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International Council for Science

**Workshop on the Review of the  
GCOS Surface Network (GSN),  
GCOS Upper-Air Network (GUAN) and related  
atmospheric networks**

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## Table of Contents

<b>1. INTRODUCTION .....</b>	<b>1</b>
<b>2. GCOS UPPER-AIR NETWORK (GUAN).....</b>	<b>1</b>
2.1 MEASUREMENT REQUIREMENTS FOR GRUAN.....	3
2.2 REQUIREMENTS FOR GUAN MEASUREMENT SCHEDULING .....	4
2.3 MONITORING, QUALITY ASSURANCE AND CERTIFICATION .....	4
2.4 SUPPORT FOR THE GUAN NETWORK AND IDENTIFICATION OF GAPS.....	5
2.5 CAPACITY TRAINING AND DEVELOPMENT.....	5
2.6 MANAGEMENT OF CHANGE .....	6
2.7 GUAN NETWORK MANAGEMENT .....	6
<b>3. GCOS SURFACE NETWORK (GSN).....</b>	<b>6</b>
3.1 REFERENCE CLIMATE STATIONS AND TIERS .....	7
3.2 COMPLIANCE OF GCOS SURFACE STATIONS .....	8
3.3 DAILY CLIMAT MESSAGES.....	8
3.4 EXTRA REPORTING STATISTICS .....	9
3.5 CHANGES AND MODIFICATIONS TO THE GSN .....	9
<b>4. DATA RESCUE .....</b>	<b>9</b>
<b>5. RESULT OF THE DISCUSSION ON NETWORK DEFINITIONS .....</b>	<b>10</b>
<b>6. RELATED ATMOSPHERIC NETWORKS AND DATA REPOSITORIES.....</b>	<b>11</b>
<b>7. LIST OF ACTIONS .....</b>	<b>12</b>
<b>REFERENCES .....</b>	<b>14</b>
<b>AGENDA .....</b>	<b>15</b>
<b>LIST OF PARTICIPANTS.....</b>	<b>17</b>
<b>CBS LEAD CENTRES FOR GCOS .....</b>	<b>21</b>
<b>MAP OF GUAN .....</b>	<b>23</b>
<b>MAP OF GSN.....</b>	<b>25</b>
<b>GRUAN INPUT TO AOPC DISCUSSION ON THE GRUAN-GUAN INTERFACE AND THE FUTURE OF GUAN.....</b>	<b>27</b>

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## **1. Introduction**

Following the recommendation from the eighteenth Session of the Atmospheric Observation Panel for Climate (AOPC), which is jointly sponsored by the Global Climate Observing System (GCOS) and the World Climate Research Programme (WCRP), a workshop was arranged to review the requirements of the GCOS Surface Network (GSN) and Upper-Air Network (GUAN) 20 years after their establishment, in the light of changes in both technology and data needs, and to consider general matters concerning the designation of networks. The workshop also discussed the role of related networks such as the GCOS Reference Upper-Air Network (GRUAN) and the Global Atmosphere Watch (GAW). It was held on 7 and 8 April 2014 at the European Commission Joint Research Centre (JRC) in Ispra, Italy, preceding the nineteenth session of the AOPC.

The meeting included experts for specific operational networks, monitoring and archive centres, and data users. Chaired by Phil Jones, participants discussed the design, scientific principles, performance and use of data from the GSN and GUAN, and their roles in relation to the comprehensive surface and upper-air networks. The meeting agenda and list of participants are given in Annex 1 and Annex 2, respectively.

The meeting began with a series of presentations and accompanying plenary discussions. These highlighted a number of issues that were identified and discussed further within breakout groups during the rest of the first day and the whole of the second day. The breakouts reported back to a plenary meeting during the second day. The first breakout session constituted a pair of breakouts which considered the future of the GUAN and GSN networks respectively. The second set of breakout groups discussed Data Rescue and the network of networks (often termed system of systems) concept.

## **2. GCOS Upper-Air Network (GUAN)**

Breakout discussions were informed by the pair of earlier presentations in plenary given by Peter Thorne and Tom Peterson which, whilst agreeing that maintaining GUAN as it stood was not desirable, had given very different prescriptions as to how to address the issue. Participants welcomed these presentations, which had clearly been given considerable thought and preparation. Plenary discussions had also highlighted other salient points, which naturