The Global Climate Observing System 2021:

Executive Summary

GCOS-239

ГЛОБАЛЬНАЯ СИСТЕМА
НАБЛЮДЕНИЙ ЗА КЛИМАТОМ
НЕУСТАННО СЛЕДИМ ЗА КЛИМАТОМ

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D'OBSERVATION DU CLIMAT
NOUS VEILLONS SUR LE CLIMAT

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EXECUTIVE SUMMARY

This report aims to inform policy makers, and those with oversight over observing networks and satellite observations, about the status of the global climate observing system, its recent improvements and achievements, as well as its gaps and deficiencies.

The Global Climate Observing System (GCOS) was established in 1992 to aid in developing and coordinating a Global Climate Observing System that simultaneously supports scientific understanding of climate change, policy development, public information and planning for adaptation and mitigation.

GCOS prepares regular reports on the state of the global climate observing system (so-called "status" or "adequacy" reports) and submits them to the United Nations Framework Convention on Climate Change (UNFCCC). This is the fifth such report and it reviews developments in the observing system since the previous report published in 2015 (GCOS-195).

In 2014, the Intergovernmental Panel for Climate Change (IPCC) stated that evidence of climate change was unequivocal and so the 2016 GCOS Implementation Plan (2016 GCOS-IP, GCOS-200) indicated that the emphasis of GCOS needed to expand beyond the scientific observation of the climate to also supporting policy and planning. This resulted in two new areas of work for GCOS.

The first area looks at how well global climate cycles[1] are monitored. By assessing how well these are observed by the Essential Climate Variables (ECVs)[2]as a whole, GCOS has identified gaps and inconsistencies in the global climate observing system. The 2016 GCOS Implementation Plan (2016 GCOS-IP) took the new approach of not only concentrating on the quality of a single ECV, but also considering that the ECVs are increasingly being used to close the global, or continental scale budgets of energy, carbon and water. Understanding changes in these budgets and how they are linked is vital. For example, changes in the amount of water in the different components of the Earth system directly affect access to water of good quality, which is a basic human requirement, while changes in the energy cycle directly drive impacts such as terrestrial and ocean heatwaves, extreme precipitation and drought. Changes in the carbon cycle directly drive changes in the energy cycle and impact emission targets. Thus, understanding and observing the Earth's cycles is important for both climate science and for determining and monitoring key policy targets set in the Paris agreement framework.

The second area of new work for GCOS looks at how the global observing system can support adaptation. Climate data supplied by a global system is an essential component in delivering the products and information needed for adaptation. Data products derived from climate monitoring, together with climate predictions generated from a global climate model and downscaled to the regional and national level, provide climate information at multiple spatial and time scales that meet the requirements of adaptation. At the global scale, observations can be used to review the collective progress on adaptation by all countries. GCOS international coordination ensures that high-quality global climate data are available and accessible, providing critical support for adaptation.

Securing and extending the observing systems needed for the long-term monitoring of the Earth system as a whole requires substantial efforts and collaboration at all levels including international organizations, national agencies, and scientific communities. The systematic climate observations supported and reviewed by GCOS are implemented through the World

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[1] GCOS has looked at the water and carbon cycles and the energy balance but there are other important Earth system cycles (e.g. Nitrogen cycle) that are impacted by climate change and human activities.

[2] An Essential Climate Variable (ECV) is a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth' s climate.

Meteorological Organization (WMO), the Global Ocean Observing System (GOOS), the Joint Working Group on Climate (WGClimate) of the Committee on Earth Observation Satellites (CEOS), the Coordination Group for Meteorological Satellites (CGMS), and a broad range of other partners and relevant organizations.

The approach

The writing of this report has been guided by a writing team, while experts from the three GCOS panels[3] have provided the technical information and assessments. Each Panel has appointed "ECV Stewards" to monitor the performance of the observing system for specific ECVs. Similarly, experts were appointed to report on each of the actions on the 2016 Implementation Plan (IP Actions). All assessments have been internally and externally reviewed. The whole report was publicly reviewed with over 500 comments received. Finally, the report was approved by the writing team and the GCOS Steering Committee.

