Summary report on the Earth Information Day COP 22, Marrakech, Morocco, 8 November 2016

Note by the Chair of the SBSTA

21 March 2017

I. Objective

1. 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 and opportunities to support decision making on risk assessment, adaptation and mitigation.

2. 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 intergovernmental process and Paris Agreement implementation.

A. Mandates and submissions

3. The Subsidiary Body for Scientific and Technological Advice held its forty-fifth session (SBSTA 45), 7–14 November, Marrakech, Morocco.

4. The Global Climate Observing System (GCOS) secretariat submitted the GCOS 2016 implementation plan, *The Global Observing System for Climate: Implementation Needs* (hereinafter referred to as the GCOS implementation plan),[1] as requested at SBSTA 37.[2]

5. The World Meteorological Organization (WMO) provided two submissions to SBSTA giving up-to-date information on the state of the global climate and the atmospheric concentration of greenhouse gases (GHGs):

a) WMO The Global Climate in 2011–2015;[3]

b) WMO Greenhouse Gas Bulletin: The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2015.[4]

B. Background and approach

6. The Convention calls on Parties to promote and cooperate in research and systematic observation of the climate system, including through support to existing international programmes and networks.[5]

7. 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.[6] 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.

8. The GCOS implementation plan describes the proposed implementation of the global observing system for climate, building on current actions and taking into consideration the climate monitoring needs

[1] Available at <http://unfccc.int/files/science/workstreams/systematic_observation /application/pdf/gcos_ip_10oct2016.pdf> and <http://gcos.wmo.int>.
[2] FCCC/SBSTA/2012/5, paragraph 37.
[3] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/ wmo_1179_statement2016_5years_web_en.pdf>.
[4] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/wmo_ghg_doc_num.php.pdf>.
[5] Convention Articles 4.1(g) and 5 <http://unfccc.int/ 6036>.
[6] Decision 1/CP.21 <http://unfccc.int/9485>.

of the Convention in the context of the Paris Agreement,[7] Agenda 2030[8] and its sustainable development goals,[9] as well as the United Nations Convention to Combat Desertification,[10] the Convention on Biological Diversity,[11] the Sendai Framework for Disaster Risk Reduction[12] and other multilateral environmental agreements.

9. The GCOS implementation plan sets out the framework for the science community to provide the data and information to implement the global climate observing system, advance scientific research knowledge and support climate services and the development of indicators.

10. The Earth Information Day provided the opportunity to look in more detail at the GCOS implementation plan and provide an up-to-date picture of the status of the climate and current future outlook. It was an opportunity to optimise engagement and connect information and requirements between the science community, Parties and all stakeholders at the Conference of the Parties (COP) to benefit the negotiation process and the implementation of the Paris Agreement and its goals. It also provided the opportunity to support the global stocktake informing on the state of the climate with the intention to motivate acceleration of progress based on the best available science.

11. The Earth Information Day featured speakers from the heads of UN and international science organizations and agencies and the scientific community on:

a) The state of the climate and the global carbon budget and the development of indicators to support adaptation and mitigation;

b) The GCOS implementation plan – explaining the essential climate variables, indicators and actions to support the Paris Agreement and the Sustainable Development Goals;

c) New developments in the estimation of GHG emissions from Earth observations to support national inventories;

d) Earth observation actions and services to support adaptation in Africa

II. Summary of the proceedings

12. The Earth Information Day was held on 8 November 2016, 10:15–18:00, Plenary Casablanca, COP 22, Marrakech, Morocco.[13]

13. The programme began with an opening session and then two main parts: Part I Current Observations and Knowledge and Part II Developments and Opportunities. Part I and Part II both featured presentations and discussion and were supported by a poster session where delegates were able to interact with experts on a one-on-one basis.

A. Opening

14. The Earth Information Day was opened by Mr. Richard Kinley, Deputy Executive Secretary, Ms. Elena Manaenkova, Deputy Secretary General, WMO and Mr. Vladimir Ryabinin, Executive Secretary, Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO-IOC).

15. Mr. Kinley highlighted the importance that science knowledge had in the achievement of the landmark Paris Agreement. He stressed that the Paris Agreement is universal, uniting nations in meaningful action on climate change and that action is based on sound science and represented by a long-term goal. He paid tribute to the dedicated observation and research community worldwide of thousands who supplied the science information, assessed by the Intergovernmental Panel on Climate Change (IPCC), to inform the UNFCCC political process. He stated that decisions on implementation of the Paris Agreement must also be based on sound planetary science to provide the tools for nations to build the path towards a sustainable, climate-safe future and stay on that path.

[7] As requested at SBSTA 43, see FCCC/SBSTA/2015/5, paragraph 28.
[8] <https://sustainabledevelopment.un.org/post2015/transformingourworld/publication>.
[9] <http://www.un.org/sustainabledevelopment/sustainable-development-goals/>.
[10] <http://www2.unccd.int/>.
[11] <https://www.cbd.int/>.
[12] <https://sustainabledevelopment.un.org/content/documents/2157sendaiframeworkfordrren.pdf>.
[13] <http://unfccc.int/9949.php>.

16. Ms. Manaenkova explained how WMO, with the National Meteorological and Hydrological Services of WMO Member countries, is providing systematic observations on essential climate variables that underpin the assessment reports of the IPCC and the WMO reports on GHG emissions and the state of the climate (see paragraph 5). This includes national level support through the Global Framework for Climate Services to provide short and medium term data to support risk assessment and management and the Integrated Global Greenhouse Gas Information System (see paragraphs 77–82).

17. Mr. Ryabinin highlighted that with 93% of heat attributed to global warming and 28% of anthropogenic CO_2 emissions ending up in the oceans,[14] oceans have acted as the most important mitigation factor of climate change thus far. He stated that the oceans are getting hot, sour and breathless. IOC is the lead agency for the global ocean observing system (GOOS) and for two targets of the sustainable development goal 14, life below water. He pointed out that the central role of the ocean in climate change is not reflected in detail under the UNFCCC, with only one reference to oceans in the preambular to the Paris Agreement, although scientific aspects of oceans are discussed under the SBSTA research and systematic observation agenda item. Scientific data and knowledge on oceans has increased in the last few decades but more needs to be done, including at greater depth (beyond 2,000m) and on new variables, to fully monitor climate change impacts including on ocean life and food supply, human livelihoods, coastal impacts, ocean system services and extreme events.

B. Part 1: Current observations and knowledge

1. The state of the climate

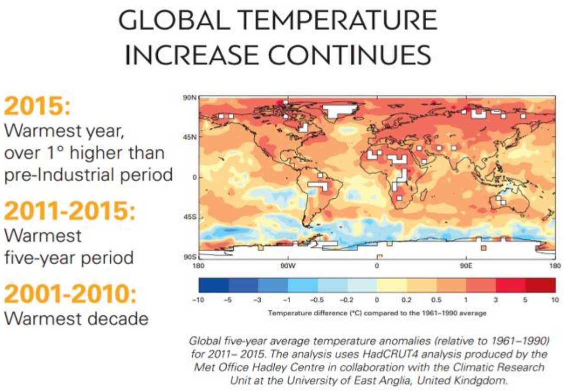
18. The first presentation[15] from Mr. Omar Baddour provided a summary of the WMO report the *Global climate in 2011–2015*[16] to COP 22 and was supported by the poster *The Status of the Global Climate in 2011–2015*.[17] Following the Earth Information Day, the WMO published on 14th November 2016 a provisional statement on the status of the global climate in 2016.[18]

19. The Global climate in 2011–2015 report looked at different components of the Earth-climate system including indicators relevant to the Paris Agreement: temperature; precipitation; GHG concentrations in the atmosphere; oceanic indicators at surface and sub-surface; sea level; cryosphere including sea ice, ice-sheets and snow cover; major modes of climate variability; extreme events; and socio economic impacts.[19]

20. The WMO identified that the last five years have been globally the hottest on record (figure 1). The concentration of GHGs in the atmosphere continued to increase. In 2015, the average CO_2 concentration in the atmosphere passed the symbolic threshold of 400 ppm for the whole year. Sea levels continued to rise (figure 2). The level of inter-annual variability in global sea level over the period was high by the standards of the satellite era due to a strong El Niña in 2011–2012 and a strong El Niño in 2015. Arctic sea ice extent continued to decline with the 2011–2015 mean September sea ice extent being nearly 30% below the 1981–2010 average.

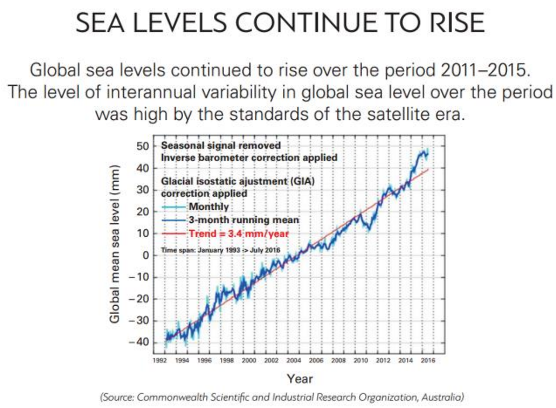
[14] IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.
[15] <http://unfccc.int/files/adaptation/application/pdf/i.1__wmo__baddour.pdf>.
[16] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/wmo_1179_statement2016_5years_web_en.pdf>.
[17] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/8.wmo_global-climate-outlook.pdf>.
[18] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/wmostatement_on_the_status_of_the_global_climate_2016.pdf>.
[19] For all WMO Status of the Climate reports see <http://www.wmo.int/pages/prog/wcp/wcdmp/statement.php>.

Figure 1
Global average temperature



Source: Slide 5 of the presentation by Mr. Omar Baddour.

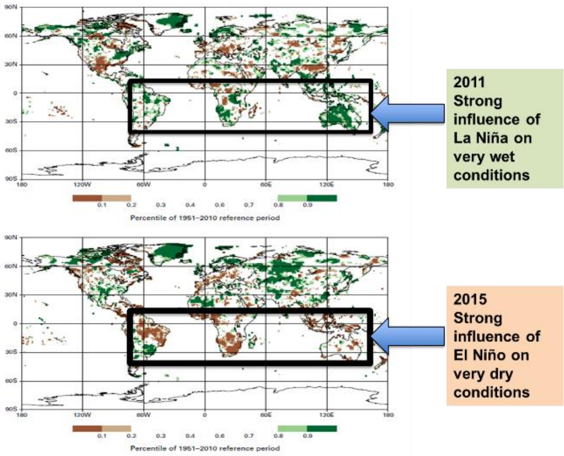
Figure 2
Global average sea level



Source: Slide 9 of the presentation by Mr. Omar Baddour.

21. The El Niño-Southern Oscillation (ENSO) cycle influenced global precipitation early and late on in the 2011–2015 period (figure 3).

Figure 3
Global average precipitation

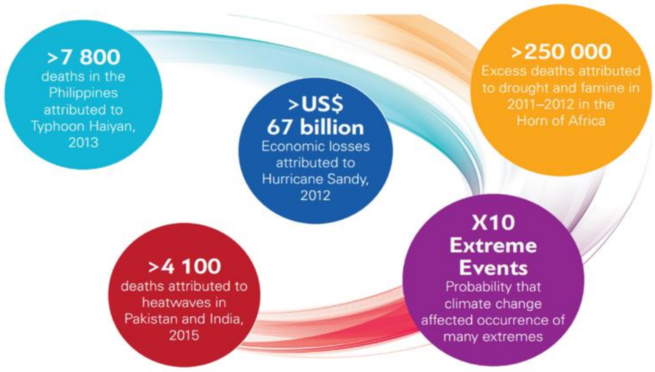


Source: Slide 11 of the presentation by Mr. Omar Baddour.
Annual total precipitation expressed as a percentile of the 1951–2010 reference period for areas that would have been in the driest 20% (brown) and wettest 20% (green) of years during the reference period, with darker shades of brown and green indicating the driest and wettest 10%, respectively, for 2011 (top) and 2015 (bottom). Source: Global precipitation climatology centre, Deutscher Wetterdienst, Germany

22. There were large numbers of extreme weather and climate events during 2011–2015 (figure 4), including heatwaves and coldwaves, tropical cyclones, flooding, droughts and severe storms. Recent research on attribution shows that in some cases the probability of an extreme event occurring is multiplied due to the impact of climate change, and this can be up to a factor of 10.20

[20] See WMO Global Climate in 2011-2015 and Herring, S. C., A. Hoell, M. P. Hoerling, J. P. Kossin, C. J. Schreck III, and P. A. Stott, Eds., 2016: Explaining Extreme Events of 2015 from a Climate Perspective. Bull. Amer. Meteor. Soc., 97 (12), S1–S145, doi:10.1175/BAMS -ExplainingExtremeEvents2015.1. <http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-ExplainingExtremeEvents2015.1>.

Figure 4
High impact extreme events 2011–2015



Source: Slide 12 of the presentation by Mr. Omar Baddour.

2. The GCOS implementation plan – explaining the essential climate variables, indicators and actions to support the Paris Agreement and the Sustainable Development Goals

23. Ms. Carolin Richter provided a summary of the GCOS implementation plan and the importance, challenges and needs for the global climate observation system. The presentation was supported by four GCOS posters:

a) *GCOS Climate Monitoring: Examples of recent performance monitoring statistics for climate observations;*[21]

b) *GCOS Implementation Plan 2016: Observations for adaptation, mitigation and climate science;*[22]

c) *Capacity Development*: *The GCOS Cooperation Mechanism – practical support for Parties to improve their observations through equipment, people and communications*;[23]

d) *How climate observations will play a role in the global stocktake*.[24]

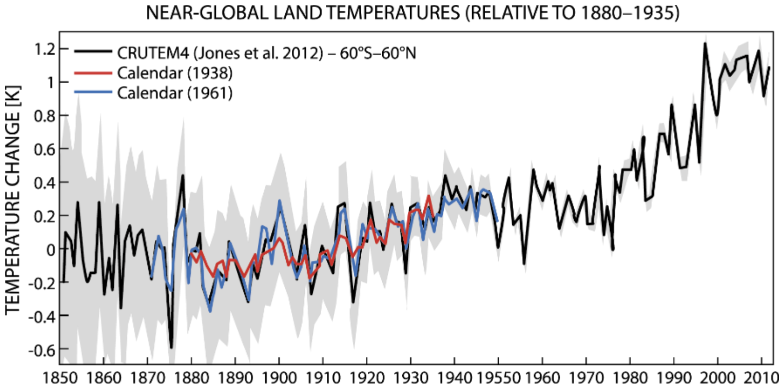
24. A status report of the global climate observing system was submitted to SBSTA 43 (2015).[25] The poster *GCOS Climate Monitoring: Examples of recent performance monitoring statistics for climate observations* complemented this report by providing an update on climate observations of the surface, upper-air atmospheric monitoring, ocean monitoring and terrestrial monitoring.

25. Ms. Richter referred to the funding needed for continued and accurate long term measurement of the climate system. Ms. Richter cited radiosondes as one important example of funding needs. Radiosondes are vital for measuring temperature from the Earth's surface vertically up to the troposphere, and reduce errors in weather forecasting. However, many national and meteorological services and agencies worldwide cannot afford to fly them.

26. She highlighted the early measurements of global temperature collected by Guy Stewart Callendar who made the first plot of CO_2 rise in the atmosphere using 10 year running means, based on 147 stations globally, and detected a 0.5 ºC global rise in temperature between 1890 and 1935.[26] The measurements of Callendar were confirmed by scientists of his era as well as later measurements taken by himself in 1961 and many scientists up to the present day (Figure 5). Ms. Richter also highlighted the work started by Charles David Keeling in 1957 and the importance of long-term sustained CO_2 measurements in order to understand the changes in the global climate (Figure 6).

[21] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/18.cop22poster_gcos4.pdf>.
[22] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/2.cop22poster_gcos1.pdf>.
[23] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/19.cop22poster_gcos3.pdf>.
[24] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/20.cop22poster_gcos2.pdf>.
[25] <https://www.wmo.int/pages/prog/gcos/ReviewVersionpPDF/2015_GCOS_Status_Report_for_public_review_24-July-2015_reduced_size.pdf>.
[26] Quarterly J. Royal Meteorological Society 64, 223 (1938), <http://onlinelibrary.wiley.com/doi/10.1002/qj.49706427503/full>.

Figure 5
Measuring global average temperature

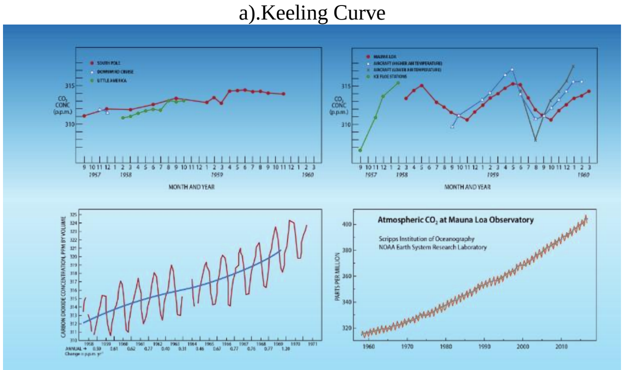


Source: Slide 5 of the presentation by Ms. Carolin Richter.

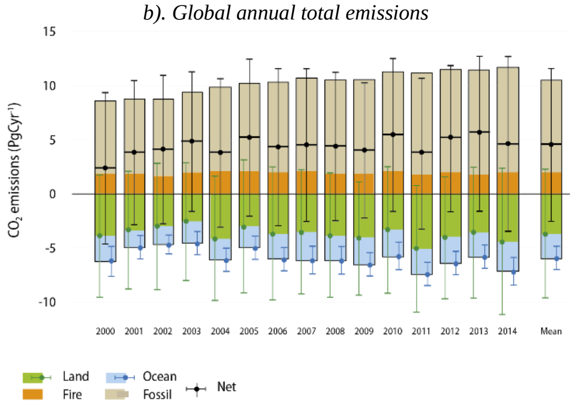
27. However, she stated that CO_2 and temperature are not enough to understand the whole climate system and the impacts of climate change. To understand the whole system, a holistic set of information is needed across atmosphere, ocean and land. GCOS has provided a comprehensive set of essential climate variable (ECV) requirements, adequacy reports and plans, which identify the observations, products and open data needed to inform science, assessments and policy needed by climate services, risk assessments, early warning and disaster risk reduction policies and that can lead to successful adaptation and mitigation, reduced climate risks, enhanced livelihoods, and increased food and water security.

Figure 6
Measuring carbon dioxide concentrations

a).Keeling Curve



b). Global annual total emissions



Source: Slides 7–10 of the presentation by Ms. Carolin Richter.
a). The first two plots are the original measurements made by Keeling in 1957, 1958 and 1959 in Antarctica and on Mauna Loa. Keeling's aim was to measure a baseline but in fact he captured the annual temperature increase at the South Pole. He secured funding to continue monitoring at Mauna Loa (third Plot) although was not able to continue in Antarctica. Lack of funding resulted in the gap visible in the data in 1964 when the equipment broke down. Now there is a long time series (fourth plot) at Mauna Loa.
b). With increased monitoring it is now possible to monitor the distribution of CO_2 emissions across all latitudes.[27]

28. Ms. Richter stated that the new GCOS Implementation Plan, which takes into account the Paris Agreement and the sustainable development goals, provides the implementation needs of the global climate observing system for the next decade. GCOS provided an overview of the plan in the second poster *GCOS Implementation Plan 2016: Observations for adaptation, mitigation and climate science*.

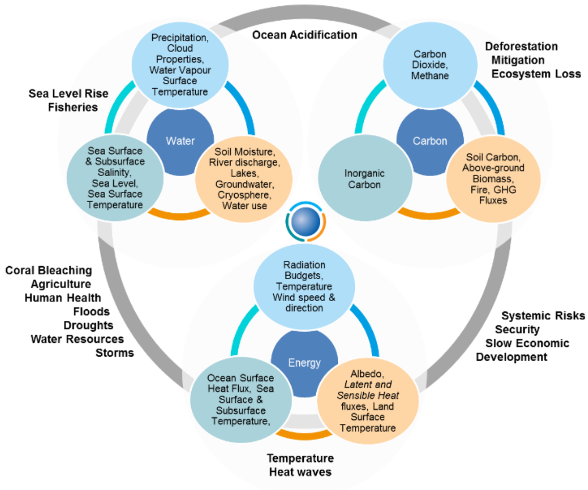
29. Ms. Richter highlighted the six aims of the implementation plan (figure 7). The plan includes support for higher spatial and temporal resolution of data for adaptation. It aims to accurately measure and 'close' the three Earth's cycles of water, energy and carbon (figure 8) through better understanding of the key ECVs involved. It also provides a greater emphasis on support for networks in developing countries.

[27] <https://www.esrl.noaa.gov/gmd/ccgg/carbontracker/fluxtimeseries.php?region=Global#imagetable>.

Figure 7
The six implementation aims of the GCOS implementation plan

Source: Slide 18 of the presentation by Ms. Carolin Richter.

Figure 8
Understanding the Earth's climate cycles



Source: Slide 21 of the presentation by Ms. Carolin Richter and figure 2 of the GCOS Implementation Plan 2016: Observations for adaptation, mitigation and climate science poster.[28]
Observations in the three different domains: land, air and oceans all contribute to the knowledge needed for the water energy and carbon cycle to support knowledge and understanding of: ocean acidification, deforestation, mitigation, ecosystem loss, systemic risks, security, slow economic development, coral bleaching, agriculture, human health, floods, droughts, water resources, storms, sea level rise and fisheries.

30. She presented the list of ECV, most of which are already being used from the previous implementation plan but some existing ECVs have been updated, and some are new: lightning, ocean surface stress, ocean surface heat flux, nitrous oxide, marine habitat properties, land surface temperature and GHG fluxes (figure 9).

31. In regards to the inclusion of the new ECV on anthropogenic fluxes of GHGs, this is the key driver of changes of the carbon cycle - in the form of fossil fuel combustion, cement production, land use and land-use change. There is also a clear link of the ECV to fire disturbance, soil carbon, land use and above-ground biomass ECVs. Measuring this ECV will support the understanding of carbon exchanges between the ocean and atmosphere and land and atmosphere which currently need to be estimated, as well as exchanges between land and ocean which are measured through transport of organic material by rivers.

32. Ms. Richter emphasized the need to renovate, repair, reinstall and improve observing systems worldwide. She highlighted the importance of the GCOS Cooperation Mechanism (GCM),[29] a summary of which is provided in the third GCOS poster *Capacity Development*: *The GCOS Cooperation Mechanism – practical support for Parties to improve their observations through equipment, people and communications*. The GCM is intended to address priority needs in atmospheric, oceanic, and terrestrial observing systems for climate, including data rescue, analysis, and archiving activities. However, the activities that it has funded to date have been mainly in the atmospheric domain. The GCM is intended to complement, and work in cooperation with, existing funding and implementation mechanisms (for example, the WMO Voluntary Cooperation and GFCS Programme, the Global Environment Facility (GEF), the United Nations Development Programme (UNDP), and national aid agencies), many of which deal with GCOS-related activities and, in particular, support capacity-building. Support needs to be focused on those most in need and where priority adaptation needs are identified.

[28] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/2.cop22poster_gcos1.pdf>.
[29] Decision 11/CP.9

Figure 9
Essential climate variables in the GCOS implementation plan

Measurement Domain	Essential Climate Variables in the 2016 Implementation Plan
Atmospheric	Surface: Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget. Upper-air: Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget, Lightning. Composition: Carbon Dioxide (CO_2), Methane (CH_4), Other long-lived greenhouse gases (GHGs), Ozone, Aerosol, Precursors for aerosol and ozone.
Oceanic	Physics: Temperature: Sea surface and Subsurface, Salinity: Sea Surface and Subsurface, Currents, Surface Currents, Sea Level, Sea State, Sea Ice, Ocean Surface Stress , Ocean Surface heat Flux. Biogeochemistry: Inorganic Carbon, Oxygen, Nutrients, Transient Tracers, Nitrous Oxide (N_2O), Ocean Colour. Biology/ecosystems: Plankton, Marine habitat properties.
Terrestrial	Hydrology: River discharge, Groundwater, Lakes, Soil Moisture. Cryosphere: Snow, Glaciers, Ice sheets and Ice shelves, Permafrost. Biosphere: Albedo, Land cover, Fraction of absorbed photosynthetically active radiation, Leaf area index, Above-ground biomass, Soil carbon, Fire, Land Surface Temperature. Human use of natural resources: Water use, GHG fluxes.

Source: GCOS Implementation Plan 2016: Observations for adaptation, mitigation and climate science.[30]

33. Ms. Richter concluded her talk with the message that implementing the plan will contribute to successful adaptation and mitigation, reduce climate risks, enhance livelihoods, and food and water security through:

a) Securing and improving observation systems;

b) Supporting countries to implement the appropriate observations that meet their needs and priorities;

c) Providing open access to observations and data access;

d) Ensuring the delivery of high resolution global products.

