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GRUAN input to AOPC discussion on the GRUAN-GUAN interface

(Submitted by WG-GRUAN)

Summary and Purpose of Document

DRAFT – FOR COMMENT AND DISCUSSION AT ICM-6

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WG-GRUAN
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Introduction

Preceding the next AOPC meeting, there will be a two- day Network Meeting (7./8. April 2014) for discussion around the future of the GCOS Surface and Upper-Air Networks (GSN & GUAN) and their potential rescoping/re-engineering. The purpose of this document is to outline how the Working Group on GRUAN (WG-GRUAN) and the broader GRUAN community sees the GRUAN-GUAN interface and how lessons learnt in GRUAN implementation may be applicable to a GUAN re-evaluation, hence how GUAN can benefit from GRUAN practices and expertise.

This document was prepared for ICM-6 and will be discussed at this meeting with subsequent revisions based upon input from the GRUAN community. The revised document will be submitted to the AOPC Network Meeting. It provides specific recommendations on how to ensure that the scientific advances accrued in GRUAN flow to GUAN as this was always an intended purpose of GRUAN. It also proposes a number of potentially inexpensive innovations that could help improve the science value of the GUAN network and differentiate it from other upper-air stations of the Global Observing System (GOS).

The following sections make specific recommendations on what might be considered when rescoping GUAN to achieve the goals defined in the Commission for Instruments and Methods of Observations (CIMO) Guide and the Manual on the GOS as summarized in Annex 1. The suggestions are of varying complexity, cost, and benefit, and first estimates these categories are given. Where possible these have been denoted in the sections ranking each 1 to 5. This ranking should be discussed by the Network Meeting.

1) Metadata collection and centralized data processing

Complexity: 2-4 (dependent upon ambition)
Cost: 3
Benefit: 5

Many GUAN data are still transmitted solely as TEMP reports. This significantly limits the data and metadata transmitted and hence the value of the data to the climate science user community. There exist a range of options to consider to improve this situation. The two extremes are outlined here.

At the simplest end is transmitting full reports in BUFR over the WIS. These reports would need to contain metadata as well as data and be collected and archived at one or more regional or global GUAN monitoring centres. This would provide a step forward compared to current state of the art data collection and retention.

A more ambitious target would be the use of a raw data and metadata collection tool such as the RSLaunchClient[1] developed for GRUAN, which also submits the raw data and metadata to a centralized data processing facility. This would result in significant improvements in homogeneity of data quality across the network. Centralized data processing as developed in GRUAN - while not converting GUAN data into a full GRUAN product - would have the advantage of providing a well derived and well founded estimate of the uncertainty on the measurements. This would also provide a clear point of difference between GUAN radiosonde data and radiosonde data from other sites in the GOS. However, significant resources and additional support for GRUAN would be required to start up and maintain such functionality. This would not be a facility that under current or envisaged resources can be extended at no cost from GRUAN to GUAN.

The use of a centralized collection tool would ensure that data sent from sites always makes it to the GUAN data centre by circumventing the issues associated with transmission through several intermediary steps on the WMO Information System (WIS) where restrictions and coding errors can lead to myriad reasons why data are not received at the GUAN repository despite the measurements having been made. Of course, this does not resolve the issue if sites fail to share their data – a problem which no data collection tool can resolve and which can only be addressed through monitoring and certification procedures (see below).

Central processing of the original data allows reprocessing of the data on a periodic basis as new data discoveries are made. This way of capturing and storing data from GUAN launches would considerably differentiate its data properties and scientific value for climatic studies from that of the remainder of the global radiosonde network by allowing the potential for periodic reprocessing. This would require significant resource and network operator buy-in.