Benefits

Sustained long-term support for a global system of climate observations, both in situ and satellite, provides many benefits. All countries can benefit from the outputs of global models, forecasts and predictions supported by global climate observations. Emergency warning systems use local models and observations that are embedded in a global modelling system, while planning often uses models downscaled from global results. Climate-related policy is driven by data: the UNFCCC is a science-based process that uses IPCC assessments of the state of the climate based on the climate observations as well as observation-based reports on the state of the climate.

Achievements

Since the 2016 GCOS Implementation Plan was published there has been substantive progress in many areas of the Earth's climate observation system and this effort needs to be maintained and supported by sustainable, long-term, and adequate finance. The major improvements include:

- Satellite observations have improved their coverage spatially, temporally and in terms of observed variables. Satellite data are accessible and well curated[4]. Many ECVs, especially terrestrial ECVs such as land cover, leaf area index and FAPAR (Fraction of Absorbed Photosynthetically Active Radiation), are now available from satellites providing a near-global coverage with good resolution.
- WMO and, through its Members, the worldwide network of National Meteorological and Hydrological Services (NMHSs) ensure the required long-term monitoring, with established practices and instruments, for many ECVs. Many of these data are exchanged internationally and support weather and climate modelling.
- Observations of atmospheric variables have further improved in the past decade thanks to new in situ observations from the ground and from commercial aircrafts.
- Most ground-based networks are well managed and archives appropriately stewarded in data centres such as the National Centers for Environmental Information (NCEI) hosted by the National Oceanic and Atmospheric Administration (NOAA) in the US; the National Snow and Ice Data Center (NSIDC) in the US and the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). The Copernicus Climate Change Service (C3S) also provides access to data and derived products as well as tools to use the data.

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[3] Atmospheric Observation Panel for Climate (AOPC), Ocean Observations Physics and Climate Panel (OOPC), Terrestrial Observation Panel for Climate (TOPC)

[4] e.g. see the ECV Inventory https://climatemonitoring.info/ecvinventory/

- GCOS and WMO are now working together to establish a reference network for atmospheric and land surface meteorological observations, which will be the surface equivalent to the GCOS Reference Upper-Air Network (GRUAN).
- The ocean observing community is working in structuring ocean observations in a fit-for-purpose observing system, with agreements on best practices for observations and data and metadata standards.
- The decision was made to expand the Argo program to the full water column and under sea ice, including biogeochemical variables. These subsurface measurements are critical to monitor and forecast the climate system.
- Technological innovations have contributed to expanding the ocean observing system and its capability, in particular with the development of autonomous platforms and suitable sensors for a range of ECVs.

Sustainability

Long-term continuity of some satellite observations is not assured. While satellite observations have been a major success, there are gaps:

- No follow up mission for Aeolus (wind profiles) is planned.
- No continuity is assured for cloud radar and lidar on research satellites.
- Only one limb sounder with similar capabilities to the Aura Microwave Limb Sounder (MLS) is planned. The MLS provides near-global coverage every day for water vapour vertical profiles from the upper troposphere through the mesosphere but has now exceeded its expected lifetime.
- High-inclination altimetry is still problematic with only two research satellites flying (CryoSAT-2 and ICESat-2). In the future, European missions Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) and Copernicus Imaging Microwave Radiometer (CIMR) would extend operational monitoring capabilities to the late 2020s (if confirmed). Sentinel-3A/B altimeter data could be optimized for sea ice in the future.
- High-latitude sea-ice thickness monitoring is at risk (when CryoSat-2 and ICESat-2 or, for thin ice <50 cm, SMOS, stop working) and a gap might occur if CRISTAL is delayed.

Sustained funding is needed for in situ observations. While many atmospheric observations have sustained long-term funding, most ocean and terrestrial observations are supported through short-term research funding, with a typical lifetime of a few years, leaving the development of long-term records vulnerable. This is particularly true for parameters that are not traditionally monitored for weather prediction. Since these observations are executed by a large range of actors, a functional and effective observing system for climate needs appropriately funded support and coordination bodies are essential.

Many otherwise successful projects have not led to long-term sustained improvements. One clear message from the GCOS Regional Workshops is that most of the projects in developing countries that have a component devoted to observations have not led to sustainable long-term improvements in the observational capacity of these countries due to lack of resources and planning. More sustainable solutions are needed such as the proposal for WMO's Global Basic Observing Network (GBON) and the Systematic Observations Financing Facility (SOFF) discussed below.

