/systematic-observation/earth-information-day-2019.

[2] See https://unfccc.int/process-and-meetings/the-convention/what-is-the-united-nations-framework-convention-on-climate-change.

[3] Convention Articles 4.1(g) and 5.

[4] See https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

[5] See https://unfccc.int/topics/science/events-meetings/systematic-observation/earth-information-day.

[6] FCCC/SBSTA/2019/2, paragraph 58.

[7] FCCC/SBSTA/2019/5 paragraphs 26–42.

[8] Available at https://www4.unfccc.int/sites/submissionsstaging/Pages/Home.aspx and https://unfccc.int/topics/science/workstreams/systematic-observation/chronology.

10. The SBSTA Chair prepared an information note in advance of the event to provide an overview of the three themes addressed and the guiding questions to help focus presentations and discussions.[9] The themes and guiding questions were:

1) **Updates on the State of the global climate -** What is the latest knowledge on the state of the global climate? What is the latest knowledge on the impacts of climate change and associated projected risks?

2) **Updates on implementing Earth observation: for region and country support, and needs -** What is the current status on the implementation of the GCOS implementation plan, including monitoring, reporting and quality control of all essential climate variables in oceanic, terrestrial and atmospheric domains? How are the needs of countries and regions with limited observation network coverage in particular being addressed by ongoing developments to maintain, access and/or improve long term data record? What are the needs to support NDCs, national inventories and the global stocktake that new capabilities for Earth observation can support?

3) **Earth observation for science, policy and practice: retooling global cooperation to respond to future climate risk** - What is the role and value of Earth observations in supporting the implementation of the Paris Agreement? How can decision-making be supported by advances in using earth observation data for improving and validating earth systems models, including for near-term climate projections? How do we ensure universal equitable coverage of, and open-access to, (big) data and information?

11. The Earth Information Day was held on 3 December 2019 with a discussion session 10:00–13:00 and poster session, 13.15–15.00, Plenary Loa, COP 25, Madrid, Spain.[10]

# II. Summary of the proceedings: discussion session

12. The first part of the discussion session of the dialogue was chaired by the Chair of SBSTA, Paul Watkinson (France). The Vice-Chair-of SBSTA, Annela Anger-Kraavi (Estonia), chaired the remainder of the session. The programme was opened by the SBSTA Chair with statements from Andrés Couve, Science, Technology, Knowledge and Innovation Minister of Chile and Petteri Taalas, Secretary-General, World Meteorological Organization (WMO).

13. Presentations on theme 1 were provided by John Kennedy, WMO, Valerie Masson-Delmotte, IPCC WG1 and Hans-Otto Pörtner, IPCC WGII and followed by a question and answer session.

14. Presentations on theme 2 were provided by Carolin Richter, GCOS and WMO, Joerg Schulz, CEOS/CGMS and Toste Tanhua, GOOS and IOC-UNESCO and followed by a question and answer session.

15. Theme 3 was addressed by a panel discussion led by Steven Ramage, GEO, with Maisa Rojas Corradi, Center for Climate and Resilience Research, Chile, Jean-Noël Thépaut, European Copernicus Climate Change Service, Prabir K. Patra, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Mokoena France, Lesotho and Cheryl Jeffers, Saint Kitts and Nevis, and included questions from the floor.

## A. Opening

16. **Mr. Andrés Couve**, Science, Technology, Knowledge and Innovation Minister of Chile stressed three key points in his statement.[11] Firstly, it is only through the best science and observational evidence that we can understand climate change. Secondly, the reports from IPCC, WMO and other relevant organizations are vitally important and they also clearly identify the importance of quality information and the need for more of it particularly to support developing country regions. Thirdly, Mr. Couve welcomed the initiatives, such as the Earth Information Day, which provide a space for discussion in the presence of delegates and policy makers and provide the evidence that will make its way to public policy and inform decision making.

[9] See https://unfccc.int/sites/default/files/resource/COP25_EarthInformationDay_Informationnote.pdf.
[10] See https://unfccc.int/topics/science/events-meetings/systematic-observation/earth-information-day-2019.
[11] Webcast 00:07:13.

17. **Mr. Petteri Taalas**, Secretary-General, WMO highlighted the important role of WMO for coordinating systematic observation including in setting standards for observation, monitoring the status of observations and producing the state of the global climate reports – the *WMO provisional statement on the state of the global climate 2019* is presented in more detail below (paragraphs 21–37).[12] A new record was set in 2019 for levels of greenhouse gases (GHGs) in the atmosphere with increasing impacts being seen around the globe.[13]

18. He highlighted the role of the WMO since 1873 in setting standards and creating global observation systems, such as the global atmosphere watch programme,[14] as well as championing free access to data. He also highlighted that **there is not yet an optimal global observation system globally**. **Data is lacking from Africa, Pacific Islands and some parts of South America**. **The global GHG monitoring network cannot yet enable complete understanding of the carbon cycle and carbon budget, including anthropogenic fluxes to the atmosphere, changes in the biosphere and intake of carbon to oceans and to vegetation. More monitoring stations are needed to be able to follow the success of the implementation of the Paris agreement**. The integrated global greenhouse gas information system (IG3IS) is supporting this work.

19. Mr. Taalas emphasized the important role of satellites in Earth monitoring. WMO recognise the governments who are either running a GHG satellite monitoring programme or are planning to do so, recently this includes the European countries.

20. He spoke on the cooperation and engagement work of WMO. The state of the global climate report was based on data from the WMO, FAO, WHO, UNESCO and several other players. The WMO in collaboration with WMO, IPCC, UNEP, Global Carbon Project and Future Earth recently published the United in Science Report[15] at the Climate Action Summit in September 2019. In closing, Mr. Taalas spoke on the structural reform being undertaken at WMO in favour of an Earth System approach to their work.

## B. Theme 1: Update on the state of the global climate

21. **Mr. John Kennedy**, WMO opened theme 1 with a presentation on **Climate change drivers, indicators and impacts**[16] summarizing some of the information from the *WMO provisional statement on the state of the global climate 2019*. He emphasized that the details in the report are underpinned by observation networks and WMO members who provide detailed information of the weather and climate events in their countries. Furthermore, scientific experts provide specific information on key indicators and UN agencies provide information on impacts of weather and climate related events.

22. Mr. Kennedy presented the latest values for a number of global indicators. The first key indicator presented was **greenhouse gas (GHG) concentrations**. Greenhouse gases drive the long term warming in the climate and in 2018 they reached record global concentrations (figure 1). Carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) all reached record concentrations in 2018: $CO_2$ reached 407.8ppm, 147% above pre-industrial levels; $CH_4$ was 1869 ppb, 259% above pre-industrial levels; and $N_2O$ was 331ppb, 123% above pre-industrial levels. This is data for 2018. Indications from individual sites show that 2019 continued the increase in GHG concentrations.

12 Webcast 00:09:35.

13 See https://library.wmo.int/doc_num.php?explnum_id=10108.

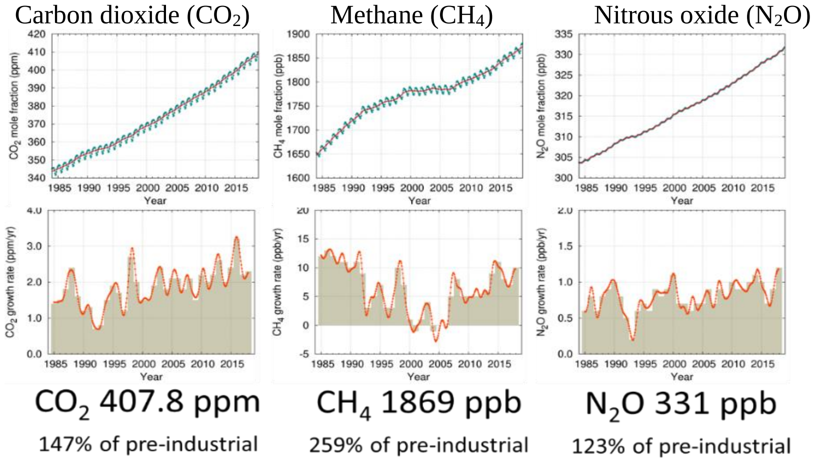
14 See https://public.wmo.int/en/programmes/global-atmosphere-watch-programme.

15 See https://public.wmo.int/en/resources/united_in_science.

16 See https://unfccc.int/sites/default/files/resource/1%20WMO_State_of_the_Climate_2019_clean.pdf. Webcast 00:16:46.

Figure 1

**Greenhouse Gases reached new record global concentrations in 2018**



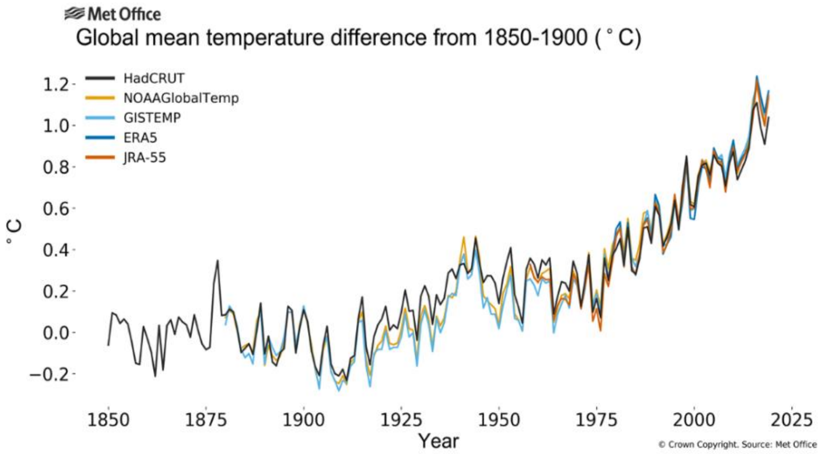

*Source:* Slide 3 of the presentation by Mr. John Kennedy

Top row: Globally averaged mole fraction (measure of concentration), from 1984 to 2018, of $CO_2$ in parts per million (left), $CH_4$ in parts per billion (centre) and $N_2O$ in parts per billion (right). The red line is the monthly mean mole fraction with the seasonal variations removed; the blue dots and line show the monthly averages. Bottom row: the growth rates representing increases in successive annual means of mole fractions for $CO_2$ in parts per million per year (left), $CH_4$ in parts per billion per year (centre) and $N_2O$ in parts per billion per year (right). Source: WMO Global Atmosphere Watch.

23. The rise in GHGs are driving warming of the climate. The next key indicator is **global temperature rise** (figure 2). Observations show that 2019 is due to be 1.1±0.1°C above pre-industrial. It will be the 2nd or 3rd warmest year on record. The decade 2010–2019 is the warmest decade on record. All this is showing continued warming in the climate system.

Figure 2

**The past 5 years are the 5 warmest years on record**

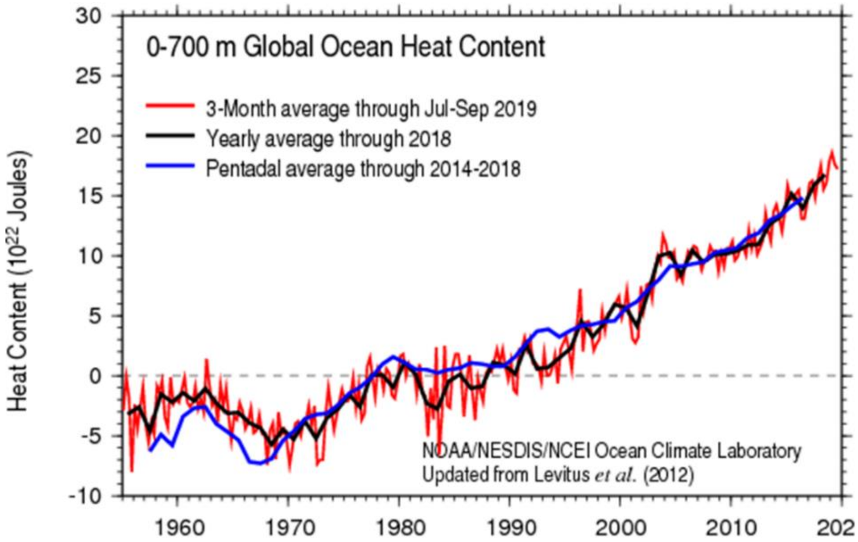



*Source:* Slide 4 of the presentation by Mr. John Kennedy

Global annual mean temperature difference from pre-industrial conditions (1850–1900, °C). The two reanalyses (ERA5 and JRA55) are aligned with the in-situ data sets (HadCRUT, NOAAGlobalTemp and GISTEMP) over the period 1981–2010. 2019 is the average for January to October.

24. Ninety per-cent of the energy that is being trapped by GHGs is going into the ocean causing continued warming of the oceans (figure 3). The next key indicator is **global ocean heat content** is a measure of the energy absorbed by the ocean in the 0–700m upper layer. Ocean heat reached a new high in 2019.

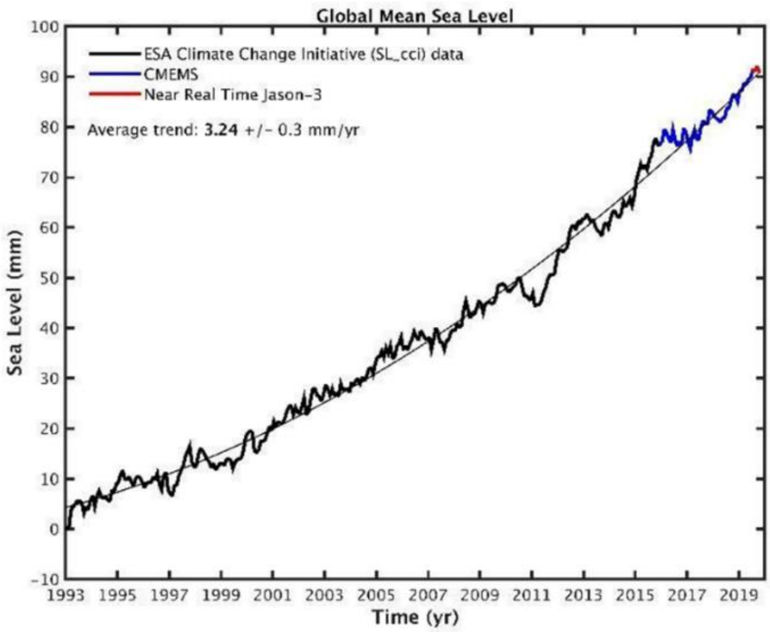
Figure 3
**Continued warming of the oceans**




*Source:* Slide 5 of the presentation by Mr. John Kennedy
Ocean heat content anomaly in the upper 700m of the ocean (relative to 1955–2006 average). Source: National Centers for Environmental Information, US. The red line is the 3-month average, the black line shows yearly averages and the blue line shows 5-year averages.

25. As the oceans warm, they expand and this along with ice melt causes **sea level rise** which is the next key indicator. Global mean sea level rise, recorded from satellite altimeters, reached record highs in 2019 (figure 4). The figure shows global mean sea-level rise from January 1993 to October 2019. During this period the average rate of increase is around 3.2 mm per year. However sea-level rise has accelerated over these past 27 years, due to increasing ice loss from Greenland and Antarctica. Variations in the acceleration of sea level rise are due to El Niño and La Niña, which can temporarily raise or lower sea-level.

Figure 4
**Global mean sea-level record high in 2019**

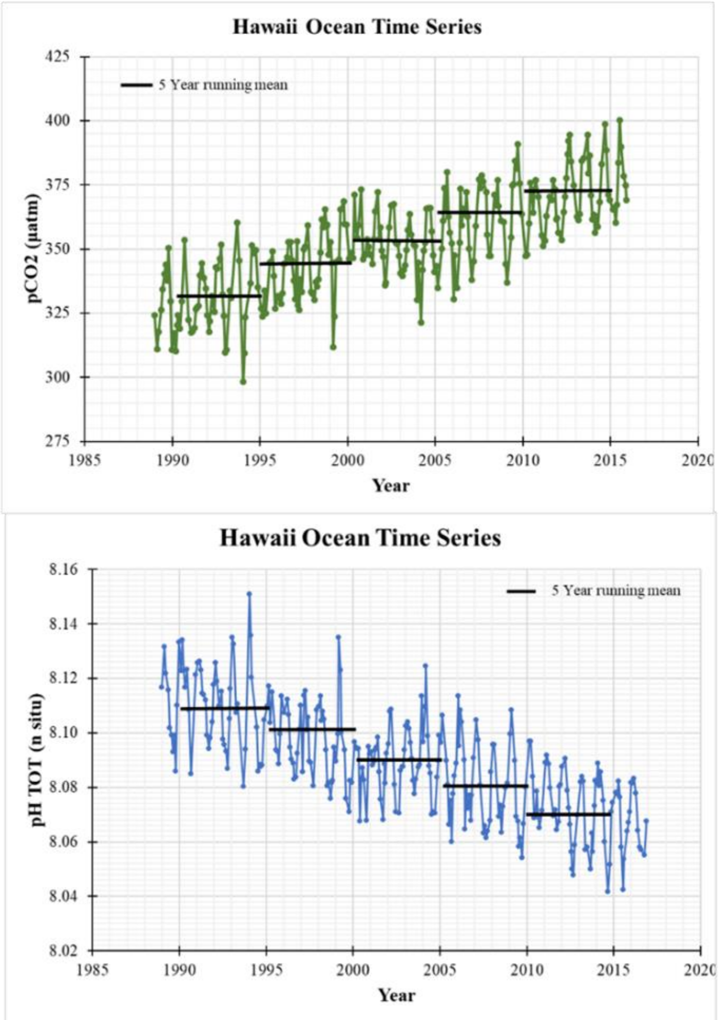



*Source:* Slide 6 of the presentation by Mr. John Kennedy
Global mean sea level evolution for January 1993 - October 2019 from high-precision altimetry. The thin black curve is a quadratic function that best fits the data.

26. Another consequence of increasing concentrations of $CO_2$ in the atmosphere is that around 22% of $CO_2$ emissions in the past decade have been absorbed by the ocean. This $CO_2$ reacts with the seawater to decrease the pH of the seawater and this process is known as **ocean acidification**. This key indicator can be demonstrated by the Hawaii ocean time series (figure 5). The top graph shows the increasing concentration of $CO_2$ in seawater since 1990, leading to a steady decrease in pH of the ocean shown in the

bottom graph. Over the past 20–30 years there has been a clear decrease in the pH of open ocean sites such as this one in Hawaii. Since preindustrial times there has been approximately a 26% increase in the Hydrogen ion concentration measure of the pH in the oceans.

Figure 5
**Ocean acidification**

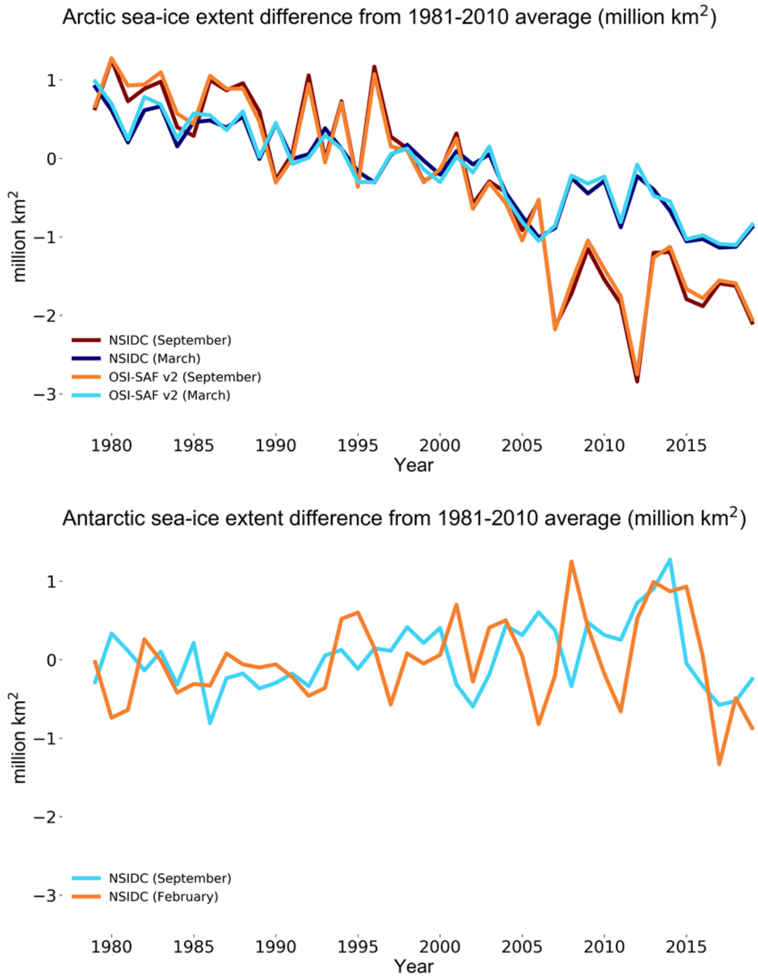



*Source:* Slide 7 of the presentation by Mr. John Kennedy
Long-term observations from the open ocean at the Hawaii Ocean Time Series site show an increase in $pCO_2$ (top graph) and a decrease in pH (bottom graph) over the last 30 years. Black horizontal lines are 5-year averages. Source: Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), NOAA Pacific Marine Environmental Laboratory (NOAA PMEL), International Atomic Energy Agency Ocean Acidification International Coordination Centre (IAEA OA-ICC).

27. The final key indicator is **sea ice extent** of the Arctic and the Antarctic (Figure 6). In regards to the Arctic sea ice extent, top graph, the sea ice extent is shown as a difference from the mean from 1981 to 2010 for two months: March in blue (at the end of the winter, the end of the freezing season when the maximum extent of arctic sea ice occurs) and September shown in orange and red (at the end of the Summer when the minimum arctic sea ice extent occurs). In 2019 the September extent showed the third lowest monthly minimum and the March extent showed the seventh lowest maximum. In both of these months and in all other months there is a continuing decline in Arctic sea ice extent.

28. In regards to the sea ice extent for Antarctica the picture is somewhat more complex as shown in the bottom graph. The blue line is the annual maximum and the orange line is the annual minimum ice extent. There was a slight increase in Antarctic sea ice extent around 2015 but then in 2016 there was a sudden drop that offset some of that increase. In 2019 sea ice extent has remained relatively low with a number of months having record low extents.