<u>2) Establishing a scientific basis for the design of GUAN</u>
Complexity: 1
Cost: 1
Benefit: 2

The process needs to start by clearly identifying the users of GUAN data and their specific scientific needs. The four user communities considered by GRUAN were:

i) *The climate detection and attribution community:* the long-term stability and homogeneity of GRUAN data provide time series needed to robustly detect and attribute changes in the climate of the free atmosphere. GRUAN data will also be used to constrain and validate data from more spatially comprehensive global networks for improved climate detection and

[1] GRUAN aims for central, unified data processing throughout the Network by having developed a so-called Radiosonde Launch Client software (RSLaunchClient) [GRUAN-TD-3]. The GRUAN RSLaunchClient is a javascript client requiring internet connection and the specified fields ensure that adequate metadata and data are directly associated with each launch upon receipt circumventing potential issues with BUFR/CLIMAT formatting being able to contain either all desired metadata or the high temporal resolution data that may distinguish GUAN from other radiosonde stations (see later).

attribution.

ii) *The satellite community:* GRUAN data products are used to validate satellite-based measurements and to provide the input needed for radiative transfer calculations required to improve and evaluate retrieval algorithms. GUAN is already a network set regularly monitored as part of NOAA retrieval validations as part of its NPROVS suite.

iii) *The atmospheric process studies community:* by providing high precision and high vertical resolution measurements with defined uncertainties of a range of upper-air climate variables, GRUAN data products will aid in developing a deeper understanding of the processes affecting the atmospheric column. Because GRUAN will make profile measurements at vertical resolutions much higher than can be retrieved from satellites, it will provide valuable insights into the potential limitations of satellite-based measurements for the analyses of specific atmospheric phenomena.

iv) *The numerical weather prediction (NWP) community:* The reference quality of GRUAN data makes them useful for verifying NWP model outputs, and for validating and correcting other data being assimilated into NWP models. Measurements made at GRUAN sites can also be directly assimilated in real-time, or near real-time, into NWP models, provided this is not detrimental to achieving the primary purposes of the network, as defined above. GRUAN reference measurements can also be assimilated into meteorological reanalyses.

It would be likely that the same four communities would be the key target communities for GUAN, although the importance of each may differ between the two networks. A necessary first step to successful redesign of GUAN has to be identifying and prioritizing intended users and their needs. This identification should be cognizant that GUAN may have value for multiple ways of approaching the climate monitoring problem – as a monitoring network in its own right, as a cal/val tool for more globally complete satellite data, or as input to data assimilation schemes to enable reanalyses, for example.

The design of the network should then be such that the needs of the identified target communities are met at minimal cost. Specifically the questions that need to be answered are (1) where should sites be and (2) why should they be there and (3) when should they observe to maximize scientific value. The use of sensitivity studies and methodologies such as Observing System Experiments (OSEs), Observing System Simulation Experiments (OSSEs) or ensemble data assimilation impact studies would be essential in this regard.

The outcomes of, and lessons learned from the GRUAN Network Expansion Workshop would be directly applicable to GUAN but now considering a network of ~160 sites rather than the 35-40 sites expected of GRUAN. GUAN network decisions could use this report and the methodologies explained therein as at least a starting point for further consideration of the issue of network design.

<u>3) Measurement requirements</u>

Complexity: 5
Cost: 1-5 (depending upon ambition)
Benefit: 3-5

A ‘one size fits all’ requirement on measurement attributes although by far the easiest option for managing a network of this size for all sites within GUAN is perhaps scientifically questionable, particularly in regards to measurement frequency. Of course this depends on the intended use of the data and which targeted user communities are being accommodated. For example, while 4D-var assimilation used in NWP might prefer regularly spaced soundings in time with accurate measurements and small uncertainties, the climate trends detection and attribution community may want measurement frequency to be increased during time of high natural variability compared to periods of low natural variability. For the climate trends community ensuring long-term homogeneity of the measurement series is more important than aiming for measurements with small uncertainties. Satellite users will likely desire launches collocated with overpasses. If the GUAN network really wishes to serve some of these purposes and do so in a distinct manner then it would be worth considering GUAN launch schedules being other than 00 and 12Z each day if alternatives proved to increase the scientific utility of the data. Further research is required in this regard and is also an ongoing area of research and debate within GRUAN.

