GLOBAL CLIMATE OBSERVING SYSTEM

WMO | of UNESCO | UNEP | ICSU

WORLD METEOROLOGICAL ORGANIZATION

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

# GRUAN Implementation Plan 2009-2013

**July 2009**

**GCOS-134**

**(WMO/TD No. 1506)**

UNITED NATIONS ENVIRONMENT PROGRAMME

INTERNATIONAL COUNCIL FOR SCIENCE

Chairperson, Publications Board
World Meteorological Organization (WMO)
7 *bis*, avenue de la Paix
P.O. Box No. 2300
CH-1211 Geneva 2, Switzerland

Tel.: +41 (0)22 730 84 03
Fax: +41 (0)22 730 80 40
E-mail: Publications@wmo.int

# IMPLEMENTATION PLAN FOR THE GLOBAL CLIMATE OBSERVING SYSTEM REFERENCE UPPER AIR NETWORK 2009-2013

**July 2009**

**GCOS - 134**

**(WMO/TD No. 1506)**

*(Intentionally blank)*

# TABLE OF CONTENTS

*(Intentionally blank)*

# IMPLEMENTATION PLAN FOR THE GLOBAL CLIMATE OBSERVING SYSTEM REFERENCE UPPER AIR NETWORK 2009-2013

## CAPSULE

*This document provides a five-year roadmap for Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) implementation during the years 2009-2013, detailing the steps needed to reach the goal of establishing a reference upper air network for climate.*

# 1. Introduction

## *1.1. Rationale*

To understand our changing climate and the underlying causes requires an understanding of changes not just at the surface but also throughout the atmospheric column. Existing records of upper-air atmospheric measurements are manifestly not good enough for studying long-term climate change to the required degree of accuracy. They greatly lack the necessary continuity, homogeneity and representativeness of data, because past observations were never made for climate research, but mainly for the purpose of short term weather forecasting. Evidence of the issues this causes abounds. The uncertainty in temperature trends has caused major political and scientific controversy spawning more than 100 papers on the subject over the last 20 years and two dedicated high-level expert reviews (NRC, 2001; Karl et al., 2006). Similarly, upper tropospheric water vapour trends, a key determinant of climate sensitivity to greenhouse gas forcing, are very poorly known (Rosenlof, 2003). Similar examples exist for all other relevant upper-air GCOS Essential Climate Variables (cf. Appendix 1 for full list).

If the monitoring of upper-air climate continues to be driven largely by non-climate monitoring requirements, unacceptable long-term biases in the observations will persist despite somewhat better focus on climate and much better instrumentation than has been the case historically. Recognising this, since the early 1990s, the climate research community has been calling for a ground-based reference observing system for measuring upper-air changes (Karl et al., 1996; Karl et al., 2006; NRC, 1999; GCOS-92; Trenberth et al., 2002). The GCOS Reference Upper Air Network (GRUAN henceforth) is proposed as the ground-based calibration/validation programme to close this gap in climate observations. When fully implemented, taken together with dedicated satellite-based infrastructure, such as a successful GSICS[1] programme and the proposed reference quality satellite missions (e.g. CLARREO[2]), GRUAN promises a robust upper-air climate record for the future. All these programmes are important and need strong support if we are to gain the unimpeachable long-term record that is necessary to support climate-based decision making and climate services in the future.

[1] The Global Space-based Inter-Calibration System (GSICS) project was launched in 2005 by WMO and the Coordination Group for Meteorological Satellites (CGMS) in order to improve climate monitoring and weather forecasting by examining and harmonizing data from operational meteorological satellites: http://gsics.wmo.int/

[2] NASA's "Climate Absolute Radiance and Refractivity Observatory" mission: http://clarreo.larc.nasa.gov/

## *1.2. Goals*

The reliable and sustained detection of changes in the atmosphere along a vertical profile from near the ground to the lower stratosphere requires very high-quality observations of upper-air Essential Climate Variables. Such observations are currently not available on a global scale at sufficient spatial sampling. For this reason, the concept of a reference upper-air network consisting of eventually 30-40 sites worldwide, the GRUAN, was developed during 2005-2007. GRUAN was first called for in the 2004 *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* (GCOS Implementation Plan henceforth; GCOS-92, WMO/TD 1219) and the relevant text is repeated verbatim below:

> *"There remain outstanding issues concerning the quality of all radiosonde measurements for climate monitoring and climate change detection purposes. Radiation errors cause uncertainties in temperature, and standard radiosondes are not capable of measuring water vapour at low concentrations with sufficient accuracy. A network of about 30 such reference sites is proposed to permit systematic observations across all climate zones. This network will be extensively used to calibrate and validate various satellite observations including GPS occultation, as well as microwave and infrared sounding data on both temperature and water vapour. In addition to providing a network for climate purposes, the network will provide new information on water vapour in the upper troposphere and lower stratosphere that is vital for understanding the greenhouse effect.*
>
> *The operational observing programme for such a reference radiosondes (frequency and instrumentation performance requirements) needs to be specified to align with the needs of all relevant users, including Space Agencies. The new network will be considered as a special component of the GUAN. Initiating and implementing this network on a five-year timetable is a very high priority. Where feasible, these reference sites should be collocated and consolidated with other climate monitoring instrumentation (e.g., GPS column water vapour measurements, ozonesonde and other GAW observatories). In addition to establishing the observation sites, it will be important to have mechanisms for quality control, archive and analysis of the data. The AOPC[3], in consultation with WMO CBS, will develop plans for the implementation of a reference network of high-altitude high-quality radiosondes, including data management, archiving and analysis."*

***Action A16 from the GCOS Implementation Plan***

> ***Action:*** *Specify and implement a Reference Network of high-altitude, high-quality radiosondes, including operational requirements and data management, archiving and analysis.*
> ***Who:*** *Parties' National Meteorological Services and research agencies, in cooperation with AOPC and WMO CBS.*
> ***Time-Frame:*** *Specification and plan by 2005. Implementation completed by 2009.*
> ***Performance Indicator:*** *Plan published. Data management system in place. Network functioning. Data availability.*
> ***Cost Implications:*** *Category IV (10M-30M USD annual recurring incremental cost).*

[3] The Atmospheric Observation Panel for Climate (AOPC) is a joint expert panel by GCOS and the World Climate Research Programme (WCRP); see section 1.4 for GRUAN governance.

The GRUAN rationale was refined in *GRUAN: Justification, requirements, siting and instrumentation options* (GCOS-112, WMO/TD No. 1379, April 2007) as being 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.

As pointed out in GCOS-112, a fully-implemented GRUAN would address

- Monitoring and detecting climate variability and change;
- Understanding the vertical profile of temperature trends;
- Understanding the climatology and variability of water vapour, particularly in the upper-troposphere and lower stratosphere, and changes in the hydrological cycle;
- Understanding and monitoring tropopause characteristics;
- Monitoring ozone, trace gases and aerosols;
- Improvement of climate prediction;
- High-quality reanalyses of climate change;
- Understanding climate processes and improving climate models;
- Satellite calibration and validation;
- Improvement of Quality Control and Quality Assurance for the GUAN network;
- Provision of high quality, high resolution atmospheric profile data to support operational forecasting and NWP.

GRUAN is expected to make full use of the best upper-air observational capability and expertise worldwide, and build on existing measurement capabilities and experiences that meet the necessary requirements (see GCOS-112, pp 9-10). Currently, the comprehensive, spatially-dense Global Observing System (GOS) of the World Meteorological Organization (WMO), encompassing the majority of operational radiosoundings in the world, is the in-situ observational basis for all meteorological applications, such as numerical weather prediction, nowcasting and short-term forecasting, including severe weather forecasting and warnings. The GUAN as a subset and "global backbone for climate" of the GOS, is designed to provide global coverage and long-term observations necessary to characterize hemispheric and global scale patterns of changes in upper-air temperature, wind and humidity. However, GUAN instrumentation and site operation practices manifestly do not meet the need for reference-quality observations (cf. GRUAN Requirement Tables in Appendix 1). For this reason, GRUAN was designed to represent a reference-quality network that builds upon, but is not limited to, existing GUAN sites. In the context of the WMO networks, GRUAN will effectively be the climate reference backbone of the existing GUAN (see Figure 1).

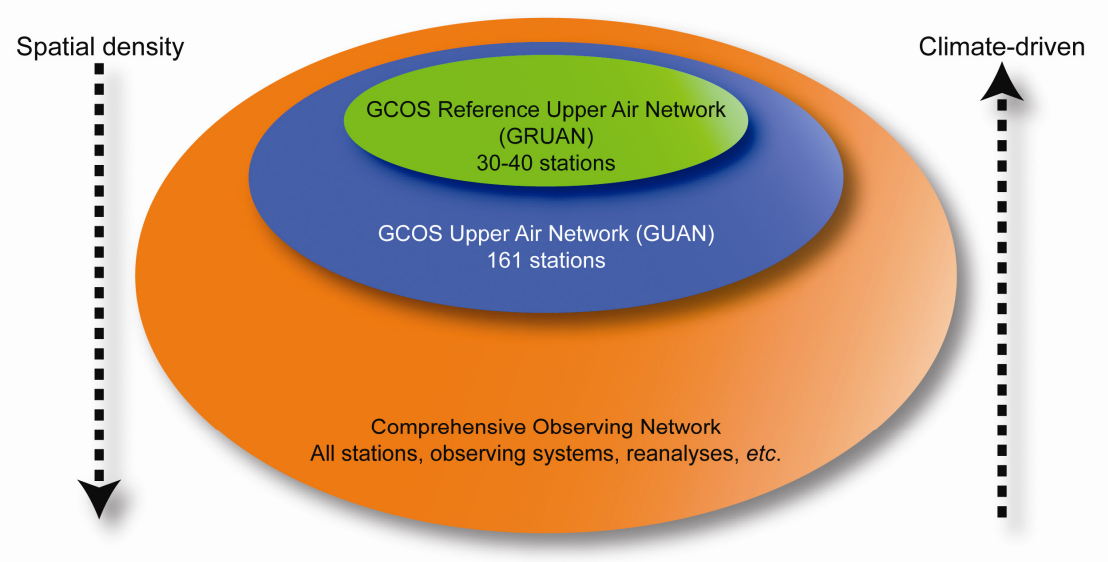


Figure 1. GRUAN's relationship to existing observational networks (from Seidel et al., 2009).

GRUAN sites will provide anchor points for existing global networks with data that

- are very well-characterised, particularly with respect to their relative biases over time;
- comprehensively characterise the atmospheric column; and
- are the best measurements currently feasible.

## *1.3. The GRUAN challenge*

The instrumentation for in situ observations of upper-air Essential Climate Variables operates in conditions that are difficult to replicate in a controlled environment (e.g., a test chamber). External influences, such as solar radiation or clouds at the time of measurement, are difficult to quantify. Furthermore, the goal of a worldwide observational network that fully characterizes the atmospheric column requires frequent observations with relatively low cost instrumentation, limiting the amount of resources that can be put into any single observation. This is further complicated by the fact that the instrumentation is frequently not recovered after use, and re-calibration or re-characterization after a measurement is often not possible even if the instrument is recovered.

GRUAN as a reference network is facing these challenges and must strive to quantify all parameters it sets out to measure in a traceable manner, that is, traceable to SI standards or a well-characterised and stable relative standard. GRUAN operations should also aim to obviate any requirement for recalibrations after the fact and dispel any doubts about instrument performance. Data and information provided by GRUAN will support scientific studies and enable evaluation of the quality and limitations of GRUAN and other observations.

The scale of the challenge that GRUAN faces in meeting these aims is huge. A reference measurement provides not only the best estimate for a parameter being measured, but also the best estimate for the level of confidence that is associated with this measurement. This estimate for the level of confidence is expressed as measurement uncertainty and is a property of the measurement that combines instrumental as well as operational uncertainties. To provide the best estimate for the instrumental uncertainty, a detailed understanding of the instrumentation is required for the conditions under which it is used.

The challenge addressed by GRUAN will therefore be:

- to reduce the instrumental uncertainty as well as the operational uncertainty (i.e. uncertainty induced by instrument set-up, sampling rates and the application of algorithms for data analysis),
- to quantify these uncertainties,
- to verify these uncertainties, and
- to make the entire process transparent and traceable.

GRUAN is not building a network from scratch where, at the outset, each site has identical instrumentation, data processing, and sampling intervals and therefore identical protocols. Hence, sites collecting data from different instruments will almost certainly currently use different averaging and data processing algorithms, different instrument pre-checks, different instrument post data checks, etc. These differences will result in different data uncertainties and metadata. This needs to be recognized at the start. Sites will have to move from their current individual protocols towards – insofar as is practical – a common GRUAN network protocol over time for all instrumentation.