Figure 6
**Difference in the Arctic and Antarctic sea-ice extent from 1981–2010 average**



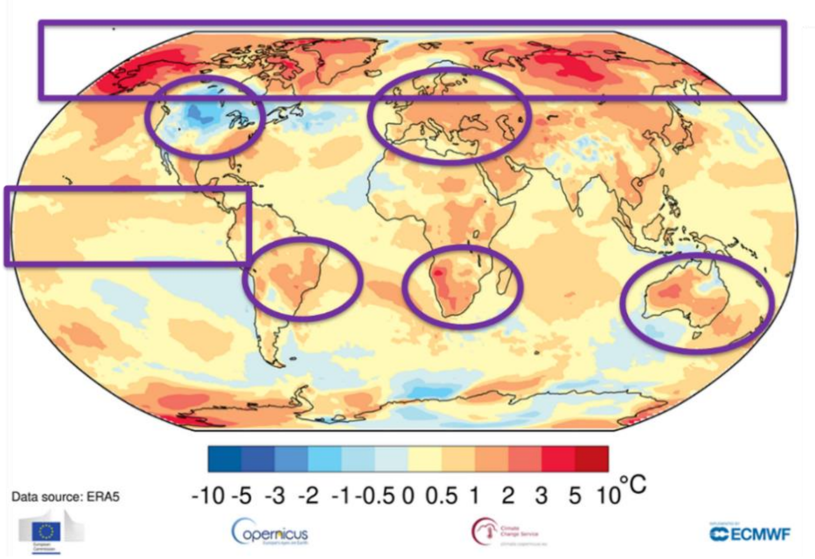

*Source:* Slide 8 of the presentation by Mr. John Kennedy
Monthly September and March ice extent anomalies (relative to 1981–2010 average) for 1979 to 2019. Sources: National Snow and Ice Data Center (NSIDC) version 3.0, US; and Satellite Application Facility on Ocean and Sea Ice (OSI-SAF v2).[17]

29. Mr. Kennedy then highlighted more specific events and regional information. **Global warming is not uniform** (figure 7). The figure shows the temperature difference between the average for October 2019 compared with 1981–2010, highlighting areas that are warmer or colder than average. This is consistent with our understanding of weather and climate variability working in concert with climate change. For example, North America has been particularly cold at the start of 2019, particularly in February, whilst in contrast Alaska has been very warm for the year so far. The Arctic as a whole has been warmer than average (in many areas over 3 degrees) for the year. Siberia also has high anomalies relative to the baseline and there have been wildfires in that region. Other regions with unusual warmth were Europe, southwest Asia and the Middle East. There were two significant heatwaves in Europe during 2019 with a number of national records broken and heat related impacts on human health.

30. In the Southern hemisphere there were areas of unusual warmth in parts of Brazil, southwest Africa and Australia. Australia had its warmest summer on record in January 2019. Also in 2019, there has been a weak El Niño in the tropical Pacific from the start of the year to mid-year. In the ocean there were noticeable marine heatwaves in the northeast Pacific and around the Tasman Sea.

[17] Lavergne T, Sørensen AM, Kern S *et al*. 2019. Version 2 of the EUMETSAT OSI SAF and ESA CCI sea-ice concentration climate data records. *Cryosphere* 13: 49–78.

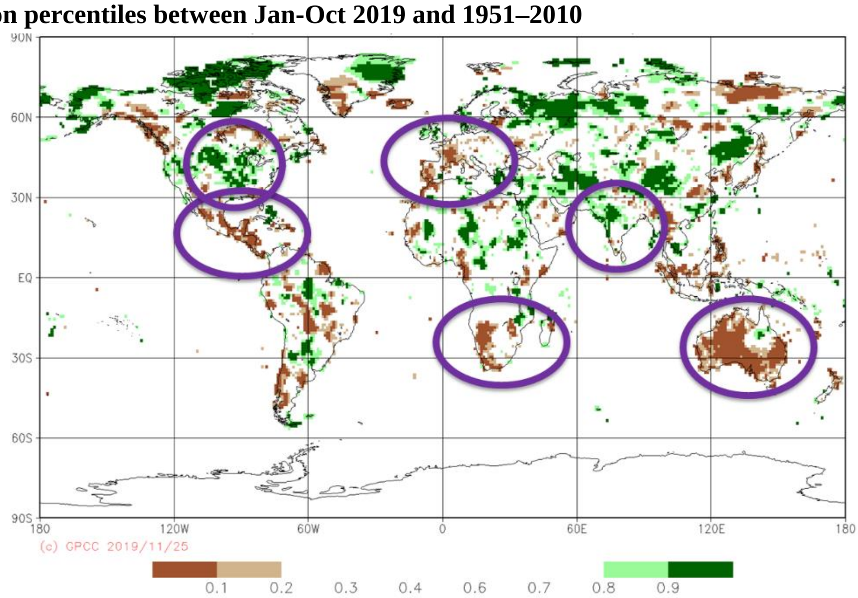
Figure 7
**Temperature difference between January - October 2019 and 1981–2010**




*Source:* Slide 9 of the presentation by Mr. John Kennedy
*Surface-air temperature anomaly for January to October 2019 with respect to the 1981–2010 average. Source: ECMWF ERA5 data, Copernicus Climate Change Service.*

31. Mr. Kennedy then highlighted areas of **particularly heavy impacts in regards to precipitation** (figure 8). In the figure, for January to October 2019, areas of particularly dry conditions are shown in brown and particularly wet conditions are shown in green.

Figure 8
**Precipitation percentiles between Jan-Oct 2019 and 1951–2010**




*Source:* Slide 10 of the presentation by Mr. John Kennedy
Annual total precipitation in January to October 2019 expressed as a percentile of the 1951–2010 reference period for areas that would have been in the driest 20% (brown) and wettest 20% (green) of years during the reference period, with darker shades of brown and green indicating the driest and wettest 10%, respectively. Source: Global Precipitation Climatology Centre, DWD.

32. Central America was particularly dry with low lake levels and restricted traffic along the Panama Canal. Honduras and Guatemala had severe crop losses due to the lack of rainfall. In southwest Africa it was very dry, and in May Namibia declared a state of emergency due to the droughts. Australia has been very dry and it was the driest January to October since 1902. Indonesia was also very dry and it has been a significant fire season there with the most significant fire season since 2015. Europe has had the second consecutive hot dry summer in some areas.

33. In contrast in the US there has been a very wet period from mid-2018 to mid-2019 with flooding on the Mississippi river in some places for several months. Another area of high rainfall was India where the monsoon withdrawal was the latest on record and had the highest rainfall total for the monsoon since 1994 with associated flooding and heavy loss of life.

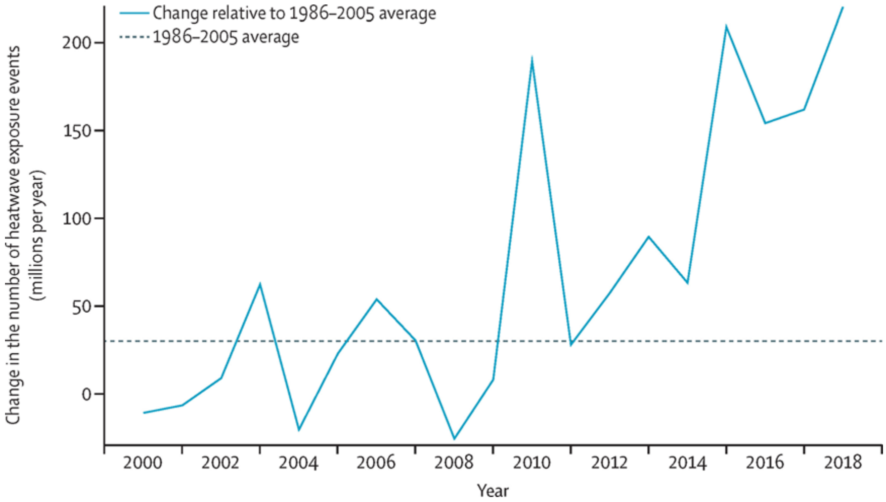
34. Mr. Kennedy concluded his presentation with some information provided by UN agencies on **climate change impacts due to extreme weather events and their impact on human lives**.

35. **Displacement information** from the UNHCR and IOM shows ten million new internal displacements from January to June 2019, of these 7 million were triggered by hazard events such as cyclone Idai and cyclone Fani in the East of India and Hurricane Dorian in the Atlantic. Floods and storms contributed most to the displacements followed by droughts.

36. He showed information from WMO on the **increasing exposure of human populations to extreme heat** from 2000 to 2018 (figure 9). In 2018 the latest year for which information is available, 220 million more heatwave exposures were experienced by vulnerable people over 65 than the baseline of 1986 to 2005.

37. In regards to hunger, information from the FAO was presented showing that over **820 million people, one in every nine people in the world, suffered** from **hunger in 2018**. There has been a rise in global hunger after a long term decline. Drivers of this rise in global hunger vary but among 33 countries affected by food crises in 2018 climate and weather were a compounding driver in 26 of those countries.

Figure 9
**Change in the number of heatwave exposure events relative to 1985–2005 average**



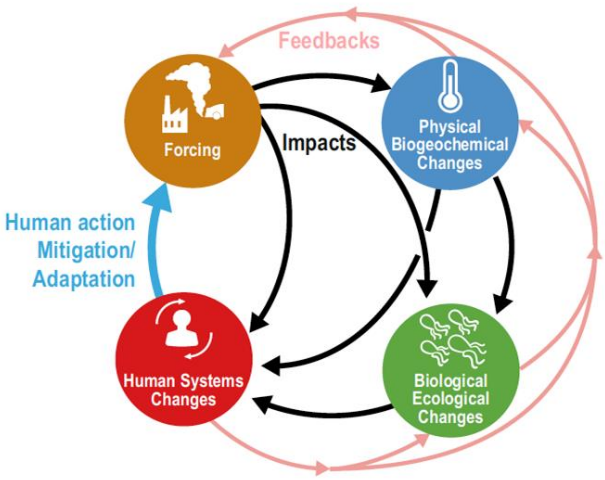

*Source:* Slide 11 of the presentation by Mr. John Kennedy.

38. **Ms. Valerie Masson-Delmotte,** IPCC **WG1 and Mr. Hans-Otto Pörtner, IPCC WGII** presented on **Observed changes and impacts and projected risks identified in the IPCC special reports on climate change and land and the ocean and cryosphere in a changing climate**.[18] Ms. Masson-Delmotte identified that the presentation would be from the perspective of both WGI and WGII of the IPCC and she thanked all the authors involved in both reports for their dedication.

39. Mr. Pörtner stated that there are many systems being observed and covered by the two reports (figure 10). The two IPCC reports assessed 14000 scientific publications and considered 59451 review comments. Studies assessed include not just those of the physical systems but it is also important to consider the biological systems and changes in human systems, as well as their interactions. This makes observations very challenging.

[18] See https://unfccc.int/sites/default/files/resource/2%20IPCC_Earthinfoday-2019.pdf. Webcast 00:29:25.

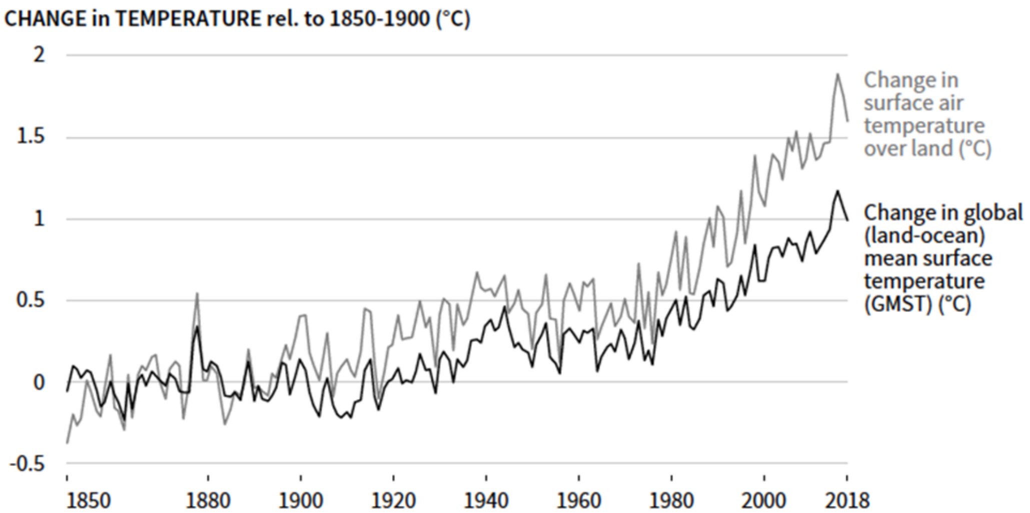
Figure 10
**IPCC provide integrated assessments of the state of knowledge**




*Source:* Slide 2 of the presentation by Ms. Valerie Masson-Delmotte Mr. Hans-Otto Pörtner.

40. Ms. Masson-Delmotte reported firstly on information from SRCCL that **warming is greater over land than at the global scale** (figure 11). When looking at the decade 2006–2015 globally warming has reached 0.87 °C compared with the 1850–1900 baseline, but **over land warming is already 1.5 °C above** this baseline.

Figure 11
**Change in temperature relative to 1850–1900**




*Source:* Slide 3 of the presentation by Ms. Valerie Masson-Delmotte Mr. Hans-Otto Pörtner.

41. She highlighted a number of **the consequences of global warming over land**:

1) Increasing frequency, intensity and duration of heat waves;

2) Increasing intensity of heavy rainfall events;

3) Increasing frequency and intensity of drought (in the Mediterranean, West and Northeast Asia, regions in South America and Africa);

4) Shifts of climate zones affecting many plant and animal species;

5) Contrasting vegetation trends with greening in some regions due to $CO_2$ effects and a longer growing season, but also browning areas due to increased water stress;

6) Exacerbation of land degradation (such as soil erosion, coastal erosion, permafrost thaw);

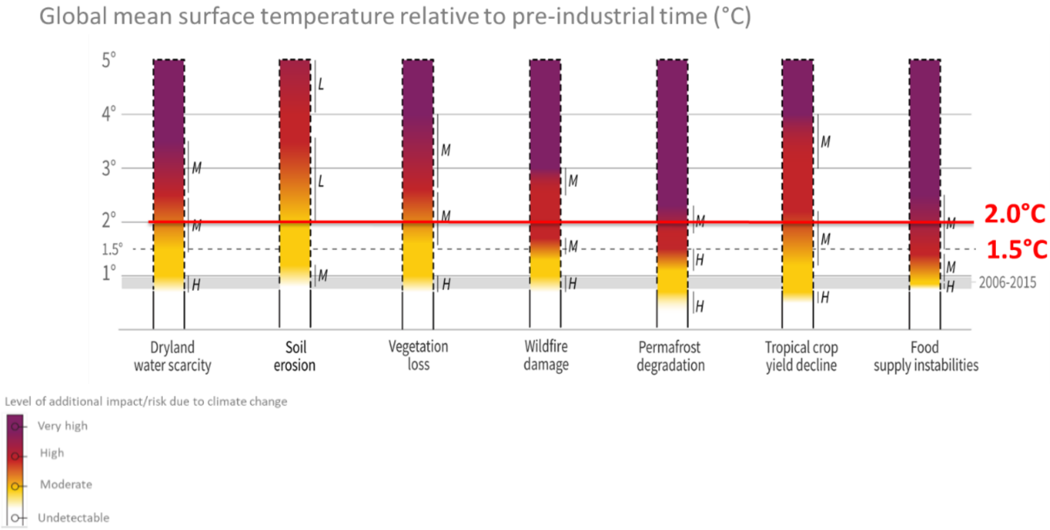
7) Increasing area of drylands in drought by +1% per year in average since 1961;

8) Increasing frequency and intensity of dust storms in many dryland areas.

42. Climate change has already affected food security due to warming, changing precipitation patterns, and greater frequency of some extreme events.

43. Mr. Pörtner presented some of the IPCC risk assessments from SRCCL examining a range of sectors in terms of how they are changing depending on the change in global mean surface temperature (figure 12). The risk assessment is indicated here in a colour code from white-undetectable, to yellow-moderate risk, to red-high risk and to purple-very high risk. The sectors shown in the figure are: dryland, water scarcity, soil erosion, vegetation loss, wildfire damage, permafrost loss and degradation, tropical crop yield decline and food supply instabilities. **The most sensitive sector is food supply, where global mean surface temp and global mean surface warming of between 1.5 and 2 °C already means that human food security is already at high risk**.

Figure 12
**Risks to humans and ecosystems from changes in land-based processes as a result from climate change**




*Source:* Slide 5 of the presentation by Ms. Valerie Masson-Delmotte Mr. Hans-Otto Pörtner.

44. **In regard to high mountain regions, melting glaciers, snow and ice and thawing permafrost (frozen ground) are very visible symbols of climate change. Global warming has led to widespread shrinking of the terrestrial cryosphere**:

1) Ice sheets and glaciers worldwide have lost mass. The mass loss from Greenland has doubled in the last decade compared to the previous decade due to surface melting. The loss of ice from Antarctica has tripled due to increased ice flow;

2) Arctic June snow cover extent over land declined by 13.4 ± 5.4% per decade from 1967 to 2018 (2.5 million $km^2$);

3) In high mountain areas, the depth, extent and duration of snow cover have declined over recent decades, especially at lower elevations;

4) Changes in snow and glaciers have changed the amount and seasonality of runoff and water resources in snow dominated and glacier-fed basins;

5) Permafrost temperatures increased by 0.29°C ±0.12°C from 2007 to 2016 averaged across polar and high-mountain regions, globally;

6) Total global mean sea level rise in mm/year between 2006–2015 is 3.6 ± 0.5 (also see paragraph 48 below). Over half of this rise is caused by loss of land-based ice: Greenland: 0.77 ± 0.03; Antarctica: 0.45 ± 0.05; Glaciers worldwide: 0.61 ± 0.08.

45. A total of 670 million people in high mountain regions and many 100s of millions more downstream are dependent on water from mountain cryosphere. Over the past decades, exposure of people and infrastructure to natural hazards has increased due to growing populations, tourism and socioeconomic development. **Terrestrial cryosphere changes affect hazards, ecosystems and human activities, and include**:

1) Permafrost thaw and glacier retreat have decreased the stability of high-mountain slopes;

2) Cryospheric and associated hydrological changes have impacted plant and animal species and ecosystems;

3) The shrinking cryosphere in the Arctic and high-mountain regions has led to predominantly negative impacts on food security, water resources, water quality, livelihoods, health and well-being, infrastructure, transportation, tourism and recreation, as well as culture of human societies, particularly for indigenous peoples.

46. Arctic residents have adjusted the timing of activities to respond to changes in seasonality and safety of land, ice, and snow travel conditions.

47. Ms. Masson-Delmotte presented on the **global ocean which plays a key role in the climate system and has warmed unabated since the 1970s and taken up more than 90% of the excess heat in the climate system** due to anthropogenic GHG emissions. **This makes climate change irreversible**.

48. Climate changes in the ocean include:

1) Global mean sea level (SLR) is rising with acceleration in recent decades due to mass loss from the Greenland and Antarctic ice sheets, as well as continued glacier mass loss and ocean thermal expansion. SLR between 1901–1990 was 1.4 ±0.8–2.0 mm/year and between 2006–2015 was 3.6 ± 0.5 mm/year (see also paragraph 25 above);

2) Marine heatwaves have doubled in frequency since 1982 and are increasing in intensity;

3) The ocean has taken up 20–30% of total anthropogenic $CO_2$ emissions since the 1980s. The decline in ocean pH has already emerged from background variability for > 95% of the ocean surface area;

4) Surface ocean warming is enhancing density stratification and inhibiting mixing between surface and deep waters;

5) From 1970 to 2010, the open ocean lost oxygen by 0.5–3.3% over the upper 1000 metres.

49. **Due to warming of the sea and air, increases in tropical cyclone winds and rainfall, and increase in extreme waves, combined with relative sea level rise, exacerbate extreme sea level events and coastal hazards**.

50. Mr. Pörtner presented the **impacts on ocean life, as a consequence of the key climate drivers including ocean warming and oxygen loss, and ocean acidification**:

1) Ocean acidification and oxygen loss are already negatively impacting systems such as two of the four major upwelling systems;

2) Ocean warming has contributed to an overall decrease in maximum catch potential, compounding the impacts from overfishing for some fish stocks, this is compounded by the shifts occurring in species distribution;

3) Coastal ecosystems are affected by ocean warming, including intensified marine heatwaves, acidification, loss of oxygen, salinity intrusion and sea level rise, in combination with adverse effects from human activities on ocean and land;

4) Impacts are already observed on habitat area and biodiversity, as well as ecosystem functioning and services;

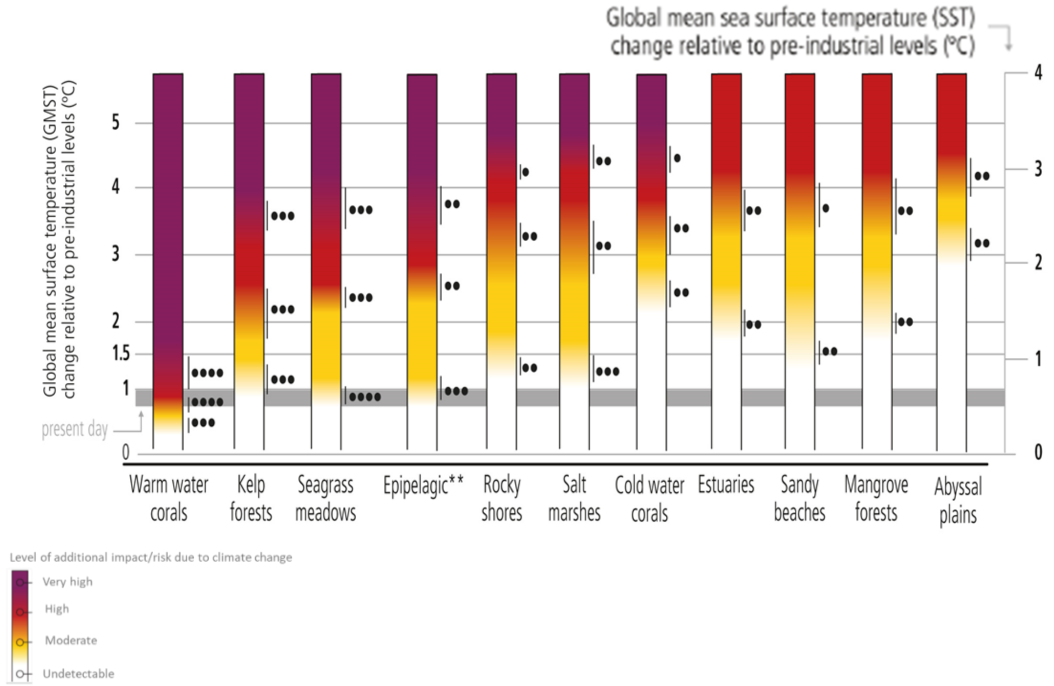
5) Many marine species have undergone shifts in geographical range and seasonal activities in response to climate change. Poleward shifts since the 1950s: 52 ± 33 km per decade (upper 200 m ecosystems) 29 ± 16 km per decade (seafloor ecosystems).

51. The IPCC SROCC provided risk assessments for some of the main ocean ecosystems including warm water corals, kelp forests, seagrass meadows, epipelagic, rocky shores, salt marshes, cold water corals, estuaries, sandy beaches, mangrove forests, and abyssal plains (figure 13).

52. Warm water coral reefs are already on a demise and have passed a tipping point.

53. Ecosystems would benefit from ambitious mitigation.

Figure 13
**Impacts and risks to ocean ecosystems from climate change**




*Source:* Slide 14 of the presentation by Ms. Valerie Masson-Delmotte Mr. Hans-Otto Pörtner.

54. In regard to **large scale shifts in biomass in the ocean, which are a challenge for observations, global temperature increase will lead to the lower latitudes being cleared over time from higher marine life** (figure 14). Depending on the emission scenarios, the trend is especially strong with unabated emissions as shown in the lower image in the figure.

55. This indicates that, as a high level conclusion beyond that discussed in the SROCC**, it is important to observe and monitor changes in marine and terrestrial biodiversity. These would be useful to verify model projections and improve forecasts of biodiversity shifts and losses**.

56. Mr. Pörtner stressed the need for **continuous observations for sustainability including: essential variables for biology and biodiversity; and monitoring of human food security**. This monitoring will enhance successes in ambitious mitigation, sustainable land and ocean management, supporting biodiversity conservation and food security for human society.

57. Ms. Masson-Delmotte stressed that both the land and the ocean and cryosphere reports flag the **opportunity for high returns on investments related to sustained long-term monitoring, sharing of data, information and knowledge, and early warning systems.** Improved observation and monitoring systems are an important investment moving forward including those needed for:

1) Land use including land degradation and desertification;

2) Context-specific ocean and cryosphere monitoring;

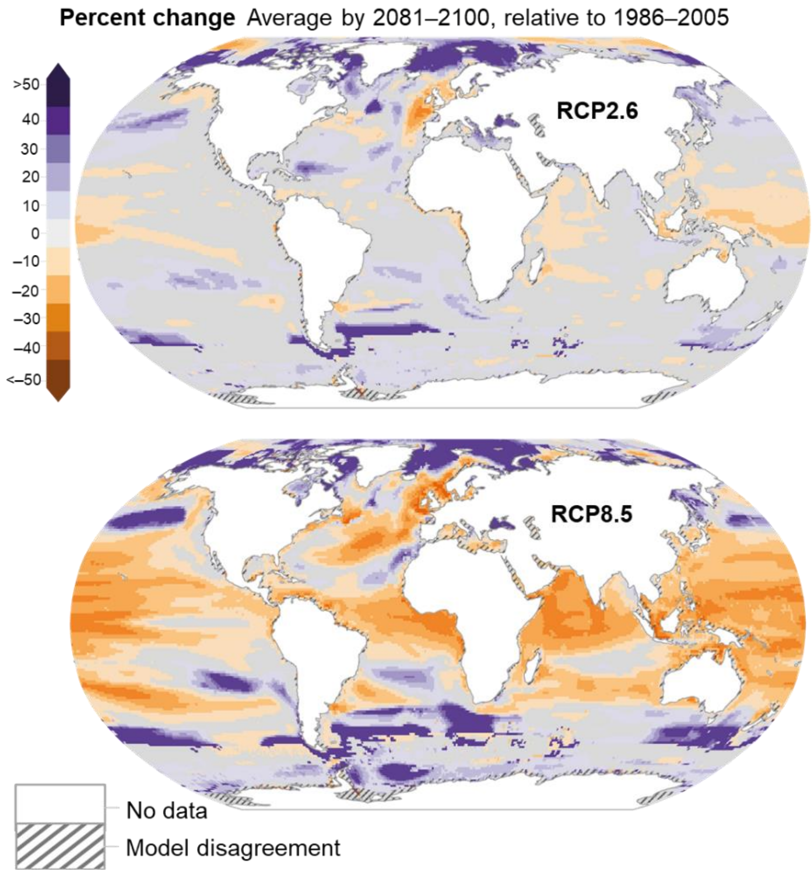
3) Biodiversity monitoring;

4) Improved context-specific forecasts (e.g. ENSO, marine heat waves, tropical cyclones);

5) Risk reduction, managing losses and adverse impacts;

6) Opportunities associated with new information and communication technologies.

Figure 14
**Future large scale shifts in animal biomass (including fish and invertebrates)**




*Source:* Slide 15 of the presentation by Ms. Valerie Masson-Delmotte Mr. Hans-Otto Pörtner
Simulated total animal biomass (depth integrated, including fisheries and invertebrates from the Fisheries and Marine Ecosystem Models Intercomparison Project (FISHMIP)) at RCP2.6 and RCP 2.8 see SROCC SPM.3.

**Discussion**[19]

58. Catastrophic events are increasing as a result of climate change. Some organisations are working on international responses such as Inter-American institute for Cooperation on Agriculture supporting states in South America and the Caribbean. However, there is consistent worsening of catastrophic events in the Caribbean and other small island States due to climate change. We have seen and experienced the worsening of conditions due to climate change, such as in the Bahamas. Even though small islands are not the major culprits, we are experiencing the major impacts. How can the unevenness of response be addressed?

*Mr. Pörtner: In regard to catastrophic events occurring in small island states and the international response system – the immediate response time is too long and there are no insufficient long-term response measures enforcing adaptation. We need international systems which go beyond short term responses to strengthen government systems, remove obstacles and support resilience against these increasing extreme events. Global warming is continuing and a system should be in place to reinforce resilience building.*

59. What are the irreversible impacts as a result of the unprecedented increases in GHGs already occurring?

*Ms. Masson-Delmotte: The last chapter of the SROCC report has a dedicated chapter dedicated to cyclones. For instance, it concludes anthropogenic climate change has increased observed precipitation and winds but with low confidence and extreme sea level events with high confidence associated with some tropical cyclones based on available literature. It also flags an increase in the average intensity and proportion of category 4 and 5 cyclones and associated precipitation rates for any increase in temperature at 2 °C at the global scale.*

[19] Webcast: 00:42:40.

60. It is important to understand the driving forces behind continued increased in GHGs. What are the key drivers in the ongoing increases in GHGs?

*Ms. Masson-Delmotte: With respect to causes of increased GHG concentrations, there are elements related to land-use drivers in SRCCL. For $CO_2$, the drivers will be covered in the AR6 WGI and WGIII reports which will be available for review soon and all colleagues are invited to contribute to the review of the reports. However, AR5 WG1 report has explored multiple lines of evidences that a large fraction of the sustained growth of GHGs arise from industrial activities.*

61. In regards to GHGs, once emissions begin to decrease, when do you expect GHG levels in the atmosphere to drop?

*Ms. Masson-Delmotte: This depends on the feedbacks from the carbon cycle both on land and in the ocean. There are elements related to that question identified in the first chapters of SR1.5. AR6 WGI assessment report will assess if $CO_2$ emissions reach a peak and decline, how long it will take to see the consequences in terms of atmospheric concentrations.*

62. What specifically is the WMO doing to increase the capacity of developing countries to monitor global GHG emissions?

*Mr. Kennedy: WMO is helping the capacity of developing countries to monitor various aspects of the climate. GCOS also has the implementation plan to identify the monitoring needs for the climate.*

63. Do you think the public across the world is aware of the severity of climate change impacts? What can be done to improve awareness?

*Mr. Kennedy: In terms of climate change impacts and their severity, the difficulty in bringing this to peoples' attention is getting timely information in place and bringing that together with physical information to build a picture of what is happening to provide useful authoritative information on a short time scale. What is often asked is attribution of events so mechanisms are needed for putting together impacts information, and modelling and analysis to attribute events.*

*Mr. Pörtner: In regards to improving awareness, from the point of view of WGII, it was certainly a surprise when looking at the risk transition in the special reports how much the response for the diverse systems in land and ocean are well behind what is required from the goals of the Paris Agreement and identified by the scientific knowledge. The future challenges are to develop implementation solutions and make them work.*

*Ms. Masson-Delmotte: Event based attribution and regular communication activities are needed to communicate to the public in each region a better understanding of what is human-induced climate change. The two special reports emphasise the importance of increasing climate literacy to enhance knowledge and understanding.*

*Mr. Couve: We have the compelling evidence of the importance to communicate on climate change, and we need to engage scientists in regards to regular communication with the public. However, this is not enough and we need to engage communication specialists to communicate with policy makers and all wider stakeholders. Chile is setting up ministerial division called Science and Society which will make information available to the public in a systematic and regular way.*

## C. Theme 2: Updates on implementing Earth observation: for region and country support, and needs

64. **Ms. Carolin Richter**, GCOS secretariat, presented on **how regional and national systematic observations of the climate are so important as part of a global effort**.[20]

65. Ms. Richter highlighted the mandate from SBSTA 45 requesting GCOS to undertake regional workshops.[21] Three workshops have been undertaken so far by GCOS, together with the WMO Integrated Global Observing System (WIGOS), in association with UNFCCC. These workshops have been held for the South Pacific Small Island Developing States (2017), East Africa (2018) and the Caribbean region (2019).[22]

[20] See https://unfccc.int/sites/default/files/resource/3%20GCOS_Earthinfoday-2019.pdf. Webcast 01:00:58.
[21] FCCC/SBSTA/2016/4, paragraph 39.
[22] See https://gcos.wmo.int/en/regional-workshops.

66. The three workshops considered:

1) Basic data needs for current climate models and reanalysis;

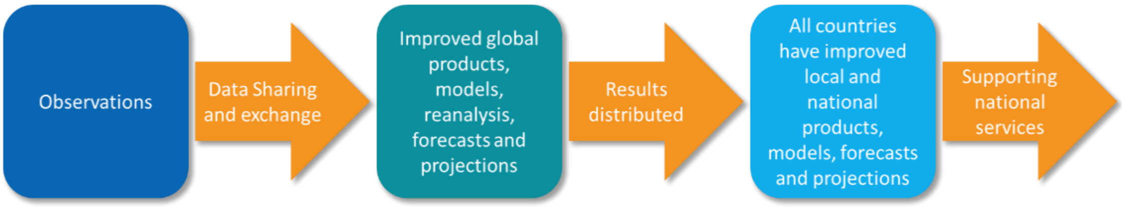
2) Surface and Upper Air Meteorological Observations;

3) Considered why the observation data was not available internationally;

4) Considered national contributions to global models.

67. Ms. Richter emphasized not just the importance of countries' consistent long-term systematic observations, but the importance of this data for contributing to global products and local services (figure 15). This was an important part of the discussions at the three workshops.

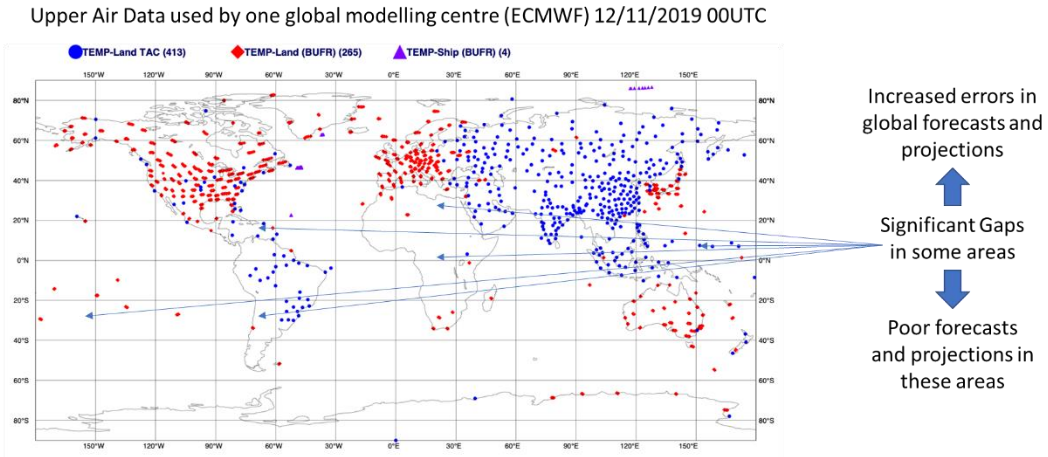
Figure 15
**Sharing and exchanging data leads to benefits in all countries – it is a global good**




*Source:* Slide 2 of the presentation by Ms. Richter.

68. While there are many varied essential climate variables, the workshops focused on national surface and upper air observations which underpin climate modelling and planning. **Existing significant gaps lead to poor forecasts and climate projections** (figure 16).

Figure 16
**Global Models Need Local Data**




*Source:* Slide 5 of the presentation by Ms. Richter.

69. Ms. Richter highlighted briefly the key messages from the workshops:[23]

1) **South Pacific SIDS, 2017**

- **Existing project-based funding does not lead to sustainable observations;**
- Countries have very large EEZ and small GDP;
- Communications and travel time are time-consuming and expensive;
- A lot of cooperation between countries on procurement, maintenance etc is needed;
- WMO is developing the Global Basic Observing Network (GBON) and finding to address these issues.

[23] The key messages from each of the workshops have been provided in the information notes by the SBSTA Chair for SBSTA 47, 49 and 51. See https://unfccc.int/topics/science/workstreams/systematic-observation/chronology.

2) **East Africa – Lake Victoria Region, 2018**

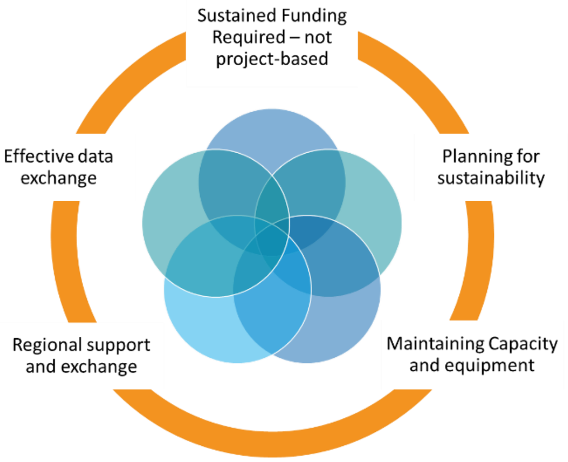
- **Sustainability first – funding second**;
- Funding in this region is not leading to sustainable networks;
- Only about 30% of the existing GCOS Surface Network stations and no GCOS Upper Air stations report as needed according to WMO guidelines;
- Planning (including funding) for sustainable networks is needed;
- Little understanding of the need and benefits of data exchange – this capacity needs to be developed.

3) **Caribbean Region, 2019**

- External sustained funding is the only way to lead to sustained observations;
- Coverage of monitoring is generally good;
- Upper Air Observations depend on sustained external funding (USA);
- Some technical issues around data exchange so not all observations are used;
- Need for better knowledge and information exchange.

70. Ms. Richter summarised the **elements for a national based sustained system for observations, identified through the workshops** (figure 17). She identified that, as a response to the workshop outcomes, WMO is establishing the **Global Basic Observing Network (GBON)**. GBON will provide the minimum data needed to support global climate models, forecasts and projections and weather forecasts. WMO is developing the **Systematic Observations Financing Facility** that would both support the development of GBON and its ongoing operation. GBON would cost about USD 750 million by 2025 and lesser amounts thereafter.

Figure 17
**Elements of a nationally based sustainable system**




*Source:* Slide 10 of the presentation by Ms. Richter.

71. Ms. Richter emphasised that although the workshops focussed on national surface and upper air observations, systematic observations must cover the whole of the climate system.

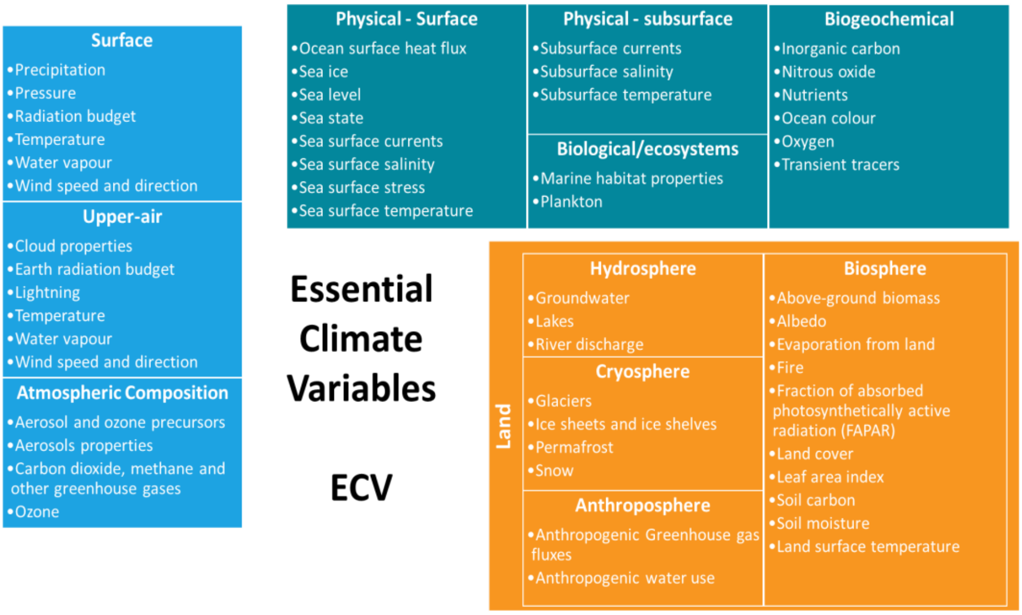
72. A **wide range of national and regional networks, ocean observations and satellites, all contribute to the Global Climate Observing System. Supporting and maintaining these networks, and sharing the data they produce, is fundamental to ensuring systematic climate observations as identified in the GCOS implementation plan**[24] **for all essential climate variables** (ECVs) (figure 18).

73. She highlighted that GCOS are identifying observations to explain climate-induced changes in the global biosphere.[25]

[24] See https://gcos.wmo.int/en/gcos-implementation-plan.

[25] Further information is provided in the poster *Observations to explain climate-induced changes in the global biosphere*, see para 174.

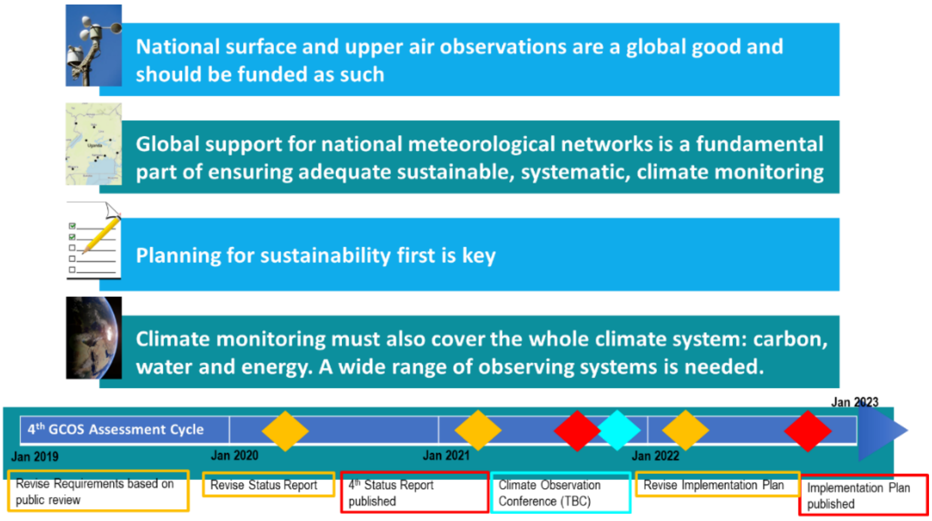
Figure 18
**GCOS Essential climate variables**




*Source:* Slide 12 of the presentation by Ms. Richter.

74. Ms. Richter summarised her presentation showing the key points from the workshops and identifying that the fourth GCOS assessment cycle will include the production of a GCOS status report in 2021 and a revised implementation plan in 2022 (figure 19).

Figure 19
**Summary**




*Source:* Slide 13 of the presentation by Ms. Richter.

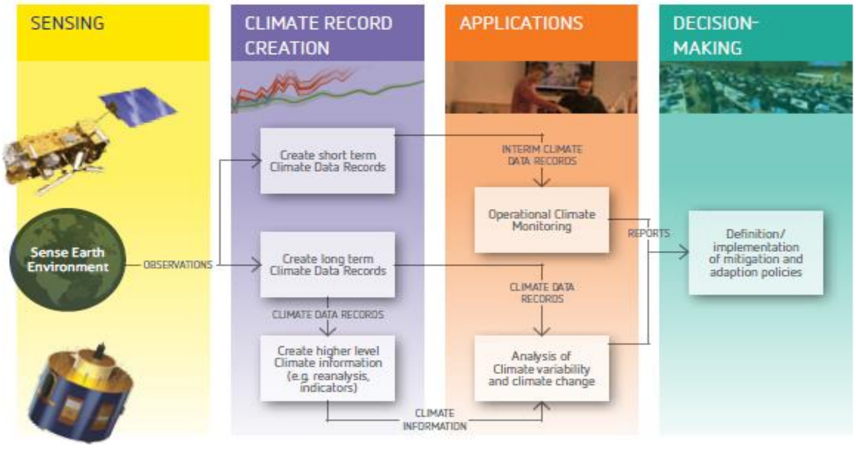
75. **Mr. Jörg Schulz**, EUMETSAT, Chair Joint CEOS/CGMS Working Group on Climate presented on **Space-based observation for supporting Nationally determined contributions (NDCs), national inventories and the global stocktake**.[26] Co-authors on the presentation included David Crisp, NASA/Jet Propulsion Laboratory, Mark Dowell, European Commission, and Albrecht von Bargen, German Aerospace Centre.

76. The space agencies are addressing the observation needs of the UNFCCC and the Paris Agreement and coordinating the response to the GCOS implementation plan through the Joint CEOS/CGMS Working Group on Climate, reporting back to the SBSTA as mandated.[27]

[26] See https://unfccc.int/sites/default/files/resource/4%20CEOS.CGMS_Earthinfoday-2019.pdf. Webcast 01:11:10.
[27] FCCC/SBSTA/2017/7 paragraph 56.