34. The fourth poster by GCOS, *How climate observations will play a role in the global stocktake*, provided an overview of how the components of the GCOS implementation plan can facilitate the global stocktake. Relevant observation information for the UNFCCC includes the state of the global climate, national climate information and ECVs on the carbon cycle, such as GHG flux.

35. Mr. Toste Tanhua GEOMAR Helmholtz Center for Ocean Research presented, on behalf of UNESCO-IOC, the ocean aspects of the GCOS implementation plan. This information was also summarized in the poster *Ocean aspects of the GCOS Implementation Plan 2016: Connection to Climate Information and Services for Adaptation, Mitigation and the SDGs.*[31]

36. Mr. Tanhua began with stating facts and providing the supporting figures from the IPCC AR5 report:[32] the ocean is warming. This has been measured by observations from in-situ, satellite and ocean-vessel-based monitoring. The warming rate of the ocean is approximately 0.11 ºC/decade in the upper 75 m and 0.015 ºC/decade at 700m. He highlighted some of the differences in temperature changes in the ocean with the Northern Hemisphere having warmed more than the Southern Hemisphere in the upper ocean (figure 10). Warming has occurred even in the deep ocean with the southern ocean heating faster than the northern (figure 11).

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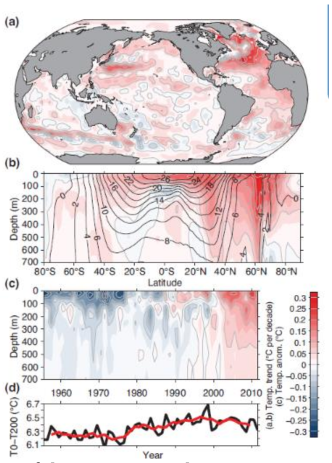
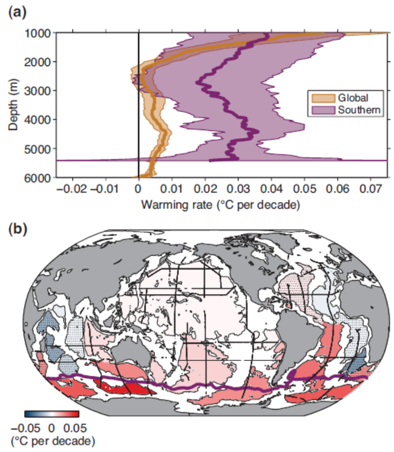
[30] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/2.cop22poster_gcos1.pdf>.
[31] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/ 3.unesco_ioc_fb2_ch_tanhua_cop22.pdf>.
[32] Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang, 2013: Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Figure 10
Temperature increase over time in the upper ocean



Source: Slide 2 of the presentation by Mr. Toste Tanhua and figure 1 of the poster *Ocean aspects of the GCOS Implementation Plan 2016: Connection to Climate Information and Services for Adaptation, Mitigation and the SDGs*,[33] from AR5 WGI Chapter 3.
(a) Depth-averaged 0 to 700 m temperature trend for 1971–2010 (longitude vs. latitude, colours and grey contours in degrees Celsius per decade). (b) Zonally averaged temperature trends (latitude vs. depth, colours and grey contours in degrees Celsius per decade) for 1971–2010 with zonally averaged mean temperature over-plotted (black contours in degrees Celsius). (c) Globally averaged temperature anomaly (time vs. depth, colours and grey contours in degrees Celsius) relative to the 1971–2010 mean. (d) Globally averaged temperature difference between the ocean surface and 200 m depth (black: annual values, red: 5-year running mean).

Figure 11
Temperature increase over time in the abyssal ocean



Source: Slide 2 of the presentation by Mr. Toste Tanhua and figure 2 of the poster *Ocean aspects of the GCOS Implementation Plan 2016: Connection to Climate Information and Services for Adaptation, Mitigation and the SDGs*, from AR5 WGI Chapter 3.
(a) Areal mean warming rates (ºC per decade) versus depth (thick lines) with 5 to 95% confidence limits (shading), both global (orange) and south of the Sub-Antarctic Front (purple), centred on 1992–2005. (b) Mean warming rates (ºC per decade) below 4000 m (colour bar) estimated for deep ocean basins (thin black out-lines), centred on 1992–2005. Stippled basin warming rates are not significantly different from zero at 95% confidence. The positions of the Sub-Antarctic Front (purple line) and the repeat oceanographic transects from which these warming rates are estimated (thick black lines) also shown.

37. The change in temperature of the ocean is related to heat content (figure 12). The ocean currently stores 93% of the excess heat caused by climate change (figure 13).

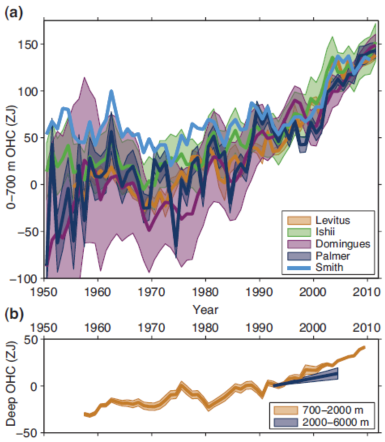
38. He stated that the salinity of the ocean is changing, with a tendency for areas with higher salinity to get more saline and areas with lower salinity to decrease their salinity. This change in salinity along with changes in temperature at different depths of the ocean contributes to increased stratification of the ocean decreasing the oxygen concentration of many parts of the ocean, particularly in the tropics, negatively affecting living creatures and ecosystems as well as the structure, productivity and circulation of the ocean.

39. Mr. Tanhua stated sea level rise is a useful indicator for climate change. A number of observing systems provide information to measure global mean sea level rise, increasing the confidence of measurements, and it is possible to measure the individual contribution of thermal expansion and of melting glaciers to sea level rise. The regional distribution of sea level rise is uneven (figure 14) and there is a need for increased measurement and understanding of these regional differences.

40. As well as storing heat, the oceans also store 28% percent of the CO_2 from anthropogenic emissions (figure 15). Ocean storage of anthropogenic CO_2 has led to long term trends of decreasing pH and calcium carbonate saturation levels, impacting the ability of carbonate forming organisms, such as coral, to survive (as the carbonate levels drop the coral starts to dissolve).

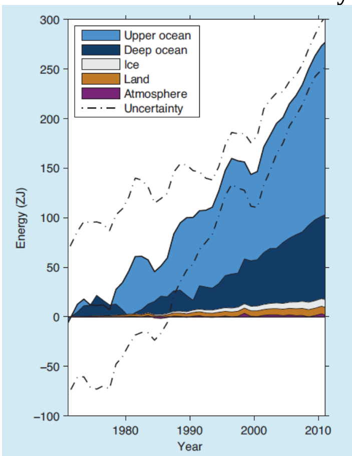
[33] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/3.unesco_ioc_fb2_ch_tanhua_cop22.pdf>.

Figure 12
Increase of ocean heat content



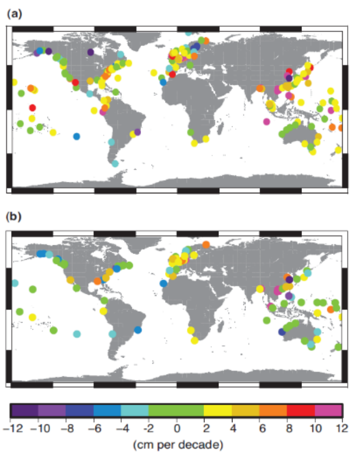
Source: Slide 3 of the presentation by Mr. Toste Tanhua and figure 3 of the poster *Ocean aspects of the GCOS Implementation Plan 2016: Connection to Climate Information and Services for Adaptation, Mitigation and the SDGs,*[34] from AR5 WGI Chapter 3.
(a) Observation-based estimates of annual global mean upper (0 to 700 m) ocean heat content in ZJ (1 ZJ = 10^{21} Joules), (b) Observation-based estimates of annual 5-year running mean global mean mid-depth (700 to 2000 m) ocean heat content in ZJ and the deep (2000 to 6000 m) global ocean heat content trend from 1992 to 2005.

Figure 13
Change in heat content of the climate system



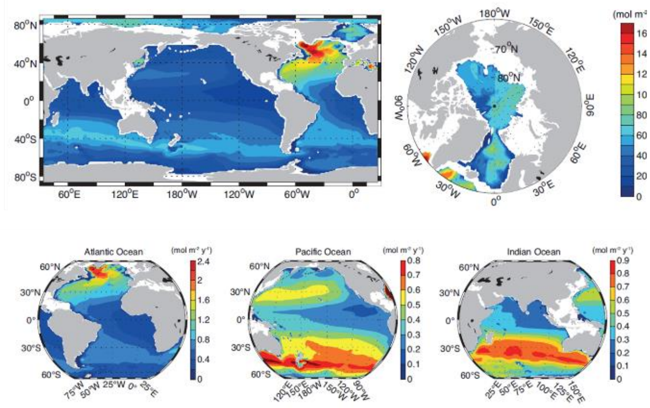
Source: Slide 3 of the presentation by Mr. Toste Tanhua and figure 4 of the poster *Ocean aspects of the GCOS Implementation Plan 2016: Connection to Climate Information and Services for Adaptation, Mitigation and the SDGs,* from AR5 WGI Chapter 3.
Plot of energy accumulation in ZJ (1 ZJ = 10^{21} J) within distinct components of the Earth's climate system relative to 1971.

Figure 14
Regional differences in sea level trends



Source: Slide 5 of the presentation by Mr. Toste Tanhua, from AR5 WGI Chapter 3
Estimated trends (cm per decade) in the height of a 50-year event in extreme sea level from (a) total elevation and (b) total elevation after removal of annual medians. Only trends significant at the 95% confidence level are shown.

Figure 15
Change in oceanic inventory of anthropogenic carbon dioxide



Source: Slide 6 of the presentation by Mr. Toste Tanhua, from AR5 WGI Chapter 3
Compilation of the 2010 column inventories (mol m^{-2}) of anthropogenic CO_2 of the global Ocean excluding the marginal seas 150 ± 26 PgC; Arctic Ocean 2.7 to 3.5 PgC; the Nordic Seas 1.0 to 1.6 PgC; the Mediterranean Sea 1.6 to 2.5 PgC; the Sea of Japan 0.40 ± 0.06 PgC.

[34] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/3.unesco_ioc_fb2_ch_tanhua_cop22.pdf>.

41. Mr. Tanhua highlighted the Framework for Ocean Observation,[35] published in 2012, and that the GCOS implementation plan encourages the ocean observing community to adopt this framework for planning, implementing, and evaluating sustained multidisciplinary ocean observation. Attaining and sustaining global coverage is the most significant challenge of the oceanic climate observing system and can only be met through national commitments to the global implementation and maintenance effort and with international coordination. Ocean observation is coordinated by The Global Ocean Observing System (GOOS) which consists of a multitude of platforms and networks to meet the ECV requirements of the GCOS implementation plan and to provide the greatest resilience of the observing system.

42. Mr. Tanhua identified a number of pressing requirements for the global ocean observing system. These include the need to:

a) Expand monitoring capabilities by obtaining global coverage using proven technologies and continue to develop novel observing technologies, to establish communications and data management infrastructure, and to enhance ocean analysis and reanalysis capacity;

b) Assess existing international, national and regional plans that address the needs to monitor and predict the coastal regions and develop plans where they do not exist;

c) Focus the development of integrated ECV data at Global Data Assembly Centres (GDACs);

d) Improve investment and management of the in situ observing activities which are currently carried out under research agency support and on research program time limits - for example the Global Repeat Hydrography Program (GO-SHIP) is an essential component of the ocean observing system providing reference quality data and full depth coverage but has mainly research driven funding;

e) Continue the satellite observation activities which are organized across satellite agencies and focused around ECV based constellations providing good alignment with GCOS requirements;

f) Encourage and utilise regular reporting by Parties on systematic observation to the UNFCCC, which includes national institutional arrangements and ocean observation activities, to assess progress in national action;

g) Make use of new technologies for additional (biogeochemical) variables and deeper observations;

h) Build and maintain a globally-distributed network of multi-disciplinary fixed-point surface and subsurface time-series, using mooring, ship and other fixed instruments, including for example the OceanSITES network, and establish a coordinated network of ship-based multidisciplinary time-series that is geographically representative.

