

# STATUS OF THE GLOBAL OBSERVING SYSTEM FOR CLIMATE

EXECUTIVE SUMMARY  
OCTOBER 2015

Atmosphere 

 Land

Ocean 



**ICSU**  
International Council for Science



This Executive Summary is extracted from the full report on the *Status of the Global Observing System for Climate* (GCOS-195), October 2015.

All GCOS publications are available at [gcos.wmo.int](http://gcos.wmo.int).

GCOS-194

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## ICSU



Founded in 1931, the International Council for Science (ICSU) is a non-governmental organization representing a global membership that includes both national scientific bodies and international scientific unions. The ICSU 'family' also includes more than 20 interdisciplinary bodies - international scientific networks established to address specific areas of investigation. Through these networks, ICSU coordinates interdisciplinary research to address major issues of relevance to both science and society. In addition, the Council actively advocates freedom in the conduct of science, promotes equitable access to scientific data and information and facilitates science education and capacity building. [<http://www.icsu.org>]

## IOC



The Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) was created in 1960. On behalf of its Member States, IOC promotes international cooperation and coordinates programmes in research, sustainable development, protection of the marine environment and capacity building for improved management and decision-making. It facilitates interagency coordination in the UN system through the UN-Oceans mechanism and collaborates on global reporting and assessment of the state of the marine environment. Through the Global Ocean Observing System (GOOS), the IOC helps improve operational oceanography, weather and climate forecasts, and monitoring. [<http://ioc-unesco.org>]

## UNEP



The United Nations Environment Programme (UNEP) is an international programme that coordinates United Nations environmental activities, assisting developing countries in implementing environmentally sound policies and practices. It was founded at the United Nations Conference on the Human Environment in June 1972. Its activities cover a wide range of issues concerning the atmosphere, marine and terrestrial ecosystems, environmental governance and green economy. UNEP has helped formulate guidelines and treaties on issues such as the international trade in potentially harmful chemicals, trans-boundary air pollution and the contamination of international waterways. UNEP and WMO jointly established the Intergovernmental Panel on Climate Change (IPCC) in 1988. [<http://www.unep.org>]

## WMO



The World Meteorological Organization (WMO) is a specialized agency of the United Nations. It is the UN system's authoritative voice on the state and behaviour of the Earth's atmosphere, its interaction with the oceans, the climate it produces and the resulting distribution of water resources. WMO has a current membership of 191 States and six Territories. It emerged from the International Meteorological Organization (IMO), which was founded in 1873. Established in 1950, the next year WMO became the agency of the United Nations specializing in meteorology (weather and climate), operational hydrology and related geophysical sciences. [<http://www.wmo.int>]

## FOREWORD

A report entitled *Status of the Global Observing System for Climate* was invited by the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) at the thirty-third session of the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA) in Cancún, Mexico, in 2010. The conclusions of SBSTA in subsequent years have reinforced the importance ascribed to this status report. The report has recently been completed under the overall guidance of the Global Climate Observing System (GCOS) Steering Committee with contributions from panel members and external experts. It was compiled and coordinated by the lead author, supported by the GCOS Secretariat. This document is the Executive Summary of the full 2015 Status Report (which is some 350 pages long), and provides an overview of its purpose, scope, main findings and conclusions.

The Status Report performs two functions: It assesses the progress made against the actions set out in the GCOS *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update)*, while also providing a more generic assessment of the overall adequacy of the global observing system for climate. It makes use of a wide range of supporting GCOS materials published since progress was reported in 2009, many of which have resulted from the outcomes of specialized workshops or working group meetings.

Work on the Status Report was initiated by a scoping meeting held in December 2013 followed by worldwide information collection over the course of a year. The lead author, Adrian Simmons, assisted by the GCOS Secretariat, compiled contributions into initial draft chapters, which were circulated to panel members and associated experts for review and comment. A revised draft was subsequently produced, which included an assessment for each Essential Climate Variable and for each action, as defined by the 2010 Implementation Plan.

A draft version of the full Status Report was submitted for public review from 24 July to 7 September 2015, and was available for open comment on the GCOS website. It was also sent to about 350 institutions and experts, including GCOS sponsors, main World Meteorological Organization (WMO) programmes, GCOS partner institutions, and GCOS panel members and experts, inviting them to comment on it and to redistribute it further as they felt appropriate. The Secretary-General of WMO invited all WMO Members to send their comments to the GCOS Secretariat. The report has thus been subjected to widespread review.

