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CLIMATE STATEMENTS OF GUIDANCE AND RELATED AOPC ISSUES

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Summary and Purpose of Document

This document summarizes the main results from the Ninth Session of the GCOS/WCRP Atmospheric Observations Panel for Climate. It includes updated drafts of three Statements of Guidance for climate applications, which have been developed by AOPC in consultation with the climate community. It also includes a brief summary of the *Second Report on the Adequacy of the Global Observing Systems for Climate Change in Support of the UNFCCC,* developed under GCOS leadership in response to the request of the UNFCCC and the GCOS Steering Committee.

ACTION PROPOSED

The meeting is invited to note the information contained in this document and provide comments as appropriate on the draft Statements of Guidance for climate applications.

DISCUSSION

1. Highlights of AOPC-IX

1.1 The Ninth Session of the GCOS/WCRP Atmospheric Observations Panel for Climate was held at the National Climatic Data Centre (NCDC) in Asheville, USA from 23-27 June 2003. The main items of discussion focussed around (i) the status and latest developments regarding the GCOS atmospheric networks, especially the GSN and GUAN; (ii) consideration of new or enhanced networks for measurement of additional parameters of importance to AOPC (surface radiation, CO_2, ozone, aerosols); (iii) further development and review of Statements of Guidance for three climate applications areas; and (iv) review of the latest status of the GCOS Second Adequacy Report to the United Nations Framework Convention on Climate Change (UNFCCC). Some highlights of these issues are presented in this document.

1.2 The performance of the GSN and GUAN networks remains well below ideal, with about 65% of expected reports being received at the GCOS Monitoring Centres for GSN and 75% for GUAN. GCOS is working closely with WMO/WWW and TCO of WMO to take specific actions to revitalize a number of GUAN stations, under the guidance of AOPC for station selection and with funding support provided recently by the USA/NOAA through its Climate Change Research Initiative. A contractor has been engaged by GCOS to carry out these activities, which are expected to continue for some time and include underperforming GSN, as well as GUAN stations.

1.3 Presentations were made at AOPC-IX by scientists from NOAA/CMDL representing global CO_2 monitoring activities and the GEWEX/WCRP Baseline Surface Radiation Network (BSRN), with a view to adding or developing GCOS baseline networks for these parameters. In the case of BSRN, it was agreed to establish a small ad-hoc group to pursue the issue of designating the BSRN as the GCOS baseline network for surface radiation. This activity is currently underway.

2. Statements of Guidance for Climate Applications

2.1 Attached as Annex A are the latest drafts of three Statements of Guidance (SOGs) for climate applications: Seasonal-to-Interannual Prediction (SIA), which was developed in cooperation with the ET and has already appeared in its documentation; Monitoring Climate Change; and Monitoring Climate Variability. The latter two were initiated by AOPC-VIII and have not yet been presented to the ET. All three of these SOGs have been developed and updated in consultation with a number of members of the climate community, including representatives of CCl, WCP and WCRP. They are presented here for further comment as appropriate by the ET. As with the SOGs for other application areas, it is anticipated that they will be updated again in the future as needed.

3. Second Adequacy Report to the UNFCCC

3.1 The *Second Report on the Adequacy of the Global Observing Systems for Climate Change in Support of the UNFCCC* was developed under GCOS guidance in response to a decision of the UNFCCC Conference of the Parties (COP-5) and endorsement by its Subsidiary Body for Scientific and Technological Advice (SBSTA-15), as well as the Executive Council of WMO (EC-LIV). It was presented to the Fourteenth WMO Congress in May 2003, and to SBSTA-18 in June. Cg-XIV strongly endorsed the conclusions of the report and urged all Members to support the implementation of its recommendations as a matter of urgency. SBSTA-18 welcomed the report and developed a draft decision for consideration by COP-9 (December 2003), which *inter alia*, requested the development of a phased five- to ten-year implementation plan for the integrated global observing systems for climate. Work is now underway to develop such a plan, with strong support from the AOPC and the other GCOS science panels as well as IPCC scientists, with a view to presenting a final document to COP-10 in December 2004.

3.2 A Summary of Conclusions of the Second Adequacy Report is presented as Annex B to this document. The full report, along with the latest draft of its Technical Supplement, is available on the GCOS Web site (www.wmo.ch/web/gcos/gcoshome.html).

4. GCOS Climate Monitoring Principles

4.1 An expanded version of the GCOS Climate Monitoring Principles was developed by AOPC in consultation with the Coordination Group on Meteorological Satellites. This updated version includes principles focussed specifically on satellite observations and was adopted by the WMO Congress in May 2003 through its Resolution 9 (Cg-XIV). The Principles have been extensively referenced in both the Second Adequacy Report and the SOGs referred to above. A copy of the GCOS Climate Monitoring Principles is included as Annex C to this document for convenience.

ANNEX A: Draft Statements of Guidance for Climate Applications

A.1 Statement of Guidance for Seasonal-to-Interannual Forecasts

Background

This Statement of Guidance (SOG) was developed through a process of consultation to document the observational data requirements to support seasonal-to-interannual (SIA) climate prediction. This version was prepared in consultation with representatives of the GCOS Panels (AOPC, OOPC and TOPC), CBS, CCl, WCRP and WCP, *[and has been accepted by the CBS ET-ODRRGOS as part of their guidance documentation for WMO Members]*. It is expected that the statement will be reviewed at appropriate intervals to ensure that it remains consistent with the current state of the relevant science and technology.

1. Introduction

Coupled atmosphere-ocean models are used to produce seasonal-to-inter-annual forecasts of climate. While empirical and statistical methods are also used to predict climate conditions a season ahead, the present assessment of how well observational requirements are met relates only to the coupled model inputs. It is noted that historical data sets also play an important role in SIA prediction by supporting calibration and verification activities.

Whilst such forecasting is still subject to much research and development, many seasonal forecast products are now widely available. The complexity of the component models ranges from simple baroclinic models to full general-circulation-model representations of both the ocean and atmosphere. There is also large variation in the approach to the assimilation of initial data, with some of the simpler models assimilating only wind information while the more complex models usually assimilate subsurface temperature information and satellite surface topography and temperature data. Indeed, major challenges remain in the development of assimilation techniques that optimise the use of observations in initialising models. At present, useful forecast skill (as measured against ocean and atmosphere indices) is restricted to around 6-8 months lead-time and is confined primarily to the tropical Pacific and those regions directly impacted by El Niño, although useful skill has also been demonstrated in some extratropical regions.

The time and space scales associated with seasonal-to-interannual variability (large scale, low frequency) suggest the key information for forecasts will derive mostly from the slow parts of the climate system, in particular the ocean. The initial conditions for the atmospheric model component are not so significant. When considering impacts such as rainfall deficiencies or increased temperatures over land, however, there are very good reasons for considering variables associated with the land surface conditions. In particular, land surface moisture and vegetation health should be specified and predicted. The models should also include up-to-date radiative forcing (e.g. greenhouse forcing), which may be important for maximising skill in forecasts of land surface air temperature anomalies relative to recent historical reference-normal periods.

Comprehensive statements on requirements of AOPC, OOPC, TOPC, WCP, WCRP and CCl have appeared in several places, most recently in the proceedings of *First International Conference on Ocean Observing Systems for Climate*, and published separately in *Observing the Oceans in the 21st Century* (published by the GODAE Office and the Australian Bureau of Meteorology). In terms of key variables, the priorities have changed little since the Tropical Oceans-Global Atmosphere (TOGA) Experiment of 1985-1994. These requirements are being entered into the CEOS/WMO data base. The above references also provide details of ocean-based and space-based platforms capable of meeting these requirements. Further, the report of the IGOS Ocean Theme Team provides a consolidated and integrated perspective for the oceans that embraces SIA forecasts explicitly.

In this SOG, the requirements for SIA forecasts are based on a consensus of the coupled atmosphere-ocean modelling community, and represent only those variables that are known to be important for initialising models or for testing and validating models. For the most part, aspects that remain purely experimental are not included. There is some attempt to capture the impacts aspects; that is, those variables that are needed for downscaling and/or regional interpretation.

2. Data Requirements

2.1 Sea surface temperature

Accurate SST determinations, especially in the tropics, are important for SIA forecast models. Ships and moored and drifting buoys provide observations of good temporal frequency and acceptable accuracy, but coverage is marginal or worse over large areas of the Earth. Instruments on polar satellites provide information with global coverage in principle, good horizontal and temporal resolution and acceptable accuracies (once they are bias-corrected using *in situ* data), except in areas that are persistently cloud-covered (which includes significant areas of the tropics). Geostationary imagers with split window measurements are helping to expand the temporal coverage by making measurements hourly and thus creating more opportunities for finding cloud-free areas and characterising any diurnal variations (known to be up to 4 degrees C in cloud free regions with relatively calm seas). Microwave measurements provide acceptable resolution and accuracy and have the added value of being able to 'see through' clouds. Blended products from the different satellites and *in-situ* data can be expected to be good for SIA forecasts.

2.2 Ocean wind stress

Ocean wind stress is a key variable for driving ocean models. It is important to recognise the complementarity between surface wind and surface topography measurements. Current models use winds derived from Numerical Weather Prediction (NWP), from specialist wind analyses or, in some cases, winds inferred from atmospheric models constrained by current SST fields. The tropical moored buoy network has been the mainstay for surface winds over the last decade, particularly for monitoring and verification, providing both good coverage and accuracy in the equatorial Pacific. Fixed and drifting buoys and ships outside the tropical Pacific provide observations of marginal coverage and frequency; accuracy is acceptable.

Satellite surface wind speed and direction measurements are potentially an important source. Currently their data reaches SIA models mostly through the assimilated surface wind products of NWP, where their positive impact is acknowledged. Overall, a two-satellite scatterometer system, or its equivalent, would provide good coverage and acceptable frequency, and it would complement the ocean-based systems. At this time, continuity and long-term commitment are a concern. Irrespective of these issues, improved integration of the data streams and operational wind stress products from NWP and other sources will be needed to achieve acceptable or better coverage, frequency and accuracy.

2.3 Subsurface temperature and salinity profiles

Many, but not all, SIA forecast models assimilate subsurface temperature data, at least in the upper ocean (down to ~500 m depth). No current model assimilates salinity data (subsurface or surface), principally because of the paucity of data and inadequate knowledge of the variability. The TAO/TRITON moored buoy network provides data of good frequency and accuracy, and acceptable spatial resolution, of subsurface temperature for the tropical Pacific, at least for the current modelling capability. The tropical moored network in the Atlantic (PIRATA) is better than marginal but does not yet have the long-term resource commitments and stability to be classified as acceptable. There is no array in the Indian Ocean. The Ships-of-Opportunity Programme (SOOP) provides data of acceptable spatial resolution over some regions of the globe but the temporal resolution is marginal. It is noted that SOOP is evolving to provide enhanced temporal resolution along some specific lines. The *Argo* Project is providing increasing global coverage of temperature and salinity profiles to ~2000 m, mostly with acceptable-to-good spatial resolution, but only marginal temporal resolution in the tropics. In all cases the accuracy is acceptable for SIA purposes.

2.4 Ocean altimetry

Ocean altimetry provides a measure of the sea surface topography relative to some (largely unknown) geoid (or mean sea surface position) that in turn is a reflection of thermodynamic changes over the full-depth ocean column. In principle, the combination of altimetry, tropical mooring and *Argo* will provide a useful system for initialising the thermodynamic state of SIA models. There are currently no altimeters with commitments for long-term operations. Research satellites are providing a mix of data with acceptable accuracy and resolution and data with good spatial resolution (along the satellite tracks) but marginal accuracy and frequency. The "synoptic" global coverage, particularly beyond the tropical Pacific, is an important requisite.

2.5 Surface heat and freshwater flux

There are a few sites in the tropical ocean where the data on surface heat flux are of some value for validation. At a selected number of reference sites the accuracy and temporal resolution will be good. NWP products, in principle, have good resolution but the accuracy is at best marginal. Satellite data provide prospects for several of the components of heat flux, particularly shortwave radiation, but at present none is used on a routine basis for SIA forecasts. Precipitation estimates are important for validation because of the fundamental role of the hydrological cycle in SIA impacts. They also have potential importance in initialisation because of the links to salinity. However, there remain significant uncertainties in estimates of rainfall over the oceans.

2.6 Ocean current data

No model currently assimilates ocean current data. However, because of the central importance of dynamics and advection, current data are important for testing and validation. For example, experimental fields of surface current for the tropical Pacific and Atlantic are now being produced routinely by blending geostrophic estimates from altimetry with Ekman estimates from remotely-sensed wind observations. Inferred surface currents from drifting buoys are acceptable in terms of accuracy and temporal resolution but marginal in spatial coverage. Moored buoys are good in temporal coverage and accuracy, but marginal otherwise.

2.7 Sea level

In-situ sea level measurements provide an additional time-series approach (good temporal resolution and accuracy; marginal spatial coverage), particularly for testing models and validating altimetry.

2.8 Atmospheric data

Since several SIA systems are driven by winds and, in several cases, surface heat flux products from operational analyses, the global (atmospheric) observing system is important for SIA forecasts and their verification.

2.9 Other data

There are many other data sets that may play a role in future-generation SIA forecasts models. Because these roles are largely unknown, it is premature to discuss the adequacy of observing systems to meet these needs; generally speaking, they are not expected to rank near the above data in terms of priority. These data sets include:

- Surface salinity (particularly from new space-based approaches). No present model uses surface salinity.
- Snow cover. Research suggests snow cover may be important, particularly at short lead times (intraseasonal-to-seasonal).
- Ice cover. Ice cover is important for high latitudes. It is implicitly included in the leading SST products.
- Soil moisture and terrestrial properties. Research suggests proper initialisation of soil moisture is important. There are also indications that terrestrial properties, such as the state of vegetation, may be important, particularly in downscaling and impacts/applications.
- Ocean colour. Ocean transparency is already included in several ocean models and is thought to be a factor in SIA models (helping to determine where radiation is absorbed). Ocean colour measurements provide a means to estimate transparency.
- Clouds. Poor representation of clouds remains a key weakness of most SIA models. Better data are needed to improve parameterisations but these needs are adequately specified under NWP and elsewhere.

3. Summary

The following key points summarise the SOG for Seasonal to Interannual forecasts:

- The data requirements for seasonal-to-interannual modelling and forecasts are now entered in the CEOS/WMO data base (as well as available in several GCOS and WCRP documents; see Section 1);
- The WCRP has concluded that models show useful skill in predicting variability of the El Niño-Southern Oscillation but there is less useful predictability beyond the Pacific. The exploitation of skill is dominated by the signal of El Niño;
- Integrated and complementary approaches to the atmospheric and oceanic observing systems is required, exploiting synergies with other areas;
- The TAO/TRITON Array of moored buoys (SST and winds; subsurface temperature; currents) provides the backbone of the ENSO Observing System in place today and its continuation is essential;
- Enhancements from satellite wind vector and surface topography estimates, from autonomous systems such as *Argo*, and from enhanced surface flux reference sites, are providing a substantial contribution.

The key observational problems affecting improvements in seasonal to inter-annual forecasting are:

- The transition of research networks and outputs to operational status (ie with sustained institutional support);
- The timely operational acquisition of data from research and non-governmental systems/sources;

- The lack of long-term commitment to
  - a two-satellite scatterometer system,
  - tropical moored arrays in the Atlantic and Indian Oceans,
  - operational satellite altimetry,
  - a network of surface flux reference sites.

A.2 *[Draft]* Statement of Guidance on Monitoring Climate Change

Background

This Statement of Guidance (SOG) is being developed through a process of consultation to document the observational data requirements to support monitoring climate change. This version has been prepared in consultation with representatives of the GCOS Panels (AOPC, OOPC and TOPC), CBS, CCl, WCRP and WCP, *[and has been accepted by the CBS ET-ODRRGOS as part of their guidance documentation for WMO Members].* It is expected that the statement will be reviewed at appropriate intervals to ensure that it remains consistent with the current state of the relevant science and technology.

1. Introduction

This Statement of Guidance covers data requirements for monitoring climate change, including both detection and attribution, on global and continental scales. Because attribution involves the comparison of three-dimensional fields of observations with fields from models covering the whole climate system, data of many types for many parts of the climate system are required. Detection must be based on analysis of high-quality homogeneous data. GCOS baseline systems, especially the GCOS Surface Network (GSN) and the GCOS Upper-Air Network (GUAN), are essential benchmarks to ensure the homogeneity of the overall database. Best-practice guidelines have been developed for both of these networks. Current networks need to be consolidated and maintained, including national (e.g. Reference Climate Stations) and regional networks (e.g. Regional Basic Climatological Network), with emphasis on continuity and homogeneity. In some cases new stations are needed to fill existing gaps.

For monitoring climate change, data on variability and extreme events are essential. Important phenomena to be monitored include tropical cyclones, heat waves, frost, floods and droughts. This requires daily data and, ideally, hourly data for precipitation. Palaeoclimatic data are needed to provide a long-term perspective. Data archaeology, recovery and digitization are extremely important, and data so generated should be made available to the research community. Operational monitoring and quality control are essential. Maximum focus in the past has been on the atmosphere and the ocean surface, but increasing emphasis needs to be placed on the subsurface ocean and on the terrestrial components of the climate system. Climate forcings must be monitored, including solar output, volcanic aerosols, greenhouse gas concentrations, and tropospheric aerosols.

The IPCC Third Assessment Report provides a recent review of the state of understanding of climate change. An important development has been the association of error estimates with some climate indices and analysed fields. Data coverage needs to be sufficient to allow these developments to continue.

The *Second Report on the Adequacy of the Global Observing Systems for Climate* provides a recent assessment of the adequacy of current observing systems for monitoring climate change, particularly to meet the needs of the UN Framework Convention on Climate Change. The GCOS Climate Monitoring Principles, which are included therein, must be adhered to when planning, developing and operating all observing systems relevant to climate change, including both *in situ* and satellite-based systems.

2. Data requirements

2.1 Surface

The longest climate records are available for terrestrial areas, primarily for variables such as temperature, precipitation and pressure. All studies of climate change require that the basic measurements be homogeneous (i.e. not affected by changes in instrument type and location or observation practices, or by undocumented data adjustments). The GSN provides a baseline set of observations against which more detailed national and regional measurements can be assessed. Coverage over land is generally good, but performance is poor in major regions of Africa and South America as well as in portions of the Pacific Islands region. Improvements to instrumentation require overlapping observations of the old and the new system for a period sufficient to identify and eliminate time-dependent biases (as per the GCOS Climate Monitoring Principles). Metadata must be acquired and kept up-to-date, both for ensuring the reliability of the records and for assessing the effects of local land-use changes. Current and historical metadata should be, to the extent possible, stored in electronic form and made readily accessible. All surface variables need to be monitored to the required accuracy (see CEOS/WMO database for a list of all required variables and monitoring accuracy).

2.2 Upper Air

In the troposphere and stratosphere, the most important variable for monitoring climate change is temperature. Humidity is also important because water vapour, especially in the upper troposphere and the stratosphere, makes a strong contribution to the greenhouse effect. It is important to be able to monitor and understand tropospheric lapse rate changes as these may reflect a mix of natural and anthropogenic influences. Stratospheric temperatures are important through their relation with ozone depletion, as well as with the greenhouse effect. They may also influence the troposphere. As all these data need to be accurate and unbiased, care must be taken to ensure that metadata are available to allow radiosonde and satellite-based temperature and humidity profiles can be determined to known quality with established error bars. Coverage of radiosonde data is poor in the tropics and over the Southern Hemisphere; networks need to be strengthened, reversing some recent declines. The continuity and consistency of satellite-based temperature and humidity retrievals (infrared, microwave, GPS occultation) needs to be assured; these variables also need to be bias-corrected and free from drift. Outputs of atmospheric reanalyses are insufficiently free of bias to be relied upon for studies of long-term climate change, owing to heterogeneous data inputs and the consequent time-varying influences of physical biases in current reanalysis models. Reanalyses need to be performed using models with minimal biases in data-sparse regions.