3. The global carbon budget

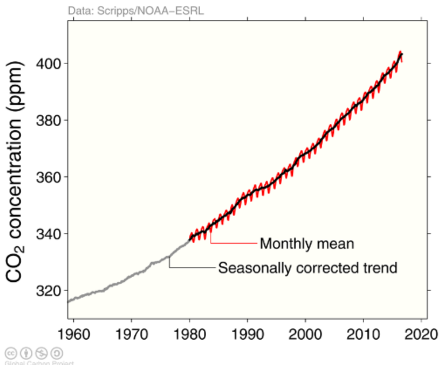
43. Mr. Glen Peters, CICERO Center for International Climate Research on behalf of the Global Carbon Project (GCP), presented on the 2015 global carbon budget. Later in the SBSTA 45 session, on 14 November following the Earth Information Day, the GCP published the global carbon budget for 2016.[36] In his presentation Mr. Peters provided the updated figures from the 2016 report.

44. Mr. Peters highlighted that global CO_2 concentration in the atmosphere increased from ~277ppm in 1750 to 399ppm in 2015 (up 44%) and that 2016 will be the first full year with global concentration above 400ppm (figure 16, see also paragraph 20). Increase in atmospheric CO_2 concentrations due to anthropogenic emissions of GHGs are the long-term driver of changes in the carbon cycle and thus directly responsible for climate change. Other factors impacting variation in this long trend include the seasonal cycle, volcanoes and ENSO.[37]

45. The sources of anthropogenic GHG emissions are fossil fuels and industry, and land use change. The sinks of these emissions are the atmosphere, land and ocean (figure 17). There is uncertainty how this balance will continue into the future and to what degree the ocean, land and atmosphere sinks will continue to absorb the increased CO_2 emissions.

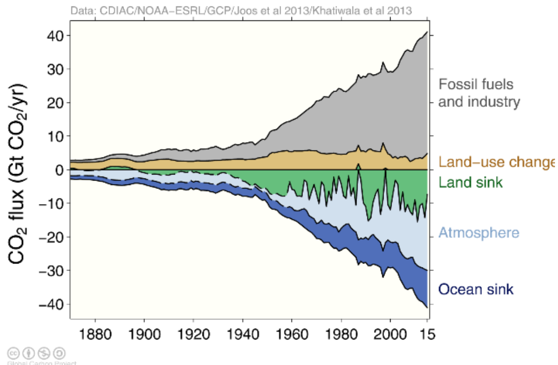
[35] <http://unesdoc.unesco.org/images/0021/002112/211260e.pdf>.
[36] <http://www.globalcarbonproject.org/carbonbudget/>.
[37] < http://folk.uio.no/roberan/t/i/MLO_weekly_drivers.gif>.

Figure 16
Globally averaged surface atmospheric CO_2 concentration



Source: Slide 7 of the presentation by Mr. Glen Peters
Data from: NOAA-ESRL, Scripps Institution of Oceanography; Le Quéré et al 2016; Global Carbon Budget 2016

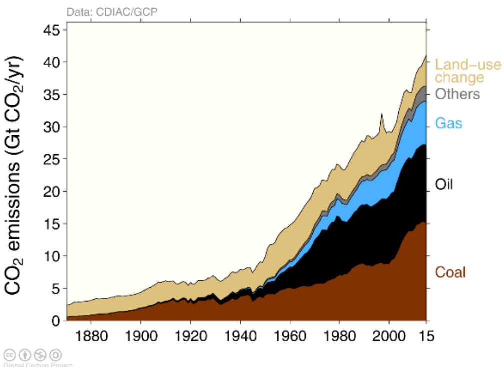
Figure 17
Global carbon budget



Source: Slide 4 of the presentation by Mr. Glen Peters
Annual anthropogenic CO2 emission and its partitioning among atmosphere, land and ocean from 1750 to 2015

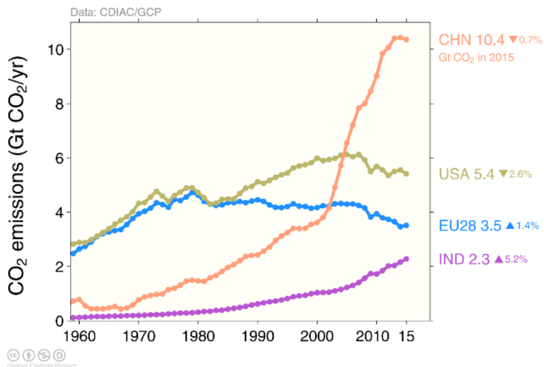
46. The top emissions sources for 2015 are shown in figure 18, other sources include emissions from cement production and gas flaring. The top four emitters in 2015 in absolute terms, covering 59% of global emissions, were China (29%), United States (15%), EU28 (10%) and India (6%) (figure 19). Bunker fuels used for international transport produce 3.1% of global emissions.

Figure 18
Total global emissions by source



Source: Slide 16 of the presentation by Mr. Glen Peters

Figure 19
Top emitters: fossil fuels and industry (absolute)

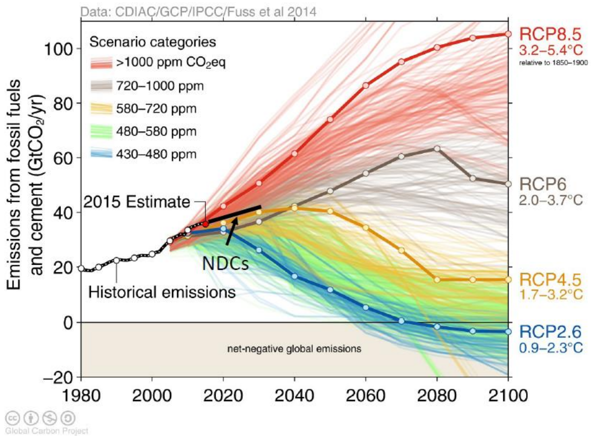


Source: Slide 17 of the presentation by Mr. Glen Peters

47. Mr. Peters identified that examination of the current pledges by governments in their Intended Nationally Determined Contributions (INDCs) to the UNFCCC, would result in a likely temperature increase of 3 ºC by the end of the century (figure 20).

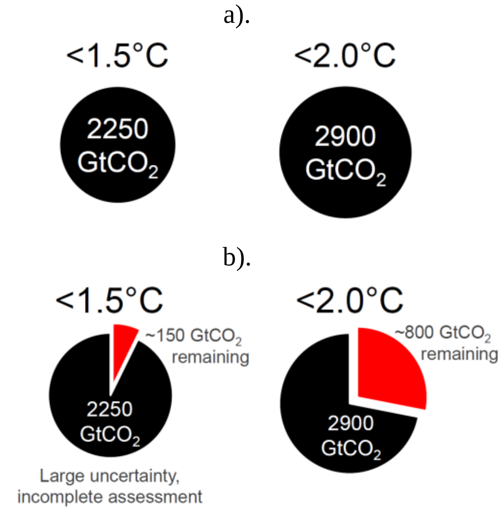
48. In regards to the carbon budget, identified by the IPCC AR5 as the amount of cumulative carbon emissions from all anthropogenic sources that can be emitted to have the chance for the Earth's warming to stay within a certain temperature range. The total carbon budget (since 1870) for a >66% chance to keep below 1.5 ºC by the end of the century is 2250 $GtCO_2$ and for 2 ºC is 2900 $GtCO_2$. As a result of historic emissions to date, the remaining budget (as of 2015) is 150$GtCO_2$ to keep below 1.5 ºC and 800 $GtCO_2$ to keep below 2 ºC (figure 21).

Figure 20
Observed CO_2 emissions and emissions scenarios



Source: Slide 16 of the presentation by Mr. Glen Peters
The IPCC Fifth Assessment Report assessed about 1200 scenarios with detailed climate modelling on four Representative Concentration Pathways (RCPs)

Figure 21
Carbon budgets for a 66% chance of staying below the indicated global temperature increase

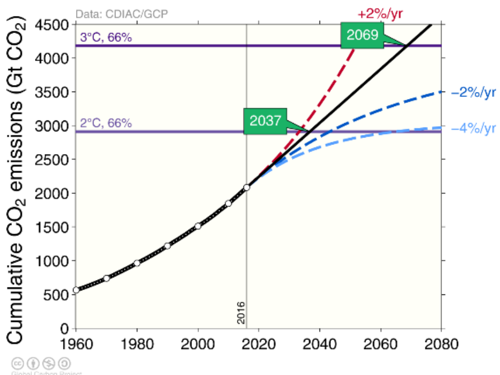


Source: Slides 20 and 21 of the presentation Mr. Glen Peters
a). Carbon budgets from 1870 for a 66% chance of a below 1.5 ºC and 2 ºC temperature rise by 2100
b). Remaining carbon budgets from 2017 for a 66% chance of a below 1.5 ºC and 2 ºC temperature rise by 2100

49. Assuming constant 2015 global emission levels, the approximate exceedance level for 2 ºC will be reached in 2037 (figure 22). The graph also shows the impact of a 2% and 4% decrease in emissions per year as well an increase in emission rate of +2%.

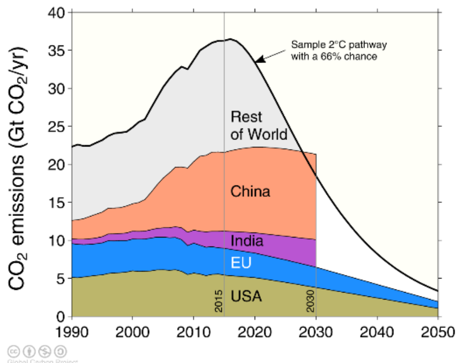
50. A study of the emission pledges from the four top emitters - US, EU, China, and India showed that at current levels of emissions, there is very little room for other countries to emit in a 2°C emission budget (66% chance).

Figure 22
Cumulative global CO_2 emissions and temperature



Source: Slide 22 of the presentation by Mr. Glen Peters
The green boxes show the year that the exceedance budgets are exceeded assuming constant 2016 emission levels
Blue dashes show effect of mitigation of -2% and -4% per year.

Figure 23
Emission pledges (INDCs) of the top-4 emitters



Source: Slide 23 of the presentation Mr. Glen Peters

4. Development of indicators to support adaptation and mitigation

51. Mr. David Carlson, WCRP, highlighted that the focus of the work of the WCRP is on understanding the Earth's complicated system, specifically the exchanges of heat, carbon and water between land, atmosphere, ocean and ice over weeks, to seasons, to decades to centuries. He defined four climate indicators that can be assembled and calibrated as indicators for the climate system: sea level; atmospheric carbon (CO_2) concentration; atmospheric methane (CH_4) concentration; and energy. More detail can also be found in the three supporting posters:

a) *The Ocean State Report of the Copernicus Marine Environment Monitoring Service*;[38]

b) *The Sea level essential climate variable: A key indicator of human-induced global climate change & internal climate variability;*[39]

c) *Towards an integrated view of the global Earth energy budget*.[40]

52. Mr. Carlson explained that the indicators can be considered as budgets where: **net change = inputs – outputs** (Box 1). He stated that these budgets provide rigour to understanding the Earth's system. Scientists who understand the uncertainties can skilfully measure the inputs and outputs to the system concerned in order to understand the net change. He explained that unlike financial budgets, greater inputs to the Earth's system compared to outputs is not a good signal.

Box 1
Climate indicators

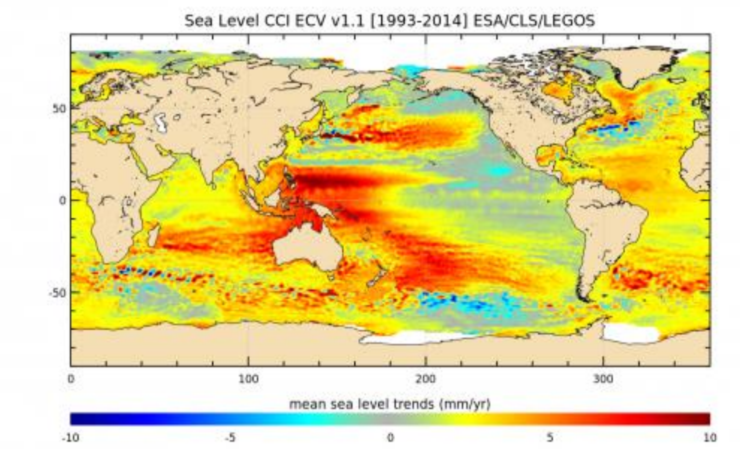
Sea level budget: Local total = global mean rise + regional variability + local oceanic processes + vertical land motions
Carbon budget: Emissions + Land use change = atmospheric concentration + ocean sink + land sink
Methane budget: Atmospheric concentration = natural sources + anthropogenic sources - chemical losses
Energy budget: Incoming solar radiation = outgoing radiation + ocean heat

53. In regards to the sea level budget, Mr. Carlson showed the mean change in sea level and the differences at regional level (figure 24). He identified that measurements are currently only available for a short timescale, since 1993, so the system as an entirety is just starting to be understood. However, there are large variations in sea level rise for different regions. In order to manage regional and local coastal resources, understanding of these variations is needed at a lower scale. For the coast, the total relative sea level rise is the sum of the global mean rise and the regional variability plus small-scale local oceanic processes and vertical land motions. Ground subsidence due to natural processes (e.g., tectonic movements, sediment loading) and/or human activities (e.g., water and oil extraction, offshore sand dredging, coastal engineering, etc.) amplify the negative impacts of climate-related sea level rise. It is proposed, starting in 2017, to develop a community - based synthesis of the sea level budget using data sets from different observing systems and different approaches, to be regularly published (yearly basis) in the Earth System Science Data journal. Further information is provided in the poster *The Sea level essential climate variable: A key indicator of human-induced global climate change & internal climate variability*.[41]

54. In regards to the carbon budget for CO_2, paragraphs 43–50 above, Mr. Carlson emphasised the large number of measurements undertaken by the global science community and the huge joint task of scientists and organizations working together to understand and produce this budget.

