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Item 5.1

Report from WG-ARO: Development of GRUAN

(Submitted by Peter Thorne)

Summary and Purpose of Document

The purpose of this document is to inform the Session about the progress made at the Implementation Meeting of the GCOS Reference Upper Air Network in Lindenberg, Germany. The documents includes the Terms of References and Membership for the Working Group on Atmospheric Reference Observations and a first draft of the meeting report. Meeting participants argeed on a list of actions which will forster the development of GRUAN and serve as a work plan for the Lead Centre and other interested parties.

ACTION PROPOSED

The Meeting is invited to note the information contained in this document for discussion under Agenda Item 5.1., and to assist in the establishment of a GRUAN data policy together with the Lead Centre, other initial sites, the WG-ARO, and GCOS Secretariat.

Report from WG-ARO: Development of GRUAN

Introduction

The Meeting on Implementation of the GCOS Reference Upper Air Network (GRUAN) was hosted by the German Meteorological Service (DWD), at the Richard Aßmann Observatory in Lindenberg, recently designated by WMO as the Lead Centre for the GRUAN network. The implementation meeting was held under the auspices of DWD and the Global Climate Observing System (GCOS) Secretariat, and was sponsored by the National Oceanic and Atmospheric Administration (NOAA). The objective of the meeting, headlined "**Start small, but start**", was to develop a work plan for the GRUAN Lead Centre and other interested parties that:

- Identifies and addresses remaining scientific and technical issues;
- Ensures observations are being made in a manner consistent with the stated GRUAN requirements henceforth at a number of initial sites; and
- Informs priorities for the GCOS Working Group on Atmospheric Reference Observations.

This report is intended to be short, mainly focusing on the results of discussions for the implementation of the GRUAN network. The presentations given at the meeting are available on the DWD website at http://metportal.dwd.de/mol.

It should be stressed that the meeting included the representation of a broad range of perspectives and that this report primarily attempts to summarize consensus positions where these were reached. Where they were not, the range of opinions is attempted to be briefly captured. This report should not be interpreted as representing the views of any of the individual participants.

The report "GCOS Reference Upper-Air Network (GRUAN): Justifications, requirements, siting and instrumentation options" (GCOS-112, WMO/TD No. 1379), summarizing the two previous workshops in Boulder and Seattle, serves as a basis for this report and should be read in conjunction with it to provide the necessary context. It should be noted that when deciding upon the format of the requirements tables in GCOS-112 there was much discussion about "objective" and "break-through" criteria, as exists in most NWP-derived requirements tables. The decision was reached that the final tables were only to consist of an objective threshold that was the desired final measuring precision to answer relevant climate questions. The idea *was not* that measurements at these specifications would be possible from initiation of the GRUAN network operation. Rather the hope was that providing a single objective it would spur the manufacture of instruments to meet the scientific requirements in a timely fashion.

Following the meeting in Lindenberg the Working Group has submitted an article about GCOS Reference Upper Air Network in the *Bulletin of the American Meteorological Society*, providing an outline of the rationale, progress and plans for the implementation of the network to the wider scientific community and inviting feedback and active participation.

1. Upper Air Instrumentation and Observing Practices

Radiosonde Instrumentation

Requirements for balloon-based observations of temperature, humidity, pressure and winds are provided in GCOS-112. Discussions in the meeting centered on development and/or use of a reference radiosonde(s). We define a reference radiosonde here as a single instrument or

combination of instruments which, launched on a regular basis, would be capable of achieving the stated requirements in GCOS-112 for temperature, humidity, and direct or indirect measurement of pressure. It was clear from the workshop discussions that at the moment there is no such operational reference radiosonde available on the market. The technical challenges in the development of such a radiosonde should not be under-estimated and clearly must form a focus of future work if GRUAN is to be successful.

However, the technology of radiosonde measurements has improved substantially during recent years, partly as a response to CIMO intercomparisons. For temperature and pressure it is very likely that standard production radiosondes or a combination of such instruments can meet the stated requirements. At the moment temperatures reported by radiosondes differ within 0.3^{o} K under most conditions. The accuracy is mainly dependent on the radiation bias. The radiation correction for the radiosondes used in the GRUAN network should be evaluated at each GRUAN site, with help from the Lead Centre (see action item 1). However, the main challenge is to meet the long-term stability requirements for temperature measurements (0.05^{o} K)

Water vapour in the Upper Troposphere and Lower Stratosphere (UT/LS) is the hardest challenge, and routine observations at the moment are not even close to the requirements given in GCOS-112, especially in the tropical upper troposphere. All mass production humidity sensors deliver biased data for moisture in the upper troposphere, if they even record any humidity tendency data there at all. There are some research radiosondes that show much greater promise in this region such as CAO Lyman-alpha FLASH-B hygrometer (Vömel, et al., 2007b), which measures water vapour in the upper troposphere and lower stratosphere at night time, Cryogenic Frostpoint Hygrometer (CFH, Vömel et al., 2007a), which measures water vapour from the surface to the middle stratosphere, and Snow White chilled-mirror hygrometer (Fujiwara, 2003, Vömel et al., 2003), which can measure water vapour up to the upper troposphere.

- The CFH is launched world wide on campaign basis for validation and scientific studies, but the measurement of temperature and pressure is based on Vaisala RS80, which is no longer in production. Interfacing with other radiosondes as replacement of the RS80 is currently underway and will be completed in the near future.
- The FLASH-B sonde has taken part in intercomparisons at Sondankylä, Costa Rica and Indonesia. The main problems are that the sonde can only be operated in the dark and during descent and that so far a detailed description of the calibration procedure used by the manufacturer, the Central Aerological Observatory/Russia, is not available.
- The current version of Snow White chilled-mirror hygrometer of Meteolabor is usable from the surface up to the upper tropopause, but the accuracy is known to decline at upper levels. It has not yet been possible to ascertain where this transition point is. To avoid this problem, the FLASH-B has been flown with a Meteolabor SRS-C34 radiosonde including the night-type Snow White at the Payerne (Switzerland) site. Snow White measures humidity accurately from the surface up to the tropopause, while FLASH-B measures humidity in the stratosphere, with some overlaps around the tropopause region with an "inflight" comparison (or validation of FLASH-B). The price of this system is about twice the CFH system.

The uncertainty for measurements of water vapour in the UT/LS is large and poorly understood, even at long-running, high-quality research sites like Boulder. As outlined in GCOS-112, the proportion of water vapour in the upper troposphere is radiatively important, and through GRUAN, there is hope to get this information to be able to verify climate models.

In conclusion, meeting participants agreed that routine launching of a reference radiosonde, whatever its design, is not currently feasible. More effort is urgently required towards the production of a reference sonde capable of being flown on a routine basis. The meeting

participants encouraged manufacturers and scientists to work quickly towards the development of such a reference sonde. However, it was recognized that GRUAN needs to begin a reference quality measurement programme in a unique way not currently included in GUAN measurements and that is affordable to candidate stations. The implications of this lack of a reference radiosonde that can meet specified requirements in terms of initial site operation are discussed later in this section.