77. To facilitate the coordinated response to the observation needs, space agencies defined and are implementing the **Architecture for Climate Monitoring from Space** (figure 20).[28] The architecture is a **value chain from monitoring, via data, to information that can be used in decision and policy making. It includes the translation of observation uncertainty into confidence of statements, such as in IPCC reports**.

Figure 20
**The Architecture for Climate Monitoring from Space**




*Source:* Slide 3 of the presentation by Mr. Schulz.

78. A special focus within the Architecture for Climate Monitoring from Space is the **Constellation Architecture for Monitoring Carbon Dioxide and Methane from Space**.[29] Space agencies and partners are implementing a system approach to monitor GHG emissions (figure 21). This involves a diverse set of ground, airborne and space measurements, and subsequent data assimilation and transport modelling.

79. The outputs are targeted to:

1) Reducing uncertainties in national emission inventory reports for carbon dioxide and methane;

2) Identifying additional emission reduction opportunities with high resolution;

3) Providing nations with timely and quantified guidance on progress towards their emission reduction targets and pledges (Nationally Determined Contributions, NDCs);

4) Tracking changes in the natural carbon cycle caused by human activities (deforestation, degradation of ecosystems, fire) and climate change.

80. The **engagement of space agencies with a wide range of stakeholders and end users is fundamental to the success of this system approach**. Engagement with the emission community providing bottom-up inventories is critical to provide iterative feedback. The CEOS/CGMS WG Climate will engage on this work through existing initiatives including the **Global Emissions initiative** (GEIA), and with **champion users** (beta testers) to make the system fit-for-purpose.

81. Mr. Schulz highlighted that CEOS/CGMS WG Climate will continue to engage with international policy frameworks including the UNFCCC SBSTA and the IPCC TFI. The 2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories[30] now mentions the potential use of satellite data in the process – space agencies look forward to making stronger contributions in this area. However, the interface and feedback approach is needed to support this work. Engagement will also continue with international initiatives such as the WMO Integrated Global GHG Information System (IG3IS).[31]

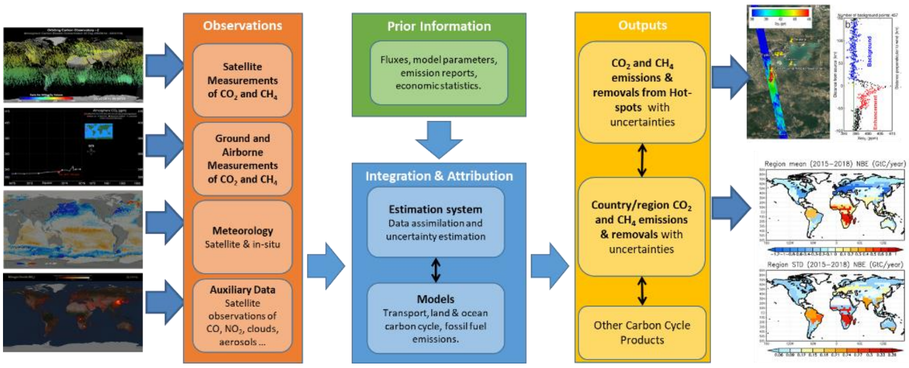
28 See http://ceos.org/document_management/Working_Groups/WGClimate/WGClimate_Strategy-Towards-An-Architecture-For-Climate-Monitoring-From-Space_2013.pdf.

29 Further information is available in the poster *A constellation architecture for space-based observations of greenhouse gases: measurement approaches, datasets, and models in support of the global stocktake*, see paragraph 156 below, as well as the white paper: http://ceos.org/document_management/Virtual_Constellations/ACC/Documents/CEOS_AC-VC_GHG_White_Paper_Publication_Draft2_20181111.pdf.

30 See https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories.

31 See https://ig3is.wmo.int.

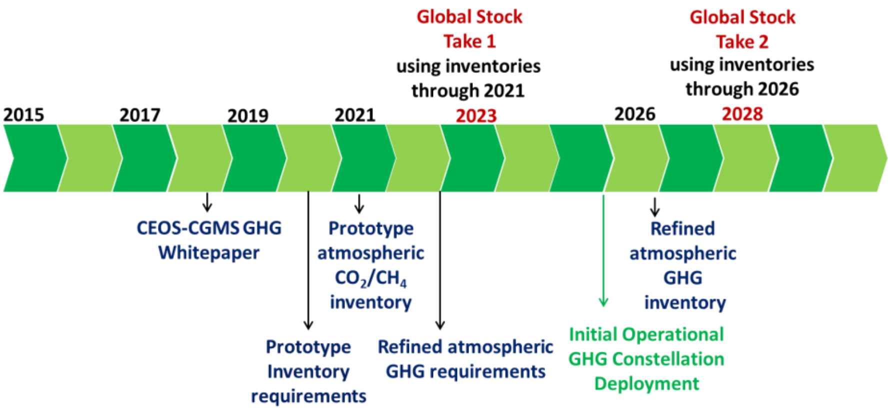
Figure 21
**Constellation Architecture for Monitoring Carbon Dioxide and Methane from Space**




*Source:* Slide 4 of the presentation by Mr. Schulz.

82. In regards to the timeline for the Constellation Architecture for Monitoring Carbon Dioxide and Methane from Space (figure 22): a first output from a prototype top-down system is planned for 2021 to provide inputs to the first global stocktake in 2023; a more refined operational system is planned for 2026 to provide inputs to the second global stocktake in 2028. The ongoing implementation is supported by a GHG satellite constellation deployment, which includes planned contributions by the European Copernicus programme (figure 23).

Figure 22
**Timeline for constellation architecture for monitoring carbon dioxide and methane from space**




*Source:* Slide 6 of the presentation by Mr. Schulz.

Figure 23
**The evolving fleet of satellites for the constellation architecture for monitoring carbon dioxide and methane from space**


*Source:* Slide 10 of the presentation by Mr. Schulz.

83. Mr. Schulz highlighted that at the global scale **the joint CEOS/CGMS WG Climate is not only working on GHGs but particularly on sustaining and further evolving space-based capabilities to monitor climate variability and change**. An integral part of this work is the **essential climate variable web-based inventory**[32] of existing and planned climate data records for GCOS Essential Climate Variables.

84. **This inventory includes a gap analysis of long term time series of data as well as current and planned implementation arrangements for ECVs. The WG Climate makes recommendations and implements actions to remedy gaps**.

85. **Everybody** with an internet connection **can download the ECV Inventory** content for their own analysis, find direct access points to climate data records in the Inventory, and get access to WG Climate gap analysis results and resulting actions.

86. The 2019 Inventory fills previously identified gaps for the ECVs including lightning, sea-surface salinity, above ground biomass, and permafrost, the latter two having significance for the study and analysis of the Earth's carbon cycle.

87. **Data access is globally free and open** without any constraint for more than 98% of the data records in the Inventory. This includes the data for the GHG monitoring system.

88. Mr. Schulz provided a summary of his presentation as follows:

1) Use of space-based observations with undoubted quality in global stocktakes, can play a supporting role by providing evidence for the success of the implementation of the Paris Agreement;

2) The Constellation Architecture for Monitoring Carbon Dioxide and Methane from Space supports the Paris Agreement, including development of national inventories. CEOS and CGMS encourage Parties and relevant organizations to continue to support and develop the constellation architecture;

3) The GHG constellation architecture follows a system approach bringing together top-down and bottom-up emission estimates for carbon dioxide and methane. Space-agencies and service providers will grant full, free and open access to the top-down data and derived information, which is available for use by all Parties;

4) Space agencies provide long-term observations for 35 out of 54 GCOS Essential Climate Variables (ECV) (37 being accessible by satellite). Data access is globally full, free and open for more than 98% of the data records;

5) The 2019 version of the web-based Inventory of climate data records of GCOS ECV observables from space fills previously identified gaps for the ECVs including lightning, sea-surface salinity, aboveground biomass, and permafrost, the latter two having significance for the study and analysis of the Earth's carbon cycle.

89. **Mr. Toste Tanhua, co-chair of GOOS, IOC-UNESCO,** presented on **Ocean observation: latest developments in support of the Paris Agreement**.[33]

90. He presented on some of the latest information from the Ocean Observation Conference, 16–20 September 2019, Hawaii.[34] The conference had over 1500 attendees and 128 community white papers. The key themes which emerged from the conference for ocean observations for climate are:

1) The need to plan for the impact required when designing observing systems;

2) Core system integration is vital to integrate between observing system elements to reach the desired impact;

3) To embrace innovation to provide better, less expensive sensors and observing elements.

91. Mr. Tanhua highlighted the importance of the **WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology in situ Observations Programme Support Centre (JCOMMMOPS)**[35] which provides observations and services for the ocean observing system.

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32 See https://climatemonitoring.info/ecvinventory/.

33 See https://unfccc.int/sites/default/files/resource/5%20GOOS.IOC_Earthinfoday-2019.pdf. Webcast: 01:21:46.

34 See http://www.oceanobs19.net.

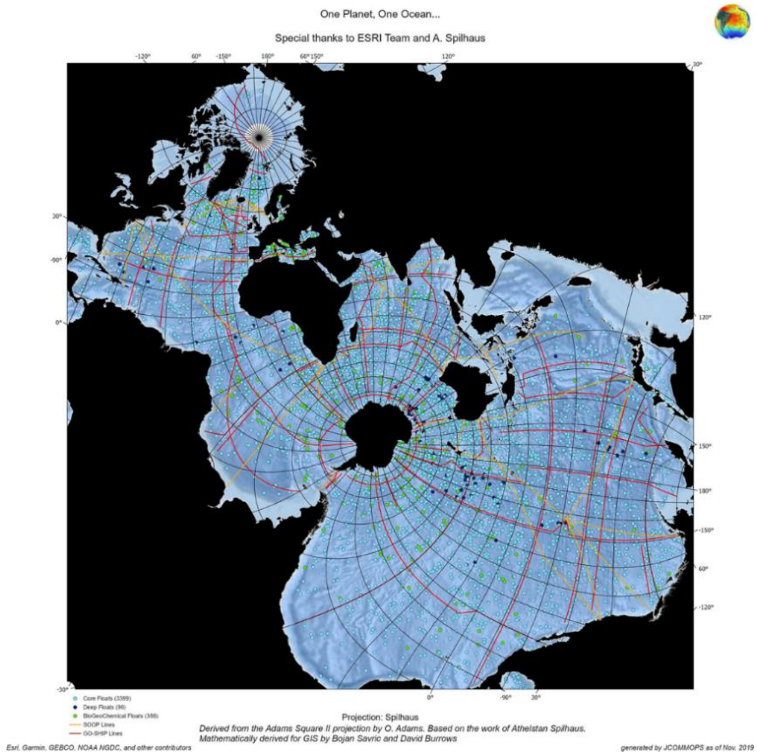
35 See http://www.jcommops.org.

92. He presented some of the findings of the JCOMMOPS 2019 report card.[36] Activities from 2018 in the report card include:

- 86 countries involved in ocean observations;
- 8,933 in situ ocean observing platforms;
- 18 Ocean and 9 Atmosphere Essential Climate Variables (ECVs) observed;
- 170 satellites continuously monitor the global ocean and atmosphere;
- 2 million Temperature and Salinity profiles acquired in 20 years by the Argo program - a historical record;
- Thousands of scientific papers based on ocean observations are published every year - adding to our knowledge and supporting societal decisions;
- Hundreds of thousands of weather forecasts issued annually by meteorological agencies that have assimilated in situ ocean observations to initialize and improve numerical model forecasts;
- USD 1,5 trillion/year - the estimated ocean economy - this will double, to USD 3 trillion, by 2030.[37]

93. He presented the JCOMMOPS map of ocean observation floats, including ARGO, and lines, that also shows the interconnectedness of the global ocean with its coverage of 70% of the Earth's surface (figure 24).

Figure 24
**Spilhaus projection showing JCOMMOPS ocean observation floats and lines**




*Source:* Slide 4 of the presentation by Mr. Tanhua.

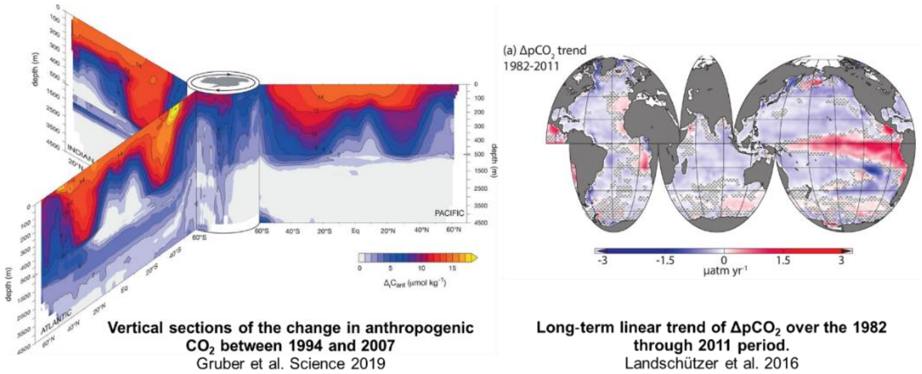
94. Mr. Tanhua stated that there are 17 ECVs for the ocean (see figure 18). He provided the latest information for a selection of these ECVs.

95. In regards to **inorganic carbon**, the ocean has taken up about 30% of the anthropogenic carbon dioxide emitted to date. However, over the last decade 22% of anthropogenic emissions have been taken up by the ocean (see also paragraph 26 above) indicating a reduction in the buffering capacity of the ocean system. He presented two aspects of the increase in ocean carbon (figure 25). The left side of the figure shows the interior storage of carbon in the ocean on a decadal scale. The ocean carbon moves through the

[36] See http://www.jcommops.org/reportcard2019.
[37] OECD (2016), The Ocean Economy in 2030, OECD Publishing, Paris. See http://dx.doi.org/10.1787/9789264251724-en.

ocean and, for example, the major carbon storage areas have moved from the north to the south Atlantic in the last few decades. The right side of the figure shows the active flux of carbon across the air/sea interface. The map shows the difference in partial pressure of $CO_2$ between atmosphere and ocean over time. Carbon flux is influenced not only by partial pressure but also by wind speed. As well as huge spatial variability in flux, there is also temporal variability which indicates the need for increasing ocean observing networks to monitor these changes.

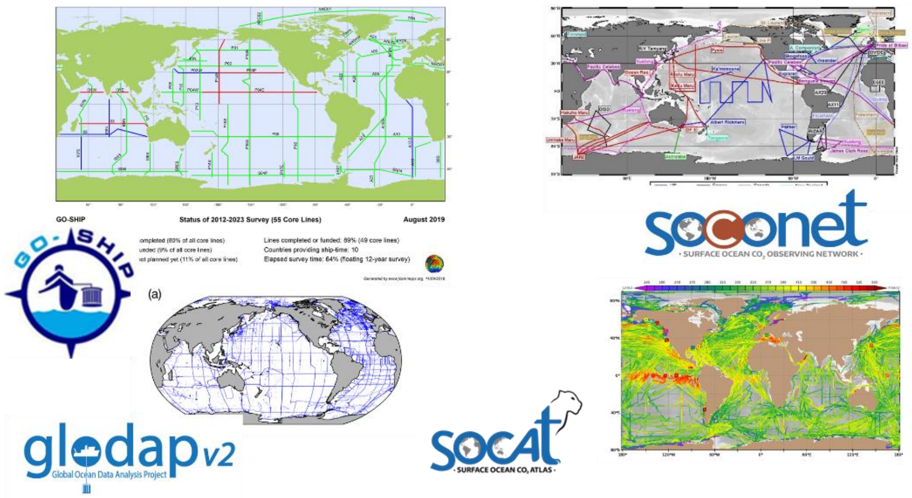
Figure 25
**Ocean carbon**




*Source:* Slide 6 of the presentation by Mr. Tanhua.
Gruber et al. (2019) The oceanic sink for anthropogenic $CO_2$ from 1994 to 2007. Science: 363 (6432), pp. 1193–1199. DOI: 10.1126/science.aau5153.
Lanschützer et al. (2016) Decadal variations and trends of the global ocean carbon sink. Global Biogeochemical Cycles 30. DOI: 10.1002/2015GB005359.

96. The ocean observation networks for carbon include GOSHIP[38] and its associated database, GLODAP,[39] and Soconet with its associated database SOCAT[40] (figure 26). GOSHIP includes 55 ships' lines of ocean observation with observation currently supported until 2023. Mr. Tanhua also highlighted that GOOS/IOC are reaching out to enable other opportunities for monitoring including on racing yachts.

Figure 26
**Observation of ocean carbon dioxide**



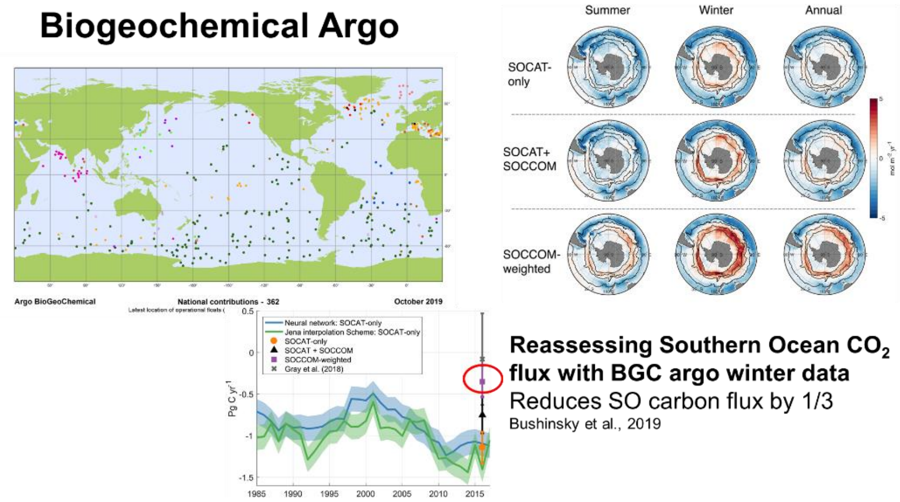

*Source:* Slide 7 of the presentation by Mr. Tanhua.

97. A further important element of ocean carbon observation is provided by the biogeochemical (BCG) Argo network (figure 27). The BCG Argo has been able to provide readings in areas not well frequented by vessels, and thus correction particularly for seasonal bias in Southern hemisphere winter time. New observations have shown that the expected carbon sink in the Southern Ocean is a third lower than had been previously estimated.

38 See https://www.go-ship.org.
39 See https://www.glodap.info.
40 See https://www.socat.info.

98. Mr. Tanhua highlighted that **observations in oxygen and carbon measurements are still not dense enough to measure de-oxygenation of the world's ocean and track the mechanisms driving the ocean carbon cycle, as identified in the SROCC**.

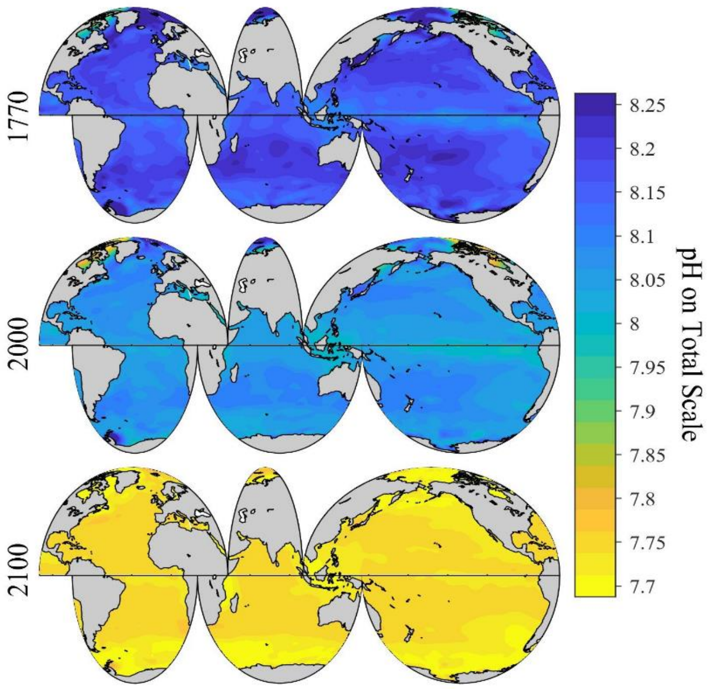
Figure 27
**Biogeochemical Argo**




*Source:* Slide 9 of the presentation by Mr. Tanhua
Bushinsky et al. (2019). Reassessing Southern Ocean air‐sea $CO_2$ flux estimates with the addition of biogeochemical float observations. Global Biogeochemical Cycles, 33, 1370–388. https://doi.org/10.1029/2019GB006176.

99. Mr. Tanhua then presented **a novel study on ocean acidification which provided the most high-resolution maps to date, showing changes in the pH of seawater since the Industrial Revolution using ground proofing data, and under future climate scenarios** (figure 28).

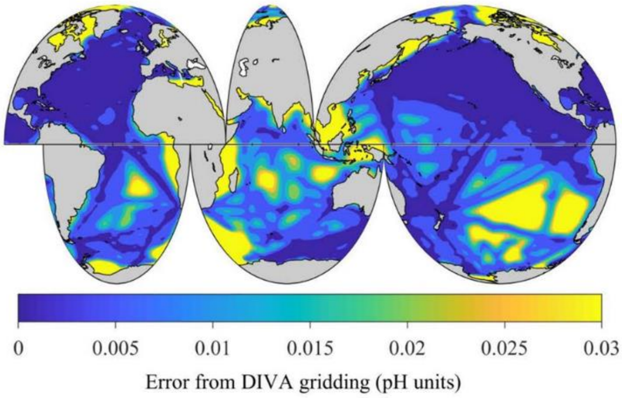
Figure 28
**Surface ph from 1770 to 2100 under rcp8.5**




*Source:* Slide 11 of the presentation by Mr. Tanhua
Jiang, L., Carter, B.R., Feely, R.A. et al. (2019) Surface ocean pH and buffer capacity: past, present and future. Sci Rep 9, 18624. DOI:10.1038/s41598-019-55039-4.
See also http://cmns.umd.edu/news-events/features/4527.