The GCOS review team received some 400 comments from individuals, scientific groups, institutions and national responsible agencies. General comments on the scope and content of the Status Report were overwhelmingly positive, with a few remarks on the need to complement or further justify some aspects. These have been reviewed and addressed in the final version. The comments will also help in the preparation of the next implementation plan in 2016.

The GCOS Steering Committee, at its 23rd meeting in Cape Town, South Africa (29 September to 1 October 2015), approved the Status Report. It will be submitted to the UNFCCC secretariat in October 2015 for consideration by the Parties at the forty-third session of SBSTA, to be held in conjunction with the twenty-first session of the Conference of the Parties, in Paris, France (December 2015).

I would like, on behalf of the GCOS Steering Committee, to congratulate the lead author and to thank him for his Herculean efforts in completing the Status Report. I would also like to thank the chairs of the three GCOS

panels and the staff of the GCOS Secretariat for their contributions to the excellent, exhaustive document. I am also grateful to the experts and representatives of partner organizations for their constructive contributions, and look forward to the cooperation of all involved parties in the preparation of the subsequent implementation plan developed in the light of the evidence given in the Status Report.

The Status Report comes at a critical time for the world's understanding and management of climate change. It emphasizes the importance of observations underpinning the science and understanding of climate change and our ability to forecast its likely trajectory. The observations are also critical to inform us of our ability to mitigate the magnitude of climate change and to adapt to changes that cannot be avoided.

Observations are the bedrock on which all other aspects of climate change are founded. The next implementation plan, informed by the Status Report, will set out the further programmes of work needed to improve and extend the observations required for our understanding and management of climate change.

A handwritten signature in black ink, appearing to read 'SAR', with a long horizontal stroke extending to the right.

Stephen Briggs, Chair of the GCOS Steering Committee  
Harwell, Oxfordshire, UK  
October 2015

## **CONTEXT AND PURPOSE OF THE REPORT ON THE STATUS OF THE GLOBAL OBSERVING SYSTEM FOR CLIMATE**

Global observation of the Earth's atmosphere, ocean and land is essential for identifying climate variability and change, and for understanding their causes. Observation also provides data that are fundamental for evaluating, refining and initializing the models that predict how the climate system will vary over the months and seasons ahead, and that project how climate will change in the longer term under different assumptions concerning greenhouse gas emissions and other human influences. Long-term observational records have enabled the Intergovernmental Panel on Climate Change (IPCC) to deliver the message that warming of the global climate system is unequivocal.

This report on the *Status of the Global Observing System for Climate* (hereinafter referred to as the Status Report) provides an extensive account of how well climate is currently being observed, where progress has been made, where progress is lacking or where deterioration has occurred. It provides a basis for identifying the actions required to reduce gaps in knowledge, to improve monitoring and prediction, to support mitigation, and to help meet increasingly urgent needs for information on impacts, adaptation and vulnerability. It documents improvements in many areas over recent years, but also makes it clear that much work remains to be done.

The Status Report has been prepared on behalf of the Steering Committee of the Global Climate Observing System (GCOS). It fulfils the responsibility of the GCOS programme to review and assess the development and implementation of the component parts of the climate observing system, and to report to sponsoring organizations and other participating agencies. The sponsors of GCOS are the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization, the United Nations Environment Programme and the International Council for Science. The report is also a response to an invitation from the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the United Nations Framework Convention on Climate Change (UNFCCC). It covers matters relevant also to the other conventions that entered into force following the 1992 Rio Earth Summit, the Convention on Biological Diversity and the United Nations Convention to Combat Desertification, and to other conventions, protocols and frameworks, most notably the intergovernmental Global Framework for Climate Services. It may also serve more generally as a source of information on the global observation of climate.

The Status Report provides the factual basis on which the GCOS programme is building its new implementation plan for the global observing system for climate, for publication in 2016.