Radiosonde Launch Schedule

Most of the presentations and points raised during the discussions argued that a simultaneous launch with the overpass of a satellite is not possible, because of the spatial and temporal difference of radiosonde and satellite measurements. The satellite overpass is instantaneous overpass, whereas the sounding takes about 90 minutes to two hours and drifts considerably in latitude and longitude.

The meeting participants agreed to retain the fixed schedules (00 and 12) for sonde launch and to start communications with satellite agencies, for example through the Global Satellite Inter-Comparison System (GSICS), to evaluate interest by the satellite community in sponsorship of additional flights on a “pay-per-flight” basis (see action item 2). No routine launches for overpasses of satellites are planned for the initial phase of GRUAN, however the issue of launch schedules has still not been unambiguously closed (see section 7, B).

Radiosonde Site Requirements

The minimum criteria for a GRUAN site are outlined in GCOS-112 (p. 9-10). During the meeting it was clearly pointed out to the participants that the minimum criteria for the simultaneous balloon-based observations of temperature, water vapour, pressure and winds, both on ascent and descent, are not stipulated in the report as to frequency of measurements.

As an interim measure, until an operational reference sonde becomes available, tiered levels of radiosonde launches, or a “cascade” of launches, was proposed to ensure both inter-station comparability and long-term continuity of the climate record. The GRUAN sites can implement the different levels / tiers of observations step by step using the following measurement protocols:

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 to the best level possible with current technology, launched together with weekly radiosonde;
3. Regular 00 and 12 (UTC or Z) 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.

Only the first two tiers / criteria were decided to be needed to be met at the initiation of a GRUAN site, with the remainder being seen as desirable activities that should be aimed for. No specific instrument or manufacturer is stipulated for any of these measurements. It goes without saying that more frequent monitoring, particularly of the UT/LS moisture signal would be highly desirable if it proves affordable. These are pragmatic minimum requirements that should serve the scientific purpose whilst being designed to ensure that they are technologically, financially and technically feasible at the present time by a number of sites. These sites include a number where routine radiosondes are not currently launched but which have a rich variety of ground-

based sensing equipment, hence the requirement for routine twice-daily observations being optional.

In order to ensure the quality of observations periodic intercomparisons between instrumentation used at all the sites will take place and are encouraged to be undertaken as often as possible at individual sites (see action item 3). The WG-ARO and Lead Centre will collaborate with CIMO and the scientific community in making such periodic intercomparisons of a large range of sonde types and in analyzing existing comparisons made by scientific or operational users.

Reassessing Radiosonde Guidance

It was proposed that a major intercomparison be held under the auspices of GCOS and CIMO, managed by the WG-ARO and Lead Centre, at one or more GRUAN or other appropriate sites to try to ascertain a best set of instrumentation and practices specifically for GRUAN operations in 2010 and that this should involve both operational production and research sondes (see action 4).
Following this exercise, and based upon the lessons learnt from such an intensive intercomparison, the operational experiences of and data from the sites to that time, and any other pertinent research findings by the scientific community, guidance on radiosonde instrumentation will then be very substantially modified by the WG-ARO and Lead Centre in consultation with other parties. This will hopefully bring about a more final resolution of the issues prior to network expansion so that new sites will know what exactly they are signing up to. A key aspect will be to manage the transition at existing sites between the interim operations procedure and any new procedure in such a way as to maintain the long-term climate signal.

2. Ground-based Instrumentation and Observing Practices

Meeting participants for the ground-based instrumentation requirements at a GRUAN site raised the needs for:

- Definition of best practices and/or a workshop to define a priority list of additional ground-based instrumentation (priority 2) and recommendations for a set of ground-based instrumentation types
- Development of guidelines and procedures for the observing practices to ensure standardization, comparability and high-quality of measurements at all sites

The meeting participants agreed with the minimum set of ground-based instrumentation defined by the previous two workshops (GCOS-112, priority 1), namely to have a ground-based GPS receiver to measure total column water vapour (GPS PW) at each GRUAN site.

The list for additional ground-based instruments (GCOS-112, priority 2) encompasses six instruments: surface radiation instruments, microwave radiometer, multi-channel infrared radiometer (e.g. FTIR), Lidar (e.g. Raman Lidar), integrated trace gas measurements and sun photometer. The cloud radar may also be useful as a basic instrument necessary to measure cloud structure. The instrumentation and measurements at BSRN sites already meet the GRUAN surface radiation specifications. A list of all BSRN stations which do not need further action with respect to this requirement is given in Appendix V.

Participants argued for the need to define priorities on this list and to recommend certain instrumentation types. These could be achieved by a specific campaign or based on the best

practices developed at the Lead Centre and other sites. The objective is to have a priority list of ground-based instruments at hand to be given as a recommendation to National Meteorological Services (NMS's) or research institutes establishing a GRUAN site (see section 7, C)

For the observing practices at the GRUAN sites, the development of a manual will be undertaken by the GRUAN Lead Centre in Lindenberg in collaboration with the WMO Commission for Basic Systems (CBS) and the WMO Commission for Instrumentation and Methods of Observations (CIMO), building upon available literature from these bodies.

The manual shall guarantee the standardization of measurements to assure the comparability and high quality of observations. The manual will define the accuracy and long-term stability for the measurements, but not the manufacturer of the instrument, in order to guarantee sustainability of observations and avoid restriction to one vendor. Best practices and lessons learned at the Lead Centre and the other initial sites shall be disseminated and guidelines for the reporting of data developed (see action item 5).

The manual on observing practices will form an important basis for the development of the GRUAN network. The experience from the GCOS Upper Air Network (GUAN) shows that the majority of the sites only fulfill the threshold requirements for observations given in the manual. Even if the reference network encompasses a much smaller number of sites, the requirements given in the manual are critical for the implementation of the network and communication to the site operators.

3. Site Selection

A first (tentative) list of twelve initial candidate sites was selected, based on the list of stations named in first GRUAN report, presentations held by meeting participants and discussions at the meeting. Gradual expansion of the network is foreseen, based on lessons learned from this initial selection of sites. Therefore an initial candidate site should have a rich variety of instrumentation, a long-standing resident expertise, and perspectives to bring to bear on the remaining scientific and technical issues that need to be addressed. At this stage, the GRUAN development is not directed towards having exact clone sites, as this reduces the chances of learning valuable lessons about the functioning of the network, especially as more challenging (politically, geographically, logistically, or economically) locations will be considered in the future.

