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GCOS REFERENCE UPPER-AIR NETWORK (GRUAN):

Justification, requirements, siting and instrumentation options

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NOTE

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Executive Summary

Shortcomings in the design and implementation of the current upper-air measurement network greatly limit the accuracy and detail of observations needed to specify how climate has varied and changed above the Earth's surface. This deficit impacts our ability to accurately predict climate change, and hence has potentially serious consequences in areas of high relevance to society, such as water resource management, the health sector, energy management, transportation, financial infrastructure, and sustainable economic development. Foremost, the GCOS Reference Upper-Air Network (GRUAN), a network for atmospheric reference observations, is required to provide the foundation for long-term datasets that can be used to reliably monitor and detect emerging signals of global and regional climate change.

Specifically, the GCOS Reference Upper-Air Network is required to:

- Provide long-term high quality climate records;
- Constrain and calibrate data from more spatially-comprehensive global observing systems (including satellites and current radiosonde networks); and
- Fully characterize the properties of the atmospheric column.

Essential characteristics of a successful GCOS Reference Upper-Air Network identified to date are:

- Close coordination with the user community;
- High-quality instrumentation;
- Redundancy of measurements of climate variables at network sites;
- Changes in the network managed in such a way that their non-climatic influences can be accurately adjusted for;
- Real-time calibration and validation;
- A strong lead centre managing the network in conjunction with station operators;
- Archival of data and metadata, and easy, free access to these for bona fide research purposes;
- Full adherence to the GCOS Climate Monitoring Principles;
- Availability of complementary measurements from other networks in a collocation database, to enable cross-calibration.

Scientific evidence clearly shows that there is a pressing need to implement such a network. Equally, it is emphasized that the GCOS Reference Upper-Air Network would be part of a tiered system of networks to which both the GCOS Upper-Air Network (GUAN) and the WMO Global Observing System (GOS) are vital components.

This report outlines progress to date in establishing network requirements, in proposing a network architecture, and in identifying technological options. At the time of publication, the inception of the GCOS Reference Upper-Air Network remains a work in progress. Areas identified as requiring further work are outlined within the conclusions.

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GCOS REFERENCE UPPER-AIR NETWORK (GRUAN):

Justification, requirements, siting and instrumentation options

1. Background

This report summarises scientific needs and technological options towards implementation of a GCOS (Global Climate Observing System) Reference Upper-Air Network (GRUAN). Such a network would address the need for high-quality reference sites that provide surface-based (fixed and balloon-borne) upper-air measurements, as identified[1] in the *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* (GCOS-92, October 2004, hereafter called the 'GCOS Implementation Plan'). The GCOS Implementation Plan has been endorsed by the WMO Commission for Basic Systems (CBS) as the Statement of Guidance for Climate Monitoring, and provides the basis for the climate monitoring component of the Global Earth Observing System of System (GEOSS). Establishing the GRUAN is also in line with national and international needs for reliable measurements of changes in the atmosphere as a basis for establishing the climate record, and for supporting climate research, climate projections, and adaptation and mitigation planning.

Progress in this area has been achieved primarily through two workshops: the NOAA/GCOS Workshop to Define Climate Requirements for Upper-Air Observations (Boulder, Colorado, USA, February 2005[2]) and the GCOS/NOAA Workshop on Reference Upper-Air Observations for the Global Climate Observing System: Potential Technologies and Networks (Seattle, Washington, USA, May 2006). These workshops saw broad representation from the climate science, operational meteorology, instrumentation and network management communities. Findings of both workshops have led to this report, including broad review by the scientific community.

2. Context: A tiered observing system

Recognising that in the past, climate considerations have been largely missing from the global observing system architecture and its implementation, participants in the Boulder workshop advocated a tiered observing system, or a "cascade" of networks (Figure 1). Each tier (i.e., benchmark network, GCOS Reference Upper-Air Network, GCOS Upper-Air Network, comprehensive network) addresses a particular aspect of climate monitoring and climate research requirements. Since all tiers complement each other, the system will work in an optimal manner only if all tiers are fully implemented and resourced.

The benchmark network would provide absolute accuracy for the measured quantities, and would be definitively tied to SI reference standards. The time series of atmospheric CO_2 concentration obtained from the NOAA Mauna Loa facility (Keeling et al., 1976, and subsequent updates) is an example of such a measurement system. There is no clear consensus that the technology to deliver such monitoring of the full characteristics of the free atmosphere (or even solely temperature and humidity) from the surface to at least the middle stratosphere currently exists. Hence, the development of a benchmark network will be left to future efforts that have the benefit of additional research and testing.

The GRUAN would provide anchor points for the global observing system for climate which:

- are very well-characterised in their relative biases over time;
- attempt to comprehensively characterise the atmospheric column; and
- are the best measurements currently available.

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[1] Action A16 in the GCOS Implementation Plan states: "Action: Specify and implement a Reference Network of high-altitude, high-quality radiosondes, including operational requirements and data management, archiving and analysis; Who: National Meteorological Services and research agencies, in cooperation with AOPC and WMO CBS; Time-Frame: Specification and plan published by 2005. Implementation completed by 2009."

[2] http://www.oco.noaa.gov/docs/ua_workshopreport_v6.pdf

In doing so, the GRUAN would fill a critical need that is not met by the current GUAN. GUAN is mandated to provide the coverage and long-term observations necessary to characterise hemispheric and global scale changes in temperature, humidity, and wind using current operational radiosonde capabilities. It consists of a set of 164 stations (January 2007) spread as evenly as possible around the globe. Although some issues regarding operating performance and the quality of instrumentation undoubtedly remain, the GUAN network has proven useful. Efforts should continue to preserve GUAN and improve reporting and observing performance.

It is important to stress that the proposal to establish the GRUAN is not and should not be seen as a replacement or substitute for the established GUAN network. Unlike the GUAN, GRUAN is not conceived to provide globally complete and spatially homogeneous coverage. At the same time, future GRUAN sites need not necessarily be current GUAN sites.

Finally, the comprehensive network provides the spatial density required to characterise changes in regional climate and dynamical characteristics. This network (except for the sub-components discussed above) also supports operational meteorology, e.g., numerical weather prediction, and, as a result, will never on its own be entirely adequate for long-term climate monitoring, since observing practices and instrumentation change rapidly. However, with careful management and data dissemination from the more climate-specific networks, those networks should provide the necessary tools to remove non-climatic influences from these data.

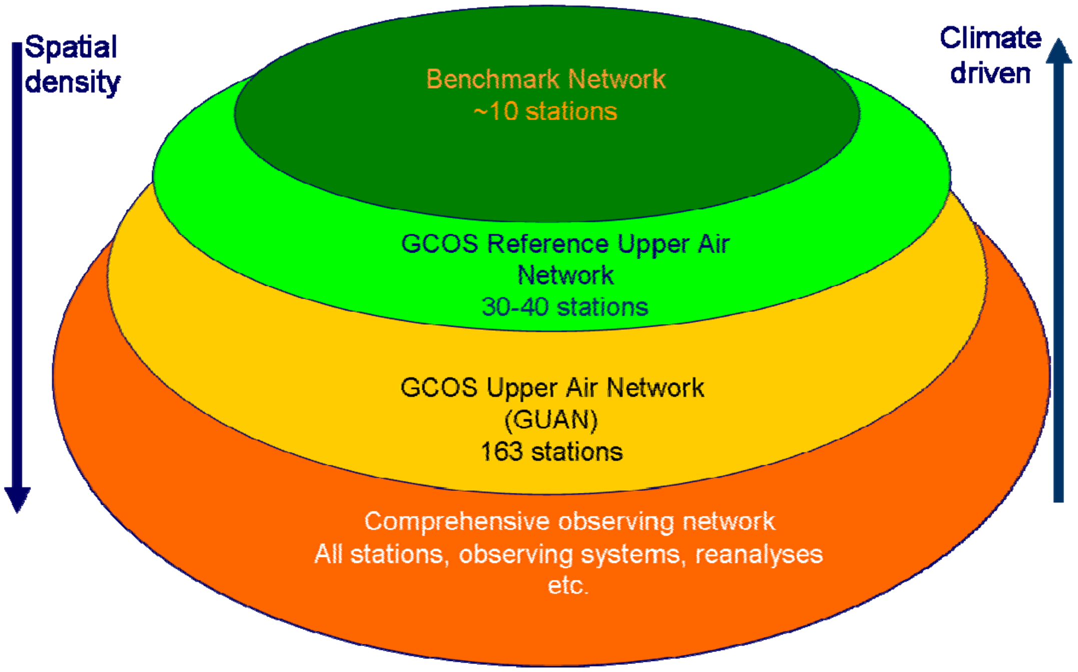

Figure 1. Tiered observing system architecture for climate as advocated at the Boulder workshop. With increasing spatial density, each network is a subset of the larger network, although some GRUAN sites may not coincide with current GUAN sites. New GRUAN sites should ideally have long-term measurement capabilities. The GRUAN and the benchmark network would almost exclusively address climate requirements.

3. Scientific justification and requirements for a Reference Upper-Air Network

Historically, observations of the free atmosphere have been undertaken for the purposes of weather research and forecasting, as well as aviation. Existing observing systems all have shortcomings when being assessed from a climate perspective. Satellite observing systems have had inadequate vertical resolution, difficulties in continuity due to drifting orbits (which alias in diurnal effects) and limited lifetimes of individual satellites. New satellite missions have higher resolution and better station-keeping, hence better control on diurnal sampling. Global Positioning System Radio Occultation (GPS RO) measures are also highly promising, at least for upper-tropospheric and lower-stratospheric temperature. Even though they represent a significant step forwards, these more recent satellite observing systems will not be adequate for climate purposes unless they can be suitably validated. The global radiosonde network (which includes GUAN) has significantly poorer spatial and temporal coverage, but much better vertical resolution than any satellite-derived measurement (although this resolution tends to be significantly degraded upon archiving of the radiosonde data). However, the absolute accuracy of radiosonde data is not well characterized because the measurements are not tied to absolute SI standards. Perhaps even more challenging, the long-term stability of the historical radiosonde data record is seriously compromised by numerous changes in instrumentation and observing methods that are undertaken without sufficient overlap, intercomparison and documentation, and thereby severely limiting the utility of the data for understanding climate trends.

Because the impact of these changes cannot be unambiguously removed from the historical upper-air data, and because there are only very few historical reference measurements, the resulting large uncertainty in observed upper-air climate changes hampers our ability to make definitive statements regarding causes of recent climate changes.

Global reanalyses from NCEP/NCAR, ECMWF, JMA and NASA have been quite revealing in this respect due to their ability to map *in situ* and satellite data to a common state (model grid). Theoretically, reanalyses provide the best tool to derive truly global homogeneous fields from the relatively sparse observational network. However, reanalyses also depend on the quality and consistency of the observational input data that are employed to constrain them. Several inconsistencies between observational data have been identified using reanalyses. Since it is impossible to unambiguously attribute these inconsistencies to a specific data source at the time of data assimilation, climate trends estimated from reanalyses are currently not as reliable as was initially hoped.

3.1. Temperature changes above the Earth’s surface: An example of the current state of science

The issue of temperature trends above the surface has been an area of intense scientific debate, because, for a long time, the available observational data suggested that there was little or no warming in the troposphere despite observed rapid warming at the surface. Running counter to the expectation of many scientists, this discrepancy was particularly marked in the tropics (Santer et al., 2005). Either there were pervasive biases in the historical data record, or the scientific expectations were incorrect. The debate led to several independent efforts to estimate recent temperature changes aloft. These identified a number of flaws in the original radiosonde and satellite datasets that had not been immediately obvious from the data (CCSP, 2006). Even after adjusting for such flaws, the current state-of-the-art datasets still give rise to a wide range of trend estimates, reflecting a large degree of fundamental uncertainty in how to identify and adjust for the many non-climatic influences in the historical data records (Figure 2) (CCSP, 2006).

The residual spread in estimates is of the same magnitude as the long-term trend. It is very likely that the existence of a set of reference-quality observations to consistently combine radiosonde and satellite datasets would have reduced uncertainty, and would have enabled definitive policy-relevant statements about our ability to analyse and model recent temperature changes in the atmosphere. By the same token, better reference-quality observations would lead to higher confidence in the models used to predict future changes in the climate system. As things stand today, we are unable to say whether a lack of scientific understanding of the underlying processes remains, even though recent advances in our knowledge of the historical data record (and limitations thereof) have significantly clarified the situation. A reference network like the GRUAN would aim to reduce the very real societal cost implications of such uncertainties by increasing our confidence in the predictions from climate change models.

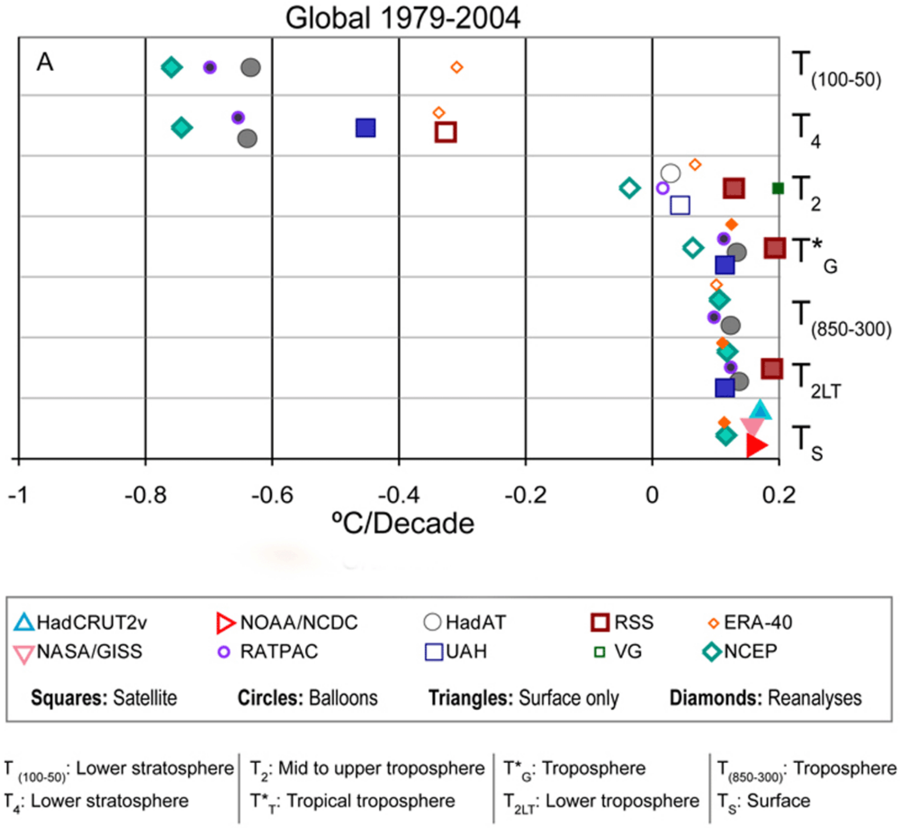

Figure 2. Global mean temperature trends 1979-2004 for a number of atmospheric layers (from the surface, T_S, through the troposphere and into the lower stratosphere, $T_{100\text{-}50}$) and for state-of-the-art radiosonde, satellite and reanalyses datasets. Filled values indicate statistically significant (non-zero) trends. Source: CCSP (2006)

3.2. Other climate research needs

Not only temperatures in the atmosphere require better reference observations for improved understanding of climate change. Achieving better understanding of climate change also necessitates the observation of changes in at least the other upper-air Essential Climate Variables (ECVs) given in the GCOS Implementation Plan (wind vector, water vapour, cloud properties, and Earth Radiation Budget; See Table 11 in GCOS (2004)). For most of these other state variables aloft, *in situ* observations to date are of lower quality than those for temperature. So, since it is not possible to meaningfully constrain temperature trend estimates, it is highly unlikely to be possible for these other variables. Nor in some cases are current technologies capable of measuring the required atmospheric properties to the needed level of accuracy and stability.

For example, the current generation of operationally-deployed *in situ* instruments, and the historical satellite data record do not allow the measurement of water vapour in the upper troposphere and lower stratosphere to the required accuracy to be useful for climate applications (Soden et al., 2004). Water vapour is the raw material for clouds and precipitation, and limited knowledge has undermined our ability to understand and predict the hydrological cycle, and understand its effect on radiative transfer (Peter et al., 2006). To bring closure to the Earth's radiation budget and balance depends on accurate assessment of the radiative properties of clouds and water vapour continuum when considering water vapour as a greenhouse gas. While most of the Earth's water vapour is contained in the lower atmosphere where it is relatively easy to measure, the water vapour content of the upper atmosphere is difficult to measure accurately. However, accurate water vapour measurements in the upper atmosphere are critical, especially for radiative budget modelling. This may require the transition of current research instruments to routine operational use. Special attention should be devoted to far-infrared measurements of outgoing long-wavelength radiation (OLR) at the top of the atmosphere (TOA) and to the retrieval of water vapour distribution in the upper troposphere and lowermost stratosphere from observations in the H_2O rotational band (Sinha and Harries, 1995).

The Boulder workshop identified a number of climate research areas that the GRUAN would need to address:

- Monitoring and detecting climate variability and change:
  Both climate variability and long-term climate change need to be well-characterized in order to unambiguously assess the ability of our climate models, and to understand the physical processes underlying recent climate changes (CCSP, 2006);

- Understanding the vertical profile of temperature trends:
  Uncertainties remain large, particularly within the tropics (CCSP, 2006);

- Understanding the climatology and variability of water vapour, particularly in the upper-troposphere and lower stratosphere, and changes in the hydrological cycle:
  Changes in the upper troposphere and lower stratosphere are very important to assessing climate sensitivity, but have as yet been inadequately characterized. Hydrological cycle changes are also important for, e.g., understanding changes in the frequency of floods and droughts, and assessing rainfall efficiency, and need to be better quantified;

- Understanding and monitoring tropopause characteristics:
  The tropopause is a sensitive indicator of changes in the properties of the troposphere and stratosphere (Santer et al., 2003; Seidel and Randel, 2005);

- Monitoring ozone, trace gases and aerosols:
  There is a need for much better understanding and monitoring of the vertical profile of ozone, aerosols and other constituents that are important climate forcing agents, but have been poorly quantified and characterized to date. A variety of new satellite instruments can be used, but they require ground-truth data to be effective for climate monitoring. For ozone monitoring, consideration of results from NDACC, SHADOZ, and recent tests, such as IONS04 and IONS06, could prove useful in ascertaining optimal instrumentation;

- Prediction of climate variations:
  There is emerging evidence that at least sub-seasonal and potentially seasonal-to-decadal predictions require an accurate characterization of initial boundary conditions. This is particularly so in mid-latitude winter seasons, with the possibility of strong stratosphere-troposphere interactions (Scaife et al., 2005);

- High-quality reanalyses of climate change:
  Reference sites will prove essential for helping to characterize observational biases and the impact of observing system changes, as well as to understand model errors, all of which are important aspects in creating high-quality reanalyses (Schubert et al., 2006);

- Understanding climate processes and improving climate models:
  Understanding and constraining climate change predictions requires better understanding and improved simulation of climate processes, and not simply changes in a single metric, such as temperature. Improved understanding of changes across a broad range of variables is therefore required. Such an approach can also usefully be applied in constraining model predictions (Forest et al., 2002);

- Satellite calibration and validation:
  Satellite radiances require calibration against a ground truth to unambiguously remove non-climatic influences, in order to be useful for climate monitoring (Ohring et al., 2005; GCOS, 2006). The GRUAN network proposed in this document, and the GSICS (Global Space-Based Intercalibration System) are complementary in meeting this need. Both are required if the future observing system is to prove adequate for climate monitoring (see section 9).

3.3. Precision and accuracy requirements

Following the Boulder workshop, requirements for the precision and accuracy of observations in the GRUAN were defined for relevant GCOS ECVs, as well as for a number of other variables which the participants identified as important (Appendix 1). Traditional NWP requirements tables were considered inadequate to describe climate reference network requirements. Constraining long-term systematic changes in a variable is particularly important for a climate reference network, an aspect not considered in NWP requirements tables. The values in the tables were initially developed by Boulder workshop participants, and subsequently refined by the combined efforts of an invited expert group and solicitation of a broad international group of climate scientists. At the Seattle workshop, these requirements were further refined. The GRUAN requirements should be interpreted as eventual measurement goals of any given network site.