[38] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/6.poster_wcrp_ocean_state_cop22.pdf>.
[39] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/7.poster_wcrp_sea_level_cop22.pdf>.
[40] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/5.poster_wcrp_earth_energy_cop22.pdf>.
[41] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/7.poster_wcrp_sea_level_cop22.pdf>.

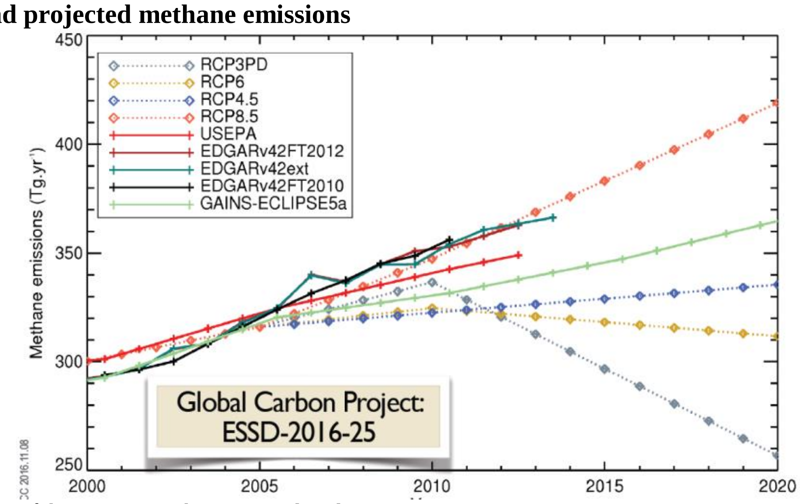
Figure 24
Regional mean sea level trend (1993–2014)



Source: Slide 7 of the presentation by Mr. David Carlson
Credits ESA/CLS/CNES/LEGOS[42] This figure is now available up to 2015[43]

55. In regards to the methane budget, published by the global carbon project on 12 December 2016,[44] Mr. Carlson highlighted the increase in emissions of methane in the atmosphere (figure 25). Methane is more difficult to assess than CO_2 as the budget consists of natural sources (such as wetlands) and anthropogenic sources (industrial and agricultural) as well as understanding the chemical reactions in the atmosphere of this potent greenhouse gas.

Figure 25
Current and projected methane emissions



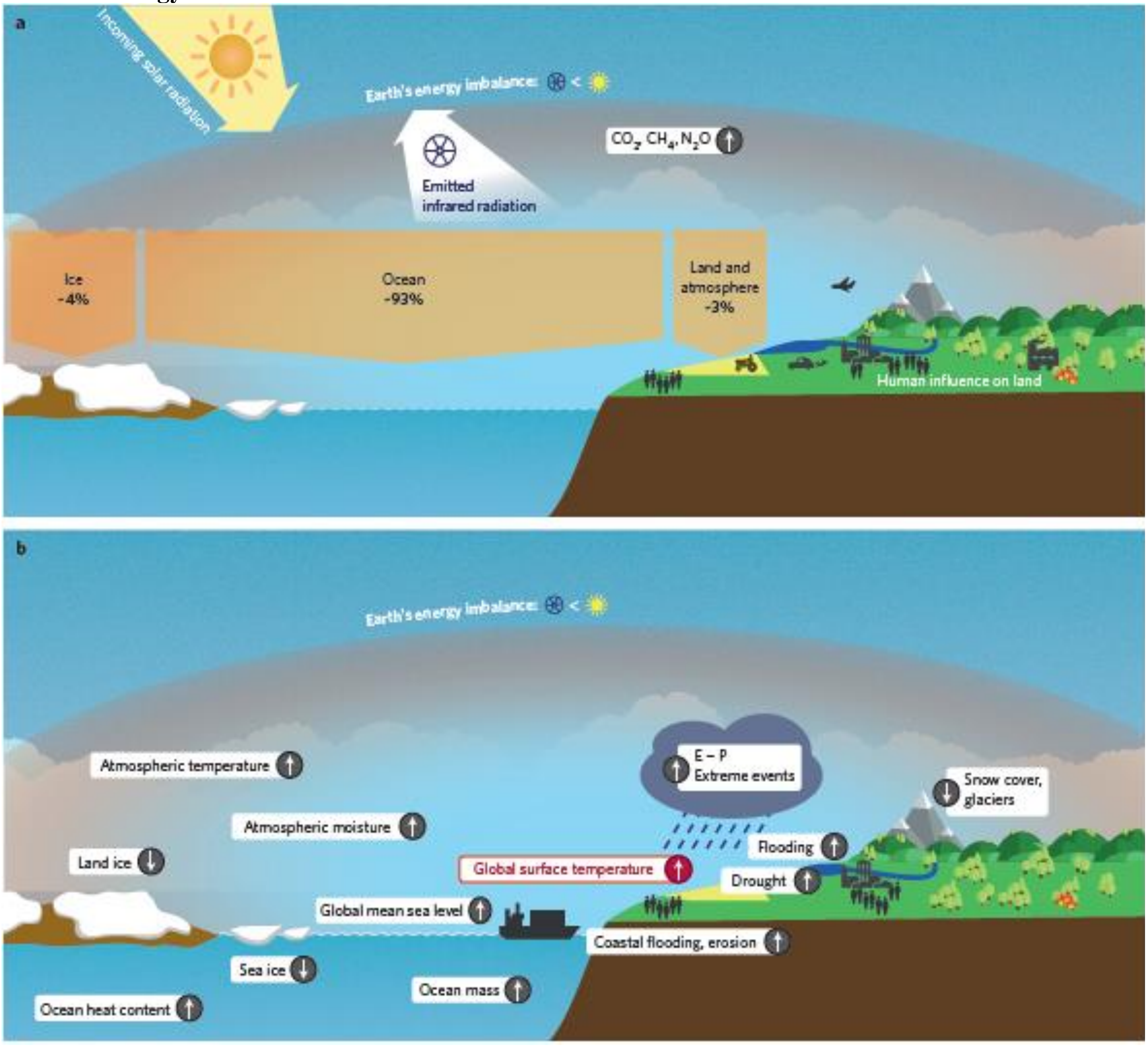
Source: Slide 12 of the presentation by Mr. David Carlson
Current emissions of methane (solid lines) and projections of future methane emission (dotted lines).
Current emission rates for CH4 are equivalent to the AR5 RCP 8.5 scenario for CH4 emissions

56. Mr. Carlson then described the fourth indicator, the energy budget, with further information being provided in the poster *Towards an integrated view of the global Earth energy budget*. The Earth's Energy Imbalance (EEI) is the most fundamental metric defining the rate of global climate change. As a result of human activities, the amount of energy leaving the atmosphere is significantly less that the amount coming in, with most of the excess energy being absorbed by the ocean. The Earth system adjusts to the energy imbalance with temperature rise, sea level rise, reductions in snow and ice cover and increases in many extremes which has a direct impact on both the marine and terrestrial environment (figure 26).[45]

42 <http://www.esa-sealevel-cci.org/image/tid/11>.
43 <http://www.esa-sealevel-cci.org/node/273>.
44 <http://www.globalcarbonproject.org/methanebudget/>.
45 Schuckmann et al. (2016). An imperative to monitor Earth's energy imbalance. Nature Climate Change 6 (2) pp 138–144. <http://dx.doi.org/10.1038/nclimate2876>.

57. The EEI initiative will use the four current approaches available to measure EEI (described in the poster) to develop a community-based synthesis of the Earth’s energy budget as a key measure to understand and monitor the Earth’s evolving climate. Different approaches to estimating the EEI have their strengths and weaknesses, but they are complementary. Combining multiple climate measurements and tools in an optimal way holds considerable promise for reducing uncertainties in EEI. Progress can be achieved with a concerted international effort.

Figure 26
Earth’s energy imbalance



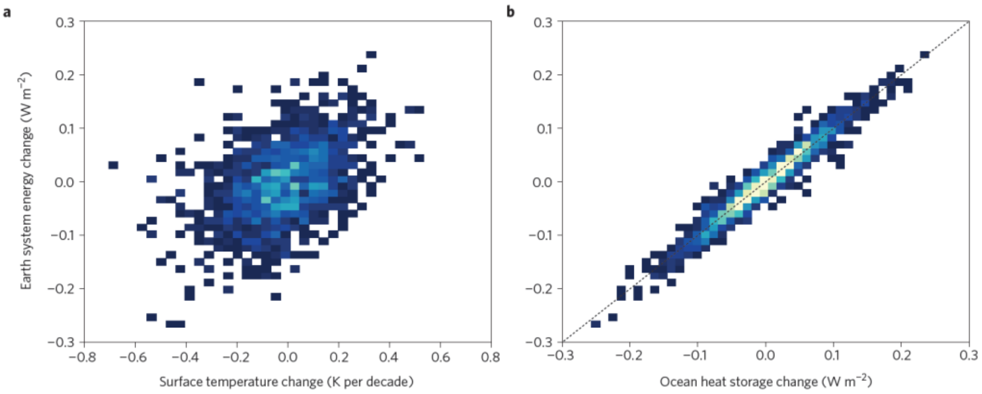
Source: Slide 13 of the presentation by Mr. David Carlson and figures 1 and 2 of the poster *Towards an integrated view of the global Earth energy budget*.[46]
Schematic representations of the flow and storage of energy in the Earth’s climate system and related consequences - Earth’s energy imbalance (EEI) as a result of human activities.
The global ocean is the major heat reservoir, with about 90% of EEI stored there. The rest goes into warming the land and atmosphere, as well as melting ice (as indicated). **b**, ‘Symptoms’ of positive EEI, including rises in Earth’s surface temperature, ocean heat content, ocean mass, global mean sea level, atmospheric temperature and moisture, drought, flooding and erosion, increased extreme events, and evaporation − precipitation (E−P), as well as a decrease in land and sea ice, snow cover and glaciers.[47]

[46] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/5.poster_wcrp_earth_energy_cop22.pdf>.
[47] Figure 2 of Schuckmann et al. (2016). An imperative to monitor Earth’s energy imbalance. Nature Climate Change 6 (2) pp 138-144. <http://dx.doi.org/10.1038/nclimate2876>.

58. Mr. Carlson stated that it is vital to closely monitor ocean heat content as it places a strong constraint on EEI on inter-annual and longer time scales. Heat uptake by the ocean is a strong buffer to climate change slowing the rate of surface warming. The ocean's ability to store and vertically redistribute heat over timescales of about a decade means that trends in global surface temperature are an unreliable indicator of global warming on these timescales (figure 26). Furthermore, research shows an unremitting warming that is now also ongoing even in the deep oceans (see figures 10 and 11 above and information presented at the seventh research dialogue[48]).

59. The ARGO system is a vital part of the observing system for the ocean heat content – but this observing system is fragile and requires continued investment. There is also a need to strengthen observation in polar regions, marginal seas and shelf regions and the deep ocean below 2000m.

Figure 26
Relationship between Earth system energy change and a) global surface temperature, and b) ocean heat content on decadel time scales.