## 1.4. GRUAN structure

The GCOS Programme provides direction and oversight of GRUAN through the Atmospheric Observation Panel for Climate (AOPC), which is jointly sponsored by the World Climate Research Programme (WCRP). The AOPC guides several atmospheric observing systems for climate, and has established a Working Group on Atmospheric Reference Observations (WG-ARO) to provide direct guidance to GRUAN (cf. Appendix 2 for current members of WG-ARO and Appendix 3 for its Terms of Reference). The day-to-day management of the GRUAN falls under the responsibility of the GRUAN Lead Centre, currently hosted by the Lindenberg Meteorological Observatory, Germany. It is responsible for the coordination among stations, including training, education and research, and ensuring the archival and dissemination of GRUAN data. The GRUAN Lead Centre became fully operational on 2 June 2008 for an initial period of five years (cf. Appendix 4 for current staffing and Appendix 5 for the Lead Centre Terms of Reference). Once GRUAN is implemented, it will become a part of the Global Observing System (GOS) in the framework of the WMO Integrated Global Observing System (WIGOS) initiative and the Commission for Basic Systems (CBS) will take a share of responsibility to oversee its operational activity and further development. The organizational structure of GRUAN is sketched in Figure 2.

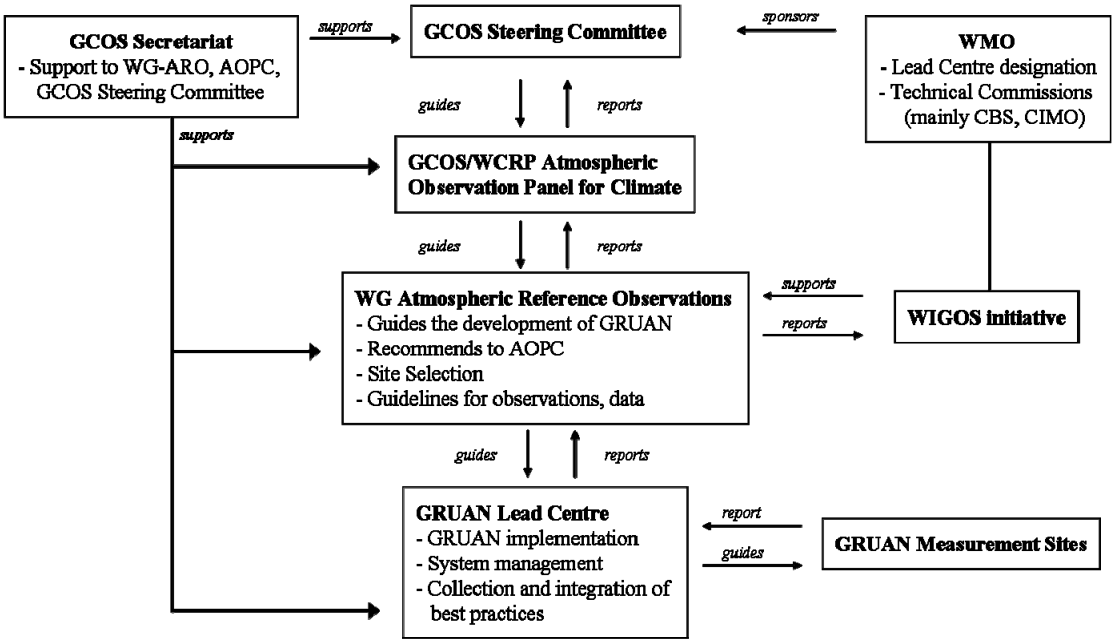


Figure 2. GRUAN organigram outlining reporting structure.

# 2. Implementation areas and timelines

This GRUAN Implementation Plan 2009-2013 (the 'GRUAN Plan') has been prepared in response to a request by the Chair of AOPC, triggered in the course of updating the GCOS Implementation Plan. This request was driven in part by the fact that the initial timescale for GRUAN implementation, as laid out in the 2004 GCOS Implementation Plan (including full implementation of GRUAN by 2009, see section 1.1), was overly optimistic and had to be revised. The GRUAN Plan is complemented by the short- and medium-term GRUAN work plans in GCOS-131, which will be updated on a yearly basis through the Implementation-Coordination Meeting (ICM) mechanism and its associated reports. Members of the Working Group, Lead Centre staff, and representatives from some of the initial sites were tasked with preparing this GRUAN Plan (GCOS-131 Action item #3). The GRUAN Plan is predicated upon the assumption that expansion to a final operational network should be largely complete by 2013-2014, consistent with a request by AOPC (XVth session).

Where mention is made of the GRUAN community in the following sections, this refers to the WG-ARO, Lead Centre, site operators, users and other interested parties. For completeness and accessibility, the current agreed short-term action items in GCOS-131 are repeated verbatim in relevant sections in this plan even though they are not the focus. Items with longer time horizons tend at this stage not to be associated with responsible parties, as discussion and agreement amongst the GRUAN community at subsequent ICMs will be required to specify individuals or groups responsible for each action and fully define the scope.

Implementation is centred around eight topics:

1. Reference observations
2. Site considerations and network composition
3. Network protocols and documentation, including observing practices and regulatory material
4. Data policy and data dissemination
5. Science issues
6. Organizational issues
7. Partnerships
8. Outreach

The work has been deliberately divided in this way into distinct areas, although many of these areas inevitably overlap.

This implementation plan will be discussed and, as needed, amended through the annual ICM mechanism and its reports. Reference to these additional reports should be made to track both progress and changes.

Finally, all aspects of GRUAN need to be well documented. For many aspects, this will be through official WMO documents and technical reports. These should also form a GRUAN report series and be mirrored upon the GRUAN website (www.gruan.org) so that all material is available in one place. Furthermore, as over-arching principle, as much of the scientific work detailed in this plan as is feasible should be published in the peer-reviewed literature in order to have a rigorous basis for operating GRUAN.

## *2.1. Reference observations*

***Defining the meaning of reference observations, and resulting actions***

GRUAN will provide reference observations of upper-air Essential Climate Variables, which will be achieved through a combination of in situ observations (reference quality radiosonde and balloon-borne research instruments) and ground-based remote sensing observations.

The term “Reference Observation” in the context of GRUAN refers to the need not only to provide a measurement of high quality, but also to provide the best estimate for the level of confidence in this measurement. This best estimate of the level of confidence is referred to as measurement uncertainty. The measurement uncertainty describes the current best knowledge of instrument performance under the conditions encountered during an observation, it describes the factors impacting a measurement as a result of operational procedures, and it makes all factors that contribute to a measurement traceable. Key is that this uncertainty will be vertically resolved (i.e., with altitude).

A common GRUAN definition of measurement uncertainty and a common procedure to establish measurement uncertainties is required to homogenize uncertainty estimates across the network. It is also needed to make the steps leading to the determination of measurement uncertainty traceable. This common definition should, ideally, be adopted by instrument providers as well.

Contributions to measurement uncertainty range from sensor calibration, sensor integration, sensor performance and external influences to operational routines such as sensor preparation and sensor ground checks. A full list of sources of measurement uncertainty will be defined in the GRUAN common definition of measurement uncertainty terms. Every GRUAN station must measure, collect, and provide all information necessary to establish an uncertainty budget for every measurement.

The uncertainty budget for every GRUAN measurement needs to be verified at regular intervals using redundant observations from complementary instruments. Observations using complementary instruments follow the same uncertainty analysis. Verification of GRUAN observations implies that observations by redundant but complementary instruments agree within their stated measurement uncertainty. Verification by itself does not provide a statement about the usefulness of a measurement; it only provides information about the completeness of an uncertainty analysis.

Simultaneous measurements and comparisons at every site are required to assure that observations across the network maintain the best possible level of homogeneity. This will be of greatest importance for sites that use instrumentation not found at other sites, and may logically include travelling reference measurements.

Traceability to recognized measurement standards (e.g., SI standards) that can be reproduced across borders and over long periods of time will be the key component enabling GRUAN to provide reference measurements useful for long-term climate observations. Traceability is a property of measurement that is conferred by an unbroken chain of measurements back to a recognized standard, with a robustly supported and fully documented uncertainty at each step. Traceability will also be essential to allowing the network to incorporate new scientific insights and new technological developments, while maintaining the integrity of the long-term climate record. To achieve traceability, metadata of all aspects relating to a measurement and its associated uncertainty will need to be collected. Each station will need to maintain accurate metadata records and share them with a GRUAN data archive(s).

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Develop a guide of common GRUAN definition and terminology for measurement uncertainty, accuracy, stability, etc., ensuring the quality of all GRUAN measurements. | Franz Immler, John Dykema, Tom Gardiner and others | Late summer 2009 | Action item #4 from ICM-1[4] |
| Develop a case study focussing on in-situ observations for the GRUAN measurements guide. | Lead Centre | Spring 2010 | Action item #5 from ICM-1 |

[4] As given in section 11 of GCOS-131

| | | | |
|---|---|---|---|
| Roll out measurement guidance to meet GRUAN requirements to all GRUAN site instrumentation based upon the prevalence of instrument types. | | 2011 | May include National Metrology Institutes |

## *2.2. Site considerations and network composition*

***Site participation / certification in the network***

(i) Deriving a site assessment and certification methodology

Some formal means of evaluating and documenting the fundamental quality of each site and each instrument for GRUAN purposes will eventually be required. Whilst developing the network and associated protocols, some degree of leeway in this regard is needed. Before attempting to expand the network, an objective set of criteria will be needed against which to assess the fundamental quality of individual sites and instruments vis-à-vis stated GRUAN requirements. This assessment will need to be on-going and associated communication / management protocols have to be put in place. Some important aspects of any assessment will be:

- Adherence to GRUAN protocols and requirements,
- Data quality (complete uncertainty analysis),
- Operational standards,
- Metadata completeness,
- Traceability,
- Management of changes,
- Temporal sampling, and
- Commitment to long-term measurements.

(ii) Soliciting new sites

Siting criteria will need to be established to ensure that there is a balance of GRUAN sites representing important climatic regions of the world and providing connectivity with GUAN and satellite programmes, including the Global Space-based Inter-Calibration System (GSICS) project. GRUAN sites will be located insofar as is practical to be representative of the significant world-wide climatic zones. Sites will have to have reasonable expectations of resources to maintain long-term operation (several decades). Cooperation and collocation with stations of existing networks, such as the Network for the Detection of Atmospheric Composition Change (NDACC), are encouraged to leverage existing infrastructure and capabilities.

In addition, the placement of GRUAN sites will consider the current locations of the 167 GUAN sites (status: 1 January 2009) world-wide, performing primarily radiosonde observations. While GUAN has upper air measurements, the sites often operate with different equipment, sensors, and operating protocols. Strategically placed GRUAN sites with high-quality radiosonde observations should be able to provide correction methodologies to GUAN radiosonde data.

Expansion of the network should concentrate on climatic zones and regions that are under-sampled in the initial network configuration, which is recognised to be heavily skewed towards Northern Hemisphere mid-latitudes. Requests from the satellite programmes should be included. The most obvious pathway forwards is to commission a site certification and expansion team, that

- looks at the regions where expansion is needed,
- suggests potential sites,

- gathers information about these potential sites and discusses their respective strengths and weaknesses,
- explores funding for these sites.

Once this has been prepared and all necessary documentation and network procedures are in place, then the institutes hosting candidate sites (national meteorological service, university, or other institution) should be approached.

(iii) Analyzing site offers

In the interim, new sites may be offered to GRUAN, such as during the XVth session of AOPC, when Japan Meteorological Agency (JMA) offered to contribute the Tateno site. Therefore, a formal mechanism needs to be set up to deal with such offers should they arise. This needs to balance the needs of all stakeholders but recognise that at this stage a willingness to participate is highly desirable.

(iv) Certifying sites on an ongoing basis

All GRUAN sites, including the candidate sites outlined in GCOS-121, will have to undergo a formal and periodic assessment as being part of the final network. Should an existing GRUAN site show significantly reduced observational capability over more than a year, as evaluated by these criteria, the Working Group will investigate the circumstances at that site, and, if needed, suspend / refuse its membership in the network.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Set up a site certification and expansion team and define an initial work package and reporting structure. | WG-ARO | At ICM-2 (2010) | |
| Agree a protocol for dealing with any site offers arising in the interim. | WG-ARO, Lead Centre | At ICM-2 (2010) | To be approved by AOPC. |
| Define a set of accepted objective criteria to assess both instrument specific measures and site performance vis-à-vis stated requirements. | Site certification and expansion team (membership TBD) | 2011 | Team composition to be determined at ICM-2 |
| Create a priority list of candidate sites for expansion based upon rigorous assessment against requirements. | Site certification and expansion team (membership TBD) | 2012 | Supersedes ICM-1 Action item #2 |
| Develop an operational capability to undertake certification analysis providing efficient feedback to sites. | Site certification and expansion team (membership TBD) | 2013 | ACRF have extensive expertise |
| Meet with current sites and candidate expansion sites (identified by the site certification and expansion team) and their governing institutions to elicit additional sites' involvement. | WG-ARO, Lead Centre | 2013 | May also be a full network "launch" event and so held at WMO HQ. |

***Determining measurement frequencies / scheduling***

Sampling intervals and data averaging schemes must be similar for measurements to be comparable. GRUAN needs to determine sampling intervals, in particular for non-continuous instrumentation (e.g., radiosondes). GCOS-121 laid down as an interim measure that radiosonde observations at GRUAN sites should be made at tiered levels, ideally consisting of (verbatim quote):

*"*

1. *1 x weekly production radiosonde with the best technology currently available at the site;*
2. *1 x monthly radiosonde capable of capturing moisture signal in the UT/LS and all other priority 1 variables[5] to the best level possible with current technology, launched together with weekly radiosonde;*
3. *Regular 00 and 12 LST (as a preference over UTC)[6] launches of a production radiosonde with best technology currently available;*
4. *Dual launches of sondes with highest quality humidity sensing capability in the UT/LS (flying the monthly radiosonde together with a second sonde also capable of measuring water vapour in the UT/LS) [added by WG-ARO after formal workshop close]; and*
5. *Periodic intercomparisons of a large range of sonde types."*

Based on GCOS-121, only the first two criteria were deemed an initial requirement. Note that these are an interim set of measurement frequency requirements pending a more quantitatively defensible assessment. Production of these quantitatively defensible guidelines, which have perhaps the greatest bearing on site running costs, needs to be afforded the highest priority.