4. Overarching network principles

4.1. General principles

The GRUAN would serve primarily as an anchor for other networks; it is not required to provide globally complete and spatially homogeneous coverage. GRUAN would adequately sample major climatic regimes and environment types in order to ensure that different temperature and radiation environments are reliably calibrated. It should be complementary to all other observations including emerging technologies, such as GPS RO. It also requires strong international participation and collaboration from many countries. Redundancy of measurements is imperative whereby a given parameter should always be measured by more than one independent method.

The GRUAN operation would be expected to adhere to the GCOS Climate Monitoring Principles (Appendix 2) and WMO Global Observing System (GOS) observing practices, as stated in the WMO Manual on the GOS (WMO, 2003) , the WMO Guide on the GOS (WMO, 1989/2005) and the WMO Guide to Meteorological Instruments and Methods of Observation (CIMO Guide, WMO (2006)). The GRUAN would strive for the highest possible (ideally absolute) measurement accuracy by employing high-quality, proven instrumentation, with a preference for commercially available systems. Changes in instrumentation and in operational procedures are desirable if they lead to improved observations, but they need to be carefully managed so that their effects are well-characterised and do not impact the long-term homogeneity of the station data record. A mechanism will be adopted to guarantee the long-term homogeneity of measurements following a change in the instrumentation.

4.2. Calibration, validation and quality control

As a principle for reference networks, the calibration of measurements in the operational environment should be traceable to SI standards (see section 8). A mechanism needs to be put in place to address the compatibility of those systems that may not be traceable to SI standards with the rest of the network. An identified and approved reference network shall be accompanied by the complete set of metadata collected during the measurement, such as processing algorithms. Changes in these algorithms also need to be carefully managed so that their effects are well characterised and do not impact the long-term stability of data. Continuous quality control and quality assurance, both on and off-site, are required, implying real-time monitoring of system performance and correction of problems. Assurance of successful transmission for the telemetry systems will also require careful monitoring. If uncorrected and corrected data are collected for a given instrument, both must be retained, along with information on the correction algorithm. Inevitably, algorithms change and errors in data processing occur that are not necessarily apparent until the data are used. Therefore, periodic reprocessing of data, including the provision of all algorithms used, is necessary.

4.3. Data formats

The GRUAN network would require agreement on a common data format based on internationally approved codes (e.g., BUFR). The data format should be able to accommodate all potentially available data and metadata, such as information on instrumentation, quality control and assurance, and observing sites. This would enable fully automated generation and processing of data and metadata. The data format should also be able to include vicarious data from other networks as appropriate.

4.4. GRUAN oversight

The GRUAN network would require a dedicated lead centre (or possibly multiple centres) to oversee and monitor the network. Responsibilities of such a centre would be:

- Real-time pro-active monitoring of the health of the network (quality control and quality assurance);
- Identification of instrument mentors (instrument experts who are familiar with the strengths and weaknesses and other limitations of the instrument, and the data it produces) and of a team of scientists to provide expertise related to site-specific climate science issues; to provide scientific overview;
- Training expertise and commitment to train staff at sites (in collaboration with CIMO);
- Succession planning, to ensure continuity of observations and of expertise to the extent possible;
- Coordination with the user community, including satellite and reanalysis communities;
- Network management, in conjunction with GRUAN station operators;
- Archival of data and ensuring easy free access for bona fide research purposes; access to be provided as soon as possible for potential operational systems use; inclusion of complementary data from satellites and other activities for ease of intercomparison also a key aspect; data format likely the major issue (if the data format is too restrictive, many potential users will not use the data); self-describing data formats are very important, as is user consultation;
- Data archiving needs to consider versioning of the data because periodic data reprocessing is required; reprocessing issues also help to clearly define the metadata that needs to be archived;
- Continuous research using GRUAN data, to identify optimal network designs and protocols;
- Ascertaining instrument error budgets in a consistent and unambiguous manner for all stations across the network; this should include proper identification of instrument performance issues that may arise after a system has been running in an operational setting for an extended period of time (“soak” testing), as well as a supplier approval system.

4.5. Implementation elements of GRUAN

The GRUAN network should take advantage of existing instruments, programmes and measurement sites to maximise its value and efficiency. This provides both a context for new observations taken under GRUAN, as well as optimising resources by realising synergistic benefits for all concerned.

Existing networks identified as candidates for such synergies are the following:

- Baseline Surface Radiation Network (http://bsrn.ethz.ch/);
- Network for Detection of Atmospheric Composition Change (http://www.ndacc.org/);
- Aeronet (http://aeronet.gsfc.nasa.gov/);
- WMO Global Atmospheric Watch ozone network;
- International GNSS (Global Navigation Satellite Systems) Service (IGS) (http://igscb.jpl.nasa.gov/);
- WMO Global Observing System;
- GCOS Upper-Air Network (GUAN);
- The Atmospheric Radiation Measurement (ARM) Program (http://www.arm.gov/);
- A number of individual national observatories;
- The network of surface GPS total column water vapour instruments.

It is recommended that the GRUAN network be implemented in a phased approach. It is important to get a number of sites starting to perform the necessary observations as soon as possible. At least in an initial implementation phase, it would prove useful to take advantage of the diversity of observing strategies that currently exist at these sites. Stations with different observing strategies (so long as they meet minimum requirements) would provide opportunities for the research community to effectively undertake intercomparisons of new techniques, instrumentation, or combinations of instrumentation, yielding optimal results at minimum costs. It must be made clear to stakeholders that the network will not be completed until all phases are implemented, and that only a completed network will be fit for purpose.

5. GRUAN site selection criteria

The GRUAN network needs to sample a variety of climatic regimes, latitudes, and surface types (including those representative of ocean conditions) to maximise its usefulness. A mix of low and high-altitude sites should also be considered, especially as many surface-based radiometers have limited vertical reach, and monitoring of the free troposphere characteristics is important. It is desirable to have network sites that are connected to a host institution with scientific experts engaged in the analysis of collected data, and with the necessary technical expertise to maintain the instrumentation. *However, it is essential that there be a full institutional commitment to the GRUAN-related activity at any particular site that is **not** dependent on a single Principal Investigator.*

It is nevertheless recognised that the network should start from appropriate existing infrastructure such as exists at some long-term monitoring and research locations. A pragmatic approach needs to be taken to the choice of at least the initial few GRUAN stations. GRUAN stations would be expected to consist of a rich diversity of instrumentation (Section 6). Therefore, the following initial station candidates are proposed which already meet or nearly meet the instrumentation and institutional requirements described elsewhere in this report:

- ARM sites (Tropical Western Pacific, Southern Great Plains, North Slope of Alaska) (http://www.arm.gov/ ; Ackerman and Stokes, 2003);
- Lindenberg, Germany (http://www.dwd.de/en/FundE/Observator/MOL/MOL.htm);
- Camborne, United Kingdom;
- Payerne, Switzerland;
- Cabauw, Netherlands (http://www.cesar-observatory.nl/);
- Boulder/Denver, USA;
- Sodankylä, Finland (http://www.sgo.fi/);
- Heredia, Costa Rica;
- Lauder, New Zealand;
- Beltsville, USA (http://meiyu.atmphys.howard.edu/beltsville/inde3.html).

Following phased implementation at these sites, the next set of candidate sites are those from existing programmes (see previous section) that ideally include a long-term historical upper-air sounding capability. This overall strategy does not preclude setting up entirely new sites, but recognises that it is more likely that GRUAN sites will successfully grow out of the existing observational network by using and augmenting the existing instrumentation and skills base with help from CIMO, CBS and other relevant bodies, following the guidelines set out in WMO (1989/2005), WMO (2003) and WMO (2006). Moreover, such sites should be considered a central activity to attract other observational activities, perhaps leading to coordination among disparate networks, such as BSRN and the ozone network.

Although ideally a candidate site would have a long-term monitoring pedigree, this is not absolutely essential. If a site with instrumentation required to meet the GRUAN monitoring requirements exists, then it should not be overlooked simply because it has not been observing for decades and sending those observations over the GTS. It will highly likely prove easier to convert such a site to meet GRUAN requirements than it would be to set up a GRUAN site at a location that currently only has a radiosonde monitoring capability. The overarching goal is, after all, to create a reference network for adequate monitoring of the atmosphere.

Only one of the initial candidate sites (ARM Tropical Western Pacific) could be considered an ocean site, and more ocean sites, both tropical and non-tropical, should be included in the network as it expands. These could be located on small islands (a few square kilometres in size), as long as these islands are surrounded by several hundred kilometres of open ocean. This ensures that the measured profiles are oceanic in nature, such that they can be used to validate satellite observations, whose footprints can easily be as large as 50 km. Ocean sites are also important because surface properties are mainly dependent on only a few parameters (SST, wind, and salinity) and can thus be deduced relatively accurately over the extent of a satellite footprint. Even the simplest land site (e.g., ARM Southern Great Plains) has heterogeneous features on small spatial scales, and is therefore difficult to characterize. It is also noted that this initial list overwhelmingly consists of North American and European stations. It is of the greatest importance to add tropical and Southern Hemisphere stations while expanding the initial GRUAN network. Some potential station candidates that could be considered in light of the above discussions are:

- Tiksi, Russian Federation (being upgraded for International Polar Year);
- Pico International Atmospheric Chemistry Observatory (PICO-NARE), Azores, Portugal (has unique chemical sounding capabilities);
- Galapagos, Ecuador;
- Bauerfield, Vanuatu;
- Penrhyn Island, Cook Islands;
- Gan, Maledives;
- Dar es Salaam, Tanzania;
- Nairobi, Kenya;
- Windhoek, Namibia;
- Port Moresby, Papua New Guinea;
- Comodor Rivadavia, Argentina;
- Punta Arenas, Chile;
- Macquarie Island, Australia;
- Norfolk Island, Australia;
- Chatham Island, New Zealand;
- Amundsen-Scott, Antarctica (US station);
- Jeju Island, South Korea (used as a super site for the Atmospheric Brown Cloud project);
- Dakar, Senegal (used in conjunction with the African Monsoon Multidisciplinary Analysis (AMMA) project and as such has upgraded upper-air infrastructure in place).