It is proposed that the following initial sites be invited by WMO to become GRUAN stations, following review and consultation with the Atmospheric Observing Panel for Climate (AOPC) and the Commission on Basic Systems (CBS) in September 2008 (see action item 6):

- Darwin, Australia
- Xilin Hot, China
- Sodankyla, Finland
- Lindenberg, Germany
- Potenza, Italy
- Cabauw, Netherlands
- Lauder, New Zealand
- Payerne, Switzerland
- Barrow, USA
- Beltsville, USA
- Boulder, USA
- Lamont, USA

It should be reiterated that at this stage the primary aim is to use an initial set of high quality stations to refine the scientific and technical issues of paramount importance to a successful GRUAN network. Hence the selection of further sites is not a high priority activity. This does not preclude discussions occurring with potential sites.

A list of all potential candidate sites and a map of all sites identified by the meeting participants is given in Appendix III. A detailed matrix listing criteria for each site (initial and potential) will be developed by the Lead Centre to provide a basis of information about the existing measurements at all sites (see action item 7). The criteria given in the matrix should include: priority 1 observations ongoing, priority 2 observations ongoing, climatic regime, science value, distance to radiosonde site, homogeneity of observations, site duplicate, infrastructure, nearby GUAN site, sustainability and institutional support, co-location with other networks (BSRN, GAW, etc.).

4. Data Dissemination and Quality Control/Quality Assurance

Quality Control/Quality Assurance

Before defining the Quality Control and Quality Assurance (QC/QA) procedures to be applied to the data, two fundamental questions have to be answered: who will be the customers/users of the data, and, how much time is available for the QC/QA procedures? The following communities are seen as possible end-users of GRUAN data: Climate data analysis (detection and attribution), satellite algorithm testing, climate model testing and improvement and as an anchor for reanalysis (a non-exhaustive list, see section 7, G).

The timeline for the access to GRUAN data needs to be defined. The representatives from other networks participating in the meeting have developed different approaches:

- ARM exchange of data in near-real time
- NDACC 1 year restricted access, then public distribution
- CEOP six months for standard data, 15 months for enhanced or experimental data
- BSRN 1 year before data dissemination

The decision about the timeliness of data release will be considered in action item 9 and 10.

The dissemination in (near) real time should be considered for operational purposes and if basic measurements are submitted in the (near) real time, the QC/QA software used for operational monitoring of radiosondes' data should be used. This will also facilitate the QC link with GRUAN/GUAN and other stations.

The argument that if a multiple-sensor radiosonde flight be used by GRUAN an intercomparison between remaining instruments would not be necessary was rejected by the meeting participants, because a relative basis for comparison would still be necessary. For the intercomparison between GRUAN stations the following possibilities were discussed to estimate the uncertainties:

- **Audits** – where a team of auditors comes to a site to observe the measurements and check that the appropriate quality controls and procedures are being followed. If appropriate, the audit team may carry calibration equipment with them to directly check the on-site instruments. This type of activity is common across national air quality monitoring networks where there are legal requirements for quality control and quality assurance across a large number of sites. The success of this activity relies on the

auditors being able to get a representative view of site operation, and that the QA/QC procedures themselves ensure suitable performance.

- **Intercomparison campaigns** – a good example of this type of activity is the International Pyrheliometer Comparison which takes place every 5 years at the World Radiation Centre, where all participants bring their equipment to Davos to conduct simultaneous solar radiation measurements. This option is ideal if the instrumentation is transportable and the measurement performance is not impacted significantly by regional differences.
- **Mobile validation facility** – a set of transportable equipment is used as a transfer standard, going from site to site to run formal side-by-side intercomparisons. An example is in NDACC, where a mobile high-resolution FTIR has been used in a series of intercomparison campaigns at the various NDACC sites with fixed solar FTIR installations. This method is ideal for validating equipment that has been permanently installed at the network sites and addresses any site-specific issues. However, it is generally expensive to establish, maintain and deploy this type of facility, particularly if there are a large number of sites in the network.
- **Use of common (reference) technique** – where an agreed 'reference' instrument type is used at all sites. An example is the WMO Ozone Monitoring Network where Standard Reference Photometers (developed and supplied by NIST) are used across the top-level network. These systems are compared to the commercial instrumentation used across the wider monitoring community. While this is an effective way of ensuring common traceability across a network, it requires a suitable reference instrument to be available.

The final decision about the procedures for QC/QA will be made after an initial set of stations have been put together, based upon the lessons learned and input from relevant experts and institutions. The National Measurement Institutes (NMIs) are seen as one valuable additional resource for collaboration and consultation in this regard that to date have not been actively engaged (see action item 8).

Data Dissemination

The data dissemination encompasses the following five points: data policy, data format, data dissemination model, tracking of usage and metadata.

The GRUAN network will follow the data policy in WMO Resolution 40 Cg-XII and WMO Resolution 25 Cg-XIII by defining as 'essential' all data from the instrument systems which are specified in GCOS-112 or any agreed revision of GCOS-112 at all GRUAN sites, to ensure the free and unrestricted availability of these data. Selection of GRUAN sites will imply acceptance of this principle.

A workable detailed data policy will be developed by the Lead Centre, in cooperation with the WG-ARO, the GCOS Secretariat and AOPC (see action item 9). For this the existing data policies from CEOP and/or BSRN can be used as an initial basis.

The decision about the other four points of data dissemination will be organized in two steps. First, the different options for data dissemination will be considered and worked out during the next few months by the Lead Centre. The National Oceanic & Atmospheric Administration (NOAA) and Atmospheric Radiation Measurement (ARM) offered in-kind support for the development of the data policy. The WG-ARO will take a decision based on the different options outlined (action item 10). Second, the data dissemination practices will be developed, including the data policy, data format, data dissemination model, tracking of usage and metadata (action item11).

The metadata management will prove key to a successful network. For example, with radiosondes it is imperative to make sure that the archived soundings contain all the information (e.g. serial number) required to know exactly which kind of sonde was launched. Equally the raw as well as the corrected data are required in-case a new correction must be applied at a later date. Reference measurements are only of value with comprehensive metadata. You can't tell from the type of Vaisala sonde, for example, which kind of humidity sensor was flown.

5. Coordination with other international and national activities

Global Space-Based Inter-Calibration System (GSICS)
Mitch Goldberg reiterated the need from the GSICS to rely upon in-situ measurements for the validation of satellite data. For satellite intercalibrations the distribution of locations for simultaneous observations by different sensors, space-based as well as in situ, is seen as essential. The collocation with a reference measurement site would be especially desirable.
Goldberg indicated the potential for support from the satellite community for additional radiosonde launches for validation purposes. Further communication between the satellite community and the GCOS secretariat is foreseen in action item 2.