100. The study was based on $pCO_2$ observations. **There are large gaps in the observational record for $pCO_2$ in certain areas leading to significant uncertainties in the estimation of ocean acidification (figure 29), with the yellow areas indicating where no observations are taken. The Global ocean acidification observing network (GOA-ON) are addressing some of the observation gaps including through engaging communities through regional hubs and capacity building and establishing more observing sites**.[41]

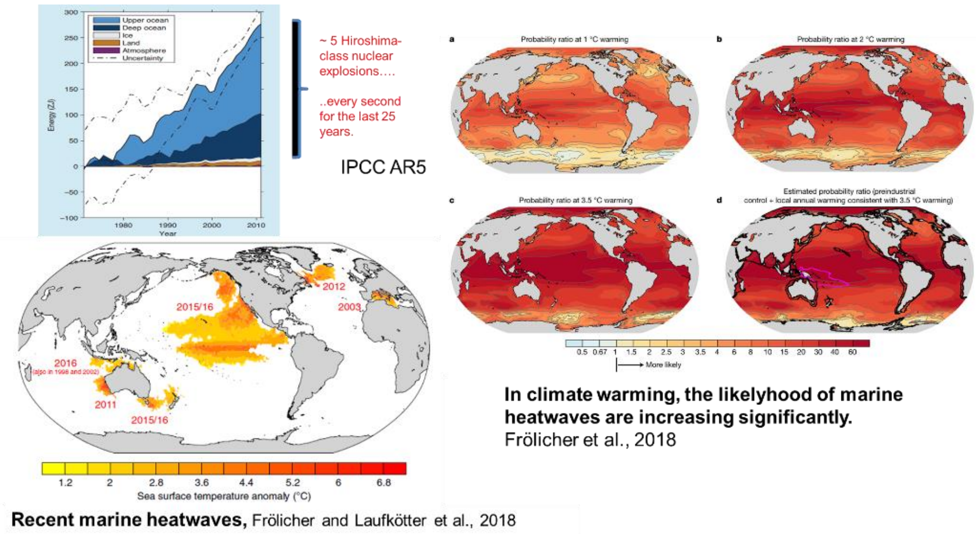
Figure 29
**Gaps in the observational record for $pCO_2$**




*Source:* Slide 12 of the presentation by Mr. Tanhua.

101. Mr. Tanhua highlighted the continued increase in **ocean heat content, and the increase in ocean heat waves as a result of climate warming** (figure 30).

Figure 30
**Ocean Heat Content and Marine Heatwaves**




*Source:* Slide 13 of the presentation by Mr. Tanhua
Frölicher and Laufkötter (2019). Emerging risks from marine heat waves. Nature Communications 9(1):650. DOI: 10.1038/s41467-018-03163-6.
Frölicher et al. (2018). Marine heatwaves under global warming. Nature 560 (7718). DOI: 10.1038/s41586-018-0383-9.

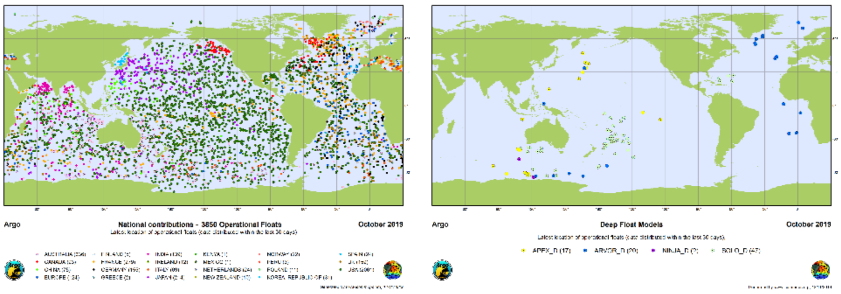
102. He highlighted that ocean heat content as well as other parameters are measured using the **Argo system of floats**. The Argo network currently includes 3850 operation core floats which can measure up to 2000m depth (figure 31a). However, half of the ocean volume is below 2000m, therefore, there are now some experimental Argo floats being deployed able to measure up to 4000m or 6000m**.** The planned GOOS **Argo 2020 design consists of 2350 core floats, 1250 deep floats and 1000 BCG floats** responding to increased requirements (figure 31b).

[41] See http://www.goa-on.org.

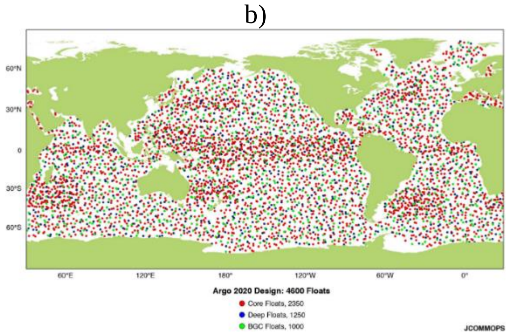
103. Mr. Tanhua highlighted that **we need full-depth, high quality and unbiased ocean temperature profile data in order to estimate thermal expansion required to understand drivers of variability and long-term change. However, deep ocean below 2000m is still rarely observed, despite deployment of some floats, limiting (for example) the accurate estimate of deep ocean heat uptake and, consequently the full magnitude of Earth's energy imbalance**.

Figure 31
**Argo system of floats – current and planned for 2020**

a)




b)




*Source:* Slide 14–15 of the presentation by Mr. Tanhua
a) deployment of operational Argo floats as at October 2019 including deep float models being tested
b) Argo 2020 planned design.

104. The final ocean ECV that Mr. Tanhua presented was **ocean deoxygenation** (figure 32). The amount of oxygen dissolved in the ocean has and continues to decrease, with far-reaching problems for marine life and dependent human populations. The IUCN report on ocean deoxygenation provides a summary of the scale and nature of the changes being driven by ocean deoxygenation.[42]

105. There are many different platforms observing ocean deoxygenation and Mr. Tanhua emphasised the **need to improve data integration between these different platforms**.

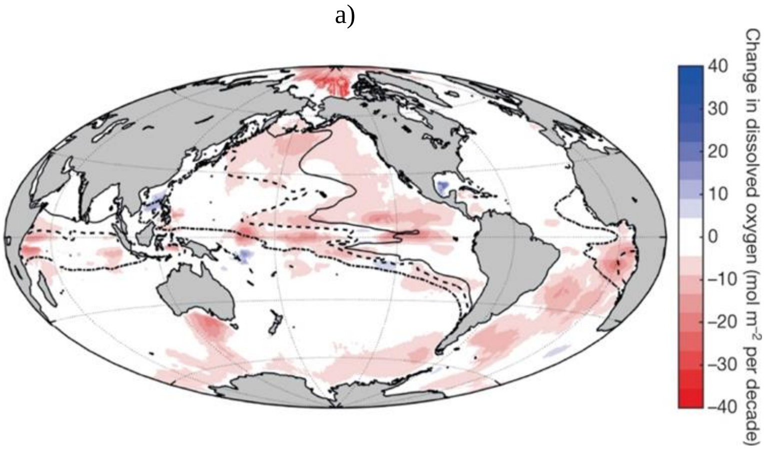
106. Mr. Tanhua highlighted that in addition to the information presented on the ocean variables above, **observations for many key ocean variables do not yet have global coverage or have not reached the required density or accuracy for detection of change, for example ocean currents, surface heat fluxes, oxygen, inorganic carbon, subsurface salinity, phytoplankton biomass and diversity**.

107. Mr. Tanhua concluded by presenting the **GOOS-Strategy published in 2019**.[43] The vision for the strategy is to provide a truly global ocean observing system that delivers the essential information needed for our sustainable development, safety, wellbeing and prosperity. He urged engagement with the UN Decade of ocean science for sustainable development (2021–2030).[44]

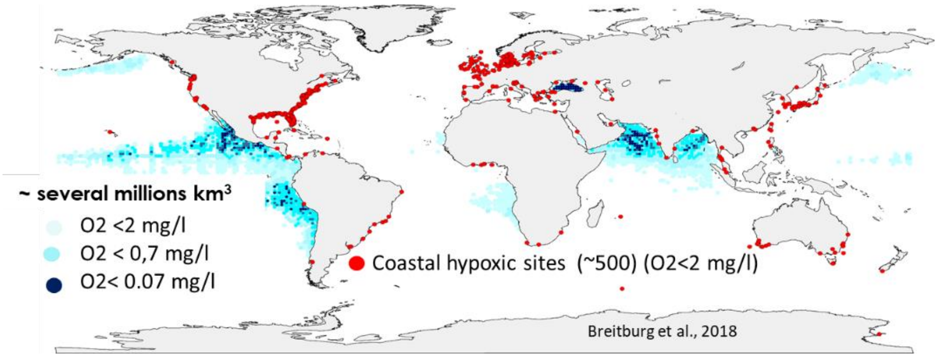
42 See https://www.iucn.org/theme/marine-and-polar/our-work/climate-change-and-oceans/ocean-deoxygenation.
43 See http://goosocean.org/index.php?option=com_oe&task=viewDocumentRecord&docID=24590.
44 See http://www.oceandecade.org.

Figure 32
**Ocean deoxygentation**

a)




b)




*Source:* Slide 17 of the presentation by Mr. Tanhua
a) Change in dissolved oxygen per decade since 1960. Lines indicate boundaries of oxygen-minimum zones (OMZs). Schmidtko et al. (2017). Decline in global oceanic oxygen content during the past five decades. Nature 542, 335–339. DOI:10.1038/nature21399.
b) Breitburg et. Al (2018). Declining oxygen in the global ocean and coastal waters. Science 359 (6371), eaam7240. DOI: 10.1126/science.aam7240.

**Discussion**[45]

108. Clearly, sustained funding is key across the board for sustained observations. How do you think we could best move to such sustained funding?

*Ms. Richter: As an outcome to the GCOS regional workshops, WMO are developing the Global Basic Observing System which could provide a focus for funding. The GBON network intends to provide the minimum atmospheric observation data which are needed by forecast and climate models. Project funding is useful but does not provide the sustainable, systematic observation of the climate needed. WMO is association with several partners has developed a new concept for a systematic observations financing facility (SOFF).[46] The Alliance for Hydromet development, launched at COP 25, has already committed to supporting this new facility.[47]*

*Mr. Schulz: For the space sector, a key focus of the joint CEOS/CGMS WG Climate is to identify how space-based information can be most applicable for climate applications. This coordination effort enables that the space agencies community benefits from use available budgets to find the best solution to monitor Earth's climate as efficiently as possible, for example in supporting the GCOS ECVs.*

*Mr. Tanhua: For the ocean, about 70% of the observation is funded by research organizations on short-term projects. This is not sustainable. There needs to be better coordination – cross-agencies, cross-organizations, cross-ministries (not just science ministries) and research funders to make the case of the importance of these observations for society at large in order to start creating sustainable structures and functions for the ocean observing system linked to observing systems at large.*

[45] Webcast: 01:33:38.
[46] See https://public.wmo.int/en/innovating-finance-%E2%80%93-systematic-observations-financing-facility-0.
[47] See https://public.wmo.int/en/our-mandate/how-we-do-it/partnerships/wmo-office-of-development-partnerships.

109. How do you think space-based observations can best support us to better track emissions and removals with high resolution, to support our work here and the global stocktake?

*Mr. Schulz: An important point to note is that the national scientific inventories provide specific estimates of $CO_2$ and $CH_4$ emissions for most but not all of the anthropogenic sources of these GHGs. They provide less insight into the natural carbon cycle or its changes due to anthropogenic activities and climate change. Space-based measurements (see paragraph 78, figure 21 above) of atmospheric $CO_2$ and $CH_4$ can complement traditional statistical inventory methods by providing spatially and temporally resolved integral constraints of the amount of these gases added or removed from the atmosphere by all processes. These measurements and information derived from these measurements could support the global stocktake, by providing a basis for accurately assessing emissions at a global scale.*

110. How is data from private sector, such as that from cube satellites and portable devices being harnessed to improve data coverage and improve predictability? Is citizen science data part of the data collected?

*Mr. Schulz: Space agencies are assessing the quality of satellite data in terms of their usefulness for numerical weather prediction, but although the data provision is too recent to be used as climate data. However, there is potential for their use for climate analysis. Before this happens, it is important to be certain about the quality of the data. Regarding climate and the UNFCCC, it is important that the private sector is open about the data they are producing, including satellite instrument calibration and further data manipulation before it is used by potential customers. This openness for data and information is vital. Nonetheless, apart from these considerations there is no reason why data from the private sector cannot be included.*

*Mr. Tanhua: There are great opportunities to engage with citizen science. For example, ocean observation can be through engagement between scientists and sailors. There are several private sector entities carrying out ocean observations. Although this data is being generated for different requirements and with different precision, some of this data could be useful for climate observations. Dialogue and communication between companies doing observations, those handling data management and the systematic observation community would be beneficial to understand needs and joint opportunities.*

111. Linking between theme 1 and 2, what are the thoughts of the panellists on the lack of climate data records measuring the biosphere, ecological and biological systems. How do we reconcile the discrepancy between what has come from the IPCC special reports in regards to key recommendations with a strong emphasis on biosphere and ecosystems and what we see in the more traditional observation reporting and records driven by the physical climate. **How do we close this gap on the need for more observation of biological systems and where we are at present?**

*Mr. Tanhua: GOOS has a BioEco (biological and ecosystems) panel which has made advancements in the last few years in defining ocean-based biological and ecosystem variables. The development of these variables have, on the whole, been driven by other questions than climate. Although it is possible to have local variables, it is difficult to map variables for biodiversity on a global scale or compare between areas. However advances are being made to build longer term records on these ocean-based ecosystem variables and report back on them.*

*Mr. Schulz: Within CEOS there are support activities using satellite data for annual monitoring of the world's forested areas, working closely with the Global Forest Observations Initiative (GFOI).[48] Starting this year, there has been coordination of using information from satellite data missions with normal capabilities to derive, in particular, above-background biomass which will also help in closing carbon budgets in the future. However, new technologies and new capabilities are needed, so it will take time to close the gap identified in the question.*

112. There are any regions where observation data is insufficient and the topography is complex, particularly the Hindu-Kush mountainous region (the third pole). Are there any plans for improving observations in this region?

*Ms. Richter: There are programs and initiatives available to provide observations and address gaps, for example, the Global Cryosphere Watch.[49]*

[48] See poster on the Global Forest Observation Initiative (GFOI) https://unfccc.int/sites/default/files/resource/2.%20ESA_GFOI%20Global%20Forest%20Observation%20Initiative.pdf, see paragraph 163 below.

[49] See https://globalcryospherewatch.org.

## D. Theme 3: Earth observation for science, policy and practice: retooling global cooperation to respond to future climate risk

113. **Mr. Steven Ramage** chaired the panel discussion on theme 3.[50] The panellists were Maisa Rojas Corradi, Center for Climate and Resilience Research, Chile; Jean-Noël Thépaut, Copernicus Climate Change Service; Prabir K. Patra, Japan Agency for Marine-Earth Science and Technology (JAMSTEC); Mokoena France, Lesotho; and Cheryl Jeffers, Saint Kitts and Nevis. He gave the regrets from Mr. Tuntiak Katan, Confederation of Indigenous Organizations of the Amazon Basin, who was unable to join the panel.

114. The discussion built on the guiding questions as provided in the information note by the SBSTA Chair. Mr. Ramage identified that it is not just **cooperation but also coordination, collaboration and communication that is required to respond to climate risk**.

115. The first part of the discussion focussed on the **role and value of Earth observations in supporting the implementation of the Paris Agreement**.

116. Ms. Rojas emphasised the **importance of observation for providing information on the state of the Earth**, as described in the first part of the dialogue above. However, she highlighted that the global view looks very different from what is lived locally. Local information for individual countries and regions needs local information, but **there are many areas of the world with very little observation information**. South America and the southwestern Pacific is one of the regions that usually looks quite empty of data.

117. Furthermore, for countries with complex topography (see paragraph 112 above), which includes western South America, **information is not available at high altitude and that is where most hydrometeorological risks occur**.

118. Ms. Rojas also highlighted that certainly in Latin America, there is **need for greater connection and cooperation in regard to linking national/regional with global information, including at high altitudes**. A lot of private companies hold a range of useful information but do not share their information with national (climate) services. Thus, **information from the private sector could support the public sector**, for example through research to help bridge the knowledge and information gap.

119. Mr. Thépaut stated that **systematic observation is the foundation for climate monitoring and information for GCOS ECVs and variables which feed into such products as the WMO statement on the state of the global climate**. He identified that Copernicus is an operational service but is only operational as long as the observations feeding into it are operational and sustainable. An important message from this event is that **if there are no observations there are no climate services**.

120. Mr. Thépaut highlighted that with the drastic emission reductions needed to respond to the Paris Agreement, **systematic observations are needed to monitor emissions very carefully**. Reflecting on the presentation by Mr. Schulz (paragraphs 75–88), this monitoring doesn't go without challenge as **we need to detect and monitor anthropogenic emissions at a very local scale, at city or local hotspot scale**. There is an ambition at the European Commission to contribute to this monitoring effort in an efficient way. It is now widely acknowledged that in situ observations are not enough, satellite observations are not enough (the latter only measure GHG concentrations). Therefore, we need the glue, the modelling infrastructure and the data assimilation infrastructure to build this knowledge. Thus, **the systematic observation community must work in collaboration with the modelling community to monitor emissions**. There are obvious parallels here with numerical weather prediction which also combines observations from in situ and from satellite and combine them with models to provide weather forecasts.

121. In regards to **climate services for adaptation, a large challenge is dealing with the pyramid of information**. Earth observation at high resolution including in situ and space observation alongside CMIP runs produce petabytes of data. This data and information must be turned into an end product – such as a map or graph so as to be useful to end users.

122. **Climate services support the whole value chain** and a lot of actors are needed to generate the end product: **from observation providers, to service providers at global or regional level such as Copernicus, to consultancies and local people** who are making the decisions and have the knowledge to make the data useful.

123. In order to go from data access to data use, Copernicus is focussing very much on making data accessible AND usable. To be usable:

[50] Webcast: 01:52:05.

1) **Data must be authoritative** – users must be confident that it is good data – so it must be generated in a **transparent** way, have **documentation** and **quality assurance for all data, tools and applications**;

2) Organizations without too many capabilities must be able to **access** the data and be provided with the **appropriate tools**;

3) **Training** must be provided to ensure that the user can understand the data and for the provider to understand the needs of the user – thus an emphasis on **co-production of knowledge** is needed.

124. Mr. Patra highlighted that modellers have to work across spatial (local to global) and temporal (hour to year) scales, including an examination of what are the expected long-term changes. In order to meet these demands, models of different complexities are developed – such as earth system models, atmospheric general circulation models, and transport models. Models can connect the emissions to the concentrations directly by accounting for all the different layers of chemical and physical interactions as well as the residence and mixing time of emission signals in the atmosphere.

125. The **continuity of observations is vital to help develop and improve models,** with local observation data needed to verify models. **Gaps in model information can only be identified through observations, in situ as well as remote sensing**. Identifying these information gaps can help build better models, and to better understand relationship between the emission and concentration changes.

126. Mr. France also emphasised the vital importance of Earth observations – it is only through observations that we confirmed that Earth's climate is changing. Now **observations are the only way that we are able to determine whether we are making progress under the Convention and the Paris Agreement**.

127. In regard to adaptation under Article 7 of the Paris Agreement, **systematic observations are urgently needed for undertaking vulnerability assessments of countries and identifying adaptation options**. The **Green Climate Fund (GCF) identifies under their investment criteria that all projects must have a climate rationale**. This means that for countries formulating NAP proposals, they have to show that they are experiencing climate change and that the projects (for which funds are requested) will adjust for these impacts. **Only the adaptation projects where a clear climate change response is attributed can be accepted for funding, and the best way to provide these criteria to the GCF is to show observation information**.

128. Ms. Jeffers referred to the presentation by WMO (paragraphs 21–37) on the statement of the state of the climate, highlighting that it clearly identified the **central role that Earth observations have in the context of the Paris Agreement**. There are many areas within the Paris Agreement which can benefit from Earth observation data and she highlighted three examples:

1) Article 2 – long term temperature goal;

2) Article 7 – need to strengthen systematic observation in a manner that informs climate services and supports decision-making. Based on the presentations today, it can be seen that we are starting this process;

3) Article 8 – speaks about enhanced action for loss and damage – as a SID, we in St Kitts and Nevis are losing our islands, we are losing our coral reefs and is important that we have the proper data and records to support that information – and we rely heavily on Earth observation.

129. Ms. Jeffers highlighted that **Earth observation plays a critical role in planning for mitigation and adaptation measures** – we look forward to continued support with relevant international organizations.

130. The next part of the discussion focussed on **how decision-making can be supported by advances in using earth observation data for improving and validating earth systems models, including for near-term climate projections.**

131. Mr. Patra highlighted that when referring to specific emission reduction targets, such as to reduce GHG concentrations in the atmosphere in the next 50 (or 100) years, **much of the emissions going into the atmosphere do not stay in the atmosphere, with almost half going to the ocean and the land for $CO_2$**. This is the current situation, however **in the future** when $CO_2$ concentrations increase, or land cover changes or the ocean is further warming, **it is uncertain how these changes will be reflected in the storage capacity of the different carbon pools and how the storage capacity will change relative to the present day**.

132. **Changes in storage capacity of the land, ocean and atmosphere and fluxes between the domains are very critical in terms of making decisions about the future**. This future is modelled by the Earth system models which are improving with time, but all models need observations to provide basic checks. **Earth observation systems are key to evaluate models**, to add the responses seen in the Earth system, and to see if they are replicated well by the models. Modelers ask many confidence-gathering questions which can only be answered with high quality, long term, widely covered observations.

133. The IPCC AR6 will evaluate Earth system models in terms of $CO_2$ fluxes and how these fluxes are changing and at different parts of the world. These evaluations will help provide improved projections for the future carbon budgets.

134. Ms. Rojas highlighted the importance of **focussing on where we know we are missing observations**: observations have tended to be focussed on areas geographically close to us. Therefore, for a long time we have overlooked the **Southern Ocean and mountainous regions**. We need to strengthen systematic observation and research capabilities with a view to strengthen knowledge in these areas.

135. Observing networks need to be sustainable – small countries with low capabilities must look to opportunities to **create synergies to maintain observation networks**. For example, South America is very urbanised with 80% of the population living in cities. As these cities are very polluted, there is a clear link and need for observations to include measurements of air quality so that observation and use of information is synergised.

136. Mr. Ramage highlighted the need for **retooling global cooperation to respond to future climate risk using synergies to strengthen interactions between different users and usages**.

137. Ms. Jeffers emphasised that **obtaining data at small enough spatial resolution** is important for SIDS, whilst also recognising and appreciating the usefulness of global observation data. St Kitts and Nevis are very small islands and not resolved in the Earth System models. Fortunately, the Caribbean has a **regional climate modelling** station which is located in the University of the West Indies, Jamaica. However, the PSIDS do not have such a system. She called for **regional models to be developed to support SIDS in other regions because the greater the resolution of the information the more small islands may recognise not just their vulnerabilities but also appropriate response, particularly in specific sectors such as water and agriculture sectors**.

138. Mr. France identified that **LDCs have similar challenges**. For example, Lesotho is a small country that is very heterogenous in terms of altitude with the highlands particularly needing monitoring as network distribution there is minimal. General circulation models (GCMs) provide only two values over the whole country yet there are a number of different climate regions within the country. So there is an **urgent need for LDCs to have high-resolution data with appropriate temporal and spatial resolution**.

139. There is also a **need to evaluate reanalysis data to check how it best represents the Lesotho local climate and can be used in the areas where there is no data**. The reanalysis data sets should be evaluated in order to identify which have gaps and which ones can be used for different sectors / areas.

140. Mr. Thépaut emphasised that it is **important to understand basic Earth information data and use this to develop models**. A **physical parameterization scheme must look at how it compares with the observations** (the truth). **Verification and validation of models on an operational footing is also important, such as hindcasts and reanalysis**. Near-time climate predictions / forecasts need observations for the initialisation of the model. At seasonal and decadal time scales, biases are important. It is not only a sensitivity issue, it is also an initial condition issue. Sea surface temperature is an example of how vital initial conditions are. Furthermore, **observations are vital to validate the model runs and simulations when carrying out attribution studies**.

141. Mr. Thépaut also highlighted that, as a reanalysis provider, ECMWF appreciates that the **feedback** from the users, e.g. Mr. France, **in regard to reanalysis and the deficiencies compared to observations, is essential**. ECMWF needs this feedback to ensure that the next model will be better and, should resolution be increased, it is important to have user feedback and observation to indicate how improvements can be made. **A two-way dialogue is needed and needs to be optimised to ensure this exchange**.

142. Mr. Filipe Lucio, WMO, gave a short intervention from the floor to announce the launch of the **state of climate services: agriculture and food security** by WMO.[51] The report highlights progress, opportunities and challenges and responds directly to Decision 11/CMA.1 requesting WMO to provide regular reports about its activities aimed at improving the availability and accessibility of comprehensive climate information.

[51] See https://public.wmo.int/en/resources/library/2019-state-of-climate-services.

143. The report puts forward **strategic recommendations addressing five major areas** in need of improvement:

1) Fit-for-purpose financial support to operationalize and scale up climate services by enhancing the global-regional-national operational hydrometeorological system to support country-level agrometeorological service delivery, especially in Africa and SIDS;

2) Systematic observations as fundamental for the provision of climate services;

3) An enhanced climate science basis for priority climate actions;

4) Addressing the "last mile" barrier through multi-stakeholder governance and partnerships;

5) Systematic monitoring and evaluation of socio-economic benefits associated with climate services.

144. As these suggestions have to be underpinned with the appropriate framework and governance, the report suggests that countries establish a **national framework for climate services** as a mechanism to coordinate, facilitate and strengthen collaboration among national institutions to improve co-production, tailoring and use of and delivery of climate services.

145. Mr. Ramage then took questions from sli.do for further discussion.

146. Is there one Earth System Model or many?

*Mr. Patra: In IPCC AR5, there are about 20 Earth system models (ESMs) developed in many countries. These models are developed by those groups that have a long history of doing weather and climate research. However, these models are available to be adapted by others, which is already happening now in several countries including India and China.*

*Mr. Thépaut: It is healthy to have several ESMs because as researchers look at general projections, it is important to be aware of the uncertainty and be able to compare between models.*

*Ms. Rojas: Data and information from regions is vital to feed back into global centres that develop ESMs. It helps to identify how the products, reanalysis models, and projections are being used and how well they are representing local climates. However, challenges exist now and will be exacerbated with the huge amount of data that is being generated. The CMIP6 models being used for AR6 are generating a much larger volume of data at higher resolution than CMIP5 models. An interactive tool – an atlas – is being developed in AR6 to help users access information.*

*It is important to note that data is different to information and information is different to decision making. For decision making, we still need the human expertise from the regions. Currently this is provided by researchers through writing papers, but there should be other opportunities developed for feedback.*

147. How are big data, artificial intelligence (AI) and other frontier information and communication technologies (ICTs) being used to improve earth observations to assess climate change an develop or monitor climate policies?

*Mr. Thépaut: The Copernicus programme and the Copernicus Climate Change Service in particular produce and deliver big data. There is now increasing awareness at the European Commission level of the opportunities for using AI and Machine Learning techniques, to accelerate model simulations, optimise extraction of information from vast amounts of very diverse data (Big Data), and to improve workflows to optimise some parts of weather and climate models as well as reanalysis. For example, in the case of physical parameterization, a radiation scheme which is very expensive could potentially be accelerated by AI techniques.*

*The next challenge for the observation community is finding clever ways of exploiting the big data being provided from satellite observations, climate models and climate reanalysis. The past methodology of downloading data and examining it is now over as there is just too much data. We need to now cleverly use the data and mine it in a more intelligent way. The Copernicus programme organised a workshop recently to discuss with communities how to use AI to mine data.[52] These approaches will be crucial in the future to determine how best to exploit the wealth of information that is not manageable in the traditional way.*

[52] See https://atmosphere.copernicus.eu/1st-artificial-intelligence-copernicus-workshop.

*Mr. Patra: The Internet of Things (IoT) is getting popular in city areas with users being able to make their own weather charts using IoT data sets. In the case of air pollution, cheap sensors can be installed in many places and on vehicles, the instruments can be harmonized and the wealth of data can be used to develop high resolution models to about 100 m. However, developing GHG sensors is not so easy at the resolutions and accuracy needed. This is something for the future. Furthermore, IoT and smart connectivity could provide advice, for example, on energy efficiency with different source-specific conditions.*

148. Mr. Ramage concluded the session highlighting that it is clear from discussions that there needs to be a **move from open data to open science** – **and to share data, algorithms, tools and knowledge**.

149. Mr. Ramage outlined a number of initiatives that GEO is involved with to provide Earth observation data to support research, policy and practice.

150. At the GEO plenary, 4–9 November 2019, Canberra, Australia,[53] GEO held a hackathon[54] with indigenous communities including elders and the youth to look at how information and knowledge that normally would not be shared could be integrated with Earth observation data and information. GEO have now set up a working group in this regard engaging with remote communities, including SIDS.

151. The GEO work programme[55] has more than 60 regional and global initiatives including:

1) Digital Earth Africa is taking analysis-ready Earth observation data and using the Open Data Cube to produce operational, decision-ready products for the entire continent (see paragraph 187 below);

2) GEOGLAM (see paragraph 188 below). This GEO flagship project was used recently in East Africa to prevent people being exposed to extreme drought;

3) GEO and Amazon Web Services offers GEO Member agencies and research organizations from developing countries access to cloud services to help with the hosting, processing and analysis of big data about the Earth to inform decisions for sustainable development.

# III. Summary of the proceedings: poster session

152. This section provides an overview of the posters presented. The posters link in topic directly with the topics of the dialogue summarized above. In total 40 posters were presented at the poster session: two posters on theme 1: Update on the state of the global climate (section A); 21 posters on theme 2: Updates on implementing Earth observation: for region and country support, and needs (section B); and 17 posters on theme 3 Earth observation for science, policy and practice: retooling global cooperation to respond to future climate risk (section C ).

## A. Theme 1: Update on the state of the global climate

153. **Earth's ice from Space**
Isobel Lawrence, Centre for Polar Observation and Modelling (CPOM)

**Observations**

The CryoSat-2 satellite, launched by the European Space Agency (ESA) in 2010, has provided nearly a decade of sea ice and ice sheet observations:

- 260 cubic kilometers of sea ice lost per year, reducing the albedo of Earth's poles and allowing more solar radiation to be absorbed;
- 283 cubic kilometers of ice sheet lost annually, corresponding to a global sea level rise of 1.6 mm per year.

CPOM lead the Ice Sheet Mass Balance Intercomparison Exercise (IMBIE) to quantify the sea level contribution due to the polar ice sheets and the Ice Sheet Model Intercomparison Project (ISMIP6) to predict their future contributions, both of which support assessments of the IPCC.

[53] See http://www.earthobservations.org/geoweek19.php.
[54] See http://www.earthobservations.org/geoweek19.php?t=hackathon_about.
[55] See https://www.earthobservations.org/geoss_wp.php.

Ice monitoring is now implemented by ESA (climate change initiative, cci) and EC (Copernicus climate service, C3S). CPOM are leading Antarctica cci and the ice C3S service, and are involved in Greenland cci and glaciers cci.

The purpose of cci and C3S is to provide essential climate variables for all users. Our CPOM sea ice thickness service has for example 700 users per month globally.

**Implications**

Ice sheet loss observations currently tracking the upper AR5 model output, which predicts 30 cm of sea level rise by 2100. One million people vulnerable worldwide per 1 cm sea level rise.

Models need to include the influence of the ocean on ice sheets. ISMIP6 intends to make improvements to model projections included in the next IPCC report, AR6.

New satellite missions will ensure the continuation of observations into the 2020s. CryoSat-2 and ICESat-2 have no planned successors - EU and ESA are exploring future mission candidates to add to current sentinels including a polar altimeter (Cristal) but that won't launch until late 2020s.

154. **The Global Climate 2015–2019**
John Kennedy, WMO

The 5-year statement summarises recent changes in global climate. The five-year period 2015–2019 is likely to be the warmest of any equivalent period on record globally, with a 1.1 °C global temperature increases since the pre-industrial. Continuing or accelerated trends are clear in key climate indicators including:

- An acceleration of rising sea levels;
- A continued decline in the Arctic sea-ice extent, an abrupt decrease in Antarctic sea ice;
- Continued ice mass loss in glaciers and the Greenland and Antarctic ice sheets;
- Clear downward trend in the northern hemisphere spring snow cover;
- More heat is being trapped in the ocean; 2018 had the largest ocean heat content values on record measured over the upper 700 meters.

In addition, the report summarises extreme and high-impact weather and climate events. Heatwaves were the deadliest meteorological hazard in the 2015–2019 period, affecting all continents. Among all weather-related hazards, tropical cyclones were associated with the largest economic losses, with floods, landslides and associated loss and damage. Climate-related risks associated with climate variability and change exacerbated food insecurity in many places.

## B. Theme 2: Updates on implementing Earth observation: for region and country support, and needs

155. **Enhancing climate monitoring and data collection across the Caribbean**
Carlos Fuller, Belize

During the past 15 years the Caribbean Community Climate Change Centre has installed over 150 climate, sea level and marine monitoring platforms with support provided by the international community. These were installed to fill gaps identified in the networks. The need for high resolution bathymetric and topographic was also identified. The Centre has now procured its own airborne LIDAR system which will utilized to conduct airborne surveys to address this need.

156. **A constellation architecture for space-based observations of greenhouse gases: measurement approaches, datasets, and models in support of the global stocktake**
David Crisp[1], Mark Dowell[2], Robert Husband[3], Albrecht von Bargen[4] and Joerg Schulz[3] for the CEOS/CGMS WGClimate GHG Task Team[56]

Atmospheric carbon dioxide ($CO_2$) and methane ($CH_4$) measurements complement bottom-up greenhouse gas (GHG) inventories by providing an integrated constraint on the exchanges of these gases between land and ocean surfaces and the atmosphere. While $CO_2$ and $CH_4$ fluxes inferred from atmospheric measurements are not as source-specific as the data sources typically used in inventories, they include contributions from sources that are often omitted or poorly characterized in bottom-up inventories. At global scales, atmospheric concentrations of $CO_2$, $CH_4$ and other

[56] [1]Jet Propulsion Laboratory, California Institute of Technology; [2]European Commission, Joint Research Centre; [3]European Organisation for the Exploitation.

well-mixed greenhouse gases (GHGs) are well characterized by precise in situ measurements from surface and airborne systems.

Recent advances in space-based remote sensing methods are providing new opportunities to augment the resolution and coverage of the ground and airborne measurements with estimates of the column-averaged $CO_2$ and $CH_4$ dry air mole fractions ($XCO_2$ and $XCH_4$). These $XCO_2$ and $XCH_4$ estimates are less precise and accurate than the in situ measurements, but can provide near global coverage at spatial scales as fine as a few km. These ground-based, airborne, and space-based atmospheric $CO_2$ and $CH_4$ estimates are now being assimilated into atmospheric transport models to estimate $CO_2$ and $CH_4$ fluxes on scales spanning individual large power plants to nations.

The long-term objective of these efforts is to develop top-down global inventories that: (i) reduce uncertainties in national emission inventory reports, (ii) identify additional emission reduction opportunities, (iii) provide nations with timely and quantified guidance on progress towards their emission reduction targets and pledges (Nationally Determined Contributions, NDCs), and (iv) track changes in the natural carbon cycle caused by human activities and climate change.

157. **Space-based capabilities to deliver climate data records for essential climate variables**

Joerg Schulz, Alexandra Nunes, Albrecht von Bargen on behalf of CEOS/CGMS WGClimate

Use of space-based observations with undoubted quality in global stocktakes can play a supporting role of providing evidence for the success of the implementation of the Paris Agreement. CEOS and CGMS are addressing this by providing a coordinated response to the UNFCCC needs for Systematic Observations facilitated by GCOS.

A Constellation Architecture for Monitoring Carbon Dioxide and Methane from Space, endorsed by CEOS in 2018 and CGMS in 2019 has relevance to support the Paris Agreement, including with respect to national inventories. CEOS and CGMS encourage Parties and relevant organizations to continue to support and develop the constellation architecture for monitoring atmospheric carbon dioxide and methane concentrations and their natural and anthropogenic fluxes from space.

The Joint CEOS/CGMS Working on Climate is implementing the Architecture for Climate Monitoring from Space[57] in response to the GCOS Implementation Plan. Space agencies provide long-term observations for 35 out of 54 GCOS Essential Climate Variables (ECV) (37 being accessible by satellite). Data access is globally full, free and open for more than 98% of the data records.

The web-based Inventory of existing and planned climate data records of GCOS ECV observable from space contains information for approximately 1300 data records. The content is fully verified and updated annually with approval from CEOS and CGMS. The Inventory informs space agency planning, improves the availability and interoperability of climate data records. The inventory provides material for all future responses of the space agencies to the GCOS status report and Implementation Plan. The content of the Inventory is used by Climate Services to choose climate data records, e.g., by the Copernicus Climate Change Service.

The 2019 version fills previously identified gaps for the ECVs lightning, sea-surface salinity, aboveground biomass, and permafrost, the latter two having significance for the study and analysis of the Earth’s carbon cycle.

158. **Toward an integrated observing system for the Southeast Pacific Ocean**

Diego Narváez[1], Laura Farías[1], Camila Fernández[1,2], René Garreaud[3], Leonardo Guzmán[4], Samuel Hormazábal[5], Carmen Morales[1], Silvio Pantoja[1], Iván Pérez[6], Doris Soto[7], Patricio Winckler[8], Chile[58]

Chile is one of the most vulnerable countries to Climate Change. Its extensive coastline makes Chile economically, culturally and socially dependent on the ocean and its resources. Yet, there is a lack of long-term and real-time observations for climate change studies and to rapidly respond to fast changes in the ocean and atmosphere.

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

[58] [1]Universidad de Concepción; [2]CNRS Francia; [3]Universidad de Chile; [4]Instituto de Fomento Pesquero; [5]Pontificia Universidad Católica de Valparaíso; [6]Universidad de los Lagos; [7]Centro Interdisciplinario para la Investigación Acuícola; [8]Universidad de Valparaíso.

This initiative aims to establish an observing system (SIOOC by its Spanish acronym), to provide information about current and future oceanic and atmospheric conditions along the Chilean coast. The initiative is built upon current individuals' efforts. The SIOOC will be applied to collect information for monitoring of Climate Change, Marine Protected Areas, development of early warning systems for coastal hazards (e.g., HABs), development of numerical models, operational uses, and to elaborate public policies based on environmental evidences.

Current challenges involve having the latest oceanic, atmospheric and computational instruments, capabilities to perform periodic maintenance and having multidisciplinary high qualify human resources to implement, analyzed and maintain the systems.

Chile needs a national policy allowing funds to be secured and human resources to be warranted via technical transfer and training of future generation of ocean observers. The future of the Southeast Pacific and the adaptation of human populations in Chile, as well as other countries, will strongly depend on decision we make today.

159. **ESA Climate Change Initiative**
Frank Martin Seifert and Susanne Mecklenburg, European Space Agency

Earth observation satellites provide a global view for monitoring and understanding the climate system. Spanning decades, their precise measurements enable the scientific community to detect signs of change, identify significant trends and improve the models that predict climate's evolution.

ESA's Climate Change Initiative (CCI) supports 23 project teams working to exploit over 40 years of archived and emerging satellite observations. CCI's long-term, global data records describe the evolution of key components of the Earth system. Its 21 Essential Climate Variables (ECVs) can be used to track changes across the ocean, atmosphere and land environment.

All ECV datasets are fully validated and have high levels of traceability and consistency, including quantitative estimates of uncertainty required by both climate science and modelling communities. All ECV datasets are free and openly available.

Earth observation data and derived information products provide an unbiased view of our environment beyond borders, they can support comparison of NDCs and contribute to information collection and technical assessment for the global stocktake.

160. **Global Forest Observation Initiative (GFOI)**
Frank Martin Seifert, European Space Agency

GFOI is an informal partnership of countries and international organisations that collaboratively assist developing countries on these issues for the purposes of reporting for REDD+ results-based payments, monitoring progress towards meeting their nationally determined contributions (NDCs) under the United Nations Framework Convention on Climate Change (UNFCCC), reporting for the World Bank's Forest Carbon Partnership Facility (FCPF) and other performance-based funds, informing the Global Forest Resources Assessment (FRA), building capacity for national GHG inventories and other country needs.

Forest monitoring and associated GHG accounting systems generate the information needed by countries to help them to meet their international reporting requirements e.g. from the Paris Agreement, establish baselines, track progress and develop effective interventions to reduce greenhouse gas (GHG) emissions.

GFOI is 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.

GFOI's work is based on four components:

- Capacity Building, a joint and coordinated effort for effective knowledge and technology transfer;
- Methods and Guidance Documentation, which provides user-friendly methods and guidance materials that address UNFCCC requirements for REDD+ and comply with the IPCC;
- Research and Development Coordination, addressing knowledge gaps, pursue progress and continuous improvements in forest monitoring; and

- Data Coordination, supporting the acquisition, availability, accessibility and capacity for countries to use data like wall-to-wall coverage of the world's forests from satellite sensors and tools such as Collect Earth, SEPAL and many others.

GFOI, which was founded in 2011, is a flagship programme of the Group on Earth Observations (GEO). The current lead partners of GFOI include the governments of Australia, Germany, Norway, the United Kingdom and the USA, and as international organisations the Committee on Earth Observation Satellites (CEOS), the European Space Agency (ESA), the Food and Agriculture Organization of the United Nations (FAO) and the World Bank.

161. **Upper air observation gaps in the South Pacific**
Bipen Prakash, Fiji Meteorological Service, Fiji

Climate prediction and risk analysis, vital for planning adaptation to climate change, depend on outputs of reanalysis and climate models which are driven by the same global Numerical Weather Prediction (NWP) models, that themselves, depend on the observational data across the globe. By making and freely exchanging the data, countries can benefit from the outputs of these models.

Upper air (radiosonde) observations are very important for global numerical weather predictions, both regionally and globally, and therefore seasonal forecasts and climate models. The impact of these observations can reach planetary scale. For example, ECMWF has stated that better upper air observations in the South Pacific are critical for extended range forecasts over Europe. Isolated radiosonde observations in the Pacific are routinely shown to have the highest impact of all observations on skill of global NWP models.

Local uncertainties in analysis are substantially larger in areas with no conventional (non-satellite) upper air observations. Isolated radiosonde stations have a large impact and twice daily soundings more so than a single daily sounding. This has implications for trend analysis, process understanding, adaptation and potential inputs into the UNFCCC Global Stocktake under the 2015 Paris Agreement.

A joint GCOS-WIGOS Workshop for the Pacific Small Island Developing States (SIDS) in October 2017 noted that the most important observation gap across the Pacific Island region is in upper air observations. Most observations sites are not operational due to maintenance and running costs. Consequently, a plan for a Regional Upper Air Observing Network for the South Pacific was developed.

162. **Reviewing the ECV observation requirements: GCOS' 4th Assessment Cycle 2020‒2022**
Stephen Briggs, Carolin Richter, Valentin Aich, Simon Eggleston, GCOS

As part of its routine work GCOS identifies and develops requirements for ECV, monitors how well these are being observed and develops plans to address gaps and deficiencies in the observing system. As part of this cycle it produces status reports and implementation plans.

GCOS is now entering the 4th review cycle by looking at the ECV requirements. GCOS will next hold a public consultation in January - March 2020 on these requirements in order to get as wide a range of views from users and data producers on which to base the next revision of the ECV requirements.

GCOS will produce a Status Report in2021 and an updated implementation plan in 2022.

163. **Atmospheric Aerosol: The missing link between Climate and Air Quality**
Valentin Aich, C. Claudia Volosciuk, Paolo Laj GCOS / WMO

Atmospheric aerosols are a critical component in terms of impacts on the climate and climate changes. Aerosols influence the global radiation balance by directly scattering solar radiation and indirectly through influencing cloud reflectivity, cloud cover and cloud lifetime.

Ambient Atmospheric Aerosol are responsible for around 4 million premature death a year. Although air quality has improved in some regions due to air quality regulation and cleaner technologies, there are still many areas in the World with very poor Air Quality.

Challenges posed by atmospheric aerosols can be addressed by improving the observation system for aerosol especially in less developed and remote regions, by developing the capacity to predict aerosol impact on climate and air quality at regional scales, and by developing policy responses for climate air quality accounting for the regional context.

164. **Consistent monitoring of water cycle variability with Earth observations: What are we missing?**
Valentin Aich, GCOS, Stephan Dietrich, German Federal Institute of Hydrology, Koblenz, Germany, Wouter Dorigo, Technical University, Vienna, Austria

Life on earth is closely linked to the availability of water in space and time. With a growing world population and living standards, human pressure on fresh water resources is continuously increasing, so is the exposure of humans to weather and climate related extremes like droughts, storms, and floods. Climate Change exacerbates our vulnerability to variability and changes in the water cycle, e.g. by causing shifts in precipitation patterns, intensification of extreme events, and glacier melt. Hence, the availability of water resources as we know it are increasingly being challenged.

The Global Climate Observing System (GCOS) defines a suite of Essential Climate Variables (ECVs), many of them related to the water cycle, that are required to systematically observe the Earth`s changing climate. However, since they are typically derived from different observation techniques, platforms, instruments, and independent retrieval algorithms, they often lack consistency at multiple spatial and temporal scales. In combination with the small signal-to-noise ratios of the datasets, detecting changes in the hydrological cycle, especially with regard to long-term trends, remains difficult.