Source: Slides 16 and 17 of the presentation by Mr. David Carlson
a). Discrete linear decadal trends in total energy (expressed in W m–2) regressed against contemporaneous decadal trends in globally averaged surface temperature (K per decade).
b) Discrete linear decadal trends in total energy regressed against contemporaneous decadal trends in full-depth, global OHC (W m–2).[49]

60. The poster *The Ocean State Report of the Copernicus Marine Environment Monitoring Service (CMEMS)* presented this upcoming report which is an important step forward into the development of comprehensive and regular reporting of the state and health of the global ocean and European seas based on CMEMS unique marine environment monitoring capabilities and providing specific characteristics and monitored changes, with contributions from about 80 experts.

61. Mr. Carlson finished his presentation by highlighting that the ongoing data and research available for all four indicators, assembled and calibrated by large teams of researchers across several institutions, is open access and results are reviewed and published in open access journals (see ESSD).[50]

5. Discussion

62. A number of questions were asked and discussed after the presentations.

63. The WCRP and GCP were asked to elucidate the numbers further in regards to the carbon budget, Mr. Carlson referred to figure 21 and confirmed that the work of the carbon project clearly identifies the values and uncertainties, and that what is remaining in the carbon budget in order not to exceed the temperatures indicated shows the seriousness of the situation for decision makers.

64. The WCRP and GCOS were asked whether there had been any consideration of indicators for the terrestrial domain. Mr. Carlson highlighted that terrestrial variables are incorporated in the calculations for the methane, carbon and sea level rise budgets, and are a small fraction of the energy budget. In regards to indicators for terrestrial ecosystems and biodiversity, he highlighted that a range of partners would be

[48] See report from the seventh meeting of the research dialogue (RD 7) Summary report, figure 4 <http://unfccc.int/files/adaptation/application/pdf/researchdialogue.2015.2.summaryreport.pdf>, and Roemmich D Church J, Gilson J, Monselesan D, Sutton P and Wijffels S (2015). Unabated planetary warming and its ocean structure since 2006. Nature Climate Change 5, 240–245. <http://dx.doi.org/10.1038/nclimate2513>.
[49] See Figure 3, Schuckmann et al. (2016). An imperative to monitor Earth's energy imbalance. Nature Climate Change 6 (2) pp 138–144. <http://dx.doi.org/10.1038/nclimate2876>.
[50] <http://www.earth-system-science-data.net/index.html>.

needed to develop these and that they would, by nature of the different ecosystems, have a regional aspect. He said that the indicators described by WCRP respond to the WCRP Grand Challenges and give a global point of view. Ms. Richter highlighted that GCOS have 15 ECVs for the terrestrial domain and that some more specific indicators are being considered in the context of the new implementation plan, such as glacier melting. She stated that GCOS plan to discuss and agree suitable indicators for climate change with the wider community in the next year.

65. GCOS representatives were asked about the fragility of the ARGO system and how this could be better supported as current funding mostly comes from research agency funding and grant awards. Mr. Tanhua stated that Argo is probably the most useful system to measure heat balance in the oceans and could also monitor the carbon and oxygen budget of the oceans. One way to support Argo would be a system of national pledges with buy in to different components that could then be reviewed on a regular basis.

66. Parties from Africa highlighted the large data gaps in Africa and the challenge and need for consistent data collection. They enquired how the international community could help in filling in the missing gaps and support modelling, particularly for decision making, including at local levels by farmers. Ms. Richter identified that the GCOS implementation plan does identify regional aspects. She also explained that the GCOS cooperation mechanism was set up to support regionally identified projects that need funding and can build up new data infrastructure in the region of need. Mr. Baddour identified that the WMO Global Framework for Climate Services (GFCS) conducts regional projects to coordinate and combine efforts to support regions where help is needed in regards to climate services for adaptation.

67. A question was asked in regards to other GHGs apart from CO_2 and CH_4, such as CFC and HFCs, how these are monitored and their contribution to global warming. Mr. Terblanche, WMO, identified that these gases are mixed well in the atmosphere so that less stations are needed to measure their concentrations. He also pointed out that the recent Kigali amendment to the Montreal Protocol has contributed to preventing a rapid rise in these trace gases and could thus avoid an approximate 0.5 ºC rise in global temperature by the end of the century.

68. A question was asked in regards to what degree carbon budgets can be apportioned to individual countries and whether carbon can be measured to ensure state actors stay within budgets. Mr. Carlson highlighted that the global carbon project data is all open access data and can be broken up by sector and country. He stated that the next steps could be challenging as, if carbon becomes a regulated commodity, the accompanying tendency would be to make carbon data proprietary which would mean that the research presented today would not be possible. He stressed the importance of keeping all aspects of the carbon project open access.

C. Part 2: Developments and opportunities

1. Earth observation actions and services to support adaptation in Africa

69. Mr. Chris Lennard, CORDEX-Africa, presented on the African Impacts Atlas initiative to co-develop knowledge on climate change impacts in Africa. Mr. Lennard explained that the vision of CORDEX including CORDEX-Africa is to advance and coordinate the science and application of regional downscaling through global partnerships.[51] The CORDEX-Africa[52] data available includes: 55 publically available scenario simulations, in addition to evaluation simulations; an ensemble consisting of simulations conducted with 6 different regional model downscaling input data from 11 global models; simulations for three different emission pathways - 12 simulations for RCP2.6, 22 simulations for RCP4.5 and 21 simulations for RCP8.5; with more simulations being developed.

70. This presentation was supported by additional information from 2 posters demonstrating some of the impacts of climate change projected for the region using the CORDEX-Africa simulations:

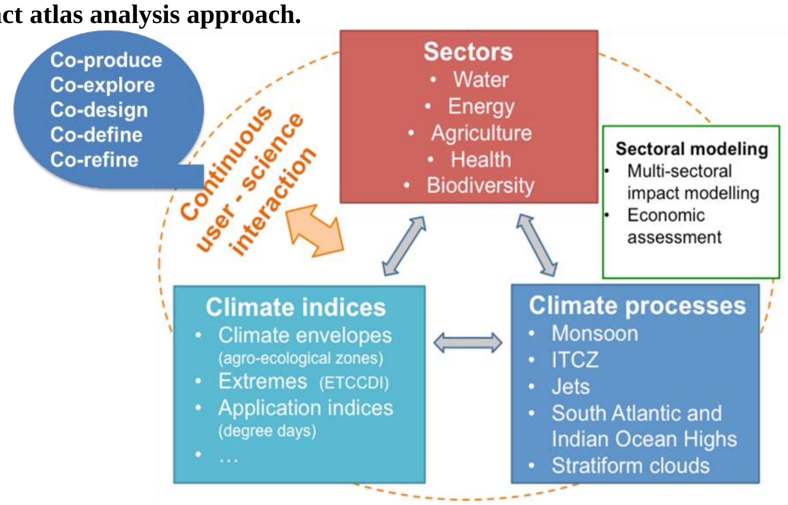
a) *The impact of 1.5°C and 2.0 °C above pre-industrial levels of global warming in semi-arid hot-spots at Africa and India*[53] showed a comparison of when the thresholds for a temperature rise of 1.5 and 2 °C compared to pre-industrial would be exceeded and subsequent impacts on rainfall;

[51] <http://www.csag.uct.ac.za/cordex-africa/>.
[52] <http://www.cordex.org/index.php?option=com_content&view=article&id=103&Itemid=489>.
[53] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/12.poster.zaroug.pdf>.

b) *Investigating the Impact of Projected Timing of Climate Departure on Crop Yield over West Africa*[54] demonstrated results for climate departure in this sub-region, which is projected to occur 1–2 decades earlier than the global average. Warming above 2°C is projected to have negative effects on crop yield over this sub-region whose mainstay economy is rain fed agriculture.

71. Mr. Lennard outlined the African Impact Atlas initiative, a systematic regional analysis of 1.5, 2 and 4°C global temperature projections, to assess **threshold exceedance** in key African sectors including health, water, agriculture and energy (figure 27). This atlas is a similar concept to the Europe Impact2C Webatlas.[55]

Figure 27
African impact atlas analysis approach.



Source: Slides 10 of the presentation by Mr. Chris Lennard
Based on **state-of-the-art transdisciplinary science**, results will be combined in a user-friendly, sector specific, **online atlas** that includes measures of robustness and limitations. This includes:
Sector information: suitability maps that indicate timing of transitions between states (e.g. agriculture good, medium, poor) and transitions from each state; how do the suitability states differ under 1.5, 2 and 4 degree global warming level; an alas of potential costs of delayed mitigation a different scales (country, economic zones)
Climate process information: change in particular processes under 1.5, 2 and 4 degrees; emerging new climates

72. The Atlas will **deliver tailored information that is relevant and useful for decision-making on adaptation based on local needs** in order to provide support for the many communities that do not currently have any detailed information about climate developments. Furthermore, it will help answer key questions including the implications of exceeding certain climate thresholds, the potential cost of delayed mitigation and how to communicate information ethically and effectively. Funding is currently being sought for the initiative. Regional expertise is essential to develop the information which requires good links between African and other institutions - this is a strength of CORDEX-Africa.

2. New developments in the estimation of GHG emissions from Earth observations to support national inventories

73. Mr. Bernard Pinty, European Commission (EC), , presented on the work of Copernicus EU[56] to provide operational capacity to monitor anthropogenic CO_2 emissions. The European Union and its Member States have jointly pledged to meet a binding target of reducing greenhouse gas emissions in the EU by at least 40% over 1990 levels by 2030. The European Parliament resolution on COP 21[57] calls on the Commission to promote efforts towards developing an EU system of measuring GHG emissions in an autonomous and non-dependent manner, using and expanding the missions of the Copernicus programme. The resolution also identifies the use of space-based assets in the implementation of measures aimed at mitigating and adapting to climate change, particularly through the monitoring and surveillance of GHG emissions.

54 <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/13.poster.egbebiyi.pdf>.
55 <https://www.atlas.impact2c.eu>.
56 <http://www.copernicus.eu/>.
57 <http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+REPORT+A8-2015-0275+0+DOC+PDF+V0//EN>.

74. The Copernicus CO_2 report: 'Towards a European Operational Observing System to Monitor Fossil CO_2 Emissions,[58] provides a set of recommendations for the EC on the need and opportunity for an independent European satellite-borne observation capacity for CO_2 to monitor the impacts of international climate agreements. The report addresses a number of questions on critical uncertainties, improving inventories from space-borne measurements, current capabilities of observation systems, how capabilities can be optimized, what the critical elements for a road map to be ready for 2030 should be.

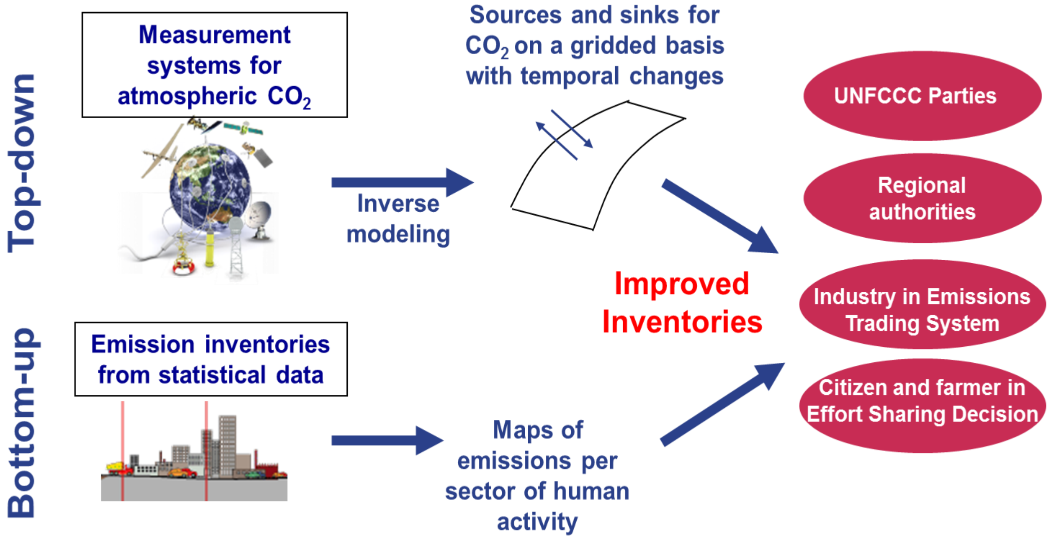
75. Copernicus provides the framework for the system which would use independent datasets to improve periodicity & reliability and reduce the uncertainty of bottom-up national GHG reporting and help countries evaluate the effectiveness of their CO_2 emission reduction strategies as part of their Nationally Determined Contributions (figure 28). Independent monitoring of fossil CO_2 emissions using inverse modeling and atmospheric measurements is feasible and the emissions can be traced back to source using measurements of wind fields.[59] Obtaining these measurements requires:

a) Dense sampling of selected emissions hotspots, such as megacities, major industrial areas and large power plants. This can be achieved with satellites measuring column CO_2;

b) The anthropogenic CO_2 component to be separated from the natural fluxes at regional scale by measurements of additional trace species, such as radiocarbon (14C in CO_2), carbon monoxide and/or nitrogen dioxide. This can be achieved in Europe by taking 14C measurements at existing CO_2 monitoring tall towers (using ICOS and national in-situ networks).