6. GRUAN site instrumentation requirements

The requirements tables (Appendix 1) include a wealth of parameters, with strict criteria, which is unrealistic for any given station to be expected to achieve in order for it to become a reference site. Therefore the Seattle workshop advocated a minimum set of instruments which a given station would need for initial inclusion, with a view that additional instrumentation would then be sought over time with appropriate advice from the GRUAN network lead centre.

6.1. Priority 1

The minimal criterion for a site encompasses the ability to monitor all priority 1 variables (basic atmospheric state variables) given in Appendix 1, to the best level possible with current technology. For some variables, such as upper-tropospheric and lower-stratospheric water vapour, this may not immediately be possible to the specified requirements, although some research instruments show considerable promise. Nevertheless, having active sites and commitment should motivate manufacturers to meet these requirements with new instrumentation that would be field-tested and validated before being used in an operational context.

A GRUAN site would initially be envisaged to cover, at a minimum:

- Standard surface variables (pressure, temperature, humidity and wind)
    - Required to calibrate upper-air instruments, therefore need to be high-quality measurements
    - Close proximity to the upper-air sounding instruments required

- Simultaneous balloon-based observations of temperature, water vapour and winds using different measurement techniques. Measurements should be made both on ascent and descent.
    - Advantage should be taken of the multiple channels available. For example, for temperature, a three-thermistor set (with different radiative properties: white, black, silver) would enable radiation corrections and provide redundancy. For humidity, at least three sensors should be tuned for operation in different parts of the atmosphere with less of a requirement to span the full dynamic range: thus one sensor is tuned for the lower troposphere, one for the upper troposphere, and one for the stratosphere.
    - Both measurements require redundancy throughout the vertical profile. This redundancy is required to diagnose instrument failure and characterise instrument biases.
    - At least one of the techniques for simultaneous measurements is required to be state-of-the-art, commercially available technology, tested in the laboratory and in the field, to provide reference quality measurements.
- Pressure and GPS/radar height on balloons
    - Redundancy of measurement required at least until absolute accuracy of GPS derivation is ascertained and provides calibration of pressure sensors.
- Ground-based GPS receivers to measure total column water vapour
    - These are very useful to monitor the full temporal variability of water vapour and thus help address sampling issues, as well as the quality of radiosonde water vapour data both in real-time and post-processed mode; they also help identify suspicious radiosonde batches.

A subset of GRUAN sites should undertake periodic intercomparisons of regional radiosonde packages, as currently carried out under the auspices of CIMO. There are six primary radiosonde vendors supplying radiosondes for 164 GUAN sites, which are supported by 68 countries (as of January 2007). With this many countries involved in the GUAN and the expense of carrying out overlapping radiosonde flights, the likelihood is slim that intercomparisons will be carried out throughout the GUAN network in a meaningful way. However, an intercomparison approach could be applied to the GRUAN sites. This would have the benefit of providing a mechanism where the GCOS need for overlapping flights to be conducted as sensor suites and or algorithms change would be addressed. This could also help solidify the support by WMO CIMO and CBS to the GRUAN concept.

6.2. Priority 2

The set of variables to be observed as priority 2 in the requirements tables (Appendix 1) should enable meaningful constraints to be placed on satellite observations. These would require at least the following instruments in addition to those detailed as priority 1:

- Surface radiation instruments as currently deployed for the Baseline Surface Radiation Network;
- Microwave radiometer to measure temperature and moisture characteristics;
- Multi-channel infrared radiometer, such as an AERI, to measure temperature and humidity properties and cloud retrieval (may need other cloud based measures, such as ceilometer);
- Lidar to provide an alternative source of water vapour and cloud monitoring;
- Integrated trace gas measurements (at least ozone and methane);
- Column aerosol measurements from sunphotometers.

6.3. Other priorities

The eventual goal would be to meet, at all GRUAN sites, all requirements with sufficient measurement redundancy and continuity to ensure that the long-term record is very well characterised. This would require a much larger suite of instruments and should be seen as a longer-term effort. It may include observations from aircraft as well as surface and balloon-borne observations. Figure 3 provides a schematic of a possible typical site. However, it is recognised that not all sites would necessarily attain such measurement capabilities. It is important that measurement implementation at any given GRUAN site adheres to the priorities set out in the requirements tables (Appendix 1) and be in consultation with the GRUAN lead centre in order to maximise the effectiveness of the network as a whole.

It is recognised that change is inevitable at all sites, and indeed should be openly embraced if it brings about improved observations. However, it is important to ensure that this is “managed change” in compliance with the GCOS Climate Monitoring Principles (Appendix 2).

Instrumentation may have to differ by climate region. For example, high-latitude sites inside the Arctic Circle exhibit extremely low water vapour contents in winter compared to equatorial sites. Therefore, instruments like water vapour radiometers operating at 23.8 and 31.4 GHz, which have limited sensitivity for integrated vapour amounts of 5 mm and below, would need to be augmented with more sensitive microwave radiometers operating near 183 GHz.

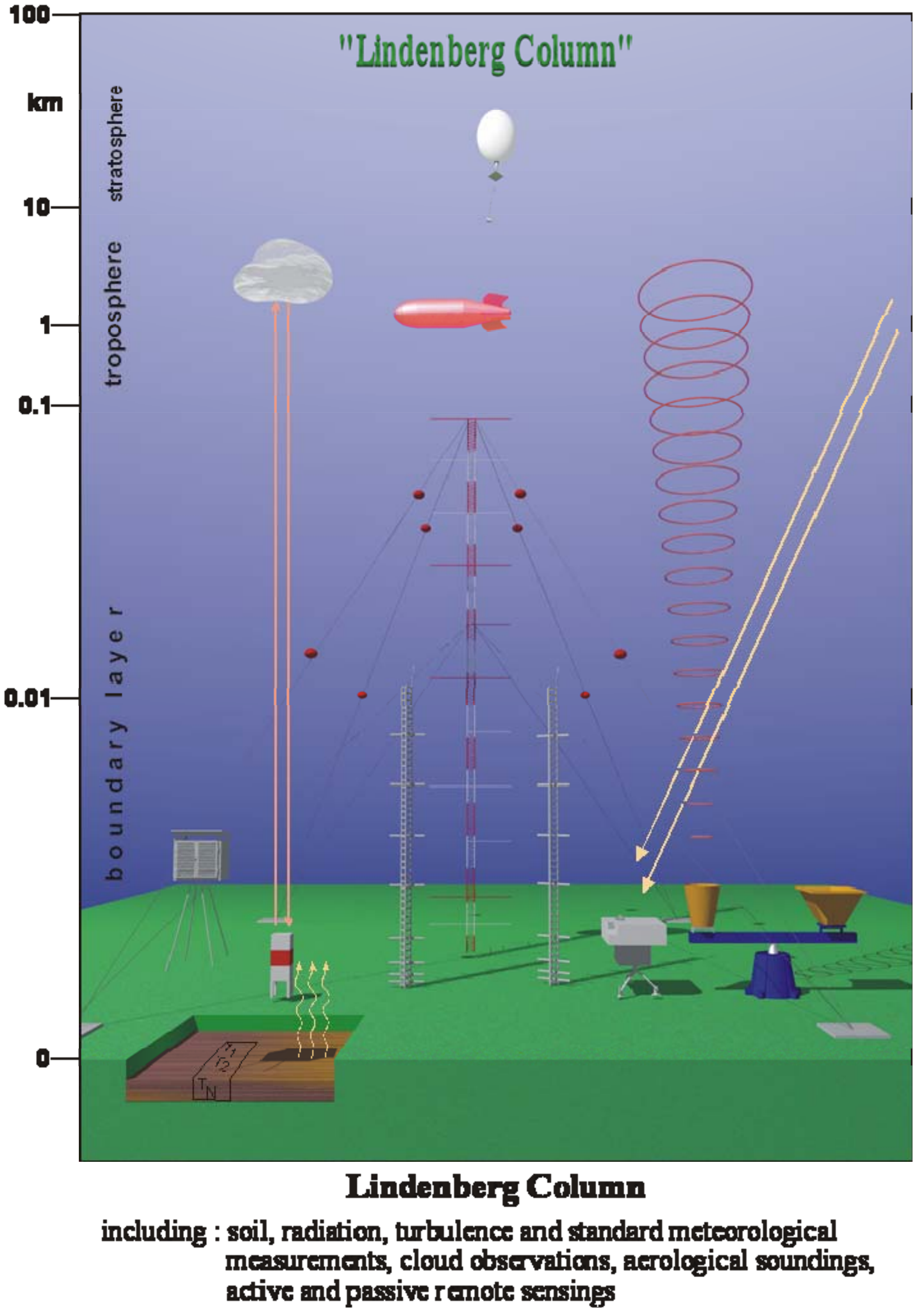

Figure 3. Site schematic of current instrumentation held at the Lindenberg observatory, Germany. Source: DWD Meteorological Observatory Lindenberg (Richard Assmann Observatory) (2006)

7. Temporal sampling issues

It is important that unambiguous observing practices are agreed and documented for all GRUAN stations. These would include targeted or special purpose observations. Because of the uncertainty of the kind of sites and their instrumentation, as well as funding issues, the following are preliminary considerations.

Most ground-based equipment makes continuous measurements except at times of required maintenance and system failures. Radiosonde-based observations incur significant unit costs, and these expendables are not generally recoverable. They have unique vertical resolution and therefore form an integral component of any upper-air reference system. It is primarily these observations whose scheduling needs careful consideration.

It is important to ensure continuity with other radiosonde data records and historical observations, therefore, radiosonde launches should be made at least at one of the standard synoptic reporting hours 00 and 12 UTC (whichever has the longest continuous record to date at the given station), and preferably at both of these times. However, there are additional considerations that should be borne in mind:

- Radiosonde launches should be made during daytime, nighttime, dawn and dusk in order to gauge the instrument behaviour under these different radiative conditions. This is especially true if the instruments, or a subset thereof, are also used as part of the comprehensive network, such that lessons learned can be transferred to this broader network both from a climate monitoring and an operational perspective.
- It is important to sample the diurnal and semi-diurnal cycles adequately in at least some places for limited time periods.
- At a minimum, stations should launch radiosondes twice daily. More frequent launches will increase the utility of a given site, regardless of whether they are at fixed times or timed to coincide with some satellite observations.

It is a matter of ongoing debate whether radiosonde launches should be made to best coincide with satellite overpass times, or at standard synoptic reporting hours, or some mix of the two.