Global Earth Observation System of Systems (GEOSS)
Alexia Massacand provided an overview about the tasks in the GEO Work Plan linked to establishment of the GRUAN:

- WE-06-11: Surface-based Global Observing System for Weather (Co-Leads: WMO, USA)
- CL-06-02: Key Climate Data from Satellite Systems (Co-Leads: GCOS, CEOS, WMO, USA)
- CL-06-01: Sustained reprocessing and reanalysis efforts (Co-Leads: WCRP, GCOS, CEOS)
- CL-07-01: Seamless Weather and Climate Prediction System (Co-Leads: WWRP/THORPEX, WCRP)

Global Atmosphere Watch / Network for the Detection of Atmospheric Composition Change (GAW/ NDACC)
Geir Braathen provided an outline about the work of NDACC. The network's main focus is on data quality. The operation of the network is governed by a number of protocols, whereas the data dissemination is a compromise between data availability & IPR.
Regular intercomparison campaigns take place at the NDACC sites with a mobile system (Lidar, FT-IR). Also intercomparison campaigns are undertaken by gathering many instruments at the same location.

Baseline Surface Radiation Network (BSRN)
Ells Dutton provided an overview about the development of the BSRN, initiated in 1988, which parallels the establishment of the GRUAN and may serve as an example of a successfully launched network. Dutton described some strategic considerations for synergies between BSRN and GRUAN activities, since many BSRN applications need high quality upper air data, and BSRN-like data provide GRUAN priority 2 observations. The combination of operations at remote field sites was therefore proposed as being more efficient and economical, plus at many current and potential sites additional national resources exist. A list of collocated GUAN and BSRN sites is listed in Appendix V.

Potential Candidate Sites from the Russian Federation
Alexander Kats outlined the already existing upper-air observations (including GUAN) in the Russian Federation. Currently new radiosondes are developed by ROSHYDROMET for the

GUAN sites. Kats proposed Tiksi as a potential GRUAN candidate site, even if the observation centre is relatively remote, and Nizhnij Novgorod, as a second potential site.

Potential U.S. Contributions to GRUAN
Howard Diamond provided an overview about the possible contributions from different U.S. agencies to the GRUAN. The ARM Climate Research Facility (ACRF) is prepared to contribute in-kind resources as follows:

- Up to 5 ACRF sites to be used as potential GRUAN sites
- Data archival and management
- In-kind QA/QC and production of value added product generation

NCAR is prepared to consider participating as follows:

- Contribute to developing and deploying a reference radiosonde
- Provide a variety of research-related data management functions
- Contribution to deployment and data processing of a ground-based GPS receiver for GRUAN
- GPS Radio Occultation (GPS-RO) work; NSF Workshop at NCAR [March 2008] (results of the workshop are provided at https://wiki.ucar.edu/display/ucargpsrocaw/Home)

NOAA can possibly contribute as follows:

- Network analyses, observing system simulation experiments, developing country and Working Group support, and partnering with ARM sites
- Design work on a reference radiosonde and testing (NOAA Air Resources Laboratory's Atmospheric Turbulence and Diffusion Division (ARL/ATDD) in Oak Ridge, Tennessee)
- Building on stratospheric water vapour observations at Boulder and Lauder
- Data archival and management (mirror to ACRF), portal hosting, post-processing QA/QC
- WMO Global Space-based InterCalibration System (GSICS) Coordination Center participation
- Collocation of GRUAN to satellite products for statistical comparisons and monitoring

All these proposed U.S. contributions are contingent upon available funding.

CMA's view on the GRUAN
Kejun Wu suggested Xilin Hot and possibly five other potential sites as a Chinese contribution to the GRUAN network.

Association of Hydro-Meteorological Equipment Industry (HMEI)
Bruce Sumner provided an overview about the work of the Association of Hydro-Meteorological Equipment Industry. HMEI represents about 100 companies from 22 countries of the hydro-meteorological Instruments and systems industry. HMEI provides the meteorological instrument manufacturers with information about new developments and requirements. For the further development of a reference radiosonde, the GRUAN will collaborate with HMEI.

6. Work Plan

No	Action	Deadline	Who
1	Evaluate the radiation correction for the temperature measurement for each radiosonde	Jan 2009	GRUAN Sites with help from Lead Centre
2	Communication to satellite community (GSICS), sponsoring for additional radiosonde launchings	Continuous	Mitch Goldberg (RSSC/CM), GCOS secretariat

3	Develop a strategy for detecting change in the measurement quality at GRUAN site, such as periodic intercomparison between instruments as often as possible at suitable intervals at each selected GRUAN sites	Continuous	Lead Centre (all sites), NMIs
4	Organize major intercomparison of operational and research radiosondes to choose which can qualify for use in the GRUAN network.	2010 and thereafter on a regular 5 year interval	Lead Centre, GCOS, CIMO, scientific community; WG (collect all available data, reports and papers)
5	First draft of manual / guidelines for GRUAN observations (assuring comparability, spreading best practices, sharing lessons, reporting)	April 2009	Lead Centre and initial sites in collaboration with WG-ARO, CIMO, CBS
6	Invite initial candidate stations to become GRUAN stations	September 2008	GCOS Secretariat following AOPC and consultation with CBS
7	Develop a matrix/spreadsheet with criteria for initial and potential sites	September 2008	Lead Centre
8	QC/QA procedures to be resolved	(2010)	ARM / Lead Centre / WG-ARO / NMI's
9	Establish data policy	September 2008	Lead Centre and initial sites, WG-ARO, GCOS Secretariat, AOPC
10	Consider various options on data dissemination	Summer 2008	Lead Centre, NOAA, ARM, WG-ARO
11	Devise data dissemination practices (model, format, metadata, monitoring of usage)	2009	ARM / Lead Centre / WG-ARO, help from many
12	Develop definition for optimal GRUAN site to decide on future sites (optimal location/climate zone, institution etc.); collect information about initial and potential GRUAN sites	Jan 2010	WG-ARO, lead centre

7. Open questions

A number of important questions remained following the meeting at Lindenberg. In this section, several of these issues are described, with proposals on the way forward.

A. It is clear that very significant and substantial work is required to advance the production of a reference radiosonde. Several different potential approaches were put forward but there was not time to resolve the issue. One possible suggestion was to initiate a specific working group answering to WG-ARO to push this forwards. Another was to organize a workshop specifically on this subject. Resolution of this issue is of the highest importance, but it is not given as a specific action item in section 6 as there was no agreement reached.

B. To overcome to closure on the issue of launch schedules for sonde-based observations, it was recognized that quantitative studies to resolve the issue would be useful. The meeting participants encouraged work such as that suggested by Carl Mears in the presentation that he provided to the meeting to move this issue forwards.

C. There was limited discussion regarding how to decide in what order instrumentation should be added, but this was not resolved. Clearly, in limited budgets such guidance based upon robust analyses would be helpful.

D. The development of a mentoring programme at the Lead Centre in Lindenberg was seen as highly desirable. The value of such a programme would be to advance best practices in instrumentation and observing system procedures among stations beginning the suite of GRUAN observations.