76. The satellite measurement of CO_2 within the Copernicus programme is being undertaken in the context of the Copernicus Space Component evolution plan and the Copernicus Climate Change Service (C3S) and Atmosphere service (CAMS) components. The proposed strategy for Copernicus is to have operational robust emission maps to independently verify CO_2 emissions and improve CO_2 reporting to the UNFCCC by 2030–2035, with a pre-operational phase available 2025. Copernicus works in collaboration with the Global Earth Observation System of Systems (GEOSS) and the Committee on Earth Observation Satellites (CEOS).

Figure 28
Improving national emissions inventories



Source: Slides 8 of the presentation by Mr. Bernard Pinty
The bottom-up emission inventories are currently used for reporting. These inventories could be improved and supported with top-down space-based information using inverse modelling which can provide current CO_2 measurements at a given place and time by tracing back the emissions to the origin (using the wind field).

77. Mr. Terblanche, WMO, opened his presentation with a description and summary of recent developments in the global atmosphere watch system (GAW), detailed in the poster, *the role of high quality observations in international policy making: lessons from the Global Atmosphere Watch*.[60] The GAW is

[58] <http://www.copernicus.eu/main/towards-european-operational-observing-system-monitor-fossil-co2-emissions>.
[59] See webcast 0:31:31 – 0:33:00 <http://unfccc.cloud.streamworld.de/webcast/earth-information-day-linking-earth-observation--2>.
[60] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/9.wmo_gaw_conventions.pdf>.

the long-term international global research programme that provides the standards and coordinates observations and analysis of atmospheric composition changes, including GHGs. It released the 12th annual Greenhouse Gas Bulletin on 24 October 2016.[61]

78. Mr. Terblanche identified that in recognition of the progress that has been made in atmospheric research, measurement and modelling, WMO has initiated the development of an Integrated Global Greenhouse Gas Information System (IG3IS), further information was also provided in the poster *Integrated Global Greenhouse Gas Information System (IG3IS) Atmospheric measurements to manage mitigation*.[62]

79. The IG3IS aims to establish consistent global methods and standards for measuring GHG concentrations ("top-down") and combine them spatially and temporally with socioeconomic emission inventory data ("bottom-up") to better inform and manage emission reduction policies and measures. The IG3IS is aiming at two streams of action: 1) pilot projects to add skill and users to the user database and 2) end to end good practice implementation guidelines.

80. Mr. Terblanche then described how the IG3IS could:

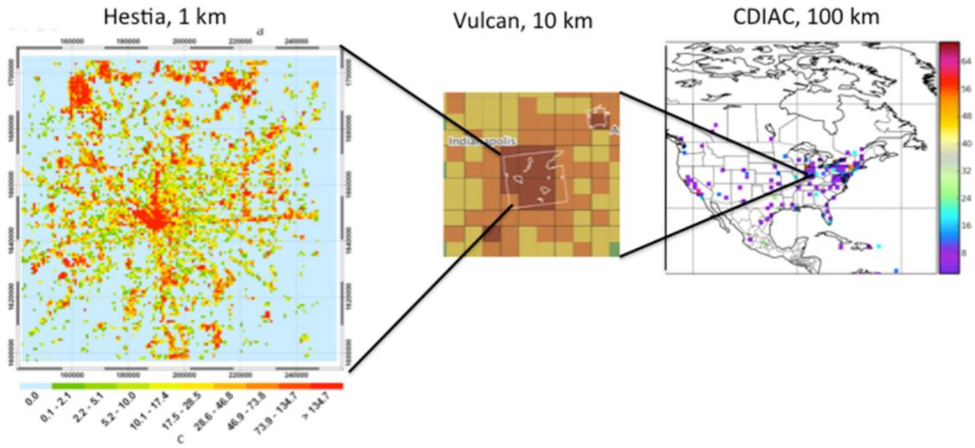
a) **Support the Paris Agreement** by providing improved national inventory reporting by making use of atmospheric measurements for all countries and timely and quantified trend assessment of NDCs in support of the global stocktake;

b) **Provide key sub-national efforts and new mitigation opportunities** through GHG monitoring in large urban source areas such as megacities; and detection and quantification of large unknown CH_4 emissions such as from oil fields and pipelines.

81. In regards to improving national inventory reporting, the UK for HFC-134[63] and Switzerland for CH_4[64] have already used methods to compare top down and bottom-up approaches to improve reporting, as shown in the IG3IS poster.

82. In regards to cities, Mr. Terblanche identified the action of cities[65] to address climate change in the face of a doubling of global urbanization by 2050. Cities can independently monitor GHG emissions using a number of tested methods (figure 29). IG3IS will design individual observation systems suitable for a given city's requirements and applications to be deployed in different parts of the world, particularly in developing countries.

Figure 29
Monitoring GHG emissions in cities

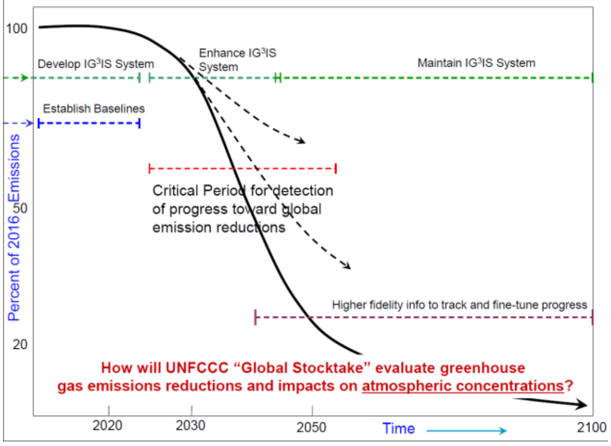


Source: Slides 17 of the presentation by Mr. Deon Terblanche
Right: Gridded annual fossil fuel CO2 emissions from a medium-size city (Indianapolis) show distinct gradients at different spatial scales. Right: CDIAC 2006 emissions for the CONUS plotted on a 1° (~100 km) show avg flux 200-600 gC/m2/yr. Middle: Vulcan 2002 emissions for the ~10,000 km2 area centered on Indianapolis on a 10 km grid. Left: Hestia 2002 emissions for the urban core on a 1 km grid. The Vulcan and Hestia plots use log-normal scales (typically >20,000 gC/m2/yr).
The Hestia Project: Quantifies all fossil fuel CO2 emissions at building and street scale.[66]

[61] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/wmo_ghg_doc_num.php.pdf>.
[62] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/11.poster-igis-cop22_v5.pdf>.
[63] <https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1606140853_DA_GHGI_1990-2014_Report_v1.pdf>.
[64] <https://www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/climate-reporting/most-recent-ghg-inventory.html> and <http://unfccc.int/resource/docs/2016/asr/che.pdf>.
[65] <http://www.c40.org/>.
[66] <http://hestia.project.asu.edu/>.

83. Mr. Terblanche presented a possible system for how IG3IS can be used as a tool under the global stocktake (figure 30) and support action by countries providing them with information to make informed science based choices about mitigation. He emphasized that it is important to monitor emissions in the atmosphere closely as changes here happen first before the impacts due to those increased GHG concentrations are felt in the rest of the Earth's system, due to the 10 year lag in the system.

Figure 30
Possible system for how IG3IS can be used to support the global stocktake



Source: Slides 22 of the presentation by Mr. Deon Terblanche

3. Integrated activities and services to support the Paris Agreement

84. Mr. Werner Kutsch, Integrated Carbon Observation System (ICOS) on behalf of GEO, presented an outline of the GEO Carbon and Greenhouse Gases Initiative, part of the GEO strategic plan 2016–2025.[67] This information was also detailed in the poster *GEO's efforts in support of the Paris Agreement*.[68]

85. The GEO carbon and GHG initiative is a global effort to promote interoperability and provide integration, cooperation and communication at all domains – atmosphere, ocean and land, particularly at domain interfaces. It will be coordinated with other observing systems and contribute to the GCOS implementation plan. It will support the whole carbon and GHG system from observations – to data – to modelling – to model integration – to knowledge – to climate services – and finally to decision making. The initiative builds on existing infrastructures and will be part of the GEO system of systems (figure 31). It focuses on 4 specific tasks:

a) Task 1 – **User needs and policy interface**: to engage with users and policy makers and ensure the consistency with their evolving needs in order to drive the activities of the GEO Carbon and GHG Initiative and address the policy agenda including in alignment with the GEO carbon strategy,[69] CEOS strategy for carbon observations from space[70] and Copernicus CO2 report.[71]

b) Task 2 – **Data access and availability**: to provide long-term, high quality and open access near-real-time data and data products, complying with the GEOSS[72] principles, from a domain-overarching carbon cycle and GHGs monitoring system.

c) Task 3 – **Optimization of observational networks**: to develop and implement a procedure for achieving observations of identified essential carbon cycle variables within user-defined specifications and at minimum total cost. This will include closing spatial observational gaps, supporting new technologies and concepts and translating user needs to observational concepts.

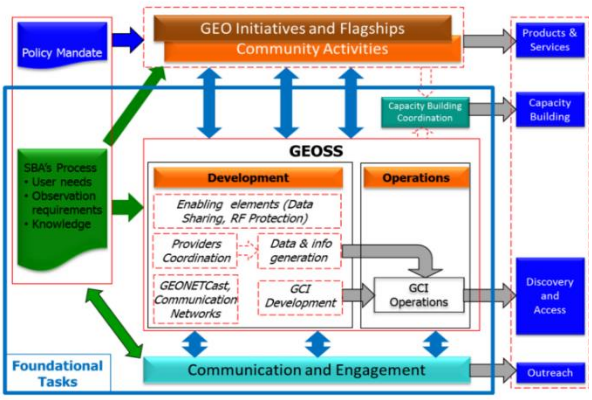
d) Task 4 –**Budget calculations and breakdown across scales**: to support the development of consistent budgets of GHGs (CO_2, CH_4, and N_2O) across scales using a combination of observations, inventories, models and data assimilation techniques.

86. In regards to task 2, Mr. Kutsch highlighted the huge task now and ahead to build up the appropriate systems to provide high quality data management, reliable long-term storage for observational data from

[67] <https://www.earthobservations.org/documents/GEO_Strategic_Plan_2016_2025_Implementing_GEOSS.pdf>.
[68] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/4.geo_kutsch_cop22.pdf>.
[69] <http://www.globalcarbonproject.org/misc/JournalSummaryGEO.htm>.
[70] <http://ceos.org/home-2/the-ceos-carbon-strategy-space-satellites/>.
[71] <http://www.copernicus.eu/main/towards-european-operational-observing-system-monitor-fossil-co2-emissions>.
[72] <http://www.geoportal.org/>.

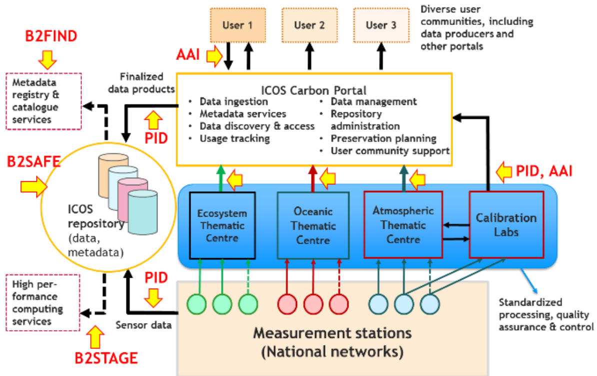
sensor networks and the provision of climate services matched to user needs. He presented the data management within ICOS as an example of one such system (figure 32).

Figure 31
The GEO system of systems workflow



Source: Slides 15 of the presentation by Mr. Werner Kutsch
The SBA's are the GEO societal benefit areas: Biodiversity and ecosystem sustainability, disaster resilience, energy and mineral resource management, food security and sustainable agriculture, infrastructure and transport management, public health surveillance, sustainable urban development and water resource management.