Details on measurement sampling frequency of other ground-based instrumentation at GRUAN sites are yet to be determined but are *equally important*. Sampling intervals and data averaging schemes need to be developed for each instrument system in order to characterize the uncertainty of their measurements, whether they are point measurements, profile measurements, or integrated column measurements. Sampling interval and data averaging schemes are determined by the desired representativeness of the spatial and temporal scale of the variable being measured. This needs to be determined for each type of measurement.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Define remit of and set-up team to ascertain quantitatively defensible guidance for both in-situ and ground-based remote sensing temporal sampling requirements. | WG-ARO | ICM-2 (2010) | |
| Quantitative assessment of in-situ (radiosonde) measurement frequency and scheduling impacts on trend and variability characterisation. Including all variables and altitudes and with a view to how frequently different units with different basic quality / capability and unit cost are likely | Temporal sampling team (membership TBD) | Winter 2010 | *"GRUAN Analysis Team for Network Design and Operations Research"* (Ad hoc GATNDOR) interested in contributing. Lead Centre could |

[5] Upper-air ECVs were classified in a priority ranking from 1 to 4 in GCOS-121

[6] The final decision about UTC or Local Solar Time has not been taken. Based on discussions at AOPC-XIV, it is recommended that radiosonde schedules at GRUAN sites should be made at Local Solar Time (LST), but recognized that local operational constraints may lead to other launch schedules at some stations, which should not preclude these stations from being designated as GRUAN stations.

| | | | |
|---|---|---|---|
| to be required. Submitted for publication. | | | provide measurements to support as could ACRF SGP site? Also, campaign data may be useful. |
| Assessment of the value and utility of satellite coincident in-situ and remote sensing measurements vis-à-vis standard times for satellite cal/val. Submitted for publication. | Temporal sampling team (membership TBD) | Summer 2011 | To be resolved in collaboration with GSICS |
| Final set of temporal sampling guidance for both in-situ and remote sensing instrumentation based upon a quantitative assessment prior to network expansion, including superseding of GCOS-121 documentation for in-situ measurements. | Temporal sampling team (membership TBD) | Winter 2011 | |

***Resolving the collocation issue***

Many of the current sites and many potential sites consist of instrument clusters with a substantial geographical spread rather than single compact sites. Some of them are in geographical locations that have complex orography and / or heterogeneous surface characteristics. There remain open questions about how physically far apart measurements can be made and still represent a GRUAN site column measurement. Therefore, appropriate collocation requirements for variables and instrumentation will have to be established to ensure the representativeness of measurements of a single column. These considerations will almost certainly be site and parameter-specific.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Quantitative investigation of collocation issue for priority 1 variables (T,q) at existing sites. | | Winter 2010 | Ad hoc GATNDOR interested in this issue |
| Formulate generic guidance on the collocation issue based upon quantitative evidence wherever available and for all variables. | Lead Centre, WG-ARO | Winter 2011 | |

***Managing instrument change***

Changes in instrumentation are both inevitable and desirable if they lead to a better representation of the true atmospheric state. They will also often be driven by the necessities of production engineering (when instrument components become unavailable or too expensive) and decisions will have to be made as to what level of component change requires additional change testing, as specified below. Following a scientifically robust replacement strategy that maximises the probability of maintaining the long-term climate record will be important for maintaining the integrity of the GRUAN measurements in the face of change.

Change from one instrument to a new instrument providing the same reference measurement requires that the same detail of uncertainty analysis is conducted for the new instrument as has been done for the instrument to be replaced. The new instrument must be tied via a comparable traceability chain back to the same recognized standard as the old instrument.

Ground check routines for in situ instruments need to be consistent between the new and the old instrument to minimize changes in procedural uncertainty contributions. The vertically resolved uncertainty estimate for both instruments will serve as a metric to evaluate the level of agreement or disagreement between the two instruments. Redundant observations, as well as potentially comparison with a travelling reference instrument, will serve to minimize the uncertainties to be introduced by the change. Consideration will need to be given to the desired strategy when more than one station in the network is making an identical (or very similar) change with respect to timing, sharing of lessons / data, and whether certain sites will act as pioneers. This will be especially important where the change is forced by a supply issue.

Issues to be resolved on an individual instrument basis include:

- length of time over which overlapping dual measurements should be taken (a month, a season, a year?);
- frequency of dual measurements;
- requirements for additional redundant observations to aid in the transition and to support an optimal and cost-effective change strategy.

In the early stages, this may be best achieved by sites undertaking a super-saturation approach to overlap so that sub-sampling can be undertaken to ascertain a minimum safe level of overlap required to preserve the record.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Prepare a position paper on a process to manage change and optimize intercomparisons at GRUAN sites. | Lead Centre | 2010 | ICM-1 Action item #6 |
| Develop an instrument replacement protocol with a solid quantitative basis. | | 2011 | Ad hoc GATNDOR interested in this issue, ACRF representatives have expertise |
| Conduct a pilot study to evaluate the efficacy of change management protocols / concepts. | | 2012 | May be best carried out at Lindenberg? |

***Expanding from priority 1 variables to full profile characterisation***

So far GRUAN has concentrated on observations of priority 1 variables (cf. Appendix 1). This focus will enable establishing and testing the guiding principles for all reference observations within the GRUAN framework, which will later be expanded to other observations. A fully functioning GRUAN that serves all envisaged purposes will require measurements of the remaining variables in the requirements table. An approach to expanding site measurement capabilities to eventually cover as many of the specified variables as possible, whilst recognising that not all variables may be observed at all stations, is required. This expansion will largely occur beyond the timescale that is the focus of this plan as concentrating too heavily on this aspect will serve as a distraction from the priority 1 variables. However, at least some initial documentation as to how the roll out is envisaged will be required before soliciting extra sites so that they have a reasonable idea of what will be expected of them.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Prepare a position paper on expansion to full column characterisation to meet all stated GRUAN measurement requirements. | | Winter 2011 | Needed so that candidate sites for expansion have a concrete idea of what an ideal station may look like. |

## *2.3. Network protocols and documentation*

***Communication / coordination issues***

Establishing a strong framework for communication and feedback between sites, Lead Centre, the GRUAN organizational structure and users is essential. The Lead Centre will be the focal point for the communication and coordination of routine operations within the network. The Lead Centre will furthermore coordinate, monitor, and validate the day-to-day GRUAN specific operations at the sites.

In addition, an efficient way to manage and report problems and changes is required. Efficient means for communication will be instigated in particular to ensure communication between the Lead Centre and GRUAN sites on an ongoing basis, as required either by the Lead Centre or the sites themselves.

Existing algorithms, potentially supplemented by future algorithms to be developed, will need to be used on a daily basis to identify systematic errors, anomalies or instrumental issues. Visual inspection of all data by science/instrument experts will be required for all instruments to minimize issues that slip through automated routines. The Lead Centre will coordinate this effort, which will be distributed across different centres involved in GRUAN. Vertically resolved uncertainty estimates, prepared independently for each site, will be used as a metric to compare the site-to-site quality of the observations. Travelling standards may also need to be instigated but have yet to be formally discussed and investigated.

An additional key component of this communication are the annual ICMs of site staff, Lead Centre and WG-ARO, which afford an opportunity to discuss issues face to face. This will be further supplemented by the regular reporting from the Lead Centre to the Working Group.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Develop a communication platform for the GRUAN community (blog, wiki, FAQ, other?). | Lead Centre (lead), WG-ARO, sites | 2010 (ICM-2) | ICM-1 Action item #9 |
| Design and instigate a framework to investigate, report and resolve data quality and instrument issues in real-time. | | 2011 | ACRF already have such a capability and should be consulted. |
| Assessment of utility against cost and logistical overhead of regular site specific intercomparisons / travelling standards to intercompare sites. | | Late 2011 | Needed to ascertain costs ahead of push for network expansion. |
| Meetings of Lead Centre, WG-ARO, Secretariat and sites | WG-ARO (lead), Lead Centre, | Annually (in Feb / March) | Until superseded |

| | | | |
|---|---|---|---|
| (ICMs). | GCOS Secretariat | | |
| Regular progress reports against specified work plan from the Lead Centre to the WG-ARO. | Lead Centre | Continuous | Minimum frequency 6-monthly |

***Manuals of operation***

Standard operating procedures need to be established within GRUAN that describe and harmonize data collection procedures and data quality control processes. They will be optimized towards minimizing operational uncertainties in the overall measurement process. They will describe instrument preparation, required ground checks, and metadata collection. Most sites will likely not have identical instrumentation, but rather, similar instrumentation (ct. section 1.3). Thus, data quality and validation has to be site specific. A standard recommendation for the use of redundant instrumentation and remote sensing instrumentation will be developed to aid in the site specific regularly scheduled validation effort. The purpose is to make sharing and communication of best practices across sites seamless and continuous.

While individual sites maintain site specific instrument documentation, the Lead Centre will have to document high-level, network-wide operations procedures, processes and reporting requirements. This will be done through an over-arching Manual of Operations which encompasses, inter alia,

- the goals and objectives of the network;
- measurement schedules and requirements;
- guidance for quality assurance at all sites;
- metadata guidance;
- general instrument-specific guidance;
- a data processing and dissemination scheme;
- a concept for managing change;
- archiving of data.

The GRUAN Manual of Operations will build upon guidance material of existing networks (e.g., GUAN, NDACC, BSRN) and will eventually be embedded into the Manual of the WMO GOS. The GRUAN Manual of Operations and related documentation of sites and instruments need to be regularly updated and readily accessible. At ICM-1, a skeletal outline of such a manual was adopted.

Further drafting of the manual needs to build on the development of quality assurance guidance material, a gap analysis exploring which parts of the manual need to be newly developed, and which ones can be based on existing guidance material. Manual development further depends on the availability of resources for the drafting process, and on assistance by WMO and its Commission for Basic Systems.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Perform a gap analysis on existing documentation (manuals) vis-a-vis the adopted skeletal GRUAN Manual of Operation, and provide a summary document of where these gaps are. | Lead Centre, GCOS Secretariat, WG-ARO, sites | 2010 (subject to sourcing funding) | ICM-1 Action item #16; Potential support through WIGOS PP |
| Draft a GRUAN Manual of Operations. | Lead Centre, GCOS Secretariat, WG-ARO, ACRF | End 2010 | Potential Assistance by WMO CBS Expert Team, and through WIGOS PP |

| | | | |
|---|---|---|---|
| Finalize the GRUAN Manual of Operations. | Lead Centre, GCOS Secretariat, WG-ARO; ACRF | Mid-2011 | Potential Assistance by WMO CBS Expert Team, and through WIGOS PP |
| Formal inclusion of GRUAN Manual of Operations into existing WMO documentation. | GCOS Secretariat, WMO Secretariat | 2012 | Through adoption by WMO Commission for Basic Systems |

## *2.4. Data policy and data dissemination*

Because GRUAN will initially consist of established sites, a plan for GRUAN data dissemination does not need to start from scratch. Usually, raw data (initial output of an instrument) are maintained. A data format (such as NetCDF) needs to be chosen. While it is beneficial to have common data processing algorithms and a centralized processing location, it is likely that each of the potential GRUAN sites have some variant of data processing that does not allow uniformity of a specific measurement at all sites. While GRUAN may choose to import the raw data from its sites that are part of another network (with established data processing algorithms) and process the data with a common process algorithm, there is danger in having different data reported from one site via each network. Such a situation needs to be avoided.

GRUAN does not necessarily need to build its own data archive and user interface. This is a rather costly operation for any large network and partnering with an established data archive with a user-friendly interface will be preferred. Excellent candidate archives exist and are currently under consideration.

Because data cannot be quality assured nor corrected in near real time, additional processing steps and uncertainty estimate assignment will be required. This key processing will be allowed to grow, and thus, data versioning will be required. Protocols need to be established that indicate when data reprocessing from beginning to end is justified. Users of the data need to be known and be able to be contacted when new versions of past data are available. There also must be a feedback mechanism for users to allow for reporting problems. Reporting protocols and guidelines on changes of data will be developed and coordinated by the Lead Centre in collaboration with the GRUAN sites.