2.3 Ocean

World-wide systematic observation of the ocean surface was started in the mid 19th century, but has developed most significantly over the last thirty years. Long-term climate change data bases of many oceanic variables are being developed. Measured oceanic parameters include:

- sea-surface water and air temperature;
- sea-surface salinity;
- sub-surface salinity and temperature;
- sea-ice extent;
- wave height.

The precision and completeness of many of these observations have been improved by blending *in situ* with infrared and microwave satellite data. For the best analyses, continued use of both satellite data and in situ observations will be required. Satellite instruments measure skin temperature, whereas it is the bulk temperature of the top metre or more of the ocean that is needed for many climate-change-monitoring purposes. Thus additional *in situ* data are required. Coverage of *in situ* temperature data is good in main shipping lanes but poor in the Southern Ocean and the Arctic, where satellite infrared observations are also prevented or degraded by cloud. Recent recommendations to launch and maintain an additional 100 drifting buoys monitoring sea surface and air temperature and pressure in the Southern Ocean should be implemented. Coverage of subsurface data is marginal or poor except in the Tropical Atmosphere Ocean (TAO) array in the tropical Pacific, the PIRATA array in the tropical Atlantic, and in some main shipping lanes. The *Argo* project offers scope for major improvement in monitoring of the sub-surface ocean worldwide. The homogeneity of both in situ and satellite data streams are necessary to allow current conditions to be put into a historical perspective.

2.4 Climate Forcing

In order to properly interpret the observed long-term changes in climate, measurements of the most significant forcing agents are required. These include:

- trace gases that absorb and re-emit in the thermal infrared such as CO2, NH4, O3, N2O, CFCs;
- aerosols (including volcanic aerosols), which have many climate roles due to their radiative scattering and absorption properties (direct effect) and their interaction with clouds (indirect effect due to modification of cloud microphysics);
- solar variability, since this impacts the entire earth radiation budget;
- land-use changes, which impact the radiative properties of the land as well as the latent and sensible heat fluxes.

For interpretation of observed long-term changes to climate, measurements of water vapour distribution are essential in both the troposphere and the lower stratosphere, since water vapour is the primary greenhouse gas and may be regarded as both forcing and feedback.

2.5 Palaeoclimate Trends

Even the longest of instrumental records is not long enough to address issues of representativeness over long time scales. Palaeoclimate data (indirect information from tree rings, ice cores, corals, historical documents, etc.) allow the instrumental record to be placed in a much longer context. They are particularly important for assessing the uniqueness of recent trends and, together with climate model results and estimates of past forcing, could reduce uncertainties in estimates of climate sensitivity. The consistency of paleoclimate data, and their interpretation in terms of instrumental measurements, requires ongoing research. Spatial resolution is best over extra-tropical land areas and poor in the tropics, except for some coral reefs.

3. Summary

The following key points summarise the SOG on Monitoring Climate Change:

- GSN and GUAN observations provide the backbone for analyses of large-scale climate change, but need to be augmented by denser national and regional networks and by additional long-term monitoring of atmospheric trace gases, solar output and aerosols.
- Improvements are needed in systematic observation of terrestrial parameters.

- The requirements for data for monitoring climate change and detecting and attributing trends are entered in the CEOS/WMO data base in terms of accuracy and bias for all relevant variables.
- Homogeneity and completeness of records are vital for all studies of long-term climate change. The GCOS Climate Monitoring Principles should be adhered to for all systems and measurements.
- Existing reanalysis products are not adequate for producing climate trends that can be considered reliable.

A.3 *[Draft]* Statement of Guidance for Monitoring Climate Variability

Background

This Statement of Guidance (SOG) is being developed through a process of consultation to document the observational data requirements to support monitoring climate variability. This version has been prepared in consultation with representatives of the GCOS Panels (AOPC, OOPC and TOPC), CBS, CCl, WCRP and WCP, *[and has been accepted by the CBS ET-ODRRGOS as part of their guidance documentation for WMO Members].* It is expected that the statement will be reviewed at appropriate intervals to ensure that it remains consistent with the current state of the relevant science and technology.

1. Introduction

Climate variability exhibits large differences depending on the parameters affected and the regions of the globe. The most common measures of local variability involve precipitation and temperature. Seasonal average temperature and precipitation show significant variability in most regions of the planet, and can have marked effects on local and regional economies. Multi-seasonal anomalies are less common, but have even stronger effects on society. Multi-year anomalies are still less common, but can have devastating social and economic consequences.

WMO monthly CLIMAT messages are a key source of observations for surface climate variability studies.

As daily (and hourly) data have become available for analysis, it has been found that the frequency of occurrences of temperature, precipitation and wind *extremes* also exhibit variability on seasonal and longer time scales. Because extreme events can cause significant damage as well as loss of life, these aspects of climate variability are also very important to society. The importance of sharing daily data, so that these types of climate impact studies can be carried out with uniform procedures globally, cannot be overemphasized. Nevertheless, it has been much more difficult to create global data sets of daily data than of monthly data. A representative, although thus far limited, database of daily data is being assembled through the GSN archive (World Data Centre for Meteorology - Ashevile), and other partial databases exist.