## **SCOPE AND CONCEPT OF THE GLOBAL OBSERVING SYSTEM FOR CLIMATE**

The IPCC's *Fifth Assessment Report* notes that there are both narrow and wide definitions of climate. Climate in the narrow sense refers to the average weather, or more rigorously to the statistical description in terms of the mean and variability of weather parameters over a period of interest. The classical averaging period is 30 years, as defined by WMO. The parameters are usually surface variables such as temperature, precipitation and wind. Climate in the wider sense concerns the state, including the statistical properties, of the

whole climate system. This system is defined by IPCC to be “the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the interactions between them”. The 2015 Status Report, like the GCOS programme itself, is concerned with climate in the latter, broader sense.

The global observing system for climate is not a single, centrally managed observing system. Rather, it is a composite “system of systems” comprising a set of climate-relevant observing, data-management, product-generation and data-distribution systems. The set includes WMO observing systems that fall within the WMO Integrated Global Observing System, the IOC led Global Ocean Observing System and various land-surface observing systems. It also incorporates the climate monitoring undertaken by other programmes concerned with particular components of the climate system or with the impacts of climate change.

## **CYCLE OF ASSESSMENT AND IDENTIFICATION OF REQUIREMENTS**

In fulfilling its tasks of assessing component observing systems and identifying requirements, the GCOS programme has placed specific emphasis on supporting the UNFCCC, seeking to address what was required for Parties to the Convention to meet their observational commitments and equally have their own needs for global observations met. In 1997, the Conference of the Parties (COP) asked SBSTA, in consultation with IPCC, to consider and report on the adequacy of the global observing system for climate. The report was in fact prepared and delivered by GCOS in 1998. A Second Adequacy Report was produced by GCOS in 2003, followed this time by an implementation plan that identified the actions required to remedy the reported deficiencies in the overall observing system. Progress on the actions from the 2004 Implementation Plan was assessed and reported after five years, and findings were taken into account when preparing an updated implementation plan that was published in 2010. These documents were, to various degrees, encouraged, guided or endorsed by SBSTA or COP. The cycle of their production was aligned to enable the conclusions of the IPCC *Third* (2001) and *Fourth* (2007) *Assessment Reports* to be taken into account when determining the status and needs.

The updated Implementation Plan was considered by SBSTA at its thirty-third session in late 2010. Among its conclusions, SBSTA invited the GCOS Secretariat to report on the progress made on implementation and encouraged the GCOS programme to review again the adequacy of observing systems. The usefulness of regularly updating the implementation plan was also noted by SBSTA. The Status Report and the 2016 Implementation Plan, which is in preparation, are the GCOS programme’s responses to SBSTA. The timing of these responses follows previous practice in that they take into account the latest IPCC assessment report, referencing the contributions of both Working Group I (The Physical Science Basis) and Working Group II (Impacts, Adaptation and Vulnerability).

In the Status Report, no single period is adopted over which to present the progress made in reaching the current state of climate observation. The time period of relevance differs from one variable to another and from one type of observation to another. Moreover, detailed evidence of progress is more readily available for recent years, reflecting a general improvement in the way that observing systems are monitored and monitoring information is reported and retained. The report has some focus on the period since the *Second Adequacy Report* was prepared in 2002, and especially on the period since 2009 when progress was last reported.



Supplementary details to the 2004 and 2010 Implementation Plans related to satellite observations and the requirements for data products based on them were published by the GCOS programme in 2006 and 2011. They were taken into account by space agencies in their responses to the satellite-specific actions and requirements set out by GCOS, as reported by the Committee on Earth Observation Satellites (CEOS) to SBSTA in 2006 and 2012, respectively. The current status and plans for space-based observation, including the status of product-generation and supporting activities, are reviewed extensively in the Status Report. Progress on most of the activities presented in the 2012 CEOS report to SBSTA and reported in the update published in 2015 by CEOS in collaboration with the Coordination Group for Meteorological Satellites is covered.

## OUTLINE, BASIS AND LIMITATIONS OF THE STATUS REPORT

An introductory discussion is provided in the Status Report covering the needs for and nature of sustained observation of the climate system, the internationally coordinated arrangements under which observations are made and processed, and the concept of the Essential Climate Variables (ECVs) that provides the organizational framework for this and earlier GCOS reports. The Status Report introduces networks and satellite constellations in general, and discusses baseline and reference measurements. Although primarily intended for scene-setting, it nevertheless notes some recent developments.

The Status Report then systematically reviews overarching and cross-cutting topics. This is followed by reviews of observing networks and the observational status of each ECV. These reviews are provided separately for atmosphere, ocean and land. Discussion is linked in an ordered manner to assessments of the 138 actions identified in the 2010 Implementation Plan.