The poster introduces the study, which aims to assess the status of consistently monitoring the variability of the hydrological cycle at various spatial and temporal scales. We critically assess the relevant land, atmosphere, and ocean water storages and the fluxes between them, including anthropogenic water use. We identify gaps in consistency and attribute their origin. We critically discuss gaps in existing observation systems based on remote sensing, in-situ observations, and reanalyses and conclude with formulating guidelines for future water cycle observation strategies.

165. **Heat stored in the Earth system: Where does the energy go?**
Karina von Schuckmann, GCOS / Mercator Ocean, France

There is currently a positive Earth Energy Imbalance (EEI) of 0.5–1 W/m2 observed through the global climate observing system, which arises from alterations in the composition of the atmosphere from human activities, i.e. increase of carbon dioxide from burning fossil fuels and emissions of other greenhouse gases. As a result, excess energy in the form of heat is trapped in the Earth system, which produce planetary heating and give rise to observed global warming and climate change.

These changes interfere with the natural variability of energy flows through the climate system. Current estimates show that more than 90% of this energy imbalance goes into heating the ocean, with much smaller amounts going into melting of ice and heating the land and atmosphere.

The knowledge of where and how much heat is stored in the different Earth system components from a positive EEI through an Earth heat inventory is of fundamental importance to unravel the current status of climate change, as well as to better understand and predict the implications of climate change.

This interdisciplinary and international scientific community paper is aiming to analyze the current status of the Earth heat inventory for the ocean, atmosphere, cryosphere and land, together with an evaluation of uncertainties and observing system capabilities.

The expected outcome is an update of the Earth heat inventory and scientific sound recommendations for the Global Climate Observing System.

166. **Regional Workshops in Association with the UNFCCC**
Carolin Richter, Valentin Aich, Simon Eggleston, Tim Oakley, GCOS and Lars-Peter Riishojgaard, Markus Repnik WMO

As requested by SBSTA 45 in 2016, GCOS has held a series of regional workshops, together with the WMO Integrated Global Observing System and in association with the UNFCCC.

Workshops in the Pacific, East Africa and the Caribbean have shown that the costs of sustained, systematic, observations are too expensive for many countries: while all countries benefit from these observations.

Based on the outcomes of these workshops, WMO has agreed the Global Basic Observing System (GBON) and is developing the Systematic Observations Financing Facility that would to support its development and ongoing operation. GBON is estimated to cost US$ 750 million by 2025 and lesser amounts thereafter.

167. **Observations to support and monitor responses to climate change**
Stephen Briggs, GCOS, and Nigel Tapper, Monash University, Australia

GCOS' mandate includes … ensure the data needs are met for climate system monitoring, for assessing the impacts of climate variability and change, and applications to national development, … (GCOS Memorandum of Understanding 1998).

The Task Team suggests that GCOS, through its ECVs, can provide clear indicators to inform adaptation (indicators for adaptation), by providing key information about hazards and the links to exposure/risk, as well as the possibility, through some ECVs (or through newly developed ECVs), to directly observe the implementation of adaptation (indicators of adaptation).

GCOS will continue to develop ECV requirements to match these needs.

168. **Developing the Global Ocean Observing System for marine life**
Nic Bax, CSIRO

A globally-coordinated and sustained ocean observing system of scientifically and societally relevant biological essential ocean variables is urgently needed to systematically assess the statis of the ocean's biodiversity and ecosystems. Tracking how ocean life is responding to increased human use and climate change will empower the global community to predict, mitigate and manage the oceans.

GOOS recommends the monitoring of ten biological essential ocean variables (EOVs): microbes; phytoplankton; zooplankton; benthic vertebrates; fish; turtles, birds and mammals; hard coral; macroalgae; seagrass; and mangroves.

Observing networks need to be effectively coordinated to provide the coverage and frequency of observations needed. Contributing networks will require standard operating procedures (SOPs), technology transfer, and in-country support especially in developing nations.

The ocean decade envisions a global ocean observing system in 2030 that is responsive to these needs with information relevant to marine life flowing from locally and remotely sourced ocean observations.

169. **Ocean acidification - aligning the SDG and global climate observing indicators**
Katherina Schoo, IOC-UNESCO

The Sustainable Development Goals, an essential part of the Agenda 2030, contain a Goal for the Ocean, the Sustainable Development Goal 14. Under this SDG, the Target 14.3 addresses Ocean Acidification and its Indicator calls for the Average marine acidity (pH) measured at agreed suite of representative sampling stations.

The Methodology for the SDG Indicator 14.3.1, developed by the Intergovernmental Oceanographic Commission (IOC) of UNESCO, together with the Global Ocean Acidification Observing Network and other experts in the field, provides guidance on how to measure and report the key carbonate chemistry variables for ocean acidification.

Aligning the Essential Climate Variables and the Essential Ocean Variables with the SDG Indicator ensures that definitions, measurements and reporting mechanisms are aligned, to provide an optimal global overview of the changing climate in all domains, including changes in ocean acidification.

170. **Ocean observing system report card 2019**
Emma Heslop, IOC-UNESCO

The sustained ocean observing networks are internationally coordinated by the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), under the Observation Coordination Group. Sustained ocean observation is critical for sustainable development and for monitoring progress towards the SDGs.

The ocean observing report card 2019 states that anthropogenic carbon dioxide emissions have "substantially increased atmospheric carbon dioxide concentrations" over the last two centuries, contributing to ocean acidification.

Challenges include the lack of long time-series observations from the deep-sea interior, below 2000 meters, and measurements of essential biology and biogeochemistry components of the ocean. Advancements in ocean observing instruments, computing, sensors and robotics are needed in order to expand ocean monitoring capabilities.

Other challenges include filling observation gaps in the Arctic and Antarctic Ocean all year long and on more biogeochemical and ecosystem variables. Currently, the availability of new technological capabilities for under ice observations, based on ocean gliders and autonomous floats, are enabling the monitoring of the increase in CO2 concentrations at high latitudes.

New technology developments, in particular for biological and biogeochemical observations, will require new resources and strong collaboration with industry. In addition, the cost of some observing techniques and sensors are prohibitive for implementation at a global scale. As we move towards sampling in coastal areas, we will need to explore new solutions, including citizen involvement. The resources available for sustained ocean observation programmes and for international coordination are insufficient to deliver these advances and largely supported by short-term, research-based project funding.

171. **Regional research infrastructures supporting the global monitoring of ECVs**

Werner L Kutsch[1], Emmanuel Salmon[1], Samuel Hammer[2], Armin Jordan[3], Dario Papale[4], Leonard Rivier[5], Richard Sanders[6], Alex Vermeulen[7], Integrated Carbon Observation System (ICOS)[59]

Essential climate variables (ECVs) need to be observed with a sufficient global coverage. However, particularly in situ observations are often organized in regional networks.

The European Research Infrastructure ICOS (Integrated Carbon Observation System) systematically observes ECVs like atmospheric composition, ocean biogeochemistry or land-atmosphere $CO_2$ fluxes (still to be defined as an ECV). ICOS also provides radiocarbon data to identify fossil fuel emissions.

Global cooperation efforts on standardization and data integration are essential to provide information on climate feedbacks on the global carbon cycle. Thus, ICOS is seeking close cooperation with respective research infrastructures in other regions towards a global observation system.

ICOS makes its data also available through global data networks: the GAW program of WMO for atmospheric data, FLUXNET for land-atmosphere fluxes, and SOCAT for the ocean biogeochemistry.

The improvement of global climate science necessitates the reduction of uncertainty in greenhouse gas observations in Africa. A combination of satellite products, ground-based stations, and data centers is needed to optimize emission measurements of $CO_2$, $CH_4$ and $N_2O$ over the African continent. ICOS is currently participating in a respective design study conducted in the framework of the H2020 project SEACRIFOG.

172. **Towards a $CO_2$ European monitoring and verification support capacity**

Salmon Emmanuel[1], Balsamo Gianpaolo[2], Engelen Richard[2], Jones Matthew[3], Kutsch Werner[1], Le Quéré Corinne[3], Pinty Bernard[4], Peylin Philippe[5], Thépaut Jean-Noël[2], and the whole CHE and VERIFY consortia.[60]

The European Union is the first major economy to put in place a legally binding framework to deliver on its pledges under the Paris Agreement and reach climate neutrality by 2050.

To achieve this, the EU is developing an operational anthropogenic $CO_2$ emissions Monitoring & Verification Support (MVS) capacity, to reduce uncertainties in the national emissions budgets, identify and monitor hot spots of fossil fuel emissions, and assess changes in emission patterns against local and national reduction actions.

Developed as a service to the Member States of the EU and their inventory communities, the MVS will bring together meteorological and satellite data (including from the future Sentinel

[59] [1]ICOS ERIC Head Office, Helsinki, Finland, [2]ICOS Central Radiocarbon Laboratory at University of Heidelberg, Germany, [3]ICOS Flask and Calibration Laboratory at Max-Planck-Institute of Biogeochemistry, Jena, Germany, [4]ICOS Ecosystem Thematic Centre at University of Tuscia, Viterbo, Italy, [5]ICOS Atmosphere Thematic Centre at Laboratoire des sciences du climat et de l'environnement, Saclay, France, [6]ICOS Ocean Thematic Centre at University of Bergen, Norway, [7]ICOS ERIC Carbon Portal, Lund, Sweden.

[60] [1]ICOS-ERIC, [2]ECMWF, [3]University of East Anglia, UK, [4]European Commission, [5]London School of Economics (LSCE); see https://www.che-project.eu/consortium; see http://verify.lsce.ipsl.fr/.

constellation), high-quality in situ observations, as well as advanced modelling and data assimilation capacities.

The comprehensive integration of data from various sources is a requirement to provide actionable knowledge at country and city scales, and to support the national climate plans.

To pave the way for the future MVS, the European Commission supports several H2020 projects like CHE and VERIFY where all the major actors in each field (in situ observation, satellite remote sensing, climate modelling, national GHG inventories…) are collaborating under the leadership of Copernicus.

The European effort aims to be amplified by further cooperation at the global level, for instance under the umbrella of WMO and CEOS, in order to contribute to the improvement of GHG reporting and monitoring towards the 2nd Global Stocktake in 2028.

173. **Key findings from decadal Japanese satellite observations for climate change**
Osamu Ochiai, Masakatsu Nakajima, Kazuo Umezawa, Japan Aerospace Exploration Agency (JAXA)

JAXA has been monitoring climate change from space more than a decade. Within this long-term archive can be found evidence of climate change across Atmosphere, Land and Ocean.

A recent provisional analysis of JAXA's GOSAT observational data shows that the global atmospheric monthly mean $CO_2$ concentration observed vertically through the whole atmosphere exceeded "400 ppm" in December 2015 for the first time; and that the $CO_2$ concentration grew 2.4ppm from September 2018 to September 2019. On land, ALOS-2 has revealed deforestation and mangrove changes. Over 140,000 logging sites in tropical forests were detected over the last three years and 6000$km^2$ of mangroves were estimated to be lost between 1996 and 2016.

GCOM-W/AMSR2 provides daily observations of sea ice concentration. In September 2019, GCOM-W/AMSR2 observed the 2$^{nd}$ smallest observed Arctic sea ice extent - 3.96M$km^2$; compared to observations of 7.04 M$km^2$ in 1979.

JAXA has 6 Earth observation satellites currently in operation and their data is openly and freely available for download. JAXA's satellites contribute to 25 of the 54 Essential Climate Variables specified by the Global Climate Observing System (GCOS). The frequency and coverage of the Earth achieved by satellite Earth observations are generally extremely favourable compared to that from ground-based observations. As such, satellite observations can complement and support national reports, including over large and inaccessible areas. Moreover, since satellite observations can be global, their data has potential in support of the Global Stocktake process.

JAXA has invested efforts to make its datasets more accessible and useful in order to support decision-making process in countries, within the UN, and even within local governments. JAXA has committed full support to help achieve the ambitions of the Paris Agreement, and works with our partner space agencies world-wide for that purpose, through the communities of GEO and CEOS.

174. **Observations to explain climate-induced changes in the global biosphere**
Mark Dowell and Nadine Gobron, Joint Research Centre (JRC), and Nic Bax, CSIRO, Australia

The purpose of this contribution is to identify the Essential Climate Variables (ECVs), defined by Global Climate Observing System (GCOS), available on the oceanic and terrestrial domains and their potential links with biosphere monitoring, including species composition and biodiversity. We briefly summarize the status of space and ground based systems in the oceanic and terrestrial domains.

The two main scientific questions are 1) are they sufficient to measure climate-induced biotic changes? and 2) whether these measures are sufficient to distinguish climate-induced changes from other anthropogenic or natural changes.

One example of relationships between ECVs and Essential Biodiversity Variables (EBV) is proposed, with two examples on phenology and habitats. Advances in global terrestrial and marine biosphere observations show that several ECVs are appropriate to explain some changes in the biosphere. We highlight recent collaborations among the observations communities of the global biosphere.

175. **The carbon cycle and the climate, an evolving system?**

David Crisp, Jet Propulsion Laboratory, NASA, and Han Dolman, University of Amsterdam.

The carbon dioxide ($CO_2$) concentration in the atmosphere is controlled by natural processes including plant photosynthesis and respiration and ocean solubility as well as human activities, such as fossil fuel combustion and land use practices. An improved understanding of these processes is critical for predicting the rate of increase in $CO_2$ in the atmosphere and its impact on the climate.

Until recently, the concentrations of atmospheric $CO_2$ and other greenhouse gases were measured only by *in situ* by instruments deployed at surface stations or on aircraft. *In situ* measurements still provide the most accurate estimates of the $CO_2$ concentrations and their trends on global scales. They also include chemical and isotopic tracers, such as carbon-14 ($^{14}C$), which help to discriminate fossil fuel from biogenic contributions to the observed $CO_2$ trends.

However, the spatial coverage and resolution of these measurements are still far too limited to identify and quantify emission sources on regional scales, particularly in arctic, boreal and tropical land regions and over most of the ocean. With the launch of Japan's Greenhouse gases Observing SATellite (GOSAT) in 2009, and NASA's Orbiting Carbon Observatory-2 (OCO-2) in 2014, space-based remote sensing estimates are complementing ground-based and airborne $CO_2$ measurements with much greater spatial resolution and coverage.

Space-based $CO_2$ estimates clearly reveal the most robust aspects of the atmospheric $CO_2$ cycle seen in *in situ* measurements, such as the seasonal $CO_2$ drawdown in the northern hemisphere spring and the large, positive $CO_2$ anomalies associated the anthropogenic emissions over East Asia, Western Europe and eastern North America.

Other features present in these space-based datasets were not anticipated. For example, since 2015, tropical forests, once thought to be net absorbers of $CO_2$, show strong, persistent positive $CO_2$ anomalies, suggesting that they are now net emitters. Efforts are ongoing to determine whether these and other features of the space-based products indicate biases in space-based $CO_2$ estimates, misinterpretations of the ground-based measurements due to limitations in their resolution or coverage, or evidence for evolution of the carbon cycle in response to climate change.

176. **Delivering sustained, coordinated and integrated observations of the Southern Ocean for global impact**

Louise Newman[1], Andrew Constable[2], Sebastiaan Swart[3] Eileen Hoffmann[4], Mike Williams[5], Phillippa Bricher[1], on behalf of Southern Ocean Observing System (SOOS)[61]

The Southern Ocean and its related atmo-, cryo-, geo- and bio-sphere, has a profound influence on the global Earth system. Although geographically remote, it directly impacts global societies through, for example, its role in maintaining Earth's heat and carbon budgets and storage, provision of food, and in providing intrinsic value for conservation and tourism. Moreover, the ocean-ice-atmosphere interactions will have far-reaching consequences for the globe through sea-level rise. Yet, the Southern Ocean remains one of the most under-observed regions in the world. The IPCC has identified uncertainties in estimations of future state of Southern Ocean processes, and highlighted that a sustained system for observing trends in physics, chemistry and biology is urgent for this region, to reduce those uncertainties. The Southern Ocean Observing System (SOOS) developed over the last decade to fill this urgent need. SOOS has established regional and capability working groups to coordinate the contributions of Antarctic nations in delivering a system for observing essential variables, and to provide data streams to the scientific community, stakeholders and policy-makers. SOOS also provides a hub for accessing data repositories, linking data from satellites, remote in-situ observations, and in-field activities. In this paper, we outline the vision for SOOS and, in particular, highlight new products that facilitate fieldwork planning and coordination, and data discovery and sharing.

[61] [1]Southern Ocean Observing System International Project Office, Hobart, Australia; [2]Australian Antarctic Division, Australia; [3]University of Gothenburg, Sweden; [4]Old Dominion University, Norfolk, USA; [5]National Institute of Water and Atmospheric Research, New Zealand.

## C. Earth observation for science, policy and practice: retooling global cooperation to respond to future climate risk

177. **A global initiative to improve living conditions for indigenous populations using Earth observation data**
Milind Pimprikar, Srini Sundaram, Thomas George, Bruce Stephen, Markus Weber, CANEUS International

Caneus International works with indigenous and northern communities in Canada to promote sustainable development that balances consideration of environmental, social and economic well-being. In a recent report published by the Council of Canadian Academics the following top 6 climate risks faced by Canada were listed: physical infrastructure, coastal communities, northern communities, human health and wellness, ecosystems, and fisheries.[62]

Caneus has formed a consortium that has broad experience in remote sensing, and financial products creation to create sustainable development solutions. Three strategic areas of focus have been identified where potential system-level interventions can be made:

1) Technology based systems for Food production;
2) Access to Credit & Inclusive finance;
3) Access to Insurance.

Using the latest, hyperspectral remote-sensing technologies, the Caneus International Consortium is looking to explore the use of hyperspectral imagery to understand the northern landscape, study the effects of various climate change events and their impact to the community.

The initial focus will be on data-driven food production. The consortium will work closely with community leaders to identify and understand current food production practices and assist local communities to adapt to new, climate-change driven regimes.

The next focus will be looking in generating financial solutions so that these communities are provided credit/working capital for investment in sustainable food-generation activities.

Once these initiatives are well established, the consortium will further advance the solution by adding promotion layers in the form of insurance.

178. **Climate risk atlas of Chile: A tool for the development of sectoral adaptation plans**
Francisco J. Meza, René Garreaud, Susana Bustos, Andrés Pica, Mark Falvey, Carolina Urmeneta, Anahí Urquiza, Patricio Winckler, Ximena Vargas, Alejandro Miranda, Patricio Pliscoff, Alvaro Lorca, Camila Cabrera, Diego Rivera, Doris Soto, Maricel Gibbs, Cristian Henriquez, Jorge Gironás, Chile.

The Climate Risk Atlas of Chile represents the most comprehensive analysis providing updated information about the key components of risk (Hazards, Exposure and Sensitivity). Developed by 13 different scientific groups uses the same basic approach and information for the development of quantitative and qualitative analysis of risks. This opens the possibility to study the joint distribution of impacts and provide critical information for decision makers at several scales.

The Climate Risk Atlas of Chile will be transferred to the Ministry of Environment so that this project will remain as a n Open Source of information for accessing climate scenarios by key risk, exposure of several systems (Agriculture, Biodiversity, Water Resources, Health, etc) and sensitivity in different metrics. The aim of our team is to create basic protocols for data exchange (upload and download) in a way that this project will be maintained and further expanded as new information becomes available.

Methods and models will be stored so that the generation of new information based on CMIP6 and other related projects derived from Earth System Models will be easier, allowing a comparison on changes of potential impacts and risks.

[62] Canada's Top Climate Change Risks - The Expert Panel on Climate Change Risks and Adaptation Potential (July, 2019).

179. **Data for biodiversity: Requirements of an Effective Support System for Policy and Management and under Current Climate Change**

Horacio Samaniego[1], Alejandro Maass[2], Leisy Amaya[3], Roberto O. Chávez[4], Derek Corcoran[5], Francisco E. Fonturbel[6], Nicolás García[7], María Fernanda Pérez[8], Elie Poulin[9], Christian Salas-Eljatib[10], Rosa Scherson[7], Florencia Tevy[11], Dante Travisany[2], Gerardo Vergara A[12], Chile[63]

The natural entropy of data's lifecycle makes the management of biodiversity information essential for the protection of our biota. More so as we learn that acquired knowledge on biodiversity is not limited to the description of organisms and its surroundings. Thus expanding our understanding of nature is contingent on developing simple, scalable infrastructure for the indexing, integration and the analysis of biodiversity data.

**Necessities for Biodiversity Data Science in Chile**

- To develop a policy of open access of biodiversity information;
- To define standards and protocols for the data exchange and analysis;
- Improve connectivity to international servers;
- Enhance the quantity and quality of biodiversity information and data;
- Develop essential infrastructure (i.e. human and material) for the integration and analysis of the various existing sources of biodiversity data;
- Develop capacity-building programs in biodiversity data science that includes curatorial, remote sensing, data interoperability, high throughput modeling of climate and biota.

**Recommendations**

- To develop a National Biodiversity Observatory for the Analysis and Management of Data that should consider (i) Remote Sensing, (ii) Field Research Networks, (iii) Ecosystem Dynamics Monitoring, (iv) Biodiversity Genetics and Genomics, (v) Mathematical Modeling;
- **For Public Policy:** Address issues related to: (i) The classification and sensitivity of current, and future, information; (ii) Access and protection of data; (iii) Develop infrastructure of data stewardship; and (iv) international engagement in scientific capacity building and international policies concerning these issues.

180. **Transparency in forest monitoring - Building trust and consensus around greenhouse gas data for increased accountability of mitigation in the land use sector**

Christopher Martius, Center for International Forestry Research (CIFOR), Martin Herold, Wageningen University, Netherlands and Hannes Böttcher, Oeko-Institut e.V. Energy and Climate Division, Berlin

The Paris Agreement poses manifold challenges to monitoring, reporting and verification. E.g. Article 13 states "*In order to build mutual trust and confidence and to promote effective implementation, an enhanced transparency framework for action and support, with built-in flexibility which takes into account Parties' different capacities and builds upon collective experience is hereby established*." This poses questions such as: How legitimate and useful is independently gathered information for various stakeholders? How to increase awareness and capacities to use these data? How to increase user trust and confidence?

Through our research in this project we have identified several key principles for improved transparency. These are:

(i) increased *accuracy* and improved documentation of *uncertainty;*
(ii) *consistency* and *completeness* of data and the appropriate scale;
(iii) *comparability*, *complementarity* and *interoperability* of different datasets;
(iv) *reproducibility* and *adaptability* of methods; and
(v) *improved access* to data and tools for increased participation.

