The GCOS Reference Upper-Air Network (GRUAN)

Holger Vömel[1], Franz H. Berger[1], Franz J. Immler[1], Dian Seidel[2], Peter Thorne[3]
[1] Deutscher Wetterdienst, Richard-Aßmann-Observatory, Lindenberg, Germany, Am Observatorium 12, 15848 Tauche OT Lindenberg, Gemany,GRUAN.LC@dwd.de
[2] Met Office, FitzRoy Road, Exeter, Devon, EX1 3PB, UK
[3] NOAA(R\ARL), 1315 East West Highway, Silver Spring, MD 20910, USA

ABSTRACT

While the global upper-air observing network has provided useful observations for operational weather forecasting for decades, its measurements lack the accuracy and long-term continuity needed for understanding climate change. Consequently, the scientific community faces uncertainty on such key issues as the trends of temperature in the upper troposphere and stratosphere or the variability and trends of stratospheric water vapour.

To address these shortcomings, and to ensure that future climate records will be more useful than the records to date, the Global Climate Observing System (GCOS) program initiated the GCOS Reference Upper Air Network (GRUAN). GRUAN will be a network of about 30-40 observatories with a representative sampling of geographic regions and surface types. These stations will provide upper-air reference observations of the essential climate variables, i.e. temperature, geopotential, humidity, wind, radiation and cloud properties using specialized radiosondes and complementary remote sensing profiling instrumentation. Long-term stability, quality assurance / quality control, and a detailed assessment of measurement uncertainties will be the key aspects of GRUAN observations. The network will not be globally complete but will serve to constrain and adjust data from more spatially comprehensive global observing systems including satellites and the current radiosonde networks.

This paper outlines the scientific rationale for GRUAN, its role in the Global Earth Observation System of Systems, network requirements and likely instrumentation, management structure, current status and future plans.

1. WHAT IS GRUAN?

- A network of several dozen stations, made operational in a phased process, that serve primarily as a long-term anchor to other networks. GRUAN will not be globally complete, but will sample major climatic regimes, latitudes, altitudes, and surface types. Each station will be associated with a host institution having the necessary scientific and technical expertise and a commitment to the long-term operation of the site.
- Adherence to the ten GCOS climate monitoring principles agreed to by the United Nations Framework Convention on Climate Change [1]. These set as priorities the quality and long-term continuity and homogeneity of the observations and metadata needed for their interpretation; the use of the data in research and assessments; the establishment of requirements at the outset of system design and implementation; and data management systems that facilitate data access, among other things.
- Measurements of the “Essential Climate Variables” identified by [1] with a focus on the highest priority upper-air variables, using high quality instruments to provide the most accurate data possible, as shown schematically in Figure 2.
- Ongoing real-time and retrospective cross-validation of different measurements of the same parameter and evaluation of measurement accuracies and drifts.
- A strong lead center providing scientific leadership and oversight, managing the network, training operators, and ensuring proper data archival and free dissemination. The Meteorological Observatory Lindenberg – Richard Aßmann Observatory - will serve as GRUAN Lead Center, based on the Deutscher Wetterdienst’s offer of substantial financial, scientific and technical support, in response to a call for interest issued by the GCOS Secretariat.
- A strong commitment to coordinate with other existing networks and observing systems and to provide scientifically robust service to the user community.

These concepts begin to trace the outlines of what GRUAN is and can be. It is also important to clearly articulate what GRUAN is not. It is not a set of identical stations; some will be more comprehensive than others, although all will make a core set of first priority observations (Figure 1). It is not a replacement either for the existing radiosonde network, whose spatial density meets weather needs that GRUAN cannot, or for the GCOS Upper Air Network (GUAN) [2]. The base of the system is the complete global upper-air observing system, serving a wide variety of purposes, primarily weather prediction, and including the operational radiosonde network, aircraft and satellite observations, etc., and embracing model-assimilated upper-air datasets and reanalyses. The 161-station GUAN is a subset of the operational radiosonde network that, in the late 1990’s committed to long-term, consistent observations, but that do not deploy any special instruments for high quality climate observations.

GRUAN is a key component of the Global Climate Observing System (GCOS), and GCOS in turn is the formal climate component of the Global Earth Observing System of Systems (GEOS). GRUAN contributes to the GEOSS goal of “understanding, assessing, pre-

© Proceedings of the 8th International Symposium on Tropospheric Profiling, ISBN 978-90-6960-233-2
Delft, The Netherlands, October 2009. Editors, A. Apituley, H.W.J. Russchenberg, W.A.A. Monna

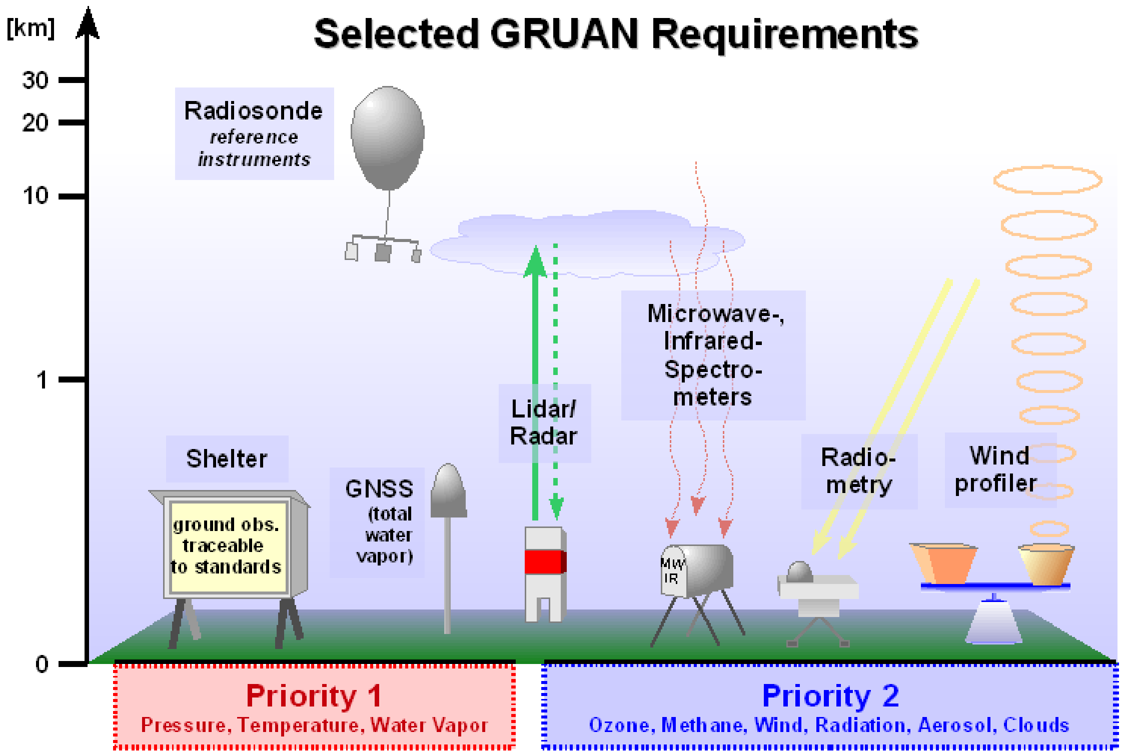

Figure 1. *Schematic diagram showing some required measurements for a generic GRUAN station. The first priority includes surface and reference upper-air meteorological variables and total column water vapor from ground-based GPS receivers. The second priority includes surface radiation parameters (ideally as measured by the GCOS Baseline Surface Radiation Network), temperature and water vapor from a ground-based remote sensor such as a microwave or multi-channel infrared radiometer, water vapor and cloud information from ground-based lidar, and total column and profile measurements of ozone, methane and aerosols. Third and fourth priority variables (not illustrated here; see GCOS 2007) include carbon dioxide profiles and detailed cloud and hydrologic variables.*

dicting, mitigating, and adapting to climate variability and change". GRUAN is also a crucial element supporting the Global Space-Based Inter-Calibration System (GSICS).

2. 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.

3. WHO WILL STEER, MANAGE, AND OPERATE GRUAN?

The coordinated efforts of many individuals and institutions are needed to ensure a successful GRUAN. GCOS provides direction and oversight through its Atmospheric Observation Panel for Climate (AOPC). The AOPC has responsibility for several observing systems, and has established a Working Group on Atmospheric Reference Observations (WG-ARO) to provide direct guidance and oversight to GRUAN, with the support of the GCOS Secretariat in Geneva. Terms of reference and member rosters for both the AOPC and its WG-ARO are on the GCOS web site at http://www.wmo.ch/pages/prog/gcos/index.php?name =aopc.

Day-to-day management of GRUAN is the responsibility of the GRUAN Lead Center, now established at the Meteorological Observatory Lindenberg, with a dedicated staff of one visiting and three permanent scientists. Lead center responsibilities include characterizing instrument error; cultivation and identification of instrument mentors to provide site-specific guidance; training station staff; succession planning to ensure continuity of observations and expertise; coordination with the user community; network management; data archival, dissemination and potential reprocessing; and research using GRUAN data.

Operation of GRUAN sites is the responsibility of the site scientific and technical staff, who in most cases will be affiliated with the governmental or academic (or perhaps a private) institution hosting the site. They are responsible for operating and maintaining instruments, some aspects of data quality control, and working with the Lead Center. As GRUAN matures, these arrangements may be adjusted.

4. WHERE WILL GRUAN STATIONS BE LOCATED?

Working with the dictum “Start small, but start”, GRUAN will begin operation at a single station, the Lead Center at Lindenberg. At the GRUAN initiation meeting February, 2008, a number of initial candidate sites, offering a rich variety of ground-based in-situ, remote-sensing and radiosonde capabilities, were identified. These were a mix of national observatories, research stations (including the U.S. DOE’s ACRF sites in the North Slope of Alaska, the Southern Great Plains, and one or more of the three sites in the Tropical Western Pacific), and operational radiosonde sites. At the time of submission of this article, WMO is initiating formal invitations to these sites. For current information on GRUAN network stations, the reader may refer to the GRUAN website http://www.gruan.org.