E. The first draft of a GRUAN Lead Centre work plan was distributed at the meeting but not discussed in detail. It included a timeline for many of the above activities. Revision of this work plan, and guidance for the Lead Centre, will be a task for the WG-ARO in the coming year.

F. After the Implementation Meeting the following proposal for the pragmatic development of the GRUAN system was raised: GRUAN Phase I concentrating upon tropospheric humidity capabilities, Phase II stratospheric aspects, dependant on cost and frequency.

G. Who will use the GRUAN data after the establishment of the observation network and for which purpose? GRUAN will need at least one Numerical Weather Prediction (NWP) centre to monitor the GRUAN and how it is used, with statistics of differences from first guess and analysis etc. and an assessment on how this is different from GUAN and other sondes? It should also be examined whether the data are actually being used as a reference.

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Working Group on Atmospheric Reference Observations
Terms of Reference and Membership

Version April 2008

The 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 GCOS AOPC,

- To provide scientific, technical and management oversight to the operations of the GRUAN lead centre which will manage the overall work and evolution of the network, reporting periodically to the WG-ARO (Figure 1 provides a depiction of lines of reporting and responsibilities).
- To ensure that the action plan agreed at the Lindenberg meeting (GCOS-xxx) is 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 the GCOS Reference Upper-Air Network (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, in consultation with AOPC AGG (Advisory Group on GSN and GUAN) and other advisory bodies as appropriate (e.g., within GSICS (Global Space Based Inter-Calibration System), 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 Global Space-based Inter-Calibration System initiative and R/SSC-CM;
- To report at least annually to AOPC on the activities of the Working Group, 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 WG 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. Terms of Reference will be subject to periodic review by AOPC in liaison with the Chairman of the Working Group.

Chairman: Peter THORNE (UK, Met Office)

Members (those highlighted are current WG members):

Name	Country	Affiliation	Relevant areas of expertise
Dian Seidel	USA	NOAA Air Resources Laboratory	Historical climate change, radiosonde data records
Tom Peterson	USA	NOAA National Climatic Data Center	Historiocal climate change, data management
Tom Gardiner	UK	National Physical Laboratory	National measurement institute, metrology
Carl Mears	USA	Remote Sensing Systems	Satellite climate data records
Franz Berger	Germany	DWD	Surface based remote sensing, site management
Chris Barnet	USA	NOAA NESDIS GSICS Coordination Center	GSICS
John Dykema	USA	Harvard	GPS-RO and metrology
June Wang	USA	NCAR	Radiosonde technologies and climate datasets
Leo Haimberger	Austria	University of Vienna	Reanalyses, radiosonde climate data records
Jimmy Voyles	USA	ARM program	Instrumentation
Masatoma Fujiwara	Japan	Hokkaido University	Radiosonde and ground-based instrumentation
Doug Sisterson	USA	ARM program	Program management expertise
Ells Dutton	USA	BSRNBSRN and NOAA/Earth System Research	Network management and instigation

		Laboratory	experience
Miro Ondras		WMO	CIMO perspective
Director GCOS secretariat (ex-officio)		WMO	Ensure that GCOS secretariat is involved (non-voting)
Head of lead Centre (ex-officio)	Germany	DWD	Ensure that lead centre is represented in discussions (non-voting)
Howard Diamond	USA	US GCOS Office	Continued presence of major program supporter in discussions (non-voting)
Bill Murray	USA	NOAA OGP	Continued presence of major program supporter in discussions (non-voting)

APPENDIX I
AGENDA

A meeting held under the auspices of the Global Climate Observing System (GCOS) and the National Oceanic and Atmospheric Administration (NOAA).

Meeting Chairs: *David Goodrich, GCOS Secretariat and Peter Thorne, UK Met office*

Meeting Organizing Committee: *Franz Berger (DWD), Leopold Haimberger (Univ. of Vienna) and Junhong (June) Wang (NCAR)*

Meeting objective: "Start small, but start"
Develop a work plan that the Lead Centre and other interested parties will work towards (with a funding commitment to achieve it!) that:

- Identifies and addresses remaining scientific and technical issues;
- Ensures observations are being made in a manner consistent with the stated GRUAN requirements henceforth at a number of initial sites; and
- Informs priorities for the GCOS working group.

Agenda Overview

Day 1 Monday 25th February (only for the members of GCOS/AOPC Working Group (WG) on Atmospheric Reference Observations)

- WG meeting (afternoon 1/2 day) - *Peter Thorne*

Day 2 Tuesday 26th February

- Session 1 - Registration and Introduction (1/4 day) - *Franz Berger*
- Tour of Lindenberg Observatory (1/4 day)
- Session 2 - Initial Site Selection (~1/2 day) - *Leopold Haimberger and Holger Voemel*
- Ice-breaker (night)

Day 3 Wednesday 27th February

- Session 3 - Radiosonde Instrumentation and Launch Schedule (1/2 day) - *Dave Goodrich*
- Session 4 - Instrumentation and Observing Practices (1/2 day) - *Miroslav Ondras*
- Dinner (night)

Day 4 Thursday 28th February

- Session 5 - Data Dissemination and QC/QA (1/2 day) - *Matthew Menne*
- Session 6 - Coordination with other International and National Activities (1/4 day) - *Dian Seidel*
- Session 7 - Development of Action Plan (1/4 day) - *Peter Thorne*

Detailed Agenda

Monday 25th February

14:00-17:00 **WG meeting, *Chair: Peter Thorne*** (Working Group members only)
Get to know each other; WG membership and TOR; coordination between the lead center and WG; discussion of meeting plans; and the BAMS article.

Tuesday 26th February

08:00-08:30 Registration

Session 1 – Introduction, *Chair: Franz Berger*

08:30-08:40 Welcome and logistics - *Franz Berger, Marion Fiedler and Stefanie Lorenz*
08:40-08:50 Workshop objectives and agenda - *June Wang*
08:50-09:15 DWD – the host of GRUAN Lead Centre - *Wolfgang Kusch*
09:15-09:45 Coffee break

09:45-12:15 **Tour of Lindenberg Observatory** (including radiosonde launch at 12:00 and group photo)

12:15-13:15 Lunch

Session 1 – Introduction (continued), *Chair: Franz Berger*

13:15-13:25 Opening speech: *Ulrich Kasparick, Federal State Secretary BMVBS*
13:25-13:30 Opening notes: *Dave Goodrich, GCOS*
13:30-13:50 Introductions around the room
13:50-14:30 Overview of GRUAN - *Dave Goodrich and Peter Thorne*
14:30-15:00 Coffee break

Session 2 – Initial Site Selection, *Chair: Leopold Haimberger and Holger Voemel*