Gaps in geographical coverage

There are still gaps in the global coverage of in situ observations.

In situ observations for almost all the ECVs are consistently deficient over certain regions, most notably parts of **Africa, South America, Southeast Asia**, the **Southern Ocean**, and

ice-covered regions, a situation that has not improved since the *2015 GCOS Status Report* (GCOS-195).

The three GCOS Regional Workshops in Fiji, Uganda and Belize[5] have looked at why some regions have problems in making sufficient observations. These issues include:

- For small nations (e.g. SIDS and PSIDS) the costs of observations may far exceed the resources available nationally amounting to a substantial fraction of the Gross Domestic Product (GDP).
- Lack of planning for foreseeable expenses (e.g. maintenance, equipment replacement, consumables).
- Lack of trained staff and poor staff retention.
- Poor understanding of the national benefits of observations: their contribution to disaster preparedness, adaptation planning and other climate services.

Furthermore, in remote and inaccessible areas, there are technical difficulties in the maintenance of operational observations.

The WMO Congress in 2019 adopted the concept for a **Global Basic Observing Network (GBON)**, which, if fully implemented, will provide essential observations for global Numerical Weather Prediction (NWP) and reanalyses, covering a few ECVs. WMO is currently working to establish a Systematic Observations Financing Facility (SOFF) that will provide financial and technical support for the implementation and operation of GBON to those Members who would not otherwise be able to implement this network. Transforming the GBON and SOFF from concepts to an operational reality requires the efforts and support of all parties.

Some of the problems related to the operation of the in situ network have been addressed by the GCOS Cooperation Mechanism (GCM). While the impact of the GCM at a station or national level can be significant, the funding available to the GCM only allows a handful of countries to be assisted. The SOFF, if funded to the level envisaged on a sustained basis, would lead to global improvements but only addresses a few ECVs. **The need for support for the remaining in situ ECV observations remains.**

Large gaps still exist in ocean observations. Subsurface measurements are critical to monitor and forecast the climate system. The decision to expand the Argo program to the full water column and under sea ice, including biogeochemical variables, addresses that challenge. More regular sampling by high-quality oceanographic cruises and an increase in the deployment of observing platforms are needed, in particular along continental boundaries, the polar oceans and marginal seas. Ocean conditions affecting the loss of ice from Greenland and the Antarctic need to be better monitored to improve projections of future rates of ice loss and sea level rise. On-ice in situ observations remain a challenge due to logistical difficulties. Improving both quality and coverage of surface flux measurements of heat, carbon, freshwater, and momentum is necessary.

Gaps in the satellite-based observations include:

- Lower tropospheric ozone (to supplement the limited coverage of surface and to determine statistically significant trends).
- An instrument that measures stratospheric CH_4 profiles globally.
- There is a regional imbalance of satellite observations. In high mountain areas satellite data acquisition of cryospheric observations is poor. For certain atmospheric ECVs in polar regions satellites have poor or no coverage.

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5 https://gcos.wmo.int/en/regional-workshops

Data Stewardship, Archiving and Access

Preservation of the fundamental climate data record is essential. Reanalysis and other added value products can always be recreated or improved from the basic data record. To address and understand climate change the longest possible time series need to be preserved in perpetuity. Not every ECV has a recognized global data repository (such as ICOADS, where almost all qualifying data has been collected). Even when there is a recognized global data repository, it can be incomplete and inadequately supported. Data should be open and freely available to all users. Adequate data stewardship, archiving and access requires sustainable, long-term, sufficient funding, as well as requirements that will ensure a consistent approach among the data centres. Clearly defined principles such as the TRUST Principles (Lin et al., 2020) and FAIR Principles (Wilkinson et al., 2016) as well as clear and enforced data management plans and data citation are required.

Data rescue from hard copy or archaic digital formats allows data series to be extended in the past and needs to be adequately planned and funded with the results openly and freely available. Sustained support to these activities is required. New approaches including citizen science and classroom-based approaches, if widely deployed, may help achieve digitization steps at the required scale.