The development of a GRUAN data dissemination model involves several steps: links between existing data archive and distribution centres need to be formalized; the dissemination / archiving capabilities of each site need to be assessed; a proposal has to be developed defining data dissemination among all GRUAN sites, in compliance with the GRUAN data policy (cf. Appendix 6). The data policy, consistent with WMO Resolution 40 (cf. Appendix 7) foresees the dissemination of high-quality records for climate research and applications in delayed mode, to allow for sufficient data quality checks. In addition it also calls for, to the extent possible, the dissemination of “standard data” (i.e., data with relatively low exploitation value and only basic quality checks applied) in near-real time for the numerical weather prediction community. After approval by all partners, the proposal of a data dissemination scheme needs to be implemented. The GRUAN data dissemination method will make use of existing infrastructure, such as the WMO Information System (WIS). The WIS requirements, e.g. on metadata, and the possibility to transmit near-real time data via the Global Telecommunication System (GTS) will be explored.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Formalize links between Lead Centre and NCDC, ACRF | Lead Centre, WG-ARO, NCDC, | 2010 | ICM-1 Action item #11 |

| | | | |
|---|---|---|---|
| program regarding data dissemination, investigate the value of NDACC / BADC involvement for high-res in-situ. | ACRF | | |
| Develop proposal to define data dissemination among all GRUAN partners, in full compliance with GRUAN data policy (i.e., delayed mode and near-real time data dissemination addressed). | Lead Centre, WG-ARO, NCDC, ACRF | 2010 | ICM-1 Action item #12 |
| Define reprocessing and version control procedures. | | 2010 | |
| Explore the possibility to publish GRUAN metadata congruent with WIS metadata standards. | Lead Centre, GCOS Secretariat | 2010 | Many or most stations, e.g. NOAA stations, provide already station metadata following WIS requirements. A user description document shall be available soon |
| Explore the possibility to disseminate near real time data via the WMO Information System (WIS) including the Global Telecommunication System (GTS) using existing infrastructure. | Lead Centre, GCOS Secretariat | 2010 | |
| Implement a final version of the data dissemination structure. | GRUAN community | 2011 | Needs to be done prior to network expansion. Needs a stable version on this timescale. |

## *2.5. Science issues*

***Guidance on scientific progress***

To be effective as reference network, GRUAN requires close interaction with the scientific community. This interaction will provide GRUAN with information about the quality of observations; recommendations for instrumental or procedural changes; guidance on processing and uncertainty analysis; and design and overall operation of the network.

Following ICM-1, an ad hoc *GRUAN Analysis Team for Network Design and Operations Research* (GATNDOR) was established comprising a small group of interested ICM-1 participants. Their aim is to undertake scientific investigations in support of GRUAN decision making and to report at subsequent ICM meetings. Several areas of investigation have been proposed (cf. issues raised in section 2.2) and it is important that these efforts be linked into the overall implementation process of GRUAN. The number, size and mandate of existing or new ad hoc science teams will be revised annually at ICMs.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Assessment based upon current sites of the collocation of measurements issue. | Ad hoc GATNDOR | Summer 2010 | Pending time and resources |

| | | | |
|---|---|---|---|
| Assessment of scientific requirements for managing instrument change to preserve the climate record fidelity. | Ad hoc GATNDOR | Winter 2010 | Pending time and resources |
| Assessment of frequency of sampling required to retain trend fidelity. | Ad hoc GATNDOR | Winter 2010 | Pending time and resources |
| Quantification of the value of redundant measurements and assessment of optimal combinations. | Ad hoc GATNDOR | TBD | Not yet a defined output |
| Assessment of scientific desirability of station locations from a variety of perspectives. | Ad hoc GATNDOR | TBD | Not yet a defined output |

## *2.6. Organizational issues*

***Instigation of expert teams***

Establishing error estimates and evaluating measurements require detailed knowledge of each instrument, the measurement technique and the operational procedures in which this instrument is applied. To evaluate the appropriateness of uncertainty estimates, the usefulness of particular measurements and operational procedures, expert teams will be formed that, in close collaboration with the GRUAN Lead Centre, synthesize the available knowledge and develop recommendations to improve GRUAN measurements and operations. These expert teams will meet at regular intervals to evaluate the current status of GRUAN observations, to identify weaknesses and to incorporate new scientific understanding into GRUAN. The expertise of these teams will also be used to support the GRUAN Lead Centre in guiding individual stations through instrumental and operational changes without impacting long-term trend series.

Each expert team will cover one measurement parameter and will convene leading scientists with the appropriate knowledge to contribute to that measurement parameter. Expert teams from existing networks, such as NDACC, shall be approached to support GRUAN operations and to avoid duplication of effort by utilizing scientific knowledge already gained by other teams. Input from metrology institutes will also be critical. Each instrument may also need a mentor (shared across the network) as this has been found to be invaluable in the ACRF program.

A users review group needs to be established that provides feedback to the Lead Centre to address data user issues such as accessibility and use of GRUAN data. This group will be selected from the scientists that are primary users or desired customers (in the early phase) of the GRUAN datasets. This group will be set up as soon as some data are available to undertake a meaningful analysis.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Formation of instrument and parameter expert teams. | WG-ARO, Lead Centre, ACRF, sites | 2010 | |
| Assessment of the quality of observations and advice on specific uncertainty issues. | Instrument specific expert teams | TBD | To be formed |
| Instigate a user review group to meet on a biennial basis. | WG-ARO | 2012 | Periodic external review group with ex-officio Lead Centre, WG-ARO |

| | | | |
|---|---|---|---|
| | | | and GCOS Secretariat membership |

***Scientific governance***

To best serve the needs of climate monitoring and research, it is essential that GRUAN be informed by a good understanding of the evolving science issues that drive the measurements and accuracy of the GRUAN data. Therefore, the establishment of an internal or external science advisory panel should be considered, with AOPC lead to review the GRUAN operations, measurements, and siting criteria in this context on a regular 3-5 year basis.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Consider the instigation of science advisory panel with remit to meet on a 3-5 year basis. | AOPC (lead), GCOS Secretariat, WG-ARO, WCRP/WOAP | As appropriate | Periodic external review group with ex-officio Lead Centre, WG-ARO and GRUAN Secretariat membership. Decision to be made by AOPC in their 2010 meeting. |

## *2.7. Partnerships (WMO, WIGOS, GSICS, other networks)*

***Relation to existing global networks and observations***

Many of the initial sites report to numerous networks and their governance and stated aims differ substantially. GRUAN is not expected to consist of a set of identical sites supported by a single funding agency. It is therefore essential to have in place protocols and agreements, such as a Manual of Operations, including common quality assurance procedures that allow the required flexibility, whilst maintaining the fundamental quality of the observations necessary to meet GRUAN aims. To date, scant attention has been paid to this issue although its importance has been recognised.

Most GRUAN initial and candidate sites are already part of the existing WMO networks such as GUAN, GAW, NDACC, BSRN and SHADOZ, hence a good level of coordination between the governing bodies of these networks (e.g., the WMO CBS) with GRUAN is required on a continuous basis.

For radiosonde specific issues, there will be a link to those responsible for upper-air observations in many of the important upper-air networks worldwide, since these are using large numbers of radiosondes and may be more aware of performance issues than the scientific community. Such a group should come out of future liaison between CBS and CIMO.

In addition, coordination of GRUAN with GSICS and other organisations supporting space borne remote sensing observations are critical. Once GRUAN datasets are available, pilot studies on enhanced datasets using these reference measurements, including reanalyses, need to be undertaken.

Furthermore, the utility of GRUAN for other user communities, such as global and regional modellers as well as the numerical weather prediction community, should be demonstrated and exploited as appropriate.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Ensure institutional / informal linkages between GRUAN community and existing/potential partners, to maintain mutual engagement, knowledge transfer, recognition. | Lead Centre candidate sites, WG-ARO, GCOS Secretariat | Continuous | E.g., membership in WG-ARO, invitations to ICM meetings, invites to formal launch event, and other linkages |
| Dialogue with satellite community (GSICS; other space agencies), e.g. on use of GRUAN data, needs / sponsoring for additional radiosonde launchings. | GSICS; representatives from space agencies | Continuous | ICM-1 Action item #1;<br>Invites to formal launch event |
| Instigate formal communication pathway to operational radiosonde community. | CIMO, CBS, WG-ARO, Lead Centre | Continuous 2010 | Regular reporting to WMO bodies, e.g. through WIGOS-PP channels; possible CBS expert team in 2010 |

***Participation in WMO-sponsored intercomparison campaigns***

Participation in major WMO intercomparisons that are focussed on GRUAN-relevant Essential Climate Variables is clearly a win-win situation for both GRUAn and WMO communities. GRUAN needs to work closely with CBS and CIMO to gain maximum benefit for all parties from these comparisons on an ongoing basis. These need not necessarily be limited solely to the regular radiosonde intercomparisons, and may well include ground-based as well as space-based observing systems.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Provide a list of technically competent potential participants (2-3) in 2010 CIMO intercomparison campaign in China to CIMO Secretariat; Head of Lead Centre to be formally involved in the organization of the campaign. | WG- ARO | August 2009 | ICM-1 Action item #13 |
| Foster participation of research radiosondes in 2010 CIMO intercomparison campaign. | WG- ARO (lead), Lead Centre | | ICM-1 Action item #14 |
| Nominate members on expert team analyzing results from CIMO intercomparison campaign. | WG-ARO | September 2009 | ICM-1 Action item #15 |
| Inform GRUAN community on upcoming CIMO activities of interest and enable input where deemed appropriate. | GCOS Secretariat, CIMO | continuous | |

***How to more better engage the instrument manufacturers***

Apart from the Seattle meeting, attendance by instrument manufacturers at GRUAN workshops and meetings has been limited to nominated representatives under the auspices of the Association of Hydro-Meteorological Equipment Industry (HMEI). A productive point of interaction with the different vendors and manufacturers will be the periodic GRUAN participation in the CIMO multi-sensor field campaigns. Engaging the manufacturers in these field campaigns will assist GRUAN not only in evaluation of the different sensors but also as a point of interaction with the vendors apart from the limited HMEI attendance at GRUAN meetings.

A close cooperation between GRUAN and instrument suppliers will help GRUAN to better understand industry capabilities and to better quantify instrumental uncertainties. This cooperation will also help suppliers to better understand GRUAN requirements, and the industry would be able to advise GRUAN of its current and prospective abilities to meet these requirements. For many of the parameters of interest (as instruments of required accuracy do not yet exist), GRUAN aims to further their development in cooperation with instrument manufacturers. It is essential to establish open and effective communication and collaboration between manufacturers and GRUAN on instrument and algorithm changes and their impacts on the GRUAN datasets. HMEI has suggested that a workshop specifically for manufacturers and open to all HMEI members would be helpful.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Workshop with manufacturers under the joint auspices of GCOS and HMEI. | WG-ARO, HMEI, GCOS Secretariat | Winter 2011 | Meeting suggested by HMEI |
| Regularly invite HMEI to ICM meetings. | ICM Organizing Committee | Continuous | |

***WIGOS***

ICM-1 participants agreed that GRUAN, or parts thereof, should become a Pilot Project under the WMO Integrated Global Observing System (WIGOS-PP[7]; see GCOS-131). A draft proposal for a GRUAN-specific Pilot Project was welcomed by WMO CBS-XIV and accepted by the responsible technical body of WMO (Report of WMO CBS-XIV and Report of 2nd session of WMO EC Working Group on WIGOS and WIS). The proposal focuses on elements of GRUAN implementation where guidance and support by WMO is particularly important, namely: (i) the development of guidance material, including a Manual of Operations, (ii) implementing a data dissemination model, (iii) overall network development, and (iv) interfacing with WMO technical bodies. Designation of these activities as a WIGOS Pilot Project ensures a regular dialogue of the GRUAN community with WMO technical bodies and governing councils, thus raising the visibility of GRUAN with national meteorological services. It is hoped that the WIGOS trust fund can provide some support for the proposed activities of the GRUAN community – a prerequisite for their on-time completion.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Submit full proposal for WIGOS-PP in conjunction with development of the GRUAN Plan. | WG-ARO, Lead Centre, GCOS Secretariat | Summer 2009 | ICM-1 Action item #17 |
| Report to WIGOS Planning Office as required. | WG-ARO chair, Lead Centre, GCOS Secretariat | Ongoing | |

[7] http://www.wmo.int/pages/prog/www/wigos/index_en.html

## *2.8. Outreach*

Outreach is the understanding that GRUAN is a product of a global society, that it obtains material support from that society, and that in return it needs to serve society's objectives. This return effort goes beyond the production of reference data. Outreach implies that GRUAN is open to the scientific and general public, provides information about GRUAN activities and invites the community to participate. Expert teams, users groups, conference presentations and coordination with scientific bodies are outreach activities within the scientific community.

| What | By whom (if applicable) | By when | Notes |
|---|---|---|---|
| Agree and implement data usage acknowledgement protocol. | WG-ARO, Lead Centre, sites, GCOS Secretariat | 2010 | Ideally required before data starts going on stream |
| Implement tracking of data usage. | | 2010 | |
| Brief science community on GRUAN by seeking to convene special sessions at relevant conferences including updates on progress. | WG-ARO | During 2011 | AMS, EGU and other meetings |
| Prepare public outreach material. | | 2012 | |
| Launch event of GRUAN full operational phase. | WG-ARO, Lead Centre | 2013 (end of implementation phase) | May be best tied in to the end of the network expansion workshop |