Regional climate anomalies can occur broadly over a large territory or can be quite strongly confined to local areas. Only with high spatial resolution of observations is it possible to obtain the accurate measures of regional climate variability that are of greatest impact to local society. Again, sharing daily and hourly information from the greatest number of regional observing sites is essential.

Climate variability can obscure or enhance underlying trends; therefore a correct assessment and understanding of climate variability is fundamental to the monitoring, detection and attribution of climate change and for understanding causes of the impacts of climate change.

The GCOS Climate Monitoring Principles must be adhered to when planning, developing and operating all observing systems relevant to climate change, including both *in situ* and satellite-based systems.

Recurring patterns of climate variability

There are a number of global-scale patterns of recurring climate variability. These involve shifts or large variations in the large scale atmospheric circulation. The most familiar of these is the El Nino-Southern Oscillation phenomenon (ENSO). Regional temperature and precipitation anomalies in the tropics from East Africa to eastern South America can be strongly associated with the state of ENSO; the warm phase typically brings heavy rains to the islands of the central Pacific and NW South America and dry conditions to the Maritime Continent, while the cold phase brings heavier rains to the eastern equatorial Indian Ocean. There are also mid-latitude regional climate variations associated with ENSO in the US, Australia and elsewhere. ENSO events tend to occur one-to-three times per decade and persist for roughly one year.

Other prominent regional patterns of climate variability include the Pacific Decadal Oscillation (PDO) and its Pacific-wide extension, the Interdecadal Pacific Oscillation (IPO); the North Atlantic Oscillation (NAO); the Arctic Oscillation (AO); and the Antarctic Oscillation (AAO). These have been clearly identified in the historical record and each is associated with significant regional climate anomalies. There are many other, smaller-amplitude anomaly patterns throughout the world whose structures and regional climate anomalies are under intensive study at present. These various patterns differ greatly in frequency of occurrence and duration of a high-amplitude condition.

The regional climate variability of any particular season is typically made up of two parts: internal ‘chaotic’ variability in the atmosphere, and interactions with regional and often global oceanic and land-surface conditions. Other factors may prove to be of consequence, such as the influence of increasing greenhouse gases on variability, but remain to be identified for each region.

2. Data Requirements

2.1 Recurring Patterns of Climate Variability

Typically, these recurring patterns have been identified through analysis of the global surface data sets augmented by upper-air data, including reanalyses. The quality of global surface data sets is crucial for climate research and climate forecasting and for identification of the regional impacts associated with each recurring pattern of climate variability. Observations of marine surface conditions, particularly sea surface temperature, sea level pressure and winds, form the bulk of the most commonly used historical ocean data set. Land-surface observations of air temperature, pressure, and precipitation form the bulk of the historical land data set.

At present, global surface data sets permit identification of the above patterns of recurring climate variability, but there may be other patterns of global or regional importance, particularly outside the mid-latitude northern hemisphere, that have not yet been identified because of the limitations of the long term global data sets.

2.1.1 Surface data

Significant shortcomings exist in each of the surface data sets. Spatial coverage and accuracy in each parameter of interest needs to be improved. The GCOS GSN network is not operating to full expectations, its historical data have not been provided to the appropriate World Data Centre, and in some cases the observations have not been made in accordance with the GCOS Climate Monitoring Principles. All of these issues are being addressed by the WMO CBS and GCOS.

The global surface marine data set produced by the WMO Volunteer Observing Ship (VOS) program has significant limitations. As access to marine weather forecasts and satellite imagery has increased, marine vessels increasingly adjust their course to avoid severe weather or to gain winds and seas favourable to their passage, thereby introducing biases. The quality of VOS SST observations is also too often problematic; biases associated with particular vessels can occasionally exceed 3 degrees C and reporting is not as careful as is needed. A programme is underway (VOSClim) to increase the accuracy of marine observations from about 200 marine vessels, but improvements to the quality of all marine vessel observations is needed. Quality SST observations are provided by surface drifting buoys (which can also measure SLP) and these are increasingly the reference SST information when a drifter is present in the region of interest. Recent recommendations to launch over 100 drifting buoys monitoring sea surface and air temperature and pressure in the Southern Ocean should be implemented.

Marine vessel surface pressure and surface wind coverage are inadequate outside of northern hemisphere middle-latitudes. Surface drifters can provide acceptable quality SLP data, but need to be deployed globally to provide the needed coverage. Surface vector wind coverage is also inadequate, and observations from ships may be affected by the ship’s structure or be based on subjective assessments of sea state. Satellite observations of surface vector winds are now proven, and an operational commitment to such sensors is needed.

Continued high-quality surface observations of land and marine temperature and pressure, precipitation over land, and winds over the ocean, are key to extension of the existing climate analysis data record. High-quality national (e.g. Reference Climate Stations) and regional networks must be maintained. It would also be highly desirable to have accurate observations of near-surface humidity everywhere, of precipitation over the ocean, and of winds over the land. At present, many data that are thought to be collected do not make their way to the global data centres; much could be gained if all data were shared with the data centres.