15:00-15:30 Keynote: GCOS / WCRP activities carried out in Lindenberg - *Franz Berger*
15:30-15:45 Atmospheric Radiation Measurement (ARM) sites - *Doug Sisterson*
15:45-16:00 Lauder, New Zealand within Network for Detection of Atmospheric Composition Change (NDACC) - *Paul Johnston*
16:00-16:15 Howard University Beltsville Research site, Maryland, U.S.A. - *Belay Demoz*
16:15-16:30 European site selection - *Reinout Boers*
16:30-16:40 Sodankylä research site - *Esko Kyrö*
16:40-16:50 Boulder research site - *June Wang*
16:50-17:00 Chinese potential sites - *Kejun Wu*
17:00-17:10 SHADOZ research site - *Masatomo Fujiwara*
17:10-17:20 Tropical site candidates - *Holger Voemel*
17:20-17:35 Partnership / Mentoring Programme – ideas to realise a worldwide homogeneous network - *Franz Berger*
17:35-18:30 Discussions and summary

19:00-21:30 Icebreaker

Wednesday 27th February

Session 3 – Radiosonde Instrumentation and Launch Schedule, *Chair: Dave Goodrich*

08:00-08:30 Radiosonde instrumentation issues and challenges - *Holger Voemel*
08:30-08:45 Rationale for using current best operational radiosondes - *Doug Sisterson*
08:45-09:00 Rationale for using reference radiosondes - *June Wang*
09:00-10:00 Discussions and summary
10:00-10:20 Coffee break
10:20-10:35 Framing the Question of GRUAN Sonde Launch Schedule - *Dian Seidel*
10:35-10:50 Rationale for coordination with satellite overpass - *Franz Berger for Carl Mears*
10:50-11:05 Rationale for fixed schedule - *Kevin Trenberth*
11:05-12:00 Discussions and summary

12:00-13:30 Lunch (with visit to the balloon hall)

Session 4 – Instrumentation and Observing Practices, *Chair: Miroslav Ondras*

13:30-14:10 Keynote speech: Potential ground-based remote sensing instruments for GRUAN and a status of their operational exploitation - *John Nash*
14:10-15:20 Ground based instrumentation requirements
- 14:10-14:30 Application and Benchmark testing of Vertical Profiles at Lindenberg Observatory - *Dirk Engelbart*
- 14:30-14:50 From science to operation: Practical problems in implementing instruments in an operational network - *Reinout Boers*
- 14:50-15:00 Ground-based GPS measurements - *June Wang for John Braun*
- 15:00-15:20 Surface and upper air developments in MeteoSwiss Payerne - *Bertrand Calpini*

15:20-15:40 Coffee break
15:40-16:30 Discussions
16:30-16:40 Introduction to 'Suitability of current WMO regulatory documentations, such as Manual and Guide on the GOS and WMO Guide to Meteorological Instruments and Methods of Observations'
16:40-17:30 Discussions

17:30-18:30 Meeting of WG to assess progress

19:30 Meeting dinner (sponsored by DWD)

Thursday 28th February

Session 5 – Data dissemination and QC/QA, *Chair: Matthew Menne*

08:00-08:40 Keynote: *Doug Sisterson*
08:40-09:30 Requirements for quality control / quality assurance
- 08:40-08:50 SI Traceability of Measurements - *Tom Gardiner*
- 08:50-09:00 Data Analysis/Fusion and Uncertainty Issues - *Alistair Forbes*
- 09:00-09:10 Follow-on to First Two Short Talks - *John Dykema*
- 09:10-09:20 Utility of Raw Radisonde Data in QA/QC - *Alexander Kats*
- 09:20-09:30 Integrated Profiling of the Atmosphere - *Reinout Boers*

09:30-10:00 Discussions

10:00-10:20 Coffee Break
10:20-11:00 Requirements for data dissemination
- 10:20-10:40 Aspects of effective data dissemination - *Holger Voemel*
- 10:40-10:50 Lessons from the other GCOS Lead Centers – *Matthew Menne*
- 10:50-11:00 CEOP data management - *Steve Williams*

11:00-12:00 Discussions

12:00-13:00 Lunch

Session 6 – Coordination with other International and National Activities, *Chair: Dian Seidel*

13:00-13:15 Global Space-Based Inter-Calibration System (GSICS) - *Mitch Goldberg*
13:15-13:30 Global Earth Observation System of Systems (GEOSS) - *Alexia Massacand*
13:30-13:40 Global Atmosphere Watch (GAW), Network for the Detection of Atmospheric Composition Change (NDACC) - *Geir Braathen*
13:40-13:45 Southern Hemisphere Additional Ozonesondes (SHADOZ) - *Masatomo Fujiwara for Anne Thompson*
13:45-14:00 Baseline Surface Radiation Network (BSRN) - *Ells Dutton*
14:00-14:05 Hydro-Meteorological Equipment Industry (HMEI) - *Bruce Sumner*
14:05-14:25 National agency perspectives
- 14:05-14:10 Inputs to GRUAN from the Netherlands - *Reinout Boers*
- 14:10-14:15 Some consideration about potential candidate sites from the Russian Federation - *Alexander Kats*
- 14:15-14:20 Potential U.S. contributions to GRUAN - *Howard Diamond*
- 14:20-14:25 CMA's view on the GRUAN - *Kejun Wu*

14:25-15:00 Discussion and Summary
15:00-15:20 Coffee break

Session 7 – Development of Action Plan, *Chair: Peter Thorne*

15:20-17:30 Development of action plan - *Peter Thorne*

17:30 Meeting closes

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APPENDIX II
LIST OF PARTICIPANTS