5. WHAT OBSERVATIONS WILL BE MADE AT GRUAN SITES?

A full description of GRUAN measurements is beyond the scope of this paper, in part because of the plethora of observations that might be available from a given site, and in part because some instrumentation plans are under development. As shown schematically in Figure 1, all stations will be equipped to take, at minimum, the GRUAN first priority observations, including: reference radiosonde observations of temperature, humidity, pressure, height, and wind; surface meteorological parameters; and total column water vapor using ground-based GPS receivers in combination with surface pressure observations. Highly desired, but not required, is the capacity for vertical profile observations using at least one ground-based remote sensing technique. Second priority observations include total column and profile measurements of traces gases (ozone and methane) and aerosols, as well as cloud and radiation parameters. Ideally, a GRUAN site would also be a GCOS Baseline Surface Radiation Network site.

The exact design of a GRUAN reference radiosonde soon will be under study and field testing, in coordination with the WMO Commission on Instruments and Methods of Observation, which has a long history of field testing and intercomparison of radiosondes. The guiding principles are to use best available technology and to ensure that instrument error can be fully characterized by making redundant measurements of a given atmospheric variable, by calibrating sensors with references traceable to national metrology institutes whenever possible, and by following the International Organization for Standards guidelines for calculating and expressing uncertainty in measurements [3].

For temperature and pressure observations, some combination of commercially-available sensors appear to meet GRUAN specifications [2], particularly for nighttime soundings when solar radiation effects can be ignored. Reference humidity observations pose a greater challenge because no single commercially-available instrument is responsive over the full dynamic range of values likely to be encountered from the surface into the troposphere and lower stratosphere. Instruments such as the Cryogenic Frostpoint Hygrometer (CFH, [4]), the Fluorescent, the Snow White chilled mirror hygrometer, may be used for reference measurements in their respective, valid altitude range. Other proven reference instruments may be introduced, with careful attention to data continuity concerns.

6. HOW WILL GRUAN OBSERVATIONS BE ARCHIVED, DISSEMINATED, AND USED?

Ensuring the early, ongoing, and widespread use of GRUAN observations is a GRUAN priority and the responsibility of the Lead Center. The importance of a committed GRUAN data center has been stressed from the outset, and a number of institutions are working together to ensure that existing data management capabilities and experience are available to GRUAN. These include the NOAA National Climatic Data Center (NCDC), which also hosts World Data Center (WDC) for Meteorology; the Global Observing Systems Information Center (see http://gosic.org); the data portal of the Network for the Detection of Atmospheric Composition Change (http://www.ndsc.ncep.noaa.gov/); the U.S. DOE ACRF archive and supporting infrastructure; and the Lead Center at Lindenberg.

It is expected that researchers from around the world will employ GRUAN data in a wide variety of studies. The AOPC Working Group on Atmospheric Reference Observations is encouraging research program managers to support projects that use GRUAN data to meet GRUAN goals, particularly those related to improving satellite data products, characterizing observational error, and understanding climate variations and change.

7. HOW CAN INDIVIDUALS AND INSTITUTIONS PARTICIPATE IN GRUAN?

The GRUAN is just beginning to be realized. Its success and continuity will depend to a large measure on the involvement of the international scientific community. Constructive feedback and responses to this article, and expressions of interest in hosting and providing long-term support for a potential GRUAN site or engaging in GRUAN in other ways, are most welcome. A communication platform is available at. http://gruan.wordpress.com. Please direct any questions to Dr. Holger Vömel, Director of the GRUAN Lead Center, Dr. Peter Thorne, Chair of the AOPC Working Group on Atmospheric Reference Observations, and Dr. Caroline Richter, GCOS Director via email at gruan.chairs@dwd.de.

8. CONCLUSIONS

In short, the main reasons for establishing GRUAN are to:

- Provide long-term high quality upper-air climate records, with complete estimates of measurement error
- Constrain and adjust data from more spatially comprehensive global observing systems (including satellites and current radiosonde networks)
- Fully characterize the properties of the atmospheric column and their changes
- Ensure that potential gaps in satellite programs do not invalidate the long-term climate record

REFERENCES

[1] GCOS 2003: The Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC. GCOS–82, WMO Tech. Doc. 1143, 85 pp.

[2] GCOS 2007: GCOS Reference Upper-Air Network (GRUAN): Justification, requirements, siting and instrumentation options. GCOS–112, WMO Tech. Doc. 1379, 42pp

[3] ISO, 1995: Guide to the Expression of Uncertainty in Measurement. International Organization for Standardization, Geneva, Switzerland.

[4] Vömel, H., D. E. David, and K. Smith, 2007: Accuracy of tropospheric and stratospheric water vapor measurements by the cryogenic frost point hygrometer: Instrumental details and observations, J. Geophys. Res., 112, D08305, doi:10.1029/2006JD007224