# 3. Collated GRUAN Plan

| Continuous | | | | |
|---|---|---|---|---|
| **Area** | **Sub-section** | **What** | **By whom** | **Notes** |
| Organizational issues | Communication / coordination | Regular progress reports against specified work plan from the Lead Centre to the WG-ARO. | Lead Centre | Minimum frequency 6-monthly |
| Partnerships | Relation to existing bodies | Ensure institutional / informal linkages between GRUAN community and existing/potential partners, to maintain mutual engagement, knowledge transfer, recognition. | Lead Centre candidate sites, WG-ARO, GCOS Secretariat | E.g., membership in WG-ARO, invitations to ICM meetings, invites to formal launch event, and other linkages |
| Partnerships | Relation to existing bodies | Dialogue with satellite community (GSICS; other space agencies), e.g. on the use of GRUAN data, needs/sponsoring for additional radiosonde launchings) e.g. on needs/sponsoring for additional sonde launches. | GSICS; representatives from space agencies | Action item #1 from ICM-1 Invites to formal launch event |
| Partnerships | Relation to existing bodies | Instigate formal communication pathway to operational radiosonde community. | CIMO, CBS, WG-ARO, Lead Centre | Regular reporting to WMO bodies, e.g. through WIGOS-PP channels; possible CBS expert team in 2010 |
| Partnerships | Engaging manufacturers | Regularly Invite HMEI to ICM meetings. | ICM organizing committee | |
| Partnerships | WIGOS | Report to WIGOS Planning Office as required. | WG-ARO Chair, Lead | |

| | | | | |
|---|---|---|---|---|
| | | | Centre, GCOS Secretariat | |
| Organizational issues | Instigation of a science advisory panel | Consider the instigation of a science advisory panel with remit to meet on a 3-5 year basis. | AOPC (lead),GCOS Secretariat, WG-ARO, WCRP/WOAP | Periodic external review group with ex-officio Lead Centre, WG-ARO and GCOS Sec. membership. |
| Reference observations | CIMO activities | Inform GRUAN community on upcoming CIMO activities of interest and enable input where deemed appropriate. | GCOS Secretariat, CIMO | |
| | | | | |
| **Periodic** | | | | |
| **Area** | **Sub-section** | **What** | **By whom** | **Notes** |
| Organizational issues | Communication / coordination | Annual meetings of Lead Centre, WG-ARO, Secretariat and sites (in Feb / March). | WG-ARO (lead), Lead Centre, Secretariat | Annually in Feb / March until superseded |
| | | | | |
| **2009** | | | | |
| **Area** | **Sub-section** | **What** | **By whom** | **Notes** |
| Reference observations | | Develop a guide of common GRUAN definition and terminology for measurement uncertainty, accuracy, stability, etc., ensuring the quality of all GRUAN measurements. | Franz Immler, John Dykema, Tom Gardiner and others | Action item #4 from ICM-1 |
| Partnerships | Participation in intercomparisons | Provide a list of technically competent potential participants (2-3) in 2010 CIMO intercomparison campaign in China to CIMO secretariat; head of lead centre to be formally involved in organization of the campaign. | WG-ARO | Action item # 13 from ICM-1 |
| Partnerships | Participation in intercomparisons | Foster participation of research radiosondes in 2010 CIMO intercomparison campaign. | WG- ARO (lead), Lead Centre | Action item # 14 from ICM-1 |
| Partnerships | Participation in intercomparisons | Nominate members on expert team analyzing results from CIMO intercomparison campaign. | WG-ARO | Action item # 15 from ICM-1 |
| Partnerships | WIGOS | Submit full proposal for WIGOS-PP in conjunction with | WG-ARO, Lead Centre, | Action item # |

| | | | | |
|---|---|---|---|---|
| | | development of GRUAN-IP. | GCOS Secretariat | 17 from ICM-1 |
| | | | | |
| **2010** | | | | |
| **Area** | **Sub-section** | **What** | **By whom** | **Notes** |
| Network protocols and documentation | Communication / coordination | Develop a communication platform for the GRUAN community (blog, wiki, FAQ, other?). | Lead Centre (lead), WG-ARO, sites | Action item #9 from ICM-1. A blog has been set up in June 2009. |
| Reference observations | | Develop a case study focussing on in-situ observations for the GRUAN measurements guide. | Lead Centre | Action item #5 from ICM-1 |
| Site considerations | | Set up a site certification and expansion team and define a initial work package and reporting structure. | WG-ARO | |
| Site considerations | Temporal sampling requirements | Define remit of and set-up team to ascertain quantitatively defensible guidance for both in-situ and ground-based remote sensing temporal sampling requirements. | WG-ARO | |
| Site considerations | Determining measurement frequencies / scheduling | Quantitative assessment of in-situ (radiosonde) measurement frequency and scheduling impacts on trend and variability characterisation. Including all variables and altitudes and with a view to how frequently different units with different basic quality / capability and unit cost are likely to be required. Submitted for publication. | Temporal sampling team (membership TBD) | Ad hoc GATNDOR interested in contributing. Lead Centre could provide measurements to support as could SGP? Also, campaign data may be useful. |
| Site considerations | Collocation resolution | Quantitative investigation of collocation issues for priority 1 variables (T,q) at existing sites. | | Ad hoc GATNDOR interested in pursuing this. |
| Site considerations | Managing change | Prepare a position paper on a process to manage change and optimize intercomparisons at GRUAN sites. | Lead Centre | Action item #6 from ICM-1 |
| Site | Expansion | Agree a protocol for dealing with any site offers arising in | WG-ARO, Lead Centre | To be |

| | | | | |
|---|---|---|---|---|
| considerations | | the interim. | | approved by AOPC. |
| Network protocols and documentation | Manuals | Perform a gap analysis on existing documentation (manuals) vis-à-vis the adopted GRUAN skeletal Manual of Operation, and provide a summary document of where these gaps are. | Lead Centre, GCOS Secretariat (from WIGOS-PP resources?), WG-ARO, sites | Action item #16 from ICM-1; Potential support through WIGOS PP |
| Network protocols and documentation | Manuals | Draft a GRUAN Manual of Operations. | Lead Centre, GCOS Secretariat, WG-ARO | Potential assistance by WMO CBS expert team, and through WIGOS-PP |
| Data dissemination | | Formalize links between lead centre and NCDC, ACRF program regarding data dissemination, investigate value of NDACC / BADC involvement for high-res in-situ. | Lead Centre, WG-ARO, NCDC, ACRF | Action item #11 from ICM-1 |
| Data dissemination | | Develop proposal to define data dissemination among all GRUAN partners, in full compliance with GRUAN data policy (i.e., delayed mode and near-real time data dissemination addressed). | Lead Centre, WG-ARO, NCDC, ACRF | Action item #12 from ICM-1 |
| Data dissemination | | Define reprocessing and version control procedures. | | |
| Data dissemination | metadata | Explore the possibility to publish GRUAN metadata congruent with WIS metadata standards. | Lead Centre, GCOS Secretariat | Many or most stations, e.g. NOAA stations, provide already station metadata following WIS requirements. A user description document |

| | | | | |
|---|---|---|---|---|
| | | | | shall be available soon. |
| Data dissemination | Near-real-time data | Explore the possibility to disseminate near real time data via the WMO Information System (WIS) including the Global Telecommunication System (GTS) using existing infrastructure existing connections. | Lead Centre, GCOS Secretariat | |
| Science issues | Guidance on scientific progress | Assessment based upon current sites of the collocation of measurements issue. | Ad hoc GATNDOR | Pending time and resources |
| Science issues | Guidance on scientific progress | Assessment of scientific requirements for managing instrument change to preserve the climate record fidelity. | Ad hoc GATNDOR | Pending time and resources |
| Science issues | Guidance on scientific progress | Assessment of frequency of sampling required to retain trend fidelity. | Ad hoc GATNDOR | Pending time and resources |
| Science issues | Guidance on scientific progress | Quantification of the value of redundant measurements and assessment of optimal combinations. | Ad hoc GATNDOR | Not yet a defined output |
| Science issues | Guidance on scientific progress | Assessment of scientific desirability of station locations from a variety of perspectives. | Ad hoc GATNDOR | Not yet a defined output |
| Organizational issues | Instigation of expert teams | Formation of instrument and parameter expert teams | WG- ARO, Lead Centre, ACRF, sites | |
| Science issues | Guidance on scientific progress | Assessment of the quality of observations and advice on specific uncertainty issues. | Instrument specific expert teams | To be formed |
| Outreach | Data usage | Agree and implement data usage acknowledgement protocol. | WG-ARO, Lead Centre, sites, GCOS Secretariat | Ideally required before data starts going on stream. |
| Outreach | | Implement tracking of data usage. | | |
| | | | | |
| **2011** | | | | |
| **Area** | **Sub-section** | **What** | **By whom** | **Notes** |
| Measurement guidance | | Roll out measurement guidance to meet GRUAN requirements to all GRUAN site instrumentation based upon prevalence of instrument types. | | May include National Metrology Institutes |
| Science issues | Expanding from priority | Prepare a position paper on expansion to full column | For consideration by WIGOS | Needed so |

| | | | | |
|---|---|---|---|---|
| | 1 variables | characterisation to meet all stated GRUAN measurement requirements. | or its partners? | that candidate sites for expansion have a concrete idea of what an ideal station may look like. |
| Site considerations | Site / instrument certification | Define a set of accepted objective criteria to assess both instrument specific measures and site performance against vis-à-vis stated requirements. | Site certification and expansion team | Team composition to be determined at ICM-2 |
| Site considerations | Determining measurement frequencies / scheduling | Assessment of the value and utility of satellite coincident in-situ and remote sensing measurements vis-à-vis standard times for satellite cal/val. Submitted for publication. | Temporal sampling team (membership TBD) | To be resolved in collaboration with GSICS |
| Site considerations | Determining measurement frequencies / scheduling | Final set of temporal sampling guidance for in-situ and remote sensing instrumentation based upon a quantitative assessment prior to network expansion, including superseding of GCOS-121 documentation for in-situ measurements. | Temporal sampling team (membership TBD) | |
| Site considerations | Collocation resolution | Formulate generic guidance on the collocation issue based upon quantitative evidence wherever available and for all variables. | Lead Centre, WG-ARO | |
| Site considerations | Managing change | Develop an instrument replacement protocol with a solid quantitative basis. | | Ad hoc GATNDOR interested in this issue. |
| Network protocols and documentation | data quality and instrument issues | Design and instigate a framework to investigate, report and resolve data quality and instrument issues in real-time. | | ACRF already have such a capability and should be consulted |
| Network protocols and | Manuals | Finalize the GRUAN Manual of Operations. | Lead Centre, Secretariat, WG-ARO | Potential assistance by |

| | | | | |
|---|---|---|---|---|
| documentation | | | | WMO CBS expert team, and through WIGOS-PP |
| Data dissemination | | Implement a final version of the data dissemination structure. | GRUAN community | |
| Partnerships | Engaging manufacturers | Workshop with manufacturers under the joint auspices of GCOS and HMEI. | Lead Centre, WG-ARO, HMEI, GCOS Secretariat | Meeting suggested by HMEI |
| Reference Observations | intercomparisons | Assessment of utility against cost and logistical overhead of regular site specific intercomparisons / travelling standards to intercompare sites. | | Needed to ascertain costs ahead of push for network expansion. |
| Outreach | | Brief scientific community on GRUAN. | WG ARO | AMS, EGU and other meetings |
| | | | | |
| **2012** | | | | |
| **Area** | **Sub-section** | **What** | **By whom** | **Notes** |
| Site considerations | Managing change | Conduct a pilot study to evaluate the efficacy of change management protocols / concepts. | | May be best carried out at Lindenberg? |
| Site considerations | Expansion | Create a priority list of candidates for expansion based upon rigorous assessment against requirements. | Site certification and expansion team (membership TBD) | Supersedes ICM-1 Action item #2 |
| Network protocols and documentation | Manuals | Formal inclusion of the GRUAN Manual of Operations into existing WMO documentation. | GCOS Secretariat, WMO Secretariat | Through adoption by WMO Commission for Basic Systems |
| Organizational issues | Instigation of expert teams | Instigate a user review group to meet on a biennial basis. | WG-ARO | Periodic external |

| | | | | |
|---|---|---|---|---|
| | | | | review group with ex-officio Lead Centre, WG-ARO and GCOS Sec. membership |
| Outreach | | Prepare public outreach material. | | |
| | | | | |
| **2013** | | | | |
| **Area** | **Sub-section** | **What** | **By whom** | **Notes** |
| Site considerations | Site / instrument certification | Develop an operational capability to undertake such an analysis providing efficient feedback to sites. | Site certification and expansion team (membership TBD) | ACRF have extensive expertise here. |
| Site considerations | Expansion | Meet with current sites and candidate expansion sites (identified by the site certification and expansion team) and their governing institutions to elicit additional sites' involvement. | WG-ARO, Lead Centre | May also be a full network "launch" event and so held at WMO HQ |
| Outreach | | End of implementation phase; Launch event of GRUAN full operational phase. | WG-ARO, Lead Centre, GCOS Secretariat | May be best tied into the network expansion workshop |

# 4. Progress to date

Subsequent to the publication of the GCOS Implementation Plan in 2004, there have been a total of four meetings related to GRUAN:

1. NOAA/GCOS Workshop to Define Climate Requirements for Upper-Air Observations [8 to 11 February 2005], Boulder, USA
2. GCOS/NOAA Workshop on Reference Upper Air Observations for the Global Climate Observing System: Potential Technologies and Networks [22 to 24 May 2006], Seattle, USA
3. Implementation Meeting of GCOS Reference Upper Air Network [26 to 28 February 2008], Lindenberg, Germany
4. 1st GRUAN Implementation-Coordination Meeting (ICM-1) [2 to 4 March 2009], Norman, USA

The first two meetings defined the over-arching scientific goal and requirements tables. The outcome of these meetings is summarised in GCOS-112. Following the preparation of this report, a call for expressions of interest in hosting a GRUAN Lead Centre was made at the behest of the WG-ARO. Along with proposals from two other institutions, Deutscher Wetterdienst responded offering their Lindenberg Meteorological Observatory facility and the requested resources. This offer was approved at AOPC-XIII (GCOS-114).