Arguments for standard synoptic hour radiosonde launches are as follows:

- Comparisons between coincident radiosonde observations and satellite observations are in principle difficult to make due to the approximately 120 minute ascent time and possible 200 km or more horizontal drift during which a radiosonde profile is measured, and the instantaneous nature of a satellite view and the different spatial sampling;
- Maintaining constant sampling within the diurnal cycle is important to avoid aliasing in diurnal components to long-term records;
- Collocations were important solely for retrieving atmospheric profiles of geophysical variables from satellite radiance data, and this is no longer deemed a high priority.

On the other hand, there are arguments for undertaking a subset of radiosonde launches in (near) coincidence with satellite overpass times:

- Collocations remain important for diagnosing drifts in satellite radiance measurements;
- Collocations could be useful for testing the fast-forward radiative transfer models needed to assimilate radiances rather than retrieved geophysical variables;
- Having data that are systematically offset in sampling the diurnal cycle reduces their utility for direct data intercomparisons if there are underlying changes in the diurnal and semi-diurnal cycles. For many variables, diurnal cycles are not well characterized, rendering the correction for time differences between *in situ* measurements and satellite measurements difficult;
- Temporally collocated, hourly measurements of wind speed were very important in the development of SSM/I products (Wentz, 1997). Similarly, *in situ* observations have proven vital to tie down the Reynolds Optimal Interpolation SST dataset (Reynolds et al., 2002);
- 00 and 12 UTC observations are no longer as important for NWP in an age of 4D data assimilation;

- Characterizing long-term trends requires less than one radiosonde launch per day (Seidel and Free, 2006), hence there is no need for 00 and 12 UTC launches every day. However, sufficient sampling of these times is deemed important;
- Satellites observations provide the most obvious transfer function to provide global fields of radiances and geophysical variables, therefore, the radiosonde launch schedule should maximise the chances of constraining these observations.

In any case, resolution of the issue of radiosonde launch schedules for climate monitoring requires further analysis and consultation. There is no unambiguous proof of the value of either argument. Unless further research demonstrates that one set of arguments is more valuable, it is almost certain that different stations will employ somewhat different radiosonde launch schedule programmes.

8. Calibration, intercomparison and validation

Key to a successful GRUAN is robust calibration and validation. Aspects of calibration and validation related to satellite instruments are further discussed by Pollock et al. (2003) and Ohring et al. (2005). However, the principles are largely universal. They outline the following requirements:

1. The sensor data uncertainty is traced to SI standards.
2. The calibration source data uncertainty is traced to SI standards.
3. Residual uncertainty is evaluated as a function of time through simultaneous measurement by independent sensors:
    a. In the operational environment, when the sensor cannot be retrieved and tested in controlled conditions;
    b. In the laboratory, when the sensor can be retrieved and tested in these controlled conditions.
4. Extended uncertainty (systematic, random and stochastic) is computed and documented for every sensor and system.

It is a challenge to make the calibration of the measurement technology in question SI-traceable in the operational environment. For example, the thermistor in a radiosonde may be calibrated to some desired uncertainty against an SI-traceable standard before launch. However, is this pre-launch uncertainty a valid estimate for the radiosonde calibration when it is collecting data in the atmosphere? Although the issues of calibration and validation have been discussed in various instances to date, the process has clearly not yet led to a set of agreed guidelines. Such a set of guidelines is a high priority if GRUAN is to prove successful.

A traditional way of demonstrating measurement accuracy is to measure the quantity of interest through two (or more) techniques, based on physically different measurement principles. Because the different techniques are subject to unique measurement uncertainties, comparisons yield a robust and continuous demonstration of measurement accuracy. This principle has resulted in successes in measurement science, such as the detection and correction of drifts in electrochemical cells used to reproduce the standard volt (Hartland, 1988) through the application of independent techniques utilizing quantum-mechanical effects.

The principle of simultaneous measurements is clearly a key requirement for GRUAN. Such a strategy additionally requires a thorough, experimentally tested measurement uncertainty budget be produced and maintained for each instrument. These uncertainty budgets are required to characterize instrument sensitivity, and to identify any artefacts that could give rise to spurious long-term trends. In this way, complementary measurement techniques with different susceptibilities to local conditions can be chosen to maximize the accuracy of the data record. Additionally, this uncertainty budget may help identify other error sources that cannot be compensated for by complementary sensors, but may be monitored *in situ.* Another possible strategy employs redundancy of identical systems to check for minor sensor failures, such as being done in the US Climate Reference Network.

As an example, the uncertainty budget may reveal that a particular thermistor sonde has a strong susceptibility to infrared radiation near the tropopause. This effect could be compensated for by twinflights with a capacitive bead sonde that has little sensitivity to infrared radiation. Thus, potential sources of uncertainty could be minimised and properly accounted for.

Radiosonde exposure and response to the changing environment (e.g., radiosonde moving through dry and wet masses of air, precipitation, layers of low and high wind speed, turbulence) is critical to the sensor reading and cannot be characterized in a calibration chamber. Therefore, to guarantee the compatibility and data homogeneity among different radiosonde systems used in GRUAN, radiosondes should participate in the WMO Field Intercomparison of High Quality Radiosonde Systems, to be organized every five years and following their testing in the calibration laboratories.

9. Relationship to other proposals

It is recognised that the GRUAN network is not the only effort being made by the NWP and climate communities to attain better observations to meet their needs, and to provide standards for calibration and validation. It is highly unlikely that any single network or programme will meet all needs. Indeed, a robust calibration and validation system would necessarily include independent but synergistic networks or programmes so that the necessary calibration and validation can be proven robust. Therefore, GRUAN is envisaged as a vital component in a suite of activities aimed at ensuring the long-term continuity of climate data records. The other significant international activity currently being proposed is the Global Space-Based Intercalibration System (GSICS), an effort focused on calibrations between satellites, and relying on a ground-based system. Associated work on satellite calibration standards is being led by a consortium of US agencies (Ohring et al., ASIC3 (Achieving Satellite Instrument Calibration for Climate Change) 2006 workshop report, in preparation). A successful GRUAN will prove vital in providing the *in situ* measurements for the satellite intercalibration of GSICS. To assure long-term continuity in our climate records, it is essential to have both ground-based and satellite-based reference systems in place.

10. Concluding remarks

Historically, systematic long-term changes in the free atmosphere have usually been smaller than the uncertainty in historical instrument accuracy and precision. Hence, historical observations are at best difficult to use for establishing any consensus on even recent climate changes. Looking forward, despite expected significant improvements in the global observing system, there is no indication that, without a reference network like GRUAN, this system will be sufficiently stable and well-characterised in the future to meet climate research and climate monitoring requirements. To avoid this risk, the GRUAN reference network must be designed and implemented as soon as possible. This network will provide the best set of measurements, taken by instruments that have been traced to a standard to insure adequate absolute observational accuracy, as part of a comprehensive and integrated, tiered network of observing systems.

This report outlines the technical requirements, a clear siting rationale and an initial implementation concept in order to meet the requirements in a step-wise manner. In making the case for the reference network, it would be helpful to have quantitative examples of the value of reference-type observations for reducing observational ambiguity, both within a given station, and between a given station and more globally comprehensive observations (e.g., by characterising inter-satellite offsets). These examples will most obviously come from the first tier of candidate stations, and many such examples likely already exist.

In a next step, consideration of calibration and validation, management, and archive and data dissemination issues is required, as well as a proposal with full cost estimates, and the initiation of the network. GRUAN network implementation should commence as soon as practical with a few stations, with the aim of growing the network from this core. This work will be carried out under the auspices of the AOPC Working Group on Atmospheric Reference Observations (WG-ARO). The group will continue to liaise with the broader community and relevant bodies within WMO to make this network a reality. It will also pursue funding avenues for GRUAN.

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- NOAA Office of Climate Observation (http://www.oco.noaa.gov);
- US GCOS Program Office (http://www.ncdc.noaa.gov/oa/usgcos/index.htm);
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Boulder workshop web site:
http://www.oco.noaa.gov/index.jsp?show_page=page_meetings_gcos.jsp&sub_page=page_sub_DCRUAO.jsp&nav=universal

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Seattle workshop web site:
http://www.oco.noaa.gov/index.jsp?show_page=page_meetings_gcos.jsp&sub_page=page_sub_DCRUAO2.jsp&nav=universal

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Appendix 1

Requirements Tables

The following tables represent the climate observation requirements for the GCOS Reference Upper-Air Network (GRUAN), as defined at the Boulder workshop and through subsequent iterations. In the tables, the following criteria are used to characterize observations of each variable:

- Each variable is given a priority ranking of 1, 2, 3, or 4, with 1 indicating the highest priority.
- Measurement ranges are meant to cover the ranges likely to be encountered over the vertical range of interest, so that any proposed instrument or set of instruments would need to be able to operate throughout that range.
- Measurement precision refers to the repeatability of the measurement, as measured by the standard deviation of random errors. However, measurement precision is closely tied to the frequency of observations, since observations are often averaged together, and the greater the sample size, the less stringent the required precision. Measurement frequencies have not been specified because they may vary over time.
- Measurement accuracy refers to the systematic error of a measurement (the difference between the measured or derived value, and the true value). It is not directly specified for many variables for which variations, and not absolute values, are needed to understand processes.
- Measurement accuracy is directly related to long-term stability, the maximum tolerable change in systematic error over time, which is a critical aspect of the reference network. In other words, the effect on measurement error of any intervention to the measurement system, such as a change in instruments, should be smaller or quantified to a much greater degree than the value given for long-term stability, to ensure that realistic climate trends can be derived from the dataset. Long-term stability is a measure of the acceptable systematic changes to the measurements on multi-decadal timescales.
- The requirements stated here are largely consistent with the GCOS ECV observation requirements, as laid down in the WMO/CEOS database as of 23 August 2006.[3]

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[3] Further information on the WMO/CEOS database is available at: http://www.wmo.int/web/sat/satsun.html

Variable	Temperature	Water Vapour	Pressure
Priority (1-4)	1	1	1
Measurement Range	170 – 350 K	0.1 – 90000 ppmv	1 –1100 hPa
Vertical Range	0 – 50 km	0 to ~30 km	0 – 50 km
Vertical Resolution	0.1 km (0 to ~30 km) 0.5 km (above ~30 km)	0.05 km (0 – 5 km) 0.1 km (5 to ~30 km)	0.1 hPa
Precision	0.2 K	2% (troposphere) * 5% (stratosphere)	0.01 hPa
Accuracy	0.1 K (troposphere) 0.2 K (stratosphere)	2% (troposphere) * 2% (stratosphere)	0.1 hPa
Long-Term Stability	0.05 K *	1% (0.3%/decade) *	0.1 hPa
Comments	*The signal of change over the satellite era is in the order of 0.1–0.2K/ decade (cf. section 3.1), therefore long-term stability needs to be an order of magnitude smaller to avoid ambiguity	*Precision, accuracy and stability are relative with respect to mixing ratio	

Variable	Wind Speed	Wind Direction*
Priority (1-4)	2	2
Measurement Range	0 – 300 m/s	0 – 360 degrees
Vertical Range	Surface to stratopause	Surface to stratopause
Vertical Resolution	0.05 km (troposphere) 0.25 km (stratosphere)	0.05 km (troposphere) 0.25 km (stratosphere)
Precision	0.5 m/s (troposphere) 1.0 m/s (stratosphere)	1 degree (troposphere) 5 degrees (stratosphere)
Accuracy	0.5 m/s *	5 degrees
Long-Term Stability	0.1 m/s (troposphere) 0.5 m/s (stratosphere)	1 degree (troposphere) 5 degrees (stratosphere)
Comments	*to delineate calm conditions from light winds	*Direction is meaningless in very light wind conditions.