4) Measurement resolution

Complexity: 1
Cost: 1-2
Benefit: 5

GUAN should aim to collect and process 6 second resolution (or better, preferably 1 second resolution) radiosonde measurements, an analog to what is currently being done with GRUAN data. High vertical resolution radiosonde data (HVRRD) have provided essential data for gravity wave and tropical wave studies [Hamilton and Vincent, 1995] with the goal of characterizing the distribution of gravity wave momentum flux to constrain gravity wave parameterizations in general circulation models. Routine analysis of upper troposphere–lower stratosphere temperature and wind has led to better understanding of seasonal and geographic variations in gravity wave activity and spectral characteristics. Since the mid-1990s, HVRRD have been exploited for a wide range of applications in fields where HVRRD provide the highest resolution available for observational parameters. Studies have been made of the finescale structure of the tropical and extratropical tropopause on climatological and regional bases with subsequent analysis of the abilities of GCMs to reproduce these features.

As meteorological networks (e.g. the NOAA network of U.S. upper air stations) provide ever higher vertical resolution data, new research applications of operational sounding data are emerging. One of the new applications facilitated by the increase to 1-second resolution data is the derivation of clear air-turbulence parameters describing the transfer of energy from large to small-scale motions and identifying potential hazards for aircraft, using Thorpe scale analysis, which was previously developed in studies of oceanic turbulence. The 1-second resolution data could be particularly useful for studies of the boundary layer, which could help improve understanding of surface-atmosphere exchange processes and dispersion of pollutants.

If GUAN were to report HVRRD it would significantly distinguish it from the remainder of the network and have clear scientific benefits. A rescoped GUAN should therefore seek to provide radiosonde profiles of temperature, pressure and humidity at the highest possible vertical resolution. This is an easily achievable, scientifically valuable goal that would add little, if any, cost to the operation of the network. The use of a data collection client proposed above may ameliorate technical issues associated with data transmission.

5) Implementation of inexpensive ground-checks
Complexity: 2
Cost: 2
Benefit: 5

The scientific value of GUAN measurements could be enhanced by reducing their measurement errors. One immediate way to make an advance in that direction is to implement additional, inexpensive ground-checks prior to the flight and transmit these in the metadata either in BUFR or in some dedicated GUAN collection client (see #1). GUAN has significant experience in ground checks which are relatively inexpensive and provide manufacturer independent checks of both temperature and humidity sensor performance prior to launch. Their execution requires relatively low skill and adds a few minutes of operator's work to typical launches.

6) Going from passive performance monitoring to active performance monitoring
Complexity: 3
Cost: 2
Benefit: 3

Monitoring of daily TEMP messages is performed by the European Centre for Medium-range Weather Forecasts (ECMWF) in Reading, UK in its capacity as the GUAN Monitoring Centre (GUAN MC). It is also stated in GCOS-144 that analysis of GUAN data will be performed by NOAA/NCDC in their capacity as the GUAN Analysis Centre. The Analysis Centre provides an annual report. WDC-Asheville acts as the archive for all GUAN data and make them available through the Integrated Global Radiosonde Archive (IGRA) (http://www.ncdc.noaa.gov/oa/climate/igra/). Currently both of these monitoring activities are 'passive' in that they only record if data were transmitted without regard to their quality or at best with black/white quality flag assessments.

Two potential, and inexpensive, avenues exist to move from a passive to an active monitoring of performance globally in a consistent manner to add value to existing regional monitoring efforts and which goes deeper than simply logging data presence / absence.

1. ECMWF and other data assimilation centres could provide observation minus background timeseries for GUAN sites.
2. NOAA through its NPROVS facility could provide similar statistics for departures between GUAN profiles and L2 retrievals from polar orbiter overpass within window match criteria.

Monthly summaries of statistics would yield several potential avenues viz:

- Allowing the GCOS Implementation Manager to alert stations which are launching but providing poor quality data to address data-quality issues.

- Monthly summaries could be sent to the site operators as a means of providing quality assurance feedback and providing some extra value and incentive to operators to undertaking GUAN operations (the stations both give and get rather than just give).
- At the very least such active monitoring would provide a cleaner toolset to identify priorities at annual AGG meetings.

<u>7) Making GUAN membership mean something through an improved assessment and certification scheme</u>

Complexity: 2
Cost: 1
Benefit: 3

Within GRUAN a site certification procedure[2] has been constructed which involves a site applying, on a data stream basis, for inclusion in the network. The certification is coming to mean something both to the certified sites and to the users. While a similar process is unlikely to be tractable with given resource for the much larger GUAN network, a more robust and active certification process than has been the case to date based on launch frequency and basic data quality assessments as discussed above could be useful. For example, there is currently no mechanism to convince Met Services to change to better sondes, even if the equipment in use is known to be of inferior quality and Met Services in the past have changed their sounding systems ignoring the requirements of GUAN. Sites not meeting minimum performance requirements, and not responding to assistance from GCOS, should be suspended from GUAN. If sites continue to be non-responsive they should eventually be removed altogether.

Assessment and certification is both a carrot and a stick which can be used to make GUAN membership mean something, give credibility and also provide some assurance of basic quality to science application users.

<u>8) Measurement redundancy and intercomparisons</u>

Complexity: 2-5
Cost: 5
Benefit: 5

To add scientific value to GUAN data above and beyond GOS sondes consideration should be given to recommending measurement redundancy at least on a periodic basis and at least for a subset of the GUAN network or periodic flying of GUAN sondes at GRUAN sites. This is not to advocate for the same systematic level of redundant measurement operations as at GRUAN sites, but rather recognizes that more periodic such activities at GUAN sites may help distinguish their value from the remainder of GOS sondes.

Several approaches exist here:

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[2] The GRUAN site assessment and certification process is described in brief in the GRUAN Manual [GCOS-170] and in detail in the GRUAN Guide to operations [GCOS-171].

- Where possible measuring on a routine basis parameters redundantly. E.g. by preference GUAN sondes should report pressure both from GPS and a pressure sensor. Note that Vaisala have responded to redundancy requirements of GRUAN by designing the RS-41 to be available in GPS only and GPS + pressure sensor
- Periodic dual rigged launches at at least a subset of GUAN sites to understand instrument stability in a broader range of regime types than is feasible at the more geographically limited GRUAN network.
- Periodic multi-instrument payload launches at a subset of GUAN/GRUAN sites and in conjunction with CIMO / WIGOS to help understand changes in instruments over time and help inform the periodic much larger CIMO intercomparisons and regional variations in performance.

Any GUAN sites undertaking such measurements should archive them as GUAN data (and many already do such as Camborne in the UK), perhaps through a dedicated GUAN sub-repository to allow ease of access by climate researchers to this wealth of data key to advancing metrological knowledge of instrumental effects.

9) Training and capacity building

Complexity: 2
Cost: 2
Benefit: 5

A number of GRUAN stations and GUAN stations have highly trained and experienced staff. GRUAN stations often have the additional benefit of having a stronger research component and a strong standing within the National Hydrological and Meteorological Service (NHMS). A closer cooperation between GUAN and GRUAN should be sought to enable capacity building and training for staff at other GUAN and GRUAN stations. Due to the larger number of stations this activity should be coordinated through WMO Regional Associations, rather than by an individual site. Funding for training and capacity building should be provided by WMO, its Commission for Basic Systems (CBS) and the NHMSs.

References

GCOS-170, The GCOS Upper-Air Reference Network (GRUAN) MANUAL, WIGOS Technical Report No. 2013-02, 2013.

GCOS-171, The GCOS Upper-Air Reference Network (GRUAN) GUIDE, WIGOS Technical Report No. 2013-03, 2013.

GRUAN-TD-3, Michael Sommer, User Guide of GRUAN RsLaunchClient, *Draft* v0.4: 17 February 2011.

Hamilton, K., and R. A. Vincent (1995), High- resolution radiosonde data offer new prospects for research, *Eos. Trans. AGU*, 76(49), doi:10.1029/ 95EO00308.

Some relevant words regarding GUAN

As stated in GCOS-73 and GCOS-144, the original prime purpose of GUAN sites was:

- To establish national commitments for the preservation of a minimum set of upper-air stations for the foreseeable future;
- To build a collection of validated data from these stations in standardized formats.
- To provide this information to the global climate community with no formal restrictions.

But these sites of course serve many other potential users. GUAN was established at a time when there was a risk that the global radiosonde network might disappear. The problem is that because observations at GUAN sites are still made primarily for weather observation and forecasting and not for climate research, the measurements made there are not reference measurements and are subject to changes driven by the requirements of the primary customer. GCOS-144 also points out that where climate research notes shortcomings in the available data sets, synoptic meteorology in general suffers from the same problem. That said, the requirements of the measurements for synoptic meteorology are much weaker than for climate research. GRUAN is therefore well positioned to help act as a component of the bridge between GUAN-type measurements and the measurements required by the climate research community. This document provides details on how that bridge might work.

GUAN and adherence to the *CIMO Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8)

A key issue is the role that GRUAN might play in assisting GUAN sites to adhere to the operational requirements detailed in the CIMO Guide and to establish a clear point of difference between GUAN and the other radiosonde sites in the GOS.

Some examples extracted from the CIMO Guide are:

- All measured data are imperfect, but, if their quality is known and demonstrable, they can be used appropriately.
- The provision of good quality meteorological data is not a simple matter and is impossible without a quality management system.
- Without investment in an effective quality management system (expected to be a few percent of the overall operational cost) the data must be regarded as being of unknown quality, and their usefulness is diminished.
- A quality system should include procedures for feeding back into the measurement and quality control process to prevent the errors from recurring i.e. quality assurance results should be returned to the observation managers for follow-up.
- An essential component of the technical requirements is the development of uncertainty analyses for each of the measurement processes, including documented and verified traceability to international metrology standards.
- Special attention has been placed on the change management process.

GUAN and adherence to the *Manual on the Global Observing System*

The 2010 edition of the *Manual on the Global Observing System* (vol. 1) requires the following of GUAN stations (Part III, Section 2.10):

- Long-term continuity should be provided for each GUAN station: this requires the provision of the necessary resources, including well trained staff, and keeping changes of location to a minimum. Changes of bias caused by changes in instrumentation should be evaluated by a sufficient overlapping period of observation (perhaps as much as a year) or by making use of the results of instrument intercomparisons made at designated test sites.
- Soundings should preferably be made at least twice per day and should reach as high as possible, noting the GCOS requirements for ascents up to a minimum height of 30 hPa. Since climate data are needed in the stratosphere to monitor changes in the atmospheric circulation and to study the interaction between stratospheric circulation, composition and chemistry, every effort should be made to maintain soundings regularly up to a level as high as 5 hPa where feasible, noting the above GCOS requirements.
- Rigorous quality control should be exercised at each GUAN site: periodic calibration, validation and maintenance of the equipment should be carried out to maintain the quality of the observations.
- Basic checks should be made before each sounding to ensure accurate data: the accuracy of a radiosonde's sensors should be checked in a controlled environment immediately before the flight. Checks should also be made during and/or at the end of each sounding to assure that incomplete soundings or soundings containing errors are corrected before transmission.
- Back-up radiosondes should be released in cases of failure: in the event of failure of a sounding instrument or incomplete sounding resulting from difficult weather conditions, a second release should be made to maintain the record from the GUAN station.
- Detailed metadata for each GUAN station should be provided: the batch identifier on the radiosondes should be logged for each flight, so that faulty batches can be identified and the data amended or eliminated from the climate records, if necessary. Up-to-date records of metadata in a standard format should be provided to the GUAN Data Centre so that shifts in the data will not be mistaken for climate change. The metadata should include detailed information about the station, such as location, elevation, operating instruments and their changes over time. Changes to operating and correction procedures should also be recorded. Both the corrected and uncorrected upper-air observation should be archived. Climate change studies require extremely high stability in the systematic errors of the radiosonde measurements.