The Status Report draws on published material that includes not only the IPCC's *Fifth Assessment Report* but also recent peer-reviewed scientific papers, workshop proceedings and observing-system manuals and guides. It relies on the expert judgement of contributors and the public-review process outlined in the Foreword. The report analyses data holdings and monitoring information provided by a number of international data centres and presents examples of observational data and derived global data products in the forms of time series and maps.



Ricerca sul Sistema Energetico, Italy

*The Plateau Rosa Global Atmospheric Watch (GAW) station, Italy*

Several key messages from recent observations and analyses are used to illuminate the discussions for particular variables. Interesting and important as such results are, the report does not focus on providing a complete picture of what has been learned from observations or of how much benefit observations bring. More attention is paid to observational uncertainties than to what is known with confidence from observations. This helps guide where emphasis has to be placed in making the required improvements. The immense existing value of past and present investments in the global observing system and the importance of sustaining the operation of well-established components of the system are not dwelt on, but should not be forgotten.

In common with earlier GCOS assessment and planning documents, the Status Report, for the most part, does not consider the various sets of observations made for quite limited durations, such as in field experiments for specific research purposes or in calibration/validation campaigns for satellite missions. Although extensive, the report is not fully comprehensive in that its focus is on the set of ECVs and related actions identified in the 2010 Implementation Plan. While this has enabled an orderly and largely quantitative assessment, the report does not cover the entirety of observational needs in depth, because there are variables that need to be observed even if they have not been designated as ECVs. The new implementation plan to be published in 2016 will set the broad scope of the next cycle of assessment.

The 2015 Status Report does not recommend actions in the light of its findings concerning the status of the global observation of climate. Recommendations will be made in the 2016 Implementation Plan.

## MAIN FINDINGS AND CONCLUSIONS OF THE STATUS REPORT

Global observation of the Earth's atmosphere, ocean and land remains essential for identifying climate variability and change, and for understanding their causes. Recent observations and analyses have shown that global mean sea level has continued to rise, and it has been possible for the first time to identify the relative importance of the contributions from thermal expansion, melting ice and the storage of water on land. The deeper ocean has continued to warm despite a slowing of nearsurface warming for around ten years prior to 2013. There have been substantial reductions in Arctic sea ice extent over recent years. There is evidence from new analyses that global mean surface air temperature rose more between 1998 and 2012 than first thought. There is little doubt over the exceptional warmth of the global atmosphere during the current El Niño event.

Global observation varies in its nature, arrangement and extent across the atmospheric, oceanic and terrestrial domains. Owing to the heritage of many decades of meteorological data collection, atmospheric observation is the best developed, with relatively dense though far from gap-free networks, clear observational standards, largely open data exchange and international data centres covering most, if not all, variables. Refinement of



University of California, Merced, USA

*The Providence Flux Tower, Southern Sierra, California, USA*

atmospheric observation is ongoing. Ocean observation has developed quickly, with international planning and implementation of observational networks, and new technologies that enable more and better autonomous data collection. While there are still limitations and some issues with established networks, overall structures are in place for the improvement to continue. Terrestrial observations have traditionally been made on smaller scales, with different standards and methods in different countries. They also have a poor history of open data exchange. Space-based observation is now providing global coverage of improving quality for a number of variables, increasingly with open data access, and there is progress in other areas, through global networks for glaciers and permafrost, for example. Standards,

methods and data-exchange protocols for key hydrological variables have been developed. However, an integrated approach to terrestrial observation is still lacking.

Most of the **principal findings** that have been drawn from the reviews that were undertaken variable by variable and action by action fall straightforwardly into two separate groups, one for in situ measurement and ground-based remote sensing and one for space-based remote sensing, even though many applications of observations make combined use of both groups of data. There are both positive and negative findings, and both need to be acknowledged and taken into account when planning what needs to be undertaken in the future.