New needs and requirements identified since the 2016 Implementation Plan

Supporting the Paris Agreement

To support attainment of the goals of the Paris Agreement the observation community needs to address knowledge gaps through those ECVs that track physical, chemical and biological cycles. Attention needs to be paid to areas particularly susceptible to the impacts of climate change and to how well ECV requirements capture the relevant temporal and spatial scales. These include:

- The feedbacks associated with changes in land use/cover, for example the timing and implications of the release of stored carbon in Arctic permafrost in different temperature and stabilization regimes (SRI.5 2018).
- Improving understanding of how response options and policies can reduce or augment the cascading impacts of land and climate, especially in relation to non-linear and tipping point changes in natural and human systems (SRCCL 2019).
- The ocean overturning circulation is a key factor that controls heat and carbon exchanges with the atmosphere, and hence global climate, however there are no direct measures of this and only sparse indirect indicators of how it may be changing. This is a critical weakness in sustained observations of the global ocean (SROCC 2019).
- Given the carbon reduction commitments that have been proposed by most countries, there is a need for quantitative assessment of anthropogenic greenhouse gas fluxes through measurements of atmospheric composition. It is also necessary to ensure that the global climate observations support the quantitative evaluation of the effect of human activities on climate change.
- Climate observations have a key role in adaptation, a major goal of the Paris Agreement.

The Earth System Cycles

In 2018 GCOS started assessments for the energy balance, and the carbon and the water cycles, identifying possible gaps and inconsistencies in existing observation systems, (von Schuckmann et al., 2020; Dorigo et al., 2021; Crisp et al., in prep). Major implications include:

- The uncertainty in the overall energy cycle is dominated by the oceanic heat uptake where there is a need to sustain and extend an integrated ocean observing system.
- The largest uncertainties in the energy fluxes are precipitation, short wave heating of the atmosphere, and the ocean and land turbulent fluxes of sensible and latent heat. Research is underway looking at improvements to the measurement capabilities for fluxes, especially over the oceans. This needs to be concluded and, if successful, implemented.
- The uncertainty (interannual variability) in the total carbon budget is dominated by the land use flux and ocean and land uptakes. These uncertainties are cause for concern as they suggest that our current observing systems do not yet have the required precision to annually monitor these trends adequately enough to guide Parties in the emission reductions that they need to achieve the Paris agreement temperature goal. This will require observational improvements particularly in the Southern Ocean and in the atmosphere over land. Satellite observations need to be complimented with a significant increase of in situ observations of GHGs with special attention given to improving the observations around urban areas.
- The largest uncertainty in the water cycle is in the evaporative fluxes over land (including polar regions) and ocean and precipitation over the ocean and mountains. There is a need to measure key variables to determine evaporative fluxes to improve water budget closure over tropical areas. A snow measurement mission is also needed to better constrain the cold land hydrology.
- A new ECV Terrestrial Water Storage (a satellite, gravimetric, observation) is being introduced. It will aid in quantifying the net effect of changes in the climate, human water use and other hydrological effects on the continental water budget and helps closing the terrestrial water balance. It will also support adaptation studies for identifying hot spots of changes in the water cycle assessing the severity of droughts.

Adaptation and Extremes

GCOS has started considering adaptation but has not yet concluded this work. Many of the major issues being addressed by adaptation, such as flooding, droughts and heatwaves, relate to extremes rather than long-term means of ECVs. Monitored data need to be relevant to the specific vulnerabilities (e.g. people, agriculture or infrastructure) rather than broader averages. Thus, in the future, attention needs to be given to monitoring extremes at appropriate spatial and temporal resolutions for each specific use. Therefore, in defining ECV requirements, single values for accuracy and resolution may not be sufficient.

It was concluded that with current capabilities in relation to its ECVs and ECV products, the global climate observing system could provide indicators for adaptation that could be used in the global stocktake. With modest enhancement of products or new products, these could be used at national level to add value to National Adaptation Plans, through assessment of climate hazards and vulnerabilities, assisting in identification of adaptation options and implementation, and in management, monitoring and evaluation of adaptation actions.

Next Steps

There have been many significant improvements in the global climate observing system since 2015. These have contributed to improved understanding of climate change and better policy development and adaptation and mitigation planning.

This report will be submitted to the UNFCCC and the GCOS co-sponsors, WMO, IOC, UNEP and ISC for their consideration. It will be followed by a new GCOS implementation Plan in 2022 that will identify key priority areas for improvement based upon the findings discussed here.

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