The Lindenberg Meteorological Observatory hosted the Implementation Meeting of GRUAN, the outcome of which was summarised in GCOS-121 and included the first work plan. It is at this point that GRUAN was incepted as there was now a dedicated resource and a work plan. There was also an agreement on a list of fourteen initial candidate sites that fulfilled most, if not all, of the stated requirements and, additionally, had a heritage of measurements. At the time of writing, all but one of these sites have formally accepted being GRUAN sites.

Most recently, the first Implementation-Coordination Meeting (ICM-1) was held in Norman, Oklahoma, USA, including a site visit to the ACRF Southern Great Plains Facility. The meeting report (GCOS-131) contains an updated work plan and a decision to propose GRUAN for consideration as a Pilot Project within the WMO Integrated Global Observing System (WIGOS-PP).

Throughout the process, expert input has been solicited through meeting attendance, calls for review of documentation by both meeting participants and the broader community, and discussions at conferences. A paper describing the GRUAN goals and objectives was recently published in the Bulletin of the American Meteorological Society (Seidel et al., 2009). After substantial efforts on the part of the Lead Centre, GRUAN also has a website for sharing information and documentation available at www.gruan.org.

# 5. References


GCOS-131, Report of the First GCOS Reference Upper Air Network Implementation and Coordination Meeting (GRUAN ICM-1), *Norman, Oklahoma, USA, 2-4 March 2009*: http://www.wmo.int/pages/prog/gcos/Publications/gcos-131.pdf

GCOS-121, Report of the GCOS Reference Upper Air Network Implementation Meeting, *Lindenberg, Germany, 26-28 February 2008:* http://www.wmo.int/pages/prog/gcos/Publications/gcos-121.pdf

GCOS-114, XIIIth session of the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC) - Consolidated List of Conclusions, Recommendations and Action Items *Geneva, Switzerland, 23-27 April 2007*: http://www.wmo.int/pages/prog/gcos/Publications/gcos-114.pdf

GCOS-112, GCOS Reference Upper Air Network (GRUAN): Justification, requirements, siting and instrumentation options, *April 2007*: http://www.wmo.int/pages/prog/gcos/Publications/gcos-112.pdf

Karl, T. R., Ed., 1996: Long-Term Climate Monitoring by the Global Climate Observing System (GCOS): International Meeting of Experts, Asheville, North Carolina, U.S.A., January 9-11, 1995. *Kluwer Academic Publishers,* 518 pp.

Karl, T. R., Ed., S. Hassol, C. Miller, and W. Murray, Eds., 2006: Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences. *U.S. Climate Change Science Program, Synthesis and Assessment Report* 1.1, 164 pp.

Nisbet, E., 2007: Cinderella science. *Nature,* 450, 789–790

Randel, W. J., F. Wu, H. Vömel, G. E. Nedoluha, and P. Forster, 2006: Decreases in stratospheric water vapour after 2001: Links to changes in the tropical tropopause and the Brewer-Dobson circulation. *J. Geophys. Res.,* 111, D12312, doi:10.1029/2005JD006744.

NRC, 1999: Adequacy of Climate Observing Systems. *National Academy Press*, 51 pp.

Rosenlof, K.., H. 2003: How Water Enters the Stratosphere, *Science,* 302, 1691-1692 doi:10.1126/science.1092703

Scherer, M., H. Vömel, S. Fueglistaler, S. J. Oltmans, and J. Staehelin, 2008: Trends and variability of midlatitude stratospheric water vapour deduced from the re-evaluated Boulder balloon series and HALOE. *Atmos. Chem. Phys.,* 8, 1391–1402.

Seidel, D. et al., Reference Upper-Air Observations for Climate: Rationale, Progress, and Plans. *Bulletin of the American Meteorological Society, March 2009*: http://www.wmo.int/pages/prog/gcos/documents/seidel_2009.pdf

Soden B.J., Turner D.D., Lesht B.M., and Miloshevich L.M. (2004): An analysis of satellite, radiosonde, and lidar observations of upper tropospheric water vapor from the Atmospheric Radiation Measurement Program. *J. Geophys. Res.,* 109, D04105, doi:10.1029/2003JD003828.

Trenberth, K. E., T. R. Karl, and T. W. Spence, 2002: The need for a systems approach to climate observations. *Bull. Amer. Meteor. Soc.,* 83, 1558–1559.

Wang, J., D. J. Carlson, D. B. Parsons, T. F. Hock, D. Lauritsen, H. L. Cole, K. Beierle, and E. Chamberlain, 2003: Performance of operational radiosonde humidity sensors in direct comparison with a chilled mirror dew-point hygrometer and its climate implication. *Geophys. Res. Lett.,* 30, 1860, doi:10.1029/2003GL016985.

WCRP, 2000: SPARC Assessment of Upper Tropospheric and Stratospheric Water Vapor.

WCRP-113, WMO/TD No. 1043, SPARC Rep. 2, 324 pp.: www.atmosp.physics.utoronto.ca/SPARC/WavasComplet.pdf.

# 6. List of Acronyms

| | |
|---|---|
| AOPC | Atmospheric Observation Panel for Climate |
| AGU | American Geosciences Union |
| AMS | American Meteorological Society |
| ARM | Atmospheric Radiation Measurement Program |
| ACRF | ARM Program Climate Research Facility |
| ACRF SGP | ACRF Southern Great Plains Site |
| BADC | British Atmospheric Data Centre (NERC) |
| BSRN | Baseline Surface Radiation Network |
| CBS | Commission for Basic Systems (WMO) |
| CEOS | Committee on Earth Observation Satellites |
| CLARREO | Climate Absolute Radiance and Refractivity Observatory (NASA) |
| Cg | Congress (WMO) |
| CIMO | Commission for Instruments and Methods of Observation (WMO) |
| DWD | German Meteorological Service (Deutscher Wetterdienst) |
| EC | Executive Council (WMO) |
| EGU | European Geosciences Union |
| ESA | European Space Agency |
| GATNDOR | GRUAN Analysis Team for Network Design and Operations Research |
| GTS | Global Telecommunication System |
| GAW | Global Atmospheric Watch |
| GCM | Global Climate Model |
| GCOS | Global Climate Observing System |
| GIP | GCOS Implementation Plan |
| GOS | Global Observing System (WMO) |
| GPS | Global Positioning System |
| GPS-RO | GPS Radio Occultation Measurement |
| GRUAN | GCOS Reference Upper Air Network |
| GSICS | Global Space-Based Inter-Calibration System |
| GUAN | GCOS Upper Air Network |
| HMEI | Association of Hydro-Meteorological Equipment Industry |
| ICM | Implementation - Coordination Meeting (GRUAN) |
| JMA | Japan Meteorological Agency |
| LC | Lead Centre (GRUAN) |
| LIDAR | Light Detection and Ranging (optical remote sensing) |
| LST | Local Solar Time |
| NASA | National Aeronautics and Space Administration (USA) |
| NCAR | National Centre for Atmospheric Research |
| NCDC | NOAA's National Climatic Data Centre |
| NDACC | Network for the Detection of Atmospheric Composition Change |
| NetCDF | Network Common Data Form |
| NERC | Natural Environment Research Council |
| NOAA | National Oceanic and Atmospheric Administration |
| NWP | Numerical Weather Prediction |
| QC/QA | Quality Control/Quality Assessment |
| SHADOZ | Sothern Hemisphere Additional Ozonesondes |
| SPARC | Stratospheric Processes And their Role in Climate (WCRP) |
| UTC | Universal Coordinated Time |
| UT/LS | Upper Troposphere and Lower Stratosphere |
| WCRP | World Climate Research Programme |
| WG-ARO | Working Group on Atmospheric Reference Observations |
| WIGOS | WMO Integrated Global Observing Systems |
| WIGOS-PP | WIGOS Pilot Project |
| WIS | WMO Information System |
| WMO | World Meteorological Organization |
| WMO HQ | World Meteorological Organization Headquarter in Geneva |

# Appendix 1: GRUAN Observation Requirements

### 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 July 2007.[8]

[8] Further information on the WMO/CEOS database is available at: http://www.wmo.int/pages/prog/sat/Databases.html#UserRequirements

| 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 – 40 km[9] | 0 – 40 km[10] | 0 – 40 km[8] |
| **Vertical Resolution** | 0.1 km (0 to ~30 km)<br>0.5 km (above ~30 km) | 0.05 km (0 – 5 km)<br>0.1 km (5 to ~30 km) | 0.1 hPa |
| **Precision[11]** | 0.2 K | 2% (troposphere) *<br>5% (stratosphere) | 0.01 hPa |
| **Accuracy[12]** | 0.1 K (troposphere)<br>0.2 K (stratosphere) | 2% (troposphere) *<br>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 – 200 m/s[13] | 0 – 360 degrees |
| **Vertical Range** | 0 – 40 km[14] | 0 – 40 km[13] |
| **Vertical Resolution** | 0.05 km (troposphere)<br>0.25 km (stratosphere) | 0.05 km (troposphere)<br>0.25 km (stratosphere) |
| **Precision** | 0.5 m/s (troposphere)<br>1.0 m/s (stratosphere) | 1 degree (troposphere)<br>5 degrees (stratosphere) |
| **Accuracy** | 0.5 m/s * | 5 degrees |
| **Long-Term Stability** | 0.1 m/s (troposphere)<br>0.5 m/s (stratosphere) | 1 degree (troposphere)<br>5 degrees (stratosphere) |
| **Comments** | *to delineate calm conditions from light winds | *Direction is meaningless in very light wind conditions. |

[9] 0-50 km in the GCOS-112 report
[10] 0 to ~30 km in the GCOS-112 report
[11] Repeatability
[12] Uncertainty
[13] 0-300 m/s in the GCOS-112 report
[14] Surface to stratopause in the GCOS-112 report

| 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** | 0 – 40 km | 0 – 40 km | 0 – 40 km |
| **Vertical Resolution** | 0.5 km (stratosphere)<br>0.2 km (troposphere) | 1 km (stratosphere)<br>0.5 km (troposphere) | 2 km |
| **Precision** | | | |
| **Accuracy** | 3% (total column)<br>5% (stratosphere)<br>5% (troposphere) | 1 % (total column)<br>3 ppmv (profile) | 2 % (total column)<br>20 ppb (profile) |
| **Long-Term Stability** | 0.2% (total column)<br>0.6% (stratosphere)<br>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.<br>#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<br>100 – 1700 $cm^{-1}$<br>190 K<$T_b$<330 K |
| **Vertical Range** | Surface | Surface | Surface to top of atmosphere.<br>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 $\mu g\ m^{-3}$ | 0.1 – 30 $\mu g\ m^{-3}$ |
| **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 para-meters, 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<br>#1–2%/decade trend (Norris, 2005) | * 1000–50mb (Rossow and Schiffer, 1999)<br># 10–40 mb variations from ISCCP<br>§ 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)<br><br>#the standard deviation of >= 100 m (Wang et al., 2000) |


Chernykh I.V., Alduchov O. A., and Eskridge R. E. (2001): *Trends in low and high cloud boundaries and errors in height determination of cloud boundaries*. Bull. Am. Meteorol. Soc., **82** (9), pp 1941-1947 <2597:CPOTPC>2.0.CO;2.

Del Genio A.D. and Kovari W. (2002): *Climatic properties of tropical precipitating convection under varying environmental conditions*. J. Climate **15**, 2597-2615, doi:10.1175/1520-0442(2002)015.

Rossow W.B. and Schiffer R.A. (1999): *Advances in understanding clouds from ISCCP*. Bull. Amer. Meteorol. Soc. **80**, 2261-2288, doi:10.1175/1520-0477(1999)080 <2261:AIUCFI>2.0.CO;2.

Seidel D.J. and Durre I. (2003): Comments on "*Trends in Low and High Cloud Boundaries and Errors in Height Determination of Cloud Boundaries*". Bull. Am. Meteorol. Soc. **84**, 237-240.