For the **in situ and other non-space-based components** of the observing system, the following findings are given in the Status Report:

- The development and contribution to climate monitoring, understanding and prediction of the Argo network since its floats that profile temperature and salinity were first deployed in the year 2000 have been outstanding. The original goal of 3 000 floats was reached in 2007. The network is now expanding into marginal seas and high latitudes, it is beginning to host novel sensors that measure biogeochemical variables and offers the prospect of profiling to greater depths.
- There have been improvements in coverage for a number of longer established in situ networks, including the main meteorological networks. The quality of measurements has also shown improvement.
- Several oceanic and terrestrial networks making in situ measurements and networks for ground-based remote sensing of atmospheric composition have been established or significantly expanded in recent years, although some requirements for forming networks have not been met.
- Fewer observations have been provided recently by some atmospheric-composition and marine-buoy networks. This has been due to planned closures, inadequate maintenance or unexpected equipment failures. Responses have been effective in limiting some of the shortfalls. Particular issues with moored-buoy networks have prompted a review of the observing system for the tropical Pacific.
- Surface meteorological measurements from ships have declined in number over the major parts of ocean basins, but have increased near coasts.
- Some gaps in the coverage of networks over land have been reduced. Local gaps that appear small from a global perspective may nevertheless be critical, especially where populations are at risk or where local changes have global impacts.
- Capacity development continues to fall far short of what is needed to fill critical network gaps in a sustainable way, and more generally to ensure that vulnerable developing countries have the local observations needed to adapt to climate change.
- Automation has increased the temporal frequency of observation, and has enabled measurements to be made at additional remote locations, although there are some remaining issues regarding data quality and loss of ancillary information.

- Progress in specifying and establishing reference observing sites and networks has been mixed. It has been good for upper-air measurements. Attaining representative global coverage is a general challenge.
- There are opportunities to benefit from expanding global near-real-time data exchange and from adopting new reporting codes and metadata standards.
- Recovery of historical data has progressed well in some respects, but it is still limited in extent and hampered by restrictive data policies.
- Generation of data products, for example, on surface air temperature, humidity and precipitation, continues to improve.
- Sustaining observing-system activities that are initiated with short-term research funding is a recurrent issue.

For the **space-based component** of the observing system, the following findings are given in the 2015 Status Report:

- The newer and planned generations of operational meteorological satellite systems offer improved quality and a broader range of measurements. China is becoming established as the provider of a third pillar in the constellation of polar-orbiting systems.
- The European Copernicus programme is placing additional types of observation on an operational basis, with increased coverage and quality of measurement, and accompanying service provision.
- There have been increases in the numbers of national providers, cooperative international missions and other collaborative arrangements.
- There has been very little progress on the continuation of limb sounding and the establishment of a reference mission.
- Continuity of observation is at risk for measurements of solar irradiance and of sea-surface temperature at microwave frequencies.
- New observational capabilities have been demonstrated, and others are being prepared for demonstration. Future deployment is uncertain for some of the demonstrated capabilities, for example, for monitoring cloud and aerosol profiles, sea-ice thickness and soil moisture.
- The generation and supply of products derived from space-based observations have progressed well, with increasing attention paid to documenting product quality and uncertainty.



ESA

*Sentinel-1 satellite for land and ocean monitoring, European Copernicus programme*

- Inter-agency cooperation has been effective in product validation and in starting to develop an architecture for climate monitoring from space and an inventory of products.
- Data access is becoming more open, although there is still progress to be made on this issue. Some data remain to be recovered from early missions, and long-term preservation of data, including occasional reprocessing, is not yet fully ensured.



CSIRO, Australia

*Launch of an Argo float, Indian Ocean*

**Data-centre** holdings are increasing with the passage of time, and are generally distributed by data type. Collections of in situ data are held by international data centres for many but by no means all ECVs. Basic satellite data are usually held by the agency that operated the satellite. Derived data products are hosted primarily by the organizations that generated the products. This arrangement is not seen to be problematic, but there are concerns over the following issues:

- There are a number of portals and Internet search engines that can be used to link to data, but product lists may not be complete, and users may be in doubt over what they are missing and how the observations or products on offer compare.
- Collections of in situ data may be some way short of being complete and up to date. They depend on submissions or access offered by owners, and thus on owners' data policies and resources, including for recovering data from paper records and obsolete media.
- Data served by a centre may not be in an easy-to-use format, and may lack quality control, merging of data from different sources, flagging of likely duplicated data, feedback from other users and so on.
- Data may not be easy to sample, notwithstanding welcome advances in visualization.