Variable	Ozone	Carbon Dioxide	Methane
Priority (1-4)	2	3	2
Measurement Range	0.005 – 20 ppmv	350 – 450 ppmv	200 – 1800 ppbv
Vertical Range	Surface to stratopause	Surface to stratopause	Surface to stratopause
Vertical Resolution	0.5 km (stratosphere) 0.2 km (troposphere)	1 km (stratosphere) 0.5 km (troposphere)	2 km

Precision			
Accuracy	3% (total column) 5% (stratosphere) 5% (troposphere)	1 % (total column) 3 ppmv (profile)	2 % (total column) 20 ppb (profile)
Long-Term Stability	0.2% (total column) 0.6% (stratosphere) 1% (troposphere)	1 ppmv	
Comments			

Variable	**Net Radiation**	**Incoming Shortwave Radiation**	**Outgoing Shortwave Radiation**
Priority (1-4)	2	2	2
Measurement Range	-300 – 1500 W/m^2	0 – 2000 W/m^2 *	0 – 1365 W/m^2
Vertical Range	Surface	Surface	Surface
Precision	5 W/m^2 *	3 W/m$^{2\ \#}$	2 W/m^2 *
Accuracy	5 W/m^2 *	5 W/m$^{2\ \#}$	3% *
Long-Term Stability	0.1 W/m^2	0.1 W/m^2	0.1 W/m^2
Comments	*Accuracy and precision units from BSRN.	*Incorporates cloud reflection effects. $^\#$Accuracy and precision units from BSRN.	*Accuracy and precision units from BSRN.

Variable	**Incoming Longwave Radiation**	**Outgoing Longwave Radiation**	**Radiances**
Priority (1-4)	2	2	2
Measurement Range	50 – 700 W/m^2	50 – 900 W/m^2	Full spectral range 100 – 1700 cm^{-1} 190 K<T_b<330 K
Vertical Range	Surface	Surface	Surface to top of atmosphere. Need TOA upwelling and surface down-welling, but not levels in-between.
Vertical Resolution	N/A	N/A	N/A
Precision	1 W/m^2 *	1 W/m^2 *	0.01%
Accuracy	3 W/m^2 *	3 W/m^2 *	0.15%
Long-Term Stability	0.1 W/m^2	0.1 W/m^2	0.03% per decade
Comments	*Accuracy and precision units from BSRN.	*Accuracy and precision units from BSRN.	Stability requirement achievable through SI traceability; precision/ accuracy requirement for mean seasonal radiances at ~1000 km spatial scale.

Variable	Aerosol Optical Depth	Total Mass Concentration	Chemical Mass Concentration
Priority (1-4)	2	2	2
Measurement Range	0.005 – 5	0.1 – 100 μg m^{-3}	0.1 – 30 μg m^{-3}
Vertical Range	Total column	0 – 6 km	0 – 6 km
Vertical Resolution	N/A	500 m	500 m
Precision	0.005	10%	10%
Accuracy	0.005	10%	10%
Long-Term Stability	0.005	10%	10%
Comments	Spectral measurements; of all aerosol parameters, this can be considered the most important. While the others become important if AOD is large, they are of little or no importance when it is small, which it mostly the case over large parts of the globe.	Size-fractionated	Size-fractionated

Variable	Light Scattering	Light Absorption
Priority (1-4)	2	2
Measurement Range	0.1 – 1000 Mm^{-1}	0.1 – 1000 Mm^{-1}
Vertical Range	0 – 6 km	0 – 6 km
Vertical Resolution	500 m	500 m
Precision	10%	10%
Accuracy	10%	10%
Long-Term Stability	10%	10%
Comments	Size-fractionated, spectral	Size-fractionated, spectral

Variable	Cloud Amount/Frequency	Cloud Base Height	Cloud Layer Heights and Thicknesses
Priority (1-4)	2	2	2
Measurement Range	0 – 100 %	0 – 20 km * (1000–50mb)	0 – 20 km
Vertical Range	0 – 20 km	Surface to 50 mb	Surface to 50 mb
Vertical Resolution	50 m	5 mb	50 m *

Precision	0.1 – 0.3% *	100 m (10 – 40 mb [#])	50 m [#]
Accuracy	0.1 – 0.3% *	100 m (10 – 40 mb [#])	50 m [#]
Long-Term Stability	0.1 – 0.2% [#]	20 m/decade [§]	50 m/decade
Comments	*1–3% variations from ISCCP [#]1–2%/decade trend (Norris, 2005)	* 1000–50mb (Rossow and Schiffer, 1999) [#] 10–40 mb variations from ISCCP [§] 44/154 m/decade for base/top from Chernykh et al. (2001), which was questioned by Seidel and Durre (2003)	* the minimum layer thickness of ~30 m (cirrus) (Del Genio et al., 2002; Winker and Vaughan, 1994) [#]the standard deviation of >= 100 m (Wang et al., 2000)

Variable	**Cloud Top Height**	**Cloud Top Pressure**	**Cloud Top Temperature**
Priority (1-4)	3	3	3
Measurement Range	0 – 20 km	1013 – 15 hPa	190 – 310 K
Vertical Range	0 – 20 km	0 – 20 km	0 – 20 km
Vertical Resolution	150 m	150 m	1 km
Precision	50 m	1 hPa	
Accuracy	150 m	15 hPa	0.3K/(cloud emissivity)
Long-Term Stability	30 m	3 hPa	0.2K/(cloud emissivity)
Comments			

Variable	**Cloud Particle Size**	**Cloud Optical Depth**	**Cloud Liquid Water/Ice**
Priority (1-4)	4	4	4
Measurement Range			
Vertical Range	0 – 20 km	0 – 20 km	0 – 20 km
Vertical Resolution	1 km	1 km	1 km
Precision			
Accuracy	10% water 20% ice	10%	25% water 0.025 mm ice
Long-Term Stability	2% water 4% ice	2%	5% water 0.005 mm ice
Comments			

Appendix 2

GCOS Climate Monitoring Principles

Effective monitoring systems for climate should adhere to the following principles[4]:

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.

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[4] *The ten basic principles (in paraphrased form) were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. This complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.*

Appendix 3

Glossary of Acronyms

AERI	Atmospheric Emitted Radiance Interferometer
AMMA	African Monsoon Multi-disciplinary Analysis
AOD	Aerosol Optical Depth
AOPC	Atmospheric Observation Panel for Climate
ARM	Atmospheric Radiation Measurement Program
BSRN	Baseline Surface Radiation Network
BUFR	coding used to transmit meteorological observations across the GTS
CBS	WMO Commission for Basic Systems
CCSP	United States Climate Change Science Program
CEOS	Committee on Earth Observation Satellites
CIMO	WMO Commission for Instruments and Methods of Observation
DWD	Deutscher Wetterdienst
ECMWF	European Centre for Medium Range Weather Forecasts
ECVs	Essential Climate Variables
GCMP	GCOS Climate Monitoring Principle
GCOS	Global Climate Observing System
GEOSS	Global Earth Observing System of Systems
GOS	Global Observing System
GPS	Global Positioning System
GPS RO	Global Positioning System Radio Occultation
GRUAN	GCOS Reference Upper-Air Network
GSICS	Global Space-Based Intercalibration System
GTS	Global Telecommunications System
GUAN	GCOS Upper-Air Network
IGS	International GNSS (Global Navigation Satellite Systems) Service
IONS04	INTEX Ozonesonde Network Study 2004
IONS06	INTEX Ozonesonde Network Study 2006
IPCC	Intergovernmental Panel on Climate Change
ISCCP	International Satellite Cloud Climatology Project
JMA	Japan Meteorological Administration
MWR	Microwave Radiometer
NASA	United States National Aeronautics and Space Administration
NCAR	United States National Center for Atmospheric Research
NCEP	United States National Center for Environmental Prediction
NDACC	Network for the Detection of Atmospheric Composition Change
NOAA	United States National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
SHADOZ	NASA/Southern Hemisphere Additional Ozonesondes network
SI	Système International (d'Unités) – International System of Units
SSM/I	Special Sensor Microwave Imager
SST	Sea Surface Temperature
TOA	Top of Atmosphere
UNFCCC	United Nations Framework Convention on Climate Change
US CRN	United States Climate Reference Network
UTC	Coordinated Universal Time
WMO	World Meteorological Organization