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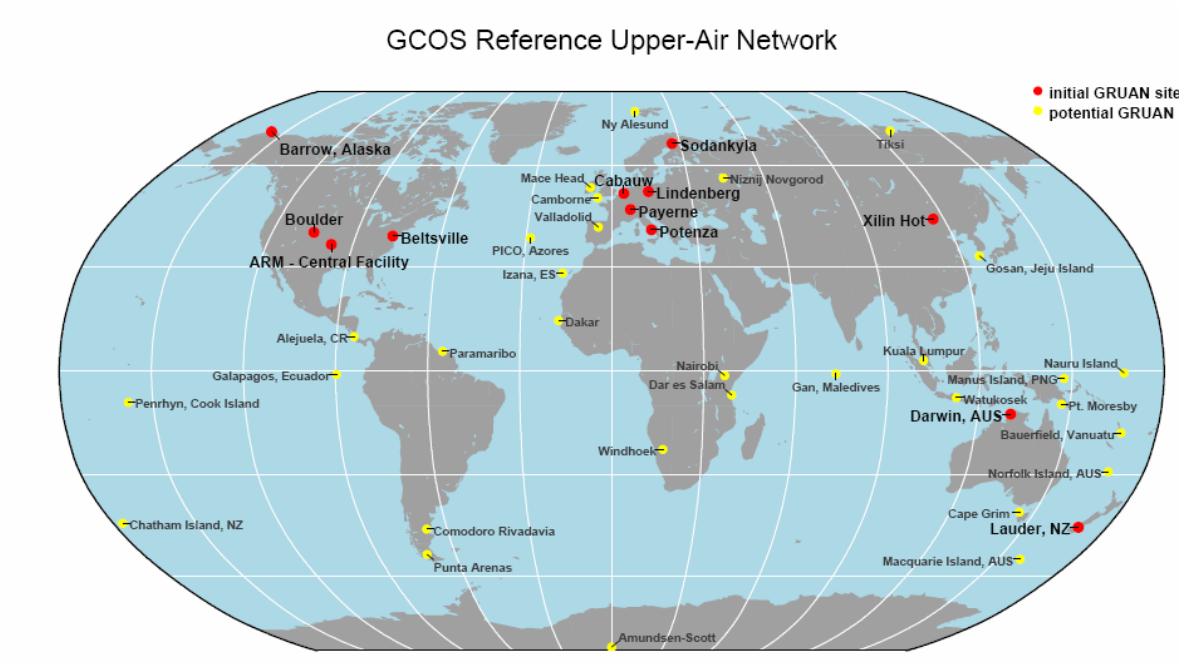
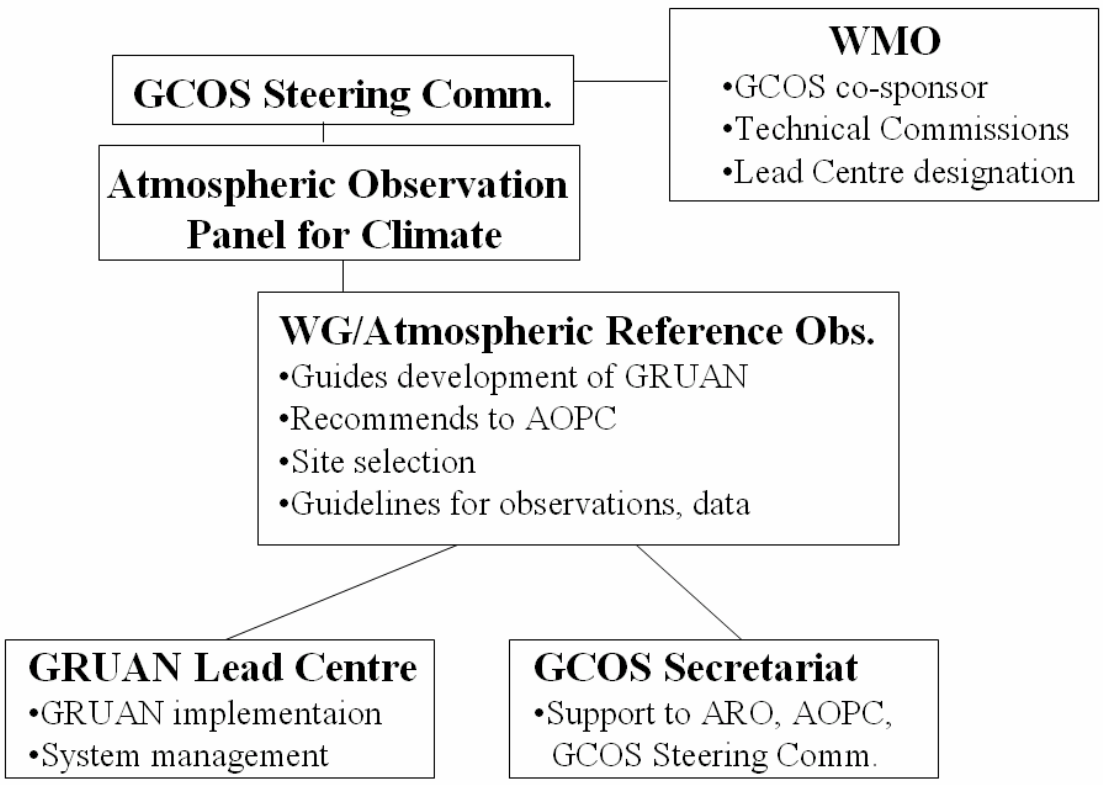
APPENDIX III
POTENTIAL FUTURE STATIONS

As potential candidate sites to be developed to meet GRUAN criteria during the next few years the meeting identified the following stations (listed alphabetically by country):

- Comodor Rivadavia, Argentina
- Cape Grim, Australia
- Macquarie Island, Australia
- Norfolk Island, Australia
- Punta Arenas, Chile
- Alajuela, Costa Rica
- Penrhyn, Cook Islands
- San Cristobal/Galapagos, Ecuador
- Watukosek, Indonesia
- Mace Head, Ireland
- Nairobi/Dagoretti, Kenya
- Kuala Lumpur, Malaysia
- Gan, Maldives
- Windhoek, Namibia
- Naru, Naru
- Chatham Island, New Zealand
- Spitsbergen, Norway
- Port Moresby W.O., Papua New Guinea
- Manus, Papua New Guinea
- Pico/Azores, Portugal
- Tiksi, Russia
- Nizhnij Novgorod, Russia
- Dakar, Senegal
- Paramaribo, Suriname
- Jeju Island, South Korea
- Valladolid, Spain
- Izana/Canarias, Spain
- Dar es Salaam, Tanzania
- Camborne, UK
- Amundsen-Scott, Antarctica (Station operated by the USA)
- Bauerfield, Vanuatu



APPENDIX IV
ORGANIGRAM OF WORKING RELATIONS FOR GRUAN



APPENDIX V
LIST OF BSRN AND GUAN STATIONS1

Existing Collocated GUAN and BSRN Sites

- Tamanrasset, Algeria
- Tateno, Japan
- Bermuda
- Barrow, Alaska
- Darwin, Aus. (ARM)
- Cocos Is, Aus.2
- American Samoa
- Lindenberg, Germany
- Lerwick, UK
- Camborne , UK
- Payerne, Switzerland
- von Neumayer, Antarc. (Germany)
- Syowa, Antarc. (Japan)
- Amundsen-Scott, Antarc. (US)