Figure 32
The data life cycle of ICOS



Source: Slide 14 of the presentation by Mr. Werner Kutsch
The red letters indicate the climate services provided by ICOS: for example B2SAFE provides the long-term data storage for GHG measurements
Further information is available from the ICOS website.[73]

87. Ms. Cat Downy, Future Earth, emphasised the huge global decarbonisation challenge ahead in order to meet the goals of the Paris Agreement: 4 years to hit peak emissions; 40 years to reach net-zero emissions; 80 years to create a new carbon sink on the scale of the oceans.[74] She highlighted that this challenge requires many solutions from many disciplines.

88. Future Earth is rising to this challenge by linking many research disciplines, knowledge systems and societal partners including in policy, business and civil society to build a **global community committed to open, solution-oriented sustainability research** providing the knowledge and support to accelerate transformations to a sustainable world. She explained that Future Earth is founded on over 30 years of environmental research, people and expertise from a number of research programmes.[75] It has global hubs in Colorado, Montreal, Paris, Stockholm, Tokyo, and regional and national bodies that adapt the vision of Future Earth in all parts of the world.

89. Ms. Downy highlighted some of the key relevant activities of Future Earth are:

a) The research projects including the global carbon project, international atmospheric global chemistry (IGAC)[76] and Past Global Changes (PAGES);[77]

b) The conference **integrating science across the IPCC on climate risk and sustainable solutions: lessons learnt from AR5 to inform AR6**, Stockholm, 29–31 August 2016. The report suggestions included more harmonized approach to addressing risk so that it is effective and consistent across all IPCC working groups;

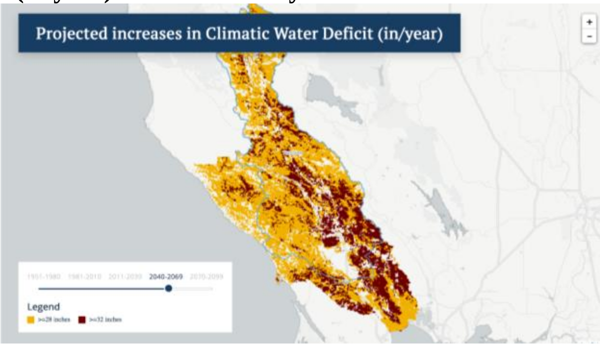
c) The **Partnership for Resilience Preparedness** (PREP),[78] a new public-private partnership with partners including GEO, CEOS, Google and Amazon to make existing climate data more open and accessible by creating "dashboards" to empower decision making (figure 33);

d) **The World in 2050,** a modelling effort to look at how the world can meet the SDGs and the Paris Agreement together (figure 34). Answering questions such as How do we link SDGs to climate targets? How do we understand the trade-offs and synergies among the SDGs? For example, if there was a sole focus on meeting the 1.5 ºC climate target and radical land use changes and geo-engineering solutions were introduced, this is likely to impact on livelihoods, biodiversity, air quality, and so on., missing the targets on many of the SDGs.

[73] <https://eudat.eu/communities/integrated-carbon-observation-system>.
[74] Rockström et al. (2016), The world's biggest gamble. Earth's Future, 4: 465–470. doi:10.1002/2016EF000392
[75] <http://www.futureearth.org/who-we-are>.
[76] <http://www.igacproject.org/>.
[77] <http://www.pastglobalchanges.org/>.
[78] <http://www.prepdata.org/>.

e) The **Decarbonisation Knowledge-Action Network,** a global research collaboration to address the critical knowledge gaps around how the world can rapidly and equitably reduce GHGs with a workshop planned for March 2017.

Figure 33
Projected increases in climatic water deficit (in/year) Sonoma County California



Source: Slide 18 of the presentation by Ms. Cat Downy
An example of one dashboard that the PREP effort.[79]
Sonoma County, California, is a partner on PREP. It is north of San Francisco and sensitive to drought. It's also well-known for winemaking (Napa Valley is here), which is a water-intensive industry

Figure 34
The World in 2050

Source: Slides 20 of the presentation by Ms. Cat Downy
A new initiative to help establish pathways to attain the UN Sustainable Development Goals[80]

90. The poster. *Space Agencies and Climate Change: 2016 Global Climate Observing System Implementation Plan*,[81] by the Committee on Earth Observation Satellites (CEOS) and Coordination Group for Meteorological Satellites (CGMS), detailed the integrated work of these groups supporting the work of GCOS and GEO, the SDGs and evolving systematic observation of climate from space. This work is grounded in the Climate Monitoring Architecture from Space (2013).[82] Upcoming activities include the use of new technologies for data access and analysis to help deliver economic, environmental and societal potential of the data and using non-meteorological applications of geo-stationary satellites to identify the implications for the production of ECV requirements

91. The poster *how forest observations and land use change support mitigation efforts*[83] from the Global Observation for Forest Cover and Land Dynamics (GOFC/GOLD) [84] land cover project office, summarized some of their work on establishing the link between space agencies, science community and the users of earth observation data and data products to support climate change mitigation. Their activities include the online LUCID data portal providing open-access information on deforestation and its drivers; [85] the GCOS/GOFC-GOLD workshop on observations for climate change mitigation;[86] and work land-based mitigation as a pilot to expand current ECV monitoring to include mitigation needs.

92. The United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) provided two posters highlighting some of their activities:

a) *Satellite technologies for national adaptation planning*[87] showed some examples of how satellite technologies can be used for example to model retention areas for flood water and irrigation for areas prone to more frequent floods and droughts; to track urban growth and assess future water and energy needs. The new Space 2030 Agenda will promote the effective use of

[79] <http://www.prepdata.org/dashboard/understanding-sonoma-countys-climate-adaptation-plan/data>.
[80] <http://www.stockholmresilience.org/research/research-news/2015-03-12-the-world-in-2050-pathways-towards-a-sustainable-future.html>.
[81] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/1.ceos_lecomte_eid_cop22.pdf>.
[82] <http://www.wmo.int/pages/prog/sat/documents/ARCH_strategy-climate-architecture-space.pdf>.
[83] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/10.gofc-gold_mherold.pdf>.
[84] <http://www.gofcgold.wur.nl/>.
[85] <http://lucid.wur.nl>.
[86] <http://www.wmo.int/pages/prog/gcos/index.php?name=ObservationsforMitigation>.
[87] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/ 16.unoosa_poster_adaptation_cop_22.pdf>.

space tools to contribute to the SDG targets, including target 13 on climate change, and will be the outcome of UNISPACE+50 and launched in June 2018.

b) *The use of satellite technologies for observation and communication of extreme and slow onset events*[88] described the opportunities provided by satellites to track tropical storms, sea level rise and its regional features, drought to identify impacts on loss and damage and improve early warning.

93. The poster *A new vision for weather and climate services in Africa* by the United Nations Development Programme gave an overview of the report of the same name launched by the Programme on Climate Information for Resilient Development in Africa (CIRDA)[89] in Marrakech to support early warning systems and resilience in 11 LDCs in sub-Saharan Africa.[90]

4. Reflections

94. Mr. Adrian Fitzgerald, least developed countries expert group (LEG), concluded the session highlighting the challenge for countries in collecting the relevant data and information for assessments to formulate and implement their national adaptation plans (NAPs). He presented points in the NAP process that would benefit by further support from climate data and information to fully support adaptation measures at all levels and in priority sectors. These fall particularly under element B of the process (figure 35) and include:

a) Generating climate scenarios – these are key in addressing how food security is affected for example in sub-Saharan Africa, especially recently with the impacts of El Nino;

b) Risk analysis;

c) Risk and vulnerability assessment;

d) Economic appraisal;

e) Implementation of adaptation solutions requires detailed climate information, which is currently lacking e.g. dam/water flow management;

f) Monitoring adaptation is important and adaptation indicators are needed to identify progress in national plans;

g) Implementation of insurance solutions to provide insurance and protection to farmers.

95. The challenges faced by the least developed countries in data and information management include:

a) Setting up and/or maintaining long-term data collection systems as the current capacity for this in many least developed countries is lacking;

b) Setting up information systems or databases to manage the data and information related to the process to formulate and implement NAPs;

c) Approaches, processes and options for data analysis, management and visualization in support of the formulation and implementation of NAPs;

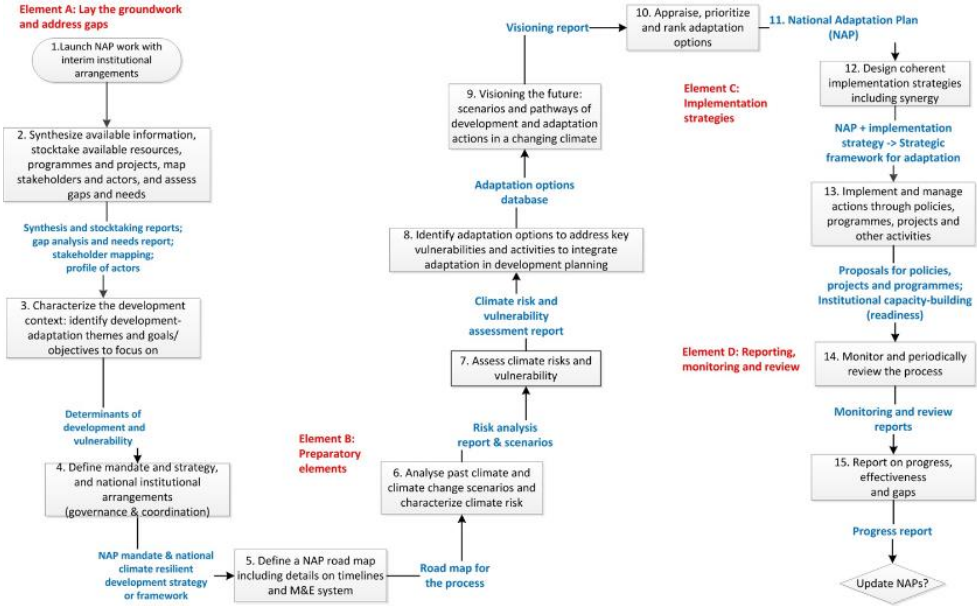
d) Access to appropriate geospatial data management and analysis tools in managing data and information over space and time, to underpin assessments in an iterative and ongoing manner;

e) Dissemination of and access to data and information to various stakeholders, including farmers, to support decision-making.

96. Mr. Fitzgerald highlighted the events being organized by the LEG to help support data and information as well as other needs to support countries to formulate and implement NAPs such as regional workshops, the annual NAP Expo and engagement with other organizations.[91]

[88] <http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/17.unoosa_poster_slow_onset_events_cop_22.pdf>.
[89] <http://adaptation-undp.org/projects/programme-climate-information-resilient-development-africa-cirda>.
[90] <http://www.undp.org/content/undp/en/home/librarypage/climate-and-disaster-resilience-/weather-and-climate-systems---africa.html>.
[91] <http://unfccc.int/nap>.

Figure 35
Sample process to formulate and implement NAPs



Source: Slides 4 of the presentation by Mr. Adrian Fitzgerald

5. Discussion

97. A number of questions were asked and discussed after the presentations.

98. The CORDEX-Africa project was asked to elucidate further its approach within the context of the African Impact Atlas project how it would manage thresholds across river basins as well as the limited observations data available for parts of Africa. Mr. Lennard replied that in regards to transboundary issues, threshold exceedance would need to be determined with the groups of relevant stakeholders, in the case of river basins this would include representative hydrologists and policy makers from the relevant countries involved. In regards to the lack of past data for Africa, this determines the baseline for modelling and although the current spread of data for some parameters such as rainfall is being collected, the baseline may need to be determined probabilistically for models.

99. Future Earth was asked how it would approach tailoring adaptation and mitigation solutions at more local levels, as is needed and asked for by Parties. Ms. Downy responded that Future Earth will engage predominantly through its regional offices with a wide array of societal actors - business, policy makers, civil society as well as through an open network forum.

100. Colleagues measuring GHG emissions were asked if the top down method described (see paragraph 73-76) could be used to determine emissions from permafrost. Mr. Pinty highlighted that it is possible as once the wind field is known, GHGs can be traced back to origin using this method. However, Mr. Kutsch explained that as the permafrost is a huge area this method would require much more dense observations than it currently has and perhaps a bottom-up ground based approach using ground, flux and chamber measurements in areas of known permafrost melting would be more efficient.

III. Looking forward

101. The Earth Information Day linked Earth observation with the global response to climate change. It provided an up-to-date picture on the implementation needs of the global climate observing system, the current state of the climate and an outlook on developments and opportunities to take the most effective climate action in support of the goals of the Paris Agreement.

102. Parties are encouraged to provide submissions on the organization of subsequent Earth Information Days by the secretariat (before SBSTA 49, December 2018) to better enable continued support of the UNFCCC process by the systematic observation community as called for in the Convention and Paris Agreement (paragraph 6-7).