LIST OF GCOS PUBLICATIONS*

GCOS-1 (WMO/TD-No. 493)	Report of the first session of the Joint Scientific and Technical Committee for GCOS (Geneva, Switzerland, April 13-15, 1992)
GCOS-2 (WMO/TD-No. 551)	Report of the second session of the Joint Scientific and Technical Committee for GCOS (Washington DC, USA, January 11-14, 1993)
GCOS-3 (WMO/TD-No. 590)	Report of the third session of the Joint Scientific and Technical Committee for GCOS (Abingdon, UK, November 1-3,1993)
GCOS-4 (WMO/TD-No. 637)	Report of the fourth session of the Joint Scientific and Technical Committee for GCOS (Hamburg, Germany, September 19-22, 1994)
GCOS-5 (WMO/TD-No. 639)	Report of the GCOS Data System Task Group (Offenbach, Germany, March 22-25, 1994)
GCOS-6 (WMO/TD-No. 640)	Report of the GCOS Atmospheric Observation Panel, first session (Hamburg, Germany, April 25-28, 1994)
GCOS-7 (WMO/TD No. 641)	Report of the GCOS Space-based Observation Task Group (Darmstadt, Germany, May 3-6, 1994)
GCOS-8 (WMO/TD No. 642) (UNEP/EAP.MR/94-9)	Report of the GCOS/GTOS Terrestrial Observation Panel, first session (Arlington, VA, USA, June 28-30, 1994)
GCOS-9 (WMO/TD-No. 643)	Report of the GCOS Working Group on Socio-economic Benefits, first session (Washington DC, USA, August 1-3, 1994)
GCOS-10 (WMO/TD-No. 666)	Summary of the GCOS Plan, Version 1.0, April 1995
GCOS-11 (WMO/TD-No. 673)	Report of the GCOS Data and Information Management Panel, first session (Washington DC, USA, February 7-10, 1995)
GCOS-12 (WMO/TD-No. 674)	The Socio-economic Benefits of Climate Forecasts: Literature Review and Recommendations (Report prepared by the GCOS Working Group on Socio-economic Benefits), April 1995
GCOS-13 (WMO/TD-No. 677)	GCOS Data and Information Management Plan, Version 1.0, April 1995
GCOS-14 (WMO/TD-No. 681)	Plan for the Global Climate Observing System (GCOS), Version 1.0, May 1995
GCOS-15 (WMO/TD-No. 684)	GCOS Plan for Space-based Observations, Version 1.0, June 1995
GCOS-16 (WMO/TD-No. 685)	GCOS Guide to Satellite Instruments for Climate, June 1995
GCOS-17 (WMO/TD-No. 696)	Report of the GCOS Atmospheric Observation Panel, second session (Tokyo, Japan, March 20-23, 1995)

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GCOS-18 (WMO/TD-No. 697) (UNEP/EAP.MR/95-10)	Report of the GCOS/GTOS Terrestrial Observation Panel, second session (London, UK, April 19-21, 1995)
GCOS-19 (WMO/TD-No. 709)	Report of the GCOS Data Centre Implementation/Co-ordination Meeting (Offenbach, Germany, June 27-29, 1995)
GCOS-20 (WMO/TD-No. 720)	GCOS Observation Programme for Atmospheric Constituents: Background, Status and Action Plan, September 1995
GCOS-21 (WMO/TD-No. 721) (UNEP/EAP.TR/95-07)	GCOS/GTOS Plan for Terrestrial Climate-related Observations, version 1.0, November 1995
GCOS-22 (WMO/TD-No. 722)	Report of the fifth session of the Joint Scientific and Technical Committee for GCOS (Hakone, Japan, October 16-19, 1995)
GCOS-23 (WMO/TD-No. 754) (UNEP/DEIA/MR.96-6) (FAO GTOS-1)	Report of the GCOS/GTOS Terrestrial Observation Panel for Climate, third session (Cape Town, South Africa, March 19-22, 1996)
GCOS-24 (WMO/TD-No. 768) (UNESCO/IOC)	Report of the Joint GCOS/GOOS/WCRP Ocean Observations Panel for Climate, first session (Miami, Florida, USA, March 25-27, 1996)
GCOS-25 (WMO/TD-No. 765) (UNEP/DEIA/MR.96-5)	Report of the GCOS Data and Information Management Panel, second session (Ottawa, Ontario, Canada, May 14-17, 1996)
GCOS-26 (WMO/TD-No. 766)	Report of the Joint CCI/CBS Expert Meeting on the GCOS Surface Network (Norwich, UK, March 25-27, 1996)
GCOS-27 (WMO/TD-No. 772) (UNEP/DEIA/MR.96-7)	Report of the Expert Meeting on Hydrological Data for Global Observing Systems (Geneva, Switzerland, April 29-May 1, 1996)
GCOS-28 (WMO/TD-No. 793) (UNEP/DEIA/MR.97-3)	*In Situ* Observations for the Global Observing Systems (Geneva, Switzerland, September 10-13, 1996)
GCOS-29 (WMO/TD-No. 794) (UNEP/DEIA/MR.97-4)	Report of the Global Observing Systems Space Panel, second session (Geneva, Switzerland, October 16-18, 1996)
GCOS-30 (WMO/TD-No. 795)	Report of the sixth session of the Joint Scientific and Technical Committee for GCOS (Victoria, British Columbia, Canada, October 28-November 1, 1996)
GCOS-31 (WMO/TD-No. 803)	Proceedings of the fifth meeting of the TAO Implementation Panel (TIP-5) (Goa, India, November 18-21, 1996)

GCOS-32 (WMO/TD-No. 796)	GCOS/GTOS Plan for Terrestrial Climate-related Observations, version 2.0, June 1997
GCOS-33 (WMO/TD-No. 798)	GHOST - Global Hierarchical Observing Strategy, March 1997
GCOS-34 (WMO/TD-No. 799)	Initial Selection of a GCOS Surface Network, February 1997
GCOS-35 (WMO/TD-No. 839)	Report of the second Joint CCI/CBS Meeting on the GCOS Surface Network (De Bilt, The Netherlands, June 25-27, 1997)
GCOS-36 (WMO/TD-No. 844) (UNESCO/IOC)	Report of the Joint GCOS/GOOS/WCRP Ocean Observations Panel for Climate, second session (Cape Town, South Africa, February 11-13, 1997)
GCOS-37 (WMO/TD-No. 845) (GOOS-10) & (GTOS-9)	Report of the Global Observing Systems Space Panel, third session (Paris, France, May 27-30, 1997)
GCOS-38 (WMO/TD-846) (GTOS-10)	Report of the Meeting of Experts on Ecological Networks (Guernica, Spain, June 17-20, 1997)
GCOS-39 (WMO/TD-No. 847) (GOOS-11) & (GTOS-11) (UNEP/DEIA/MR.97-8)	Report of the GCOS/GOOS/GTOS Joint Data and Information Management Panel, third session (Tokyo, Japan, July 15-18, 1997)
GCOS-40 (WMO/TD-No. 848)	Report of the GCOS/WCRP Atmospheric Observation Panel for Climate, third session (Reading, UK, August 19-22, 1997)
GCOS-41 (WMO/TD-No. 849) (GOOS-33)	Report of the Joint GCOS/GOOS/WCRP Ocean Observations Panel for Climate (OOPC) Ocean Climate Time-Series Workshop, (Baltimore, MD, USA, March 18-20, 1997)
GCOS-42 (WMO/TD-No. 857)	Report of the seventh session of the Joint Scientific and Technical Committee for GCOS (Eindhoven, The Netherlands, September 22-26, 1997)
GCOS-43a (GOOS-36)	TAO Implementation Panel, sixth session (Reading, U.K., November 4-6, 1997)
GCOS-43b (GOOS-55)	International Sea Level Workshop (Honolulu, Hawaii, USA, June 10-11, 1997)
GCOS-44 (GOOS-61)	Report of the Joint GCOS/GOOS/WCRP Ocean Observations Panel for Climate (OOPC), third session (Grasse, France, April 6-8, 1998)
GCOS-45 (WMO/TD-No. 922) (GOOS-58) & (GTOS-16) (UNEP/DEIA/MR.98-6)	Report of the Joint Meeting of the GCOS/WCRP Atmospheric Observation Panel for Climate and the GCOS/GOOS/GTOS Joint Data and Information Management Panel, fourth session (Honolulu, Hawaii, USA, April 28-May 1, 1998)

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GCOS-46 (GTOS-15)	Report of the GCOS/GTOS Terrestrial Observation Panel for Climate, fourth session (Corvallis, USA, May 26-29, 1998)
GCOS-47 (WMO/TD-No. 941) (GOOS-67) (GTOS-20)	Report of the Global Observing Systems Space Panel, fourth session, (College Park, Maryland, USA, October 22-23, 1998)
GCOS-48	Report on the Adequacy of the Global Climate Observing Systems (United Nations Framework Convention on Climate Change, November 2-13 1998, Buenos Aires, Argentina)
GCOS-49 (GOOS-64)	Implementation of Global Ocean Observations for GOOS/GCOS, first session (Sydney, Australia, March 4-7, 1998)
GCOS-50 (GOOS-65)	Implementation of Global Ocean Observations for GOOS/GCOS, second session (Paris, France, November 30, 1998)
GCOS-51 (GOOS-66)	Global Ocean Observations for GOOS/GCOS: An Action Plan for Existing Bodies and Mechanisms
GCOS-52 (GOOS-68)	TAO Implementation Panel, seventh session (Abidjan, Ivory Coast, November 11-13, 1998)
GCOS-53 (WMO/TD-No. 958)	GCOS Surface Network (GSN) Monitoring Centre Implementation Meeting (Offenbach, Germany, January 19-20, 1999)
GCOS-54 (WMO/TD-No. 953)	Report of the eighth session of the WMO-IOC-UNEP-ICSU Steering Committee for GCOS (Geneva, Switzerland, February 9-12, 1999)
GCOS-55	Report of the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC), fifth session (Silver Spring, MD, USA, April 20-23, 1999)
GCOS-56 (GOOS-75)	Special Report of the Joint GCOS/GOOS/WCRP Ocean Observations Panel for Climate (OOPC), fourth session (May 17, 1999); The CLIVAR Upper Ocean Panel (UOP), fourth session (May 21, 1999); A Joint Planning Meeting of the OOPC and the UOP for the OCEANOBS99 Conference (Woods Hole, MA, USA, May 18-20, 1999)
GCOS-57 (WMO/TD-No. 978) (GOOS-79)	Report of the OOPC/AOPC Workshop on Global Sea Surface Temperature Data Sets (Palisades, N.Y., USA, November 2-4, 1998)
GCOS-58 (GOOS-71**)**	Report of the sixth session of the IOC Group of Experts on the Global Sea Level Climate Observing System (GLOSS)
GCOS-59 (GTOS-22)	Report of the GCOS/GTOS Terrestrial Observation Panel for Climate, fifth session (Birmingham, UK, July 27-30, 1999)
GCOS-60 (WMO/TD-No. 1004) (GOOS-70)	GCOS/GOOS/GTOS Joint Data and Information Management Plan, Version 1.0, May 2000