**Global reanalysis**<sup>1</sup> of comprehensive sets of observations has been sustained, with improving capabilities and better understanding of user requirements and deficiencies in current products. The activity is being placed on a firmer footing in Europe, through inclusion in operational Copernicus service provision, and in Japan and the United States of America, through the commitment of providers to continue and refresh production. Atmospheric reanalysis for the radiosonde and satellite eras has been supplemented by reanalysis covering the twentieth century and more, assimilating only surface atmospheric data but constrained also by observationally based surface and radiative forcings. Reanalysis has become better established for the ocean, the land surface and atmospheric composition. Good progress has also been made in the development of data-assimilation systems that couple various elements of the climate system, the atmosphere and the ocean in particular.

**International organization of observing systems** has been strengthened, especially for the atmosphere and ocean, through the development of the WMO Integrated Global Observing System as the framework for

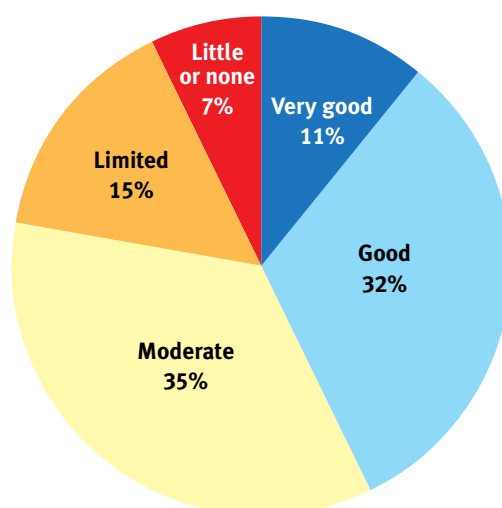
<sup>1</sup> The term reanalysis is used to describe the use of a fixed data-assimilation system to process observations that extend back in time over multiple decades, employing a model of the atmosphere, ocean or coupled climate system to spread information in space and time and between variables, and otherwise to fill gaps in the observational record.

the functioning of all WMO observing systems and the revitalization of the IOC-led Global Ocean Observing System, with guidance provided by a Framework for Ocean Observing. The withdrawal of support for the Global Terrestrial Observing System by its lead sponsor has restricted coordination and standardization for the terrestrial domain, but there has been progress for many individual elements of terrestrial observation.

**Further conclusions** concerning overarching and cross-cutting topics, and topics specific to the atmospheric, oceanic and terrestrial domains, are presented in the full Status Report.

There is **no single metric**, or small set of metrics, that comprehensively quantifies the current status of the global observing system for climate, how well it meets the broad spectrum of user needs or how far it has progressed either over many decades or over the past few years. Variations over time of data counts and quality indicators for the better-established ECVs point mainly to a situation that continues to improve, though not entirely. For variables for which observation and international organization is less well established, progress is indicated, in some cases, by reporting the establishment of an international network or data centre, or simply by being able to display a global map related to a variable. Statistics on user accesses to web-based information, to observations and data products and to data visualization tools also serve as metrics, but are often not made evident on data-centre websites.

A general **indication of progress over the past five or so years** is provided in the Status Report by assessing the accomplishment of the actions set out in the 2010 Implementation Plan. Progress has been ranked for each action on a five-category scale. The pie chart shows the distribution by category of all 138 actions. Overall progress is assessed to be moderate to good, with almost twice as many actions falling into the two highest categories than the two lowest ones. Of the actions, 22% have nevertheless been placed in the lowest two categories: progress has been at best limited for almost one action in four. Some 7% of actions lie in the lowest category, which includes cases where the action called for a network to be improved but performance actually deteriorated. Moreover, some actions relate to incremental steps towards the establishment of an adequate component of the overall observing system; good progress on this, although important, is not an end in itself.



*Overall progress of actions from the 2010 Implementation Plan*

**To conclude**, many countries of the world, developing as well as developed, have improved the contributions that they or their intergovernmental agents make to the global observing system for climate. The system continues to progress and support better the needs of an increasingly wider user community. Aided by the passage of time, the system extends the lengths of the modern instrumental data records, improving them for recent years by better observations and for earlier years by recovery and better reprocessing and reanalysis of data. Challenged by the passage of time, which makes the response to climate change ever more urgent, the system nevertheless continues to fall short of meeting some essential requirements for observationally based climate information. What needs to be done will be addressed in the forthcoming new implementation plan in 2016.





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## GLOBAL CLIMATE OBSERVING SYSTEM

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