2.1.2 Upper-air data

The global upper-air data set is not adequate in density or quality for the desired studies of the free-atmospheric manifestation of the recurring patterns of climate variability. The GUAN network of upper-air stations needs to be fully implemented as a minimal baseline for climate studies and model forecast evaluation. Additional upper-air data will be needed to support global climate data assimilation adequate to diagnose the processes at work during particular climate events.

Upper-air measurements of temperature, wind and humidity continue to be needed. Only with them will it be possible to continue the historical record; to permit study of the mechanisms that may be responsible for the recurring patterns of climate variability; and to permit evaluation of the skill of climate model simulations and forecasts. Homogeneous radiosonde data for the troposphere and stratosphere should be complemented by consistent infrared, microwave and Global Positioning System (GPS) occultation retrievals of temperature and humidity from satellites.

2.1.3 Reanalyses

Atmospheric reanalyses have a key role in monitoring, analysing and probing the processes underlying climate variability. As improved models are developed, new reanalyses should be done using the most complete and homogeneous global data available. Model biases affect data-sparse regions in particular, so the effects of the unavailability of major observing systems (e.g. satellites) in past years should be monitored carefully.

2.1.4 Predictability and data

At present some predictability of ENSO has been demonstrated, but the predictability of the other recurring patterns of climate variability is not clear. The data requirements for ENSO forecasting appear to be reasonably well-served by the ENSO observing system; the additional salinity information that will be provided by the *Argo* array is expected to improve forecast skill. Additional work on the data input sensitivity of ENSO forecast skill is ongoing.

Skill in forecasting the global seasonal SST and sea-ice distribution, irrespective of their decomposition into the recurring patterns of climate variability, remains limited. But considerable effort is being expended to identify the pathways to improved forecast skill (see also the SOG for SIA forecasts).

2.2 Shorter-duration events (fires and volcanoes)

Some events of shorter duration merit attention as being of climate significance. Major volcanic events (those which influence the stratosphere significantly) and major fires fall in this category. These events affect climate through the introduction of aerosols into the atmosphere and through land-surface changes, which can have major air-quality consequences and may create regional atmospheric circulation anomalies. At present, the observing system for atmospheric aerosols is inadequate to provide the desired information about global tropospheric and stratospheric aerosols. A combination of satellite and *in situ* data will be needed to permit characterization of the anomalies in the atmosphere introduced by large-scale fires and major volcanoes.

The combination of recurrent climate variability patterns and short-term chaotic atmospheric variability leads to extreme weather events, which can have severe human and economic impacts. Accordingly, to monitor climate variability, data on extreme events are essential. Important phenomena to be monitored include tropical and mid-latitude cyclones, heat waves, frost, floods and droughts. Therefore daily data are needed and, ideally, hourly precipitation data (in fact, for urban flooding, minute-by-minute data are needed). In addition, the social, economic and environmental impacts of extreme events, and of longer-term anomalies, need to be recorded as systematically and objectively as possible.

3. Summary

The existence of recurring patterns of climate variability is well established. Regional seasonal climate anomalies in some regions are often associated with particular recurring patterns of atmospheric circulation. Surface climate anomalies typically occur through a shift in the probability distribution of the atmospheric circulation anomalies. The presence of significant amplitude in one or several recurring atmospheric patterns in the same season often tends to enhance a regional climate anomaly. Thus, in many regions it is important to take account of the amplitudes of several such patterns. The predictability of the many recurring patterns, apart from ENSO, is still being explored.

Continuing research into the regional climate impacts associated with climate events requires continuing collection and dissemination of both surface (land and marine) and upper-air observations. The digitization and ‘rescue’ of the many past surface temperature, surface pressure, surface precipitation and surface wind data that exist are of particular interest for extending the length of the existing historical record. It is also particularly important to continue the collection of such surface data and upper-air observations of temperature, pressure and humidity to extend the record into the future for monitoring climate variability, for studies into possible mechanisms responsible for the recurring patterns of climate variability, and for evaluating the skill of seasonal forecasts.

A range of specific observing system requirements is identified above. These requirements overlap substantially with those in the Statements of Guidance for Seasonal-to-Interannual Forecasts and for Monitoring Climate Change.

SECOND REPORT ON THE ADEQUACY OF THE GLOBAL OBSERVING SYSTEMS FOR CLIMATE IN SUPPORT OF THE UNFCCC

Summary of Conclusions

The Second Report on the Adequacy of the Global Observing Systems for Climate was prepared in response to UNFCCC decision 5/CP.5 and endorsement by the WMO Executive Council and by the UNFCCC Subsidiary Body on Scientific and Technological Advice (SBSTA) at its 15th session (November 2001). The goals of the Report are to:

- Determine what progress has been made in implementing climate observing networks and systems since the First Adequacy Report in 1998;
- Determine the degree to which these systems meet with scientific requirements and conform with associated observing principles; and
- Assess how well the current systems, together with new and emerging methods of observation, will meet the needs of the Convention.