GCOS-61 (WMO/TD-No. 1031)	Report of the ninth session of the WMO-IOC-UNEP-ICSU Steering Committee for GCOS (Beijing, China, September 12-14, 2000)
GCOS-62 (WMO/TD-No. 1038)	Report of the Pacific Islands Regional Implementation Workshop on Improving Global Climate Observing Systems (Apia, Samoa, August 14-15, 2000)
GCOS-63 (WMO/TD-No. 1047) (GTOS-26)	Establishment of a Global Hydrological Observation Network for Climate. Report of the GCOS/GTOS/HWRP Expert Meeting (Geisenheim, Germany, June 26-30, 2000)
GCOS-64 (GOOS-107)	Report of the eighth session of the TAO Implementation Panel (TIP-8) (St. Raphael, France, October 15, 1999)
GCOS-65 (WMO/TD-No. 1055)	Report of the sixth session of the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC) (Geneva, Switzerland, April 10-13, 2000)
GCOS-66 (GOOS-108)	Report of the ninth session of the TAO Implementation Panel (TIP-9) (Perth, Australia, November 16-17, 2000)
GCOS-67 (WMO/TD-No. 1072)	GCOS Implementation Strategy: Implementing GCOS in the New Millennium
GCOS-68 (WMO/TD-No. 1093)	Report of the seventh session of the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC) (Geneva, Switzerland, April 30-3 May, 2001)
GCOS-69 (GOOS-98)	Report of the fifth session of the Joint GCOS-GOOS-WCRP Ocean Observations Panel for Climate (OOPC), Bergen, Norway, June 20-23, 2000.
GCOS-70 (GOOS-113)	Report of the sixth session of the Joint GCOS-GOOS-WCRP Ocean Observations Panel for Climate (OOPC), Melbourne, Australia, May 2-5, 2001
GCOS-71 (WMO/TD-No. 1099) (GTOS-29)	Report of the GCOS/GTOS/HWRP Expert Meeting on the Implementation of a Global Terrestrial Network - Hydrology (GTN-H), Koblenz, Germany, June 21-22, 2001
GCOS-72 (GOOS-116)	Report of the seventh session of the IOC Group of Experts on the Global Sea Level Observing System (GLOSS), Honolulu, April 26-27, 2001
GCOS-73 (WMO/TD-No. 1106)	Manual on the GCOS Surface and Upper-Air Networks: GSN and GUAN, April 2002
GCOS-74 (WMO/TD-No. 1109)	Report of the GCOS Regional Workshop for Eastern and Southern Africa on Improving Observing Systems for Climate, Kisumu, Kenya, October 3-5, 2001
GCOS-75 (WMO/TD-No. 1124)	Summary Report of the tenth session of the WMO-IOC-UNEP-ICSU Steering Committee for GCOS, Farnham, UK, April 15-19, 2002
GCOS-76 (WMO/TD-No. 1125)	Report of the eighth session of the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC), Wokingham, UK, May 20-24, 2002

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GCOS-77 (GOOS-122)	International Workshop for Review of the Tropical Moored Buoy Network, September 10-12, 2001, Seattle, Washington, USA. Workshop Report
GCOS-78 (WMO/TD-No. 1126)	Report of the GCOS Regional Workshop for Central America and the Caribbean. "Observing Climate from Weather Extremes to Coral Reefs", San José, Costa Rica, March 19-21, 2002 (disponible también en español)
GCOS-79 (WMO/TD-No. 1133)	Interim Report to the sixteenth session of the Subsidiary Body for Scientific and Technological Advice of the UNFCCC by the Global Climate Observing System, Bonn, Germany, June 5-14, 2002
GCOS-80 (WMO/TD-No.1140)	Report of the GCOS Regional Workshop for East and Southeast Asia on Improving Observing Systems for Climate, Singapore, September 16-18, 2002
GCOS-81 (GOOS-124)	Seventh session of the Joint GCOS-GOOS-WCRP Ocean Observations Panel for Climate (OOPC), Kiel, Germany, June 5-8, 2002
GCOS-82 (WMO/TD-No.1143)	Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC
GCOS-82 (ES) (WMO/TD-No.1176)	Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC – Executive Summary
GCOS-83 (WMO/TD-No.1155) (GTOS-33)	Report of the Global Terrestrial Network - Hydrology (GTN-H) Coordination Panel Meeting, Toronto, Canada, November 21-22, 2002
GCOS-84 (WMO/TD-No.1156) (GTOS-32)	Report of the GCOS/GTOS/HWRP Expert Meeting on Hydrological Data for Global Studies, Toronto, Canada, November 18-20, 2002
GCOS-85 (WMO/TD-No.1167)	Report of the GCOS Regional Workshop for Western and Central Africa on Improving Observing Systems for Climate, Niamey, Niger, March 27-29, 2003 (disponible en français)
GCOS-86 (WMO/TD-No.1183)	Report of the GCOS Regional Workshop for South America on Improving Observing Systems for Climate, Santiago, Chile, October 14-16, 2003 (disponible también en español)
GCOS-87 (WMO/TD-No.1189)	Summary Report of the eleventh session of the WMO-IOC-UNEP-ICSU Steering Committee for GCOS, Melbourne, Australia, April 7-10, 2003
GCOS-88 (WMO/TD-No. 1190)	Conclusions from the ninth session of the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC), Asheville, NC, USA, June 23-27, 2003
GCOS-89 (GOOS-140)	Report of the Eighth session of the Joint GCOS-GOOS-WCRP Ocean Observations Panel for Climate (OOPC), Ottawa, Canada, September 3-6, 2003
GCOS-90 (GOOS-141)	IOC Group of Experts on the Global Sea Level Observing System (GLOSS), eighth session, Paris, France, October 13 and 16-17, 2003

GCOS-90bis	Report of the GCOS/GTOS Terrestrial Observation Panel for Climate (TOPC), seventh session, Rome, Italy, December 16-18, 2003.
GCOS-91 (WMO/TD-No.1221)	Summary Report of the twelfth session of the WMO-IOC-UNEP-ICSU Steering Committee for GCOS, Geneva, Switzerland, March 15-19, 2004
GCOS-91bis	Conclusions from the tenth session of the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC), Geneva, Switzerland, April 19-23, 2004
GCOS-92 (WMO/TD-No.1219)	Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC
GCOS-92 (ES) (WMO/TD-No.1244)	Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC – Executive Summary
GCOS-93 (WMO/TD-No.1238) GTOS-35	Summary Report of the eighth session of the GTOS/GCOS Terrestrial Observation Panel for Climate, Ispra, Italy, April 6-7, 2004
GCOS-94 (WMO/TD-No.1248)	Report of the GCOS Regional Workshop for Central Asia on Improving Observing Systems for Climate, Almaty, Kazakhstan, May 24-26, 2004 (имеется также на русском языке)
GCOS-95 (GOOS-143)	Report of the ninth session of the Joint GCOS-GOOS-WCRP Ocean Observations Panel for Climate (OOPC), Southampton, UK, June 7-10, 2004
GCOS-96 (WMO/TD-No. 1255)	Analysis of Data Exchange Problems in Global Atmospheric and Hydrological Networks
GCOS-97 (WMO/TD-No. 1259)	Report of the GCOS Regional Workshop for South and Southwest Asia on Improving Observing Systems for Climate, New Delhi, India, October 11-13, 2004
GCOS-98 (GOOS-146)	Progress with the Initial Ocean Climate Observing System: A Report to the UNFCCC – April 2005
GCOS-99 (GOOS-149)	IOC Group of Experts on the Global Sea Level Observing System (GLOSS), ninth session, Paris, France, February 24-25, 2005
GCOS-100 (WMO/TD-No. 1283)	Report of the GCOS Regional Workshop for Eastern and Central Europe on Improving Observing Systems for Climate, Leipzig, Germany, April 26-28, 2005
GCOS-101 (WMO/TD-No. 1298) (GTOS-37)	Report of the 2nd Meeting of the GTN-H Coordination Panel, Koblenz, Germany, July 4-5, 2005
GCOS-102	Conclusions from the eleventh session of the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC), Geneva, Switzerland, April 11-15, 2005
GCOS-103 (WMO/TDN-No 1341)	Summary report of the thirteenth session of the WMO-IOC-UNEP-ICSU Steering Committee for GCOS, St Petersburg, Russian Federation, 5-8 October 2005

GCOS-104 (GOOS-150)	Report of the tenth session of the Joint GCOS-GOOS-WCRP Ocean Observations Panel for Climate Tenth, Geneva, Switzerland, May 9-12, 2005 Session Final Report
GCOS-105 (WMO/TD-No. 1374	Summary Report of the Thirteenth Session of the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC), Geneva, Switzerland, April 3-7, 2006
GCOS-106 (WMO/TD-No. 1337)	Report of the GCOS Regional Workshop for the Mediterranean Basin, Marrakech, Morocco, November 22-24, 2005
GCOS-107 (WMO/TD-No. 1338)	Systematic Observation Requirements for Satellite-Based Products for Climate
GCOS-108 (WMO/TD-No. 1358)	Climate Information for Development Needs an Action Plan for Africa, Report and Implementation Strategy, Addis Ababa, Ethiopia, 18-21 April 2006
GCOS-109 (WMO/TD-No 1363)	Summary report of the fourteenth session of the WMO-IOC-UNEP-ICSU Steering Committee for GCOS, Geneva, Switzerland 10-12 October 2006
GCOS-110 (WMO/TD-No. 1370) (GOOS No. 154) (WCRP No.)	Joint GCOS-GOOS-WCRP Ocean Observations Panel for Climate (OOPC), Eleventh Session, Tokyo, Japan 16-20 May 2006
GCOS-111 (WMO/TD-No. 1371) (GTOS No. 43)	Summary Report of the ninth session of the GTOS/GCOS Terrestrial Observation Panel for Climate, Ispra, Italy 28-29 March 2006
GCOS-112 (WMO/TD-No. 1379)	GCOS Reference Upper-Air Network (GRUAN): Justification, requirements, siting and instrumentation options

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