Wang J., Rossow W. B., and Zhang Y.-C. (2000): *Cloud vertical structure and its variations from a 20-year global rawinsonde dataset*. J. Climate **13,** 3041–3056.

Winker D.M. and Vaughan M.A. (1994): *Vertical distribution of clouds over Hampton, Virginia observed by lidar under the ECLIPS and FIRE ETO programs*. Atmos. Res. **34**, 117-133.

| 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<br>20% ice | 10% | 25% water<br>0.025 mm ice |
| **Long-Term Stability** | 2% water<br>4% ice | 2% | 5% water<br>0.005 mm ice |
| **Comments** | | | |

# Appendix 2: WG-ARO: Membership

**AOPC Working Group on Atmospheric Reference Observations (WG-ARO) Membership (October 2008)**

| Name | Country | Affiliation | Relevant areas of expertise |
|---|---|---|---|
| **Chairman:** Peter Thorne<br>E-mail:<br>Peter.thorne@metoffice.gov.uk | UK | Met Office Hadley Centre | Upper-air climatology |
| Christopher D. Barnet<br>E-mail: Chris.Barnet@noaa.gov | USA | NOAA NESDIS, GSICS Coordination Center | GSICS |
| Franz Berger<br>E-mail: franz.berger@dwd.de | Germany | German Meteorological Service (DWD), Meteorological Observatory Lindenberg | Surface based remote sensing, site management |
| John Dykema<br>E-mail: dykema@huarp.harvard.edu | USA | Harvard University, Division of Engineering and Applied Sciences | GPS-RO and metrology |
| Masatomo Fujiwara<br>E-mail: fuji@ees.hokudai.ac.jp | Japan | Hokkaido University, Environmental Earth Sciences (EES) | Radiosonde and ground-based instrumentation |
| Tom Gardiner<br>E-mail: tom.gardiner@npl.co.uk | UK | National Physical Laboratory (NPL) | National measurement institute, metrology |
| Leopold Haimberger<br>E-mail:<br>Leopold.haimberger@univie.ac.at | Austria | University of Vienna, Institute for Meteorology and Geophysics | Reanalyses, radiosonde climate data records |
| Carl Mears<br>E-mail: mears@sonic.net | USA | Remote Sensing Systems | Satellite climate data records |
| John Nash<br>E-mail: john.nash@metoffice.gov.uk | UK | UK MetOffice | CIMO perspective |
| Miroslav Ondras<br>E-mail: MOndras@wmo.int | | WMO, Observing and Informations Systems Department | CIMO perspective |
| Dian Seidel<br>E-mail: dian.seidel@noaa.gov | USA | NOAA Air Resources Laboratory (R/ARL) | Historical climate change, radiosonde data records |
| Douglas Sisterson<br>E-mail: dlsisterson@anl.gov | USA | Atmospheric Radiation Measurement (ACRF), Climate Research Facility (ACRF), Decision and | Programme management expertise |

| | | | |
|---|---|---|---|
| | | Information Sciences Division | |
| Russell Vose<br>E-mail: russell.vose@noaa.gov | USA | NOAA National Climatic Data Center (NCDC), Climate Analysis Branch | Historical climate change, data management |
| Jimmy Voyles<br>E-mail: jimmy.voyles@pnl.gov | USA | Atmospheric Radiation Measurement (ACRF), Climate Research Facility (ACRF) | Instrumentation |
| Junhong Wang<br>E-mail: junhong@ucar.edu | USA | National Centre for Atmospheric Research (NCAR), Earth Observing Laboratory (EOL) | Radiosonde technologies and climate datasets |
| | | | |
| **Ex-officio Members** | | | |
| Director GCOS Secretariat<br>Carolin Richter<br>E-mail: CRichter@wmo.int | | WMO, Global Climate Observing Sytem Secretariat | Ensure that GCOS Secretariat is involved (non-voting) |
| Head of Lead Centre<br>Holger Vömel<br>E-mail: Holger.Voemel@dwd.de | Germany | German Meteorological Service (DWD), Meteorological Observatory Lindenberg | Ensure that lead centre is represented in discussions (non-voting) |
| Howard Diamond<br>E-mail: howard.diamond@noaa.gov | USA | US GCOS Office / NOAA/National Climatic Data Center (NCDC) | Continued presence of major programme supporter in discussions (non-voting) |
| Christopher D Miller<br>E-mail:<br>christopher.d.miller@noaa.gov | USA | NOAA Office of Global Programs (OGP), Climate Change Data and Detection Program | Chief of the Research and Monitoring Division for NOAA's Climate Program Office (non-voting) |
| Bill Murray<br>E-mail: William.I.Murray@noaa.gov | USA | NOAA Office of Global Programs (OGP), Climate Change Data and Detection Program | Continued presence of major programme supporter in discussions (non-voting) |

# Appendix 3: WG-ARO: Terms of Reference

**AOPC Working Group on Atmospheric Reference Observations (WG-ARO)**
**Terms of Reference (August 2008)**

The GCOS/WCRP Atmospheric Observation Panel on Climate (AOPC) Working Group on Atmospheric Reference Observations (WG-ARO) was established in summer 2006 in recognition of the importance of initiating reference-quality observations of atmospheric column properties, in particular temperature and water vapour, from the surface into the stratosphere to enhance the monitoring and understanding of climate variability and change. The GCOS Implementation Plan identified the establishment of a reference-quality network as "a very high priority" for implementation by 2009. It is the Working Group's purpose to facilitate this, liaising with other groups and national and international bodies to ensure that an eventual network is fit for purpose, robust and has the required long-term commitment and management structures.

**Terms of Reference**

Under the auspices of AOPC,

- To provide scientific, technical and management oversight to the operations of the GCOS Reference Upper Air Network (GRUAN) Lead Centre, which will manage the overall work and evolution of the network, and which shall report to the WG-ARO at least twice a year (Figure 1 provides a depiction of lines of reporting and responsibilities);
- To ensure that the action plan agreed at the Lindenberg meeting (cf. GCOS-121) and any subsequent action plans are carried out, including but not limited to undertaking those activities mandated to the WG-ARO;
- To work with relevant agencies and programmes to define and promote GRUAN for long-term atmospheric reference observations of a range of variables (cf. GCOS-112, Appendix 1), making optimal use of existing and planned infrastructure within the WMO Global Observing System;
- To define and maintain (minimum and target) requirements of a GRUAN site in terms of instrumentation, variables addressed, data quality, the collection of metadata, operating practices and data management, in consultation with the Commission on Instruments and Methods of Observation (CIMO) and other relevant observing programmes;
- To provide recommendations on the composition of the GRUAN, including the selection of sites, noting that AOPC has final say in endorsing the GRUAN network composition; this should be done in consultation with AOPC AGG (Advisory Group on GSN and GUAN) and other advisory bodies as appropriate (e.g., with GSICS (Global Space Based Inter-Calibration System) and GAW (Global Atmospheric Watch));
- To define a data dissemination structure to maximise the use of resulting GRUAN data, and to promote their use in future climate monitoring and research activities;
- To recommend roles and responsibilities of the GRUAN Lead Centre and, as deemed appropriate, other centres, for data quality monitoring, analysis and capacity building purposes;
- To liaise with the WMO Space Programme, Commission on Basic Systems (CBS) and CIMO on satellite and radiosonde calibration and validation issues, including reference instrumentation and metadata, especially through the GSICS

initiative and the WMO Global Network of Regional/Specialized Satellite Centres for Climate Monitoring (R/SSC-CM);

- To report at least annually to AOPC on its activities, including the progress towards a reference network, the performance of the network once established, the uses and value of the data collected, and the implications for the global observing system;
- To provide for appropriate communication and outreach activities (through such activities as conference town meetings, making connections with other programs, organizing special sessions on GRUAN etc.).

**Operation**

The Working Group will generally correspond by e-mail and teleconferences, and take advantage of relevant workshops and conferences to hold meetings. Additional meetings will be convened by the chairman upon demand, in consultation with the GCOS Secretariat and GRUAN partner institutions. During the initial GRUAN instigation phase (until at least 2011) it is envisaged that annual meetings should be convened at initial GRUAN network sites at which Working Group members will be expected to attend. Funding for these meetings should be sought from sponsors. The group will cease to exist at such time as AOPC deems appropriate. Members will be expected to serve until at least April 2010 when membership will be reviewed. These Terms of Reference will be subject to periodic review by AOPC in liaison with the Chairman of the Working Group.

# Appendix 4: GRUAN Lead Centre: Staff

**Lead Centre at the Lindenberg Meteorological Observatory**
**Staff (July 2009)**

The dedicated Lead Centre staff members are:

Dr. Holger Vömel (Head)
Dr. Franz Immler (Scientist)
Mr. Michael Sommer (Scientist and data base manager)
Ms. Marion Fiedler (Administrative assistant and research associate)

Dr. Vömel is the main point of contact in interactions with the Lead Centre in all matters related to GRUAN. He is also the head of the in situ sounding group at the Lindenberg Observatory.
Dr. Immler is the GRUAN lead centre senior scientist working on all scientific issues relating to GRUAN.
Mr. Sommer is working on data base development, data archiving, data flow, quality control and quality assurance issues. He will also work on scientific issues.
Ms. Fiedler is supporting the GRUAN lead centre in all administrative matters as well as in data analysis and data management issues.

Dr. Ulrich Leiterer was named honorary member of the GRUAN Lead Centre. Before his retirement he was head of the long-term monitoring group (now the in situ sounding group) at the Lindenberg Observatory and a pioneer in high accuracy observations of atmospheric humidity.

All GRUAN Lead Centre staff members were hired within the last year and are integrating well into the in situ sounding group at the Lindenberg Observatory and are quickly growing together as an active team to take on all Lead Centre tasks.

*(Intentionally blank)*

# Appendix 5: GRUAN Lead Centre: Terms of Reference

**GCOS Reference Upper Air Network (GRUAN) Lead Centre**
**Terms of Reference (August 2008)**

The GRUAN Lead Centre is to be responsible for the monitoring of the Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN), including development of GCOS needs for station operation, coordination among stations, and ensuring archival and dissemination of GRUAN data (this could in principle be carried out by a third party). GRUAN is envisaged as a network of 30-40 high-quality, long-term, upper-air observing stations that are built on, but not confined to, the larger GCOS Upper Air Network. These reference network observations would: provide anchor points that are very well characterised in their relative biases over time; attempt to comprehensively characterise the atmospheric column, and; be the best systematic *in situ* atmospheric profile measurements currently available. Each site would operate a suite of instrumentation sufficient to robustly ascertain the atmospheric characteristics for meteorological variables and, in some cases, atmospheric composition and radiation variables. Further details are given in the reports GCOS-112 and GCOS-121.

Initially, the GRUAN Lead Centre would be convened under the scientific guidance of the GCOS/WCRP AOPC Working Group on Atmospheric Reference Observations (WG-ARO) and with the agreement of the relevant Permanent Representatives of WMO Members. It would serve the following functions in developing and maintaining the Network:

- *Coordination of the network (in collaboration with the host country and WMO)*
    - Monitoring output of the GRUAN network. This would include making periodic visits to each station and ensuring understanding of the GCOS Climate Monitoring Principles. This includes coordinating a mechanism for ensuring adequate overlap and comparisons when inevitable instrument changes / improvements are made.
    - Identification of (external) instrument mentors (instrument experts who are familiar with the strengths and weaknesses of the instruments and data they produce) and a team of scientists who understand the site-specific climate science issues and can provide scientific assistance and guidance to sites.
    - Assisting in succession planning to ensure continuity in observations and expertise.
    - Coordination of national contributions to the network.
    - Requesting of reference radiosonde launch schedules, particularly if synchronization of launches with satellite overpasses is required.
    - Provision of administrative and technical support for the AOPC Working Group on Atmospheric Reference Observations.

- *Training, education and research (in collaboration with the host country and WMO)*
    - Provision of advice on instrument deployments and developments.
    - Coordinating work to encourage commercial development of reference upper-air instruments.
    - Provision of expertise and a commitment to train staff at sites.

- Promotion of research activities, including a visiting scientist programme, that apply GRUAN data to climate research and monitoring issues.
- Training at the lead centre of on-site scientists to ensure required accuracies.
- Development and provision of guidelines to harmonize long-time series of upper-air observations, especially for archived datasets.

- *Data management including. reanalysis (in collaboration with the host country and WMO)*

    - Real time data quality control/quality assurance, with rapid feedback to stations having potential problems.
    - Coordination with the data user community, with special emphasis on the satellite and reanalysis communities.
    - Provision of climate datasets including their relative uncertainties.
    - Network data assembly, archive, and dissemination.
    - Where applicable, inclusion of available historical upper-air profiles and re-analysis of these data with respect to seasonal and annual variability to enable longer-term analyses.
    - Inclusion of complementary data from satellites, NWP analyses and other activities for ease of intercomparison in the upper-air database.
    - Free distribution for bona fide research and operational users.

- *Reporting*

    - The Lead Centre shall report to the WG-ARO at least twice a year (see for reporting lines the Terms of Reference of WG-ARO).