The Report concludes that there have been improvements in implementing the global observing systems for climate, especially in the use of satellite information and in the provision of some ocean observations. However, serious deficiencies remain in their ability to meet the identified needs. For example:

- Atmospheric networks are not operating with the required global coverage and quality;
- Ocean networks lack global coverage and commitment to sustained operation; and
- Global terrestrial networks remain to be fully implemented.

Based on the analysis in the Report, four overarching (and equally high priority) conclusions with accompanying recommendations for action have emerged.

1. ***Data Exchange and Standards*: **There is a need for intergovernmental and international agencies to sustain and strengthen existing intergovernmental mechanisms relating to climate data and products. In particular, for the terrestrial domain, there is a need to establish a mechanism to prepare guidance materials and develop agreements on standards and regulations for observing systems, data, and products. In all cases, adherence to the principles of free and unrestricted exchange of data should be strongly encouraged, particularly in relation to the designated Essential Climate Variables (see table below), which are both currently feasible for global implementation and have a high impact on UNFCCC requirements. Adherence to the GCOS Climate Monitoring Principles is an essential goal for all climate observations.

Domain	Essential Climate Variables	
Atmospheric (over land, sea and ice)	**Surface:**	Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour.
	Upper-air:	Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction, Water vapour, Cloud properties.
	Composition:	Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases[1], Aerosol properties.
Oceanic	**Surface:**	Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour (for biological activity), Carbon dioxide partial pressure.
	Sub-surface:	Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.
Terrestrial	River discharge, Water use, Ground water, Lake levels, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Biomass, Fire disturbance.	

2. ***Integrated Global Climate Products*: **Nations, in conjunction with the GCOS Sponsors and other

[1] Including nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and perfluorocarbons (PFCs).

international agencies, should institutionalize appropriate processes for generating and making available, on a sustained basis, a range of integrated climate-quality products relevant to the needs of the Convention, including those largely dependent upon satellite observations (see table below) and/or benefiting from the reanalysis of homogeneous historical data. In doing so, the relevant nations and intergovernmental agencies will need to address identified deficiencies in the underlying data and observing systems.

Domain	**Variables largely dependent on satellite observations**
Atmospheric (over land, sea and ice)	Precipitation, Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction (especially over the oceans), Water vapour, Cloud properties, Carbon dioxide, Ozone, Aerosol properties.
Oceanic	Sea-surface temperature, Sea level, Sea ice, Ocean colour (for biological activity).
Terrestrial	Snow cover, Glaciers and ice caps, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Fire disturbance.

3. ***National Reporting to the UNFCCC*:** SBSTA, in consultation with the GCOS Secretariat, should review the guidelines for national communications on research and systematic observation (Decision 4/CP.5) to include, *inter alia*, a specific requirement to report on the exchange of the Essential Climate Variables and associated products and on the submission of current and historical data and metadata to international data centres. All Parties are strongly urged to submit this information, as part of their national communications.

4. ***Capacity-Building and System Improvements*:** The full implementation of an integrated global observing system for climate, sustained on the basis of a mix of high-quality satellite and *in situ* measurements, dedicated infrastructure and targeted capacity-building, will require the strong commitment of all Nations. Furthermore, those Nations with the ability to do so are encouraged to contribute to a voluntary (non-UNFCCC) funding mechanism to support high-priority needs relating to global observing systems for climate in developing countries, especially the least developed countries, small island developing states, and some countries with economies in transition.

In addition, there is a continuing need for action on the priorities reflected in previous assessments and decisions, including:

- Full implementation of designated baseline observing systems;
- Rescue of historical data and metadata;
- Free and unrestricted exchange of data and their provision to international data centres;
- Development of national plans for systematic observation;
- Development and implementation of regional action plans for climate observing systems:
- Addressing the special needs of developing countries and some countries with economies in transition, particularly the least developed countries and the small island developing states;
- Use of climate data as input to decision-making processes.

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GCOS CLIMATE MONITORING PRINCIPLES

Effective monitoring systems for climate should adhere to the following principles:*

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.

2. A suitable period of overlap for new and old observing systems is required.

3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.

4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.

5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.

6. Operation of historically-uninterrupted stations and observing systems should be maintained.

7. High priority for additional observations should be focused on data-poor regions, poorly-observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.

8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.

9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.

10. Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.

Furthermore, operators of satellite systems for monitoring climate need to:

(a) Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and

(b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term interannual) changes can be resolved.

Thus satellite systems for climate monitoring should adhere to the following specific principles:

11. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.

12. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.

** The 10 basic principles were adopted (in paraphrased form) by the Conference of the Parties to the UNFCCC through Decision 5/CP.5 of COP-5 at Bonn in November, 1999.*

13. Continuity of satellite measurements (i.e. elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.

14. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.

15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.

16. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.

17. Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained.

18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on de-commissioned satellites.

19. Complementary in situ baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.

20. Random errors and time-dependent biases in satellite observations and derived products should be identified.

** The 10 basic principles were adopted (in paraphrased form) by the Conference of the Parties to the UNFCCC through Decision 5/CP.5 of COP-5 at Bonn in November, 1999.*