Applying these principles can improve stakeholder engagement in monitoring, increase confidence, stimulate action and lay the foundations for greater responsibility and accountability.

[63] [1]Lab. Ecoinformática, Universidad Austral de Chile; [2]CMM, Universidad de Chile & CNRS-UMI 2807; [3]GBIF Chile, Ministerio del Medio Ambiente; [4]Instituto de Geografía, Pontificia Universidad Católica de Valparaíso; [5]Departamento de Ecología, Pontificia Universidad Católica; [6]Instituto de Biología, Pontificia Universidad Católica de Valparaíso; [7]Departamento de Silvicultura y Conservación de la Naturaleza, Universidad de Chile; [8]Departamento de Ecología,Pontificia Universidad Católica de Chile; [9]Departamento de Ciencias Ecológicas, Universidad de Chile; [10]Universidad Mayor, Santiago, Chile; [11]GEDIS Biotech, Chile; [12]Instituto Forestal, Ministerio de Agricultura Chile.

Transparent monitoring enables countries to develop NDCs that are specific, quantifiable, linked to high-quality reporting, and that can be assessed independently. Better information builds trust with donors and the general public.

Recommendations are given to what data users and what data providers can do to improve transparency in monitoring.

1) *Users* of land use information can engage in and benefit from independent monitoring approaches through: developing guiding principles for assessing uncertainties associated with monitoring approaches and how to reduce them; advancing IPCC guidance regarding the inclusion of independent data and contributing to improved emission factors; and better tailoring models and other tools towards reporting requirements and make them more consistent with current IPCC guidelines and country GHG reporting;

2) *Data providers* can contribute to increased transparency by: Including the original data sources, clearly describe definitions, methodologies and assumptions to facilitate replication and assessment, and include accuracy assessments and uncertainties; making methods for data production publicly available and preferably published in peer-reviewed papers; providing regular data updates and consistent estimates over time; guaranteeing access to the data for a long period; providing the institutional background of the data producer; and using open assets such as Copernicus services and the ESA BIOMASS mission to deliver free and open data to stakeholders.[64]

181. **Copernicus Climate Change Service (C3S): A European operational response to climate policies and action**
Jean-Noël Thépaut, ECMWF, Copernicus Climate Change Service

The Copernicus Climate Change Service (C3S), one of the six core Services of the Copernicus programme, enters its fourth year of development. 2018 has been a critical year for C3S as a transition between a prototyping phase into a full operational Service.

A wide variety of products is now routinely made available and accessed by thousands of users. A unique and strong point of C3S is to focus on delivering operationally “authoritative” data, via its climate data store.

A prime user of the Service is the European Commission itself, and C3S strives to support the policy makers and public authorities at European level and beyond, by providing the environmental information they need to inform their policies and legislation, etc. which becomes critically important in view of following up the Paris Agreement, and supporting the UNFCCC Sustainable Development Goals, the Sendai Framework for Disaster Risk Reduction, etc.

In addition, by providing access not only to high quality data but also tools, guidance and compute facilities to handle and transform these data, C3S ambitions to be an enabler for policy makers in their routine decision-making process as well as downstream climate service applications tailored to various local and sectoral needs.

182. **Tandem-L: Highly innovative radar satellite mission for climate research and environmental monitoring**
Alberto Moreira, German Aerospace Center (DLR)

The increase in the concentration of greenhouse gases in the atmosphere and the associated climate change today make the carbon cycle a core part of climate research. The uncertainties in the carbon flows between the land and the atmosphere are very large. The main reasons for this are the incomplete monitoring and the lack of knowledge about the biomass and its changes on a global scale. Furthermore, global and national estimates of forest biomass are often not spatially relevant as they are derived from the generalization of forest inventory data. Consistent global monitoring of the condition of the forests and the influence due to human activity and climate therefore becomes an urgent necessity. Up to now, existing remote sensing configurations are not capable to estimate biomass and their variations with high accuracy on a global scale.

Tandem-L will be able to monitor policy measures to support the implementation of the Paris Agreement. One example is REDD+ (Reduction of Emissions from Deforestation and Forest Degradation). Tandem-L will measure global forest biomass and its change over time, for example through deforestation, forest fires or degradation, but also through afforestation. Bound $CO_2$ is

[64] Further reading: Stakeholder needs assessment: cifor.org/library/6875/; Transparency brief: cifor.org/library/6256/; Report to the European Commission: https://doi.org/10.2834/513344.

released into the atmosphere primarily as a result of deforestation and forest destruction. Compared to other components of the $CO_2$ cycle, there is not yet sufficient data on this. Tandem-L will thus make a key contribution to a better understanding of the $CO_2$ cycle and also provide insights into $CO_2$ sources and sinks, and by this it will offers an unique opportunity to track the status of the REDD measures and will help to monitor the carbon footprint of each nation.

Due to its novel imaging techniques and its great acquisition capacity, Tandem-L will measure biomass and its seasonal and yearly variation with unprecedented accuracy on a global scale. This will be a key contribution to drastically reducing the uncertainties in the terrestrial components of the carbon cycle. Another important contribution of Tandem-L is the assessment of the vertical forest structure and its variation. In this way, the extent and intensity of forest disturbance (e.g., through deforestation, forest fire or degradation as well as through reforestation) can be determined and its temporal fluctuations documented. The knowledge of the sources and sinks of carbon on the land surface is essential to improve near-term climate projections related to global warming.

Due to climate changes and anthropogenic influences, hydrological conditions are also changing. It is of great importance to predict such changes and their impact on the water cycle in order to limit the potential negative consequences for society and economy. Tandem-L will record the critical components of the water cycle, such as soil moisture, and the dynamics of flow and melting processes in the cryosphere on a global scale with high temporal and spatial resolution. In this way, hydrological river basin models, weather forecast models and seasonally dependent climate models can be considerably improved.

The Tandem-L mission will generate a broad range of radar raw data and higher-level information products, which will be made available free of charge to scientific users in Germany and the international community. The overall system is designed to allow the satellites to record up to 8 terabytes of radar raw data per day. On a processing and evaluation platform, users can access and process data and exchange experiences and knowledge. The data management and data usage concept ensures that all potential users of Tandem-L data can find, access, understand and evaluate mission data.

183. **Sargassum outbreaks in the Caribbean**

Tarub Bahri, UN Food and Agriculture Organisation (FAO)

There are many different kinds of sargassum. However, there are only 2 species (*Sargassum Fluitans* and *Sargassum natans*) which are solely pelagic and spend their entire lifecycle floating freely at the surface of the Atlantic Ocean. The Caribbean region is seeing Sargassum more frequently due to a new source area stretching right across the Equator between West Africa and Brazil. Furthermore, Sargassum grows faster due to more nutrients (pollution from logging, fertilizer, mining and urbanization) as well as increases in floods.

Sargassum is having huge impacts on the fisheries sector in the Caribbean: at landing sites, at sea and disrupting fish populations. Dolphinfish and Flyingfish have a 37% and 52% decrease in landings respectively. Socio-economic challenges include loss of earnings in harvest and post-harvest sectors; market changes (higher prices, new species, changing seasons); and lower profits (maintenance and fuel costs higher, reduced catches).

Sargassum has been a plague to the region's maritime activities, but has some opportunities for revenue earning, once processed, for coastal communities, such as use as biofuel, agriculture fertilizers, animal and fish feed, hair products and building materials.

CC4Fish[65] is supporting the region through a number of activities including:

- Prediction model for Sargassum;
- The quarterly Eastern Caribbean Sargassum Outlook Bulletin which warns the fishing; industry of the likely presence and abundance of sargassum influxes;
- A study on the impacts of Sargassum on key fish species;
- Best practices guide for fisherfolk coping with Sargassum;
- Sargassum uses guide;
- Sargassum management plans.

[65] See http://www.fao.org/in-action/climate-change-adaptation-eastern-caribbean-fisheries/en/.

184. **[Digital Earth Africa: decision-ready products from open data cubes]**
Steven Ramage, Sara Venturini, Group on Earth Observations (GEO)

Digital Earth Africa (DE Africa) is part of the Group on Earth Observations (GEO) Work Programme. DE Africa is developing one of the world's largest operating systems for accessing and analysing satellite imagery for the African continent.

DE Africa is taking analysis-ready Earth observation data and using the Open Data Cube to produce operational, decision-ready products for the entire continent.

DE Africa's products and data will be free, open, and continental. DE Africa enables governments to develop informed policy and make evidence-based decisions on soil and coastal erosion, agriculture, forests, desertification, water quality and changes to human settlements.

DE Africa is being established as a sovereign operational and analytic capability of Africa, with in-country expertise in data analysis, use and management. Capacity development is a core component of the programme's establishment.

DE Africa supports all of Africa to drive progress towards the global challenges outlined in the UN 2030 Agenda for Sustainable Development. In particular, it is directly relevant to Sustainable Development Goals 2 (zero hunger), 6 (clean water and sanitation), 9 (industry, innovation and infrastructure), 11 (sustainable cities and communities), 13 (climate action), 14 (life below water), and 15 (life on land).

By providing timely data and decision support tools on key socioeconomic sectors, DE Africa assists African countries with developing, implementing and monitoring climate adaptation and mitigation plans as part of their Nationally Determined Contributions (NDCs), supporting them to meet their commitments under the international climate regime defined by the Paris Agreement. DE Africa also responds to the Paris Agreement's call for enhanced, country-driven capacity building and technology transfer for climate action in developing countries.

185. **[GEOGLAM: Adaptation and early warning for the agricultural sector]**
Ian Jarvis, Steven Ramage, Sara Venturini, Group on Earth Observations (GEO) Secretariat

The Group on Earth Observations Global Agricultural Monitoring Initiative (GEOGLAM) is working to fight food insecurity and support markets in a changing climate. GEOGLAM reinforces the international community's capacity to produce and disseminate timely and accurate projections of agricultural production at national, regional, and global scales. GEOGLAM contributes to building resilience, adaptive capacity, and risk management in both developed and developing countries through improved information for decision making.

Two monthly global crop condition reports have been established within GEOGLAM, namely:

1) Crop Monitor for the Agricultural Monitoring Information System (AMIS), providing monthly status reports on agricultural production (wheat, maize, soybean, and rice) in major producing nations. These reports are based on Earth observations and expert on-the-ground assessments. The focus is to examine main production/export countries, the stabilizing/calming market factors, and avoid unexpected food price shocks;

2) Crop Monitor for Early Warning (CM4EW), to support early warning for food security response. Like the AMIS report, the monthly CM4EW reports represent a consensus assessment of crop production condition in food insecure regions. The focus is on agricultural production and markets located in East Africa, West Africa, Southern Africa, Southern Africa, Southeast Asia, Central and Southern Asia, Central America & the Caribbean.

GEOGLAM is one of GEO's flagship initiatives aiming to respond to the three main relevant international policy drivers: the Paris Agreement, the Sendai Framework for Disaster Risk Reduction, and the UN 2030 Agenda for Sustainable Development. National Adaptation Plans (NAPs) are key for achieving countries' Nationally Determined Contributions (NDCs) and the full implementation of the Paris Agreement. NAPs also contribute to and are aligned with disaster risk reduction and sustainable development objectives. GEOGLAM provides tools and information products on the near real time state and changes in agricultural production at the national to global scales. GEOGLAM decision-ready products support the development of early warning systems in agriculture that can be integrated into NAPs.

186. **Coastal blue carbon ecosystems - nature based solutions**
Kirsten Isensee, IOC-UNESCO

Blue carbon is the carbon stored in coastal and marine ecosystems. Coastal blue carbon ecosystems are found on every continent except Antarctica. Mangroves, tidalmarshes and seagrasses cover between 13.8 and 15.2 million hectares (Mha), 2.2 and 40 Mha, and 17.7 and 60 Mha, respectively.

Besides being an important factor in the global carbon cycle, mangroves, salt marshes and seagrass meadows have high biodiversity values. They provide breeding grounds and nurseries for fisheries and food security for many coastal communities around the world. They also provide ecosystem services that are essential for climate adaptation and resilience along coasts, including protection from storm surge and sea level rise, erosion prevention along shorelines and coastal water quality regulation.

Climate change is impacting the ability of blue carbon ecosystems to store carbon. There is growing evidence and consensus that the management of coastal blue carbon ecosystems, through avoided emissions, conservation, restoration and sustainable use has strong potential as a transformational tool in effective climate change mitigation and adaptation.

Furthermore, blue carbon offers the possibility to mobilize additional funds and revenue by combining best practices in coastal management with climate change mitigation goals and needs.

The Blue Carbon Initiative works to develop management approaches, financial incentives and policy mechanisms for ensuring the conservation, restoration and sustainable use of coastal blue carbon ecosystems. It engages local, national, and international governments in order to promote policies that support coastal blue carbon conservation, management and financing. The goal is to develop comprehensive methods for assessing blue carbon stocks and emissions, which will be implemented by projects around the world to demonstrate the feasibility of blue carbon accounting, management and incentive agreements. The Initiative also aims to support scientific research into the role of coastal blue carbon ecosystems for climate change mitigation.

187. **From OceanObs'19 to the Ocean Decade**
Toste Tanhua, IOC-UNESCO

The OceanObs'19 conference represented a once in a decade chance to take stock of the ocean observing system and to identify priorities for the next decade. Key messages include:

- Planning for impact;
- Cores system integration;
- Embracing innovation.

Implementing the GOOS 2030 strategy will advance the Ocean Decade through transformative partnerships for ocean climate information. Systematic Ocean Observing is key for assessing the state of the climate and can point to ocean based solutions for climate change.

188. **Ocean knowledge is key for climate action**
Dan Laffoley, International Union for Conservation of Nature (IUCN)

Excessive emissions of carbon dioxide have made the ocean warmer, reducing its ability to hold oxygen, and have caused it to become more acidic. Changing the state of the ocean in this manner alters the character, composition and distribution of marine species, its very ability to support life, the array of benefits we take for granted, and the way in which essential nutrients are recycled, with the potential for driving negative feedbacks into further climate change.

IUCN and partners have issued ground-breaking reports with leading scientists to explore, promote and act on key ocean climate science issues:

1) **Ocean acidification**: IUCN chairs one of the longest running bodies to connect science to policy on ocean acidification - the **Ocean Acidification international Reference User Group**. Through this group regions of the world are developing action plans to help get ahead of the curve of degradation;[66]

[66] See https://www.iucn.org/theme/marine-and-polar/our-work/climate-change-and-ocean/ocean-acidification.

2) **Ocean warming** - one of the most downloaded reports in the recent history of IUCN that awoke worldwide concern on the impacts of atmospheric warming on ocean habitats, species and ecosystem structure and functions;[67]

3) **Ocean deoxygenation**: There is no environmental variable of such ecological importance to marine ecosystems that has changed so drastically in such a short period of time as a result of human activities as dissolved oxygen. Hypoxia - a condition that deprives an organism of adequate oxygen supply at the tissue level - is one of the most acute symptoms of the reduction in dissolved oxygen. This ground-breaking report documents the inescapable fact human activities are now driving life sustaining oxygen from our ocean-dominated planet. Science is incomplete and awareness of ocean deoxygenation is just happening, but what is already known is very concerning.[68]

189. **Earth observation for science, policy and practice: Cases from the Asia-Pacific region**
Eko Siswanto, JAMSTEC, Japan

The project provides satellite-based oceanic and terrestrial low-trophic level organism databases and utilize them to assess the Earth's surface biological responses to global climate changes.

The land and ocean environments within the Asia-Pacific region expanding from the eastern Indian Ocean to the western North Pacific Ocean were selected as the project target areas because their geographic locations make them vulnerable to climatic perturbations.

The project has generated terrestrial and oceanic low-trophic level organism databases (such as phytoplankton, vegetation, etc.) which can be accessed from the LowTroMAP database website. The project has also produced many scientific papers mainly describing the impacts of climate change on the low-trophic level organism spatiotemporal variability.

190. **Utilization of Earth observation data for furthering Earth system models' validation and sophistication in Japan's climate model development project, TOUGOU**
P. K. Patra[1], T. Hajima[1], R. Saito[2], N. Chandra[1], M. Kawamiya[1], Japan[69]

The increase of earth's mean surface air temperature due to the rise in global mean greenhouse gases (GHGs) concentration is well established. There are emerging constraints showing the rise of GHGs concentration is linked almost entirely to the anthropogenic activities during the past 100 years. Our ability to monitor the major GHGs concentrations in ambient air has been increasing since the 1960s but remained sparse on spatial coverage. With the advent of remote sensing instruments an overwhelming amount of data covering the globe are being gathered for $CO_2$ and $CH_4$. The first in the line dedicate instrument, JAXA's GOSAT, was launched on board the Ibuki satellite in January 2009 and continue to provide measurements of $CO_2$ and $CH_4$. The NASA's OCO-2 and ESA's TROPOMI are providing much greater data density and probably at high measurement accuracy.

Time series of the global mean or a single site concentration of the long-lived GHGs inform us about the rate of global source-sink balance in the atmosphere. The onus is on the data users to extract information on regional (country to subcontinental scale) sources and sinks from the large amount of concentration data. We employ inversion (top-down) modelling that uses an atmospheric chemistry-transport model (ACTM) to disentangle the sources and sinks from the contribution of chemistry and transport signals in atmospheric data. These regional sources and sinks information will directly support the global stocktake (Paris Agreement) when sufficient accuracy is achieved. Our experiences so far suggest that the ensemble mean model results are beginning to satisfy the criteria.

The emission mitigation target and success of the ambitious Paris Agreement rely, to some extent, on our ability to derive climate responses to the changes in ambient $CO_2$ concentration, resulting from the projected changes in anthropogenic and natural fluxes. The complex earth system models (ESMs) are being developed to predict the natural capacity of the land and ocean to uptake $CO_2$ from atmosphere and maintain carbon storage in their ecosystems. In addition, one of the new challenges in developing next generation ESMs is to explicitly simulate the non-$CO_2$ GHGs

67 See https://www.iucn.org/theme/marine-and-polar/our-work/climate-change-and-ocean/ocean-warming.
68 See https://www.iucn.org/theme/marine-and-polar/our-work/climate-change-and-oceans/ocean-deoxygenation.
69 [1]RIGC, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokohama, [2]Disaster Risk Reduction and Environment SBU, Kokusai Kogyo Co., Ltd., Tokyo, Japan.

cycles. The top-down estimation of sources and sinks will support the evaluation of historical simulations and refine carbon-nitrogen-phosphorus cycles of ecosystem functioning in the ESMs.

We show results from our first attempt to use the GOSAT and OCO-2 $XCO_2$ observations; firstly, to verify consistency of MIROC4-ACTM inversion results using data from sparse in situ networks with the remote sensing observations, and then we validate the modelled $XCO_2$ by MIROC4-ACTM and MIROC-ES2L fluxes using data from the two remote sensing satellites of global coverage. Both the modelling systems are developed in JAMSTEC, in collaboration with the University of Tokyo and National Institute for Environmental Studies, Japan.

GOSAT-2 was launched as GOSAT's successor in October 2018. Data from the currently operating remote sensing satellites will be essential for reduction of uncertainty in GHGs sources and sinks estimations, and further improvement of the accuracy of climate projections.

191. **Mapping and modelling vulnerability to dengue in Vietnam and the Philippines using geospatial and time-series approaches**
Nga T. T. Pham, Vietnam National Space Center, Viet Nam

Viet Nam and the Philippines are recognized as extremely vulnerable to climate change due to regular flooding and frequent typhoons and, therefore, have an increased burden to climate change related diseases. Changes in temperature and precipitation are likely to alter the incidence and distribution of vector-borne diseases such as dengue and malaria. The objective of the project is to improve the knowledge of dengue and its vulnerability to climate variability for rural populations in both countries by using advanced geospatial technology.

The study gathered and analyzed data on disease exposure in the period 2000–2016. A geospatial database on dengue was developed that included information on temperature, precipitation, land cover, and socio-environmental conditions. Data analyses helped to identify trends in epidemiological patterns, high-risk locations and factors, thus mapping vulnerability to dengue. In addition, two mathematical approaches were applied to predict dengue in the most disease exposed regions in the two countries.

The outputs of the project included the database of climate-related diseases, with the analyses and maps of vulnerability to dengue, available at webGIS. Project results are expected to contribute to building science-based knowledge for adaption planning and decision making in the health sector via informing risk and vulnerability.

192. **UK NCEO support for regional climate information: recent findings for Africa**
Pedro Rodriguez Veiga, UK National Centre for Earth Observation

We find that satellite data for carbon can be used to address regions with limited networks by commissioning targeted observations in regions where satellite data needs verifying or referencing.

With current satellite systems, we can map biomass carbon data for forests, working alongside local organisations; teams are also working on a climate data record for biomass. Additional in situ biomass measurements should be commissioned alongside the satellite data. The satellite data can be ingested into carbon models to spatially define the strongest net sinks of carbon in forests.

Atmospheric gas information can also be derived from satellite observations. Space borne spectrometers are sufficiently accurate to determine carbon emissions into the atmosphere but the scale at which emissions can be derived does vary. ECV records of carbon dioxide and methane have been produced:

i. For methane, scientific results are interrogating net emissions at the country-scale and verifying their consistency e.g. India and the U.S.A.;
ii. For carbon dioxide, there is more confidence at the regional-scale and promising progress on obtaining consistency in estimating net emissions at our results indicate that a global stocktake for carbon is feasible at large-scale with current instruments in a pre-operational sense.

New inter-agency satellite constellations will deliver trusted information globally at regional-to-country scale and for large urban centres. Our results indicate that a global stocktake for carbon is feasible at large-scale with current instruments in a pre-operational sense.

Model developments will also improve the accuracy of the inversions from atmospheric gas concentrations to emissions. New observations such as fire, LST and soil moisture will improve the accuracy and interpretation of the carbon data in these complicated arrangements.

193. **Climate change and air quality mitigations: why should we do it together**

Sandro Fuzzi and Oksana Tarasova, WMO

The poster presents diverse impacts of that the substances emitted through human activities have on pollution levels and climate.

It is demonstrated that only selected number of emission reduction policies can lead to the simultaneous improvement of air quality and assist mitigation of global warming (win-win policy options). Some of those measures were articulated already in the WMO/UNEP Assessment of black carbon and tropospheric ozone.

Recent research also shows that to reach climate objective the action on the short-lived climate pollutants could happen later to deliver the same temperature outcome, but the late actions would compromise the attainment of many SDGs due to air pollution impacts and impacts of cumulative warming.

The 'Multiple Benefits Pathway' approach attempts to limit the rate of temperature rise and other impacts on health and ecosystems.