The AOPC Working Group on Atmospheric Reference Observations envisages establishment of the Lead Centre in 2007, collocated with an existing organization already engaged in similar or related functions for climate observing system, with an initial staff of three full time scientific professionals, one full time visiting scientist and a part time administrative/support person.

# Appendix 6: GRUAN Data Policy

**GCOS Reference Upper Air Network (GRUAN) Data Policy**
**(February 2009)**

## 1. INTRODUCTION

The Global Climate Observing System (GCOS) is a programme sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the International Council on Science (ICSU), and the United Nations Environment Programme (UNEP). The GCOS Reference Upper Air Network (GRUAN) is a global network for atmospheric reference observations, and will provide the foundation for long-term datasets that can be used reliably to monitor and detect emerging signals of global and regional climate change. Specifically, GRUAN is required to provide long-term high quality climate records, to constrain and calibrate data from more spatially-comprehensive global observing systems (including satellites and current radiosonde networks), and to fully characterize the properties of the atmospheric column.

GRUAN stations are operated by national environmental agencies (including but not limited to national meteorological services) or research institutions, under the auspices of the Working Group on Atmospheric Reference Observations (WG-ARO), the Atmospheric Observation Panel for Climate (AOPC) jointly sponsored by GCOS and the World Climate Research Programme (WCRP), and the GCOS Steering Committee. In 2007, the Richard-Aßmann Observatory in Lindenberg, Germany, has been designated by WMO as a Lead Centre for the network. Implementation of the network and the establishment of a data archive are currently under development.

The observational requirements for GRUAN are defined in the report 'GCOS Reference Upper Air Network (GRUAN): Justification, Requirements, Siting and Instrumentation Options' (GCOS-112) summarizing the results of two workshops on upper-air observations in Boulder, USA (February, 2005) and Seattle, USA (May 2006).

At the GRUAN Implementation Meeting (Lindenberg, Germany, 26 - 28 February 2008; see report GCOS-121), the following recommendations were made in terms of data policy:

- Compliance with WMO Resolution 40 (Cg-XII),
- Definition of all data from the instrument systems which are specified in GCOS-112 or any agreed revision of GCOS-112 as 'essential' at all GRUAN sites, to ensure the free and unrestricted availability of these data, and
- Dissemination in (near) real time to be considered for operational purposes, with use of the QC/QA software as employed for operational monitoring of radiosonde data.

AOPC recommended at its XIVth session (Geneva, 21-25 April 2008, report GCOS-122) that GRUAN sites should provide all GRUAN data in a free and unrestricted manner, if possible in real time, in order to be of maximum value for all applications, for example enabling the data being monitored and assimilated in numerical weather prediction systems.

## 2. DATA POLICY FOR THE GCOS REFERENCE UPPER AIR NETWORK (GRUAN)

### 2.1 WMO Resolution 40 (Cg-XII)

GRUAN was initiated by the Global Climate Observing System (GCOS), co-sponsored by, among others, WMO. It is thus appropriate that any policy for release and dissemination of GRUAN data complies with WMO policy, practice and guidelines for the exchange of meteorological and related data and products, as embodied in Resolution 40 of the Twelfth WMO Congress 1995. In this Resolution, WMO calls for free and unrestricted international

exchange of meteorological data and related data and products, as described at http://www.wmo.int/pages/about/Resolution40.html .

In the GRUAN network, GRUAN sites should designate all data from instrument systems specified in GCOS-112 (Section 6) or any revision of GCOS-112 as 'essential' data [in the sense of Annex 1 to Resolution 40 (given in Annex I of this document) , not in the sense of 'Essential Climate Variables']. A list of possible additional data shall be maintained by the GRUAN Lead Centre.

Metadata associated with GRUAN should include the identification of the GRUAN sites and information related to the acknowledgement and co-authorship aspects mentioned in hereunder paragraphs 2.3 and 2.4. The metadata should provide the information required for the use of the data. Details on metadata formats are to be provided by GRUAN data dissemination guidelines.

### 2.2 Timing of Data Release

The timing of data release involves conflicting aspects. As its core objective, GRUAN is designed to provide reference-type climate datasets of the atmospheric column. Therefore, ensuring the highest attainable quality of data is the primary goal, which will generally involved extensive, time-consuming quality checks, disallowing rapid data release. Some potential data users, particularly in the numerical weather prediction community, however, will be interested in obtaining the data as soon as possible after the time of measurement.

It is therefore suggested to separate between 'Standard Data' [1] and 'Enhanced or Experimental Data' [2] obtained at GRUAN sites:

[1] Standard Data (e.g., near surface synoptic observations, radiosonde observations) with the following characteristics:
General exploitation value, measurement technology common, generally well understood, little problems with data interpretation.

[2] Enhanced or Experimental Data (e.g., Raman LIDAR, Microwave, Surface radiation, GPS PW) with the following characteristics:
High exploitation value, measurement technology sophisticated and/or of experimental nature, contact to site scientist recommended for correct interpretation of data, high efforts necessary to maintain continuous measurements and high quality of data.

**'GRUAN data' are defined as datasets obtained at GRUAN sites that have been subject to sufficient quality checks to be expected to meet GRUAN requirements for climate applications, as laid down in GCOS-112, Appendix 1. This includes both Standard and Enhanced or Experimental Data and generally leads to delayed data release, but no later than after a turn-around period of up to six months. These data will be disseminated through a GRUAN designated data distribution system.**

Furthermore, it is recommended to, if and when possible, release Standard Data in real time or near real time, for operational purposes. Data released in this way would generally not qualify as 'GRUAN data' given the quality requirements mentioned above. However, (near) real time data release will facilitate the quality control link between GRUAN and GUAN, and other networks. The timely release of data will also enable the data being monitored and used in numerical weather prediction systems.

In addition, site operators should consider the (near) real-time release of Enhanced or Experimental Data if this is being requested by the numerical weather prediction community. Again, data released in this way would generally not qualify as 'GRUAN data' given the quality requirements mentioned above.

These recommendations are consistent with the WMO *Guide to Climatological Practices* (WMO-No. 100; Chapter II, 2.6 and Chapter III, 3.4) and the WMO *Guide to the Global Observing System* (WMO-No. 488; Part III, 3.7).

## 2.3 Acknowledgement

Whenever GRUAN data have been used in scientific work that is being published, the data origin must be acknowledged and referenced. A minimum requirement is to reference GRUAN, as a reference network of GCOS, and the data archive [not yet designated]. If only data from one GRUAN site (or a limited number of sites) has been used, additional acknowledgement to the reference site(s) and their sponsoring institutions or organizations shall be given, according to the recommendation for citation and acknowledgement given by the originator of the data.

## 2.4 Co-Authorship

The GRUAN was developed by an international panel of scientists including experts in radiosondes and remote sensing measurements for water vapour, temperature and pressure in the upper troposphere and lower stratosphere. GRUAN sites are equipped with sophisticated, state-of-the-art instrumentation and comply with strict requirements of station maintenance, exposure of instruments, calibration, quality assurance procedures and the like. To ensure that the goal of long-term high quality climate records is reached, site scientists who are leading experts for the instruments used at the respective GRUAN sites often take responsibility for individual instruments operated at the GRUAN site.

Inclusion of GRUAN scientists as co-authors of papers making extensive use of GRUAN data is justifiable and highly recommended, in particular if a site scientist has responded to questions raised about data quality and/or suitability for the specific study in question, or has been directly involved in contributing to the paper in other ways. The co-authorship is not a pre-condition for release of GRUAN data. However, it is highly recommended that any data user should contact the responsible site scientist and ask if he/she wants to become co-author, or if an acknowledgement would be sufficient. Users of GRUAN data are encouraged to establish direct contact with site scientists for the purpose of complete interpretation and analysis of data for publication purposes.

Whenever GRUAN data distributed by the data archive are being used for publication of scientific results, the author(s) shall send a copy of the respective publication, preferably in electronic form, to the Lead Centre.

Address of GRUAN Lead Centre:

GRUAN Lead Centre
Deutscher Wetterdienst
Lindenberg Meteorological Observatory / Richard-Aßmann Observatory
OT Lindenberg, Am Observatorium 12
D-15848 Tauche, Germany
Tel.: +49 33677 60-260
Email: holger.voemel@dwd.de
Web: http://www.dwd.de/mol

*(Intentionally blank)*

# Appendix 7: WMO Resolution 40 (Cg-XII)

**Data and Products to be exchanged without Charge and with no Conditions on Use**

Purpose

The purpose of this listing of meteorological and related data and products is to identify a minimum set of data and products which are essential to support WMO Programmes and which Members shall exchange without charge and with no conditions on use. The meteorological and related data and products which are essential to support WMO Programmes include, in general, the data from the RBSNs and as many data as possible that will assist in defining the state of the atmosphere at least on a scale of the order of 200 km in the horizontal and six to 12 hours in time.

Contents

(1) Six-hourly surface synoptic data from RBSNs, e.g. data in SYNOP, BUFR or other general purpose WMO Code;

(2) All available *in situ* observations from the marine environment, e.g. data in SHIP, BUOY, BATHY,TESAC codes, etc.;

(3) All available aircraft reports, e.g. data in AMDAR,AIREP codes, etc.;

(4) All available data from upper air sounding networks, e.g. data in TEMP, PILOT, TEMP SHIP, PILOT SHIP codes etc.;

(5) All reports from the network of stations recommended by the regional associations as necessary to provide a good representation of climate, e.g. data in CLIMAT/CLIMAT TEMP and CLIMAT SHIP/CLIMAT TEMP SHIP codes, etc.;

(6) Products distributed by WMCs and RSMCs to meet their WMO obligations;

(7) Severe weather warnings and advisories for the protection of life and property targeted upon end-users;

(8) Those data and products from operational meteorological satellites that are agreed between WMO and satellite operators. (These should include data and products necessary for operations regarding severe weather warnings and tropical cyclone warnings).

*(Intentionally blank)*

## *List of GCOS Publications (since 2008)*[*]

| | |
|---|---|
| **GCOS-119**<br>(WMO/TD-No. 1424) | Report of the Implementation Strategy Meeting for Central America and the Caribbean (Belize City, 28-30 January 2008) |
| **GCOS-120**<br>(GOOS-No. ) | Report on the Meeting of "IOC Group of Experts on the Global Sea Level Observing System (GLOSS), tenth session<br>(Paris, France, 6-8 June 2007) |
| **GCOS-121**<br>(WMO/TD-No. 1435) | GCOS Reference Upper Air Network (GRUAN). Report of the GRUAN Implementation Meeting (Lindenberg, Germany, 26-28 February 2008) |
| **GCOS-122**<br>(WCRP 9/2008)<br>(WMO/TD-No. 1436) | Fourteenth Session of the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC-XIV) – Conclusions and Recommendations<br>(Geneva, Switzerland, 21-25 April 2008) |
| **GCOS-123**<br>(WMO/TD-No. 1444) | Report of the Fourth Meeting of the GCOS Cooperation Board<br>(Bonn, Germany, 12 June 2008) |
| **GCOS-124**<br>(WMO/TD-No. 1463) | Report of the Sixteenth Session of the WMO-IOC-UNEP-ICSU Steering Committee for GCOS (Geneva, Switzerland, 14-17 October 2008) |
| **GCOS 125**<br>(WCRP) | Report of the WOAP-III Meeting (Boulder, CO, USA, 29 September to 1 October 2008) |
| **GCOS-126**<br>(WMO/TD No. 1464) | GCOS Annual Report 2007-2008 |
| **GCOS-127**<br>(WMO/TD No. 1477) | Practical Help for Compiling CLIMAT Reports |
| **GCOS-128**<br>(WMO/TD No. 1488) | Guidelines for the Generation of Satellite-based Datasets and Products Meeting GCOS Requirements<br>(GCOS Secretariat, March 2009) |
| **GCOS-129**<br>(WMO/TD No. 1489) | Progress Report on the Implementation of the Global Observing System for Climate in Support of the UNFCCC 2004-2008 |
| **GCOS-130**<br>(WMO/TD No. 1490) | Synthesis of National Report on Systematic Observation for Climate |
| **GCOS-131**<br>(WMO/TD No. 1492) | Report of the First GCOS Reference Upper Air Network Implementation and Coordination Meeting (GRUAN ICM-1)<br>(Oklahoma City, USA, 2-4 March 2009) |
| **GCOS-132**<br>(WCRP 6/2009)<br>(WMO/TD No. 1497) | Fifteenth Session of the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC-XV) – Conclusions and Recommendations<br>(Geneva, Switzerland, 27-30 April 2009) |
| **GCOS-133**<br>(WMO/TD No. 1498) | Summary Report of the Eleventh Session of the GCOS/GTOS Terrestrial Observation Panel for Climate (TOPC)<br>(Rome, Italy, 29-30 October 2008) |

[*]GCOS publications may be accessed through the GCOS website at: http://www.wmo.int/pages/prog/gcos

**GCOS Secretariat**
**Global Climate Observing System**
**c/o World Meteorological Organization**
**7 *bis,* Avenue de la Paix**
**P.O. Box No. 2300**
**CH-1211 Geneva 2, Switzerland**
**Tel: +41 22 730 8275/8067**
**Fax: +41 22 730 8052**
**Email: gcosjpo@wmo.int**