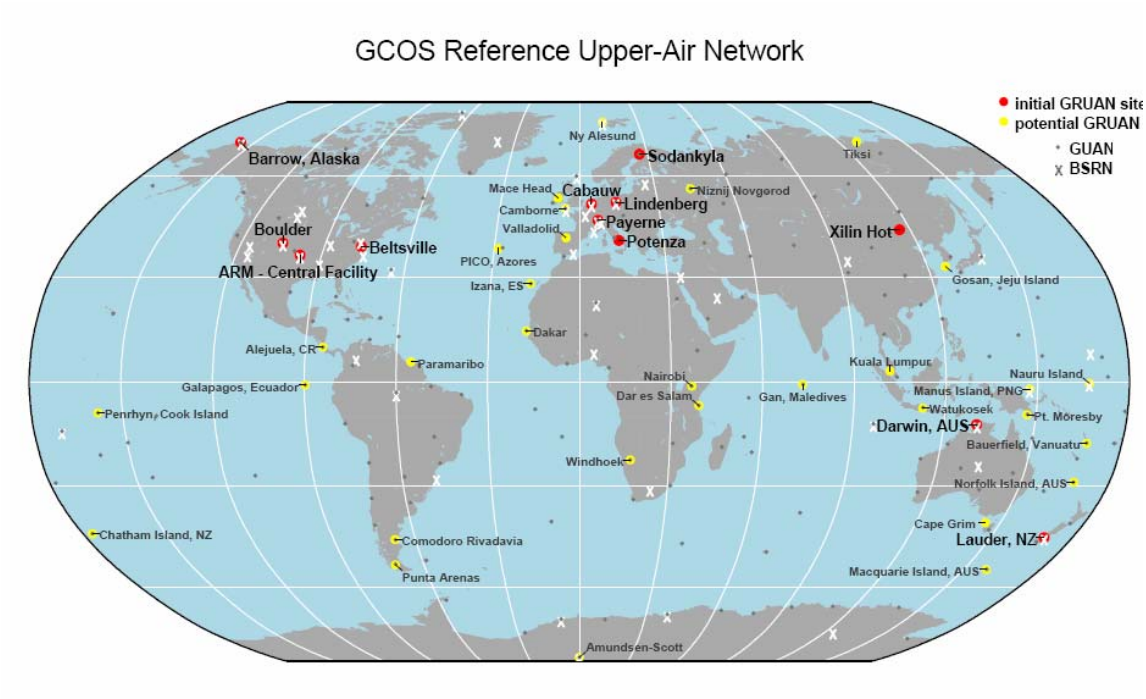
Other existing BSRN sites with collocated / near-by regular upper-air soundings that are not part of GUAN

- Kwajalein, M.I.
- Dome C, Antarc.
- Desert Rock, Nev
- Ny Ålesund, Spitsberg
- Sede Boqer, Israel
- De Aar, S. Africa
- Alice Springs, Aus.
- Denver, Colo.
- American Samoa3
- Nauru (ARM)
- Manus (ARM)
- SGP (ARM)

BSRN & Proposed GRUAN but not GUAN

- Lauder, NZ

1 Table entries subject to change due to operational considerations
2 The station is listed as a candidate site
3 The station is listedas a candidate for BSRN


GCOS Reference Upper-Air Network
initial GRUAN site
potential GRUAN
GUAN
BSRN
Barrow, Alaska
Ny Alesund
Sodankyla
Tiksi
Mace Head
Cabauw
Niznij Novgorod
Lindenberg
Camborne
Payerne
Valladolid
Potenza
Boulder
Beltsville
Xilin Hot
PICO, Azores
ARM - Central Facility
Izana, ES
Gosan, Jeju Island
Dakar
Alejuela, CR
Paramaribo
Kuala Lumpur
Nauru Island
Nairobi
Galapagos, Ecuador
Dar es Salam
Gan, Maledives
Manus Island, PNG
Watukosek
Penrhyn, Cook Island
Pt. Moresby
Darwin, AUS
Bauerfield, Vanuatu
Windhoek
Norfolk Island, AUS
Cape Grim
Chatham Island, NZ
Comodoro Rivadavia
Lauder, NZ
Punta Arenas
Macquarie Island, AUS
Amundsen-Scott

APPENDIX VI
LIST OF GEO TASKS RELATED TO GRUAN

Task: WE-06-01
Benefit Area: Weather
Title: *Surface-based Global Observing System for Weather (Co-Leads: WMO, USA)*
Achieve a complete and stable surface-based (in-situ and airborne, land and possibly ocean) Global Observing System (GOS). High priority should be given to a stable, and as much as possible automated, fully functional World Weather Watch Upper Air Network and the further development of the Aircraft Meteorological Data Relay (AMDAR) programme.

Task: CL-06-02
Benefit Area: Climate
Title: *Key Climate Data from Satellite Systems (Co-Leads: GCOS, CEOS, WMO, USA)*
Establish actions securing the provision of key data for climate studies and forecasting from satellite systems.

Task: CL-06-01
Benefit Area: Climate
Title: *Sustained reprocessing and reanalysis efforts (Co-Leads: WCRP, GCOS, CEOS)*
Ensure the development of international mechanisms to coordinate and maintain sustained climate data reprocessing and reanalysis efforts. With regard to the reprocessing of historical datasets (to obtain consistent long-time series of satellite records), make relevant synergies with Task CL-06-02.

Task: CL-07-01
Benefit Area: Climate
Title: *Seamless Weather and Climate Prediction System (Co-Leads: WWRP/THORPEX, WCRP)*
Support the development of a major initiative on "International Weather, Climate and Earth-system Science", to better address uncertainties associated with climate variability and change, and related societal impacts (e.g. health, water, agriculture, energy). Promote international multi-disciplinary (physics-biology-chemistry) collaboration on the development of a high-resolution seamless weather/climate global prediction system - including coupled atmosphere-ocean data assimilation.

APPENDIX VII
GLOSSARY OF ACRONYMS

ARL/ATDD	Air Resources Laboratory's Atmospheric Turbulence and Diffusion Division
AOPC	Atmospheric Observation Panel for Climate
ARM	Atmospheric Radiation Measurement
BSRN	Baseline Surface Radiation Network
CBS	Commission for Basic Systems
CEOP	Coordinated Energy and Water Cycle Observation Project
CFH	Cryogenic Frostpoint Hygrometer
CIMO	Commission for Instruments and Methods of Observation
CMA	China Meteorological Administration
DWD	German Meteorological Service (Deutscher Wetterdienst)
GAW	Global Atmosphere Watch
GCOS	Global Climate Observing System
GEO	Group on Earth Observation
GEOSS	Global Earth Observation System of Systems
GPS PW	Global Positioning System Percipitable Water
GRUAN	GCOS Reference Upper Air Network
GSICS	Global Space-Based Inter-Calibration System
GUAN	GCOS Upper Air Network
LIDAR	Light Detection and Ranging (optical remote sensing)
NCAR	National Centre for Atmospheric Research
NDACC	Network for the Detection of Atmospheric Composition Change
NMIs	National Measurement Institutes
NMS’s	National Meteorological Services
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
QC/QA	Quality Control/Quality Assessment
ROSHYDROMET	Russian Meteorological Service
RSSC/CM	Regional Specialized Satellite Centers/Climate Monitoring
SHADOZ	Southern Hemisphere Additional Ozonesondes
UTC	Universal Coordinated Time
UT/LS	Upper Troposphere and Lower Stratosphere
WG-ARO	Working Group on Atmospheric Reference Observations
WMO	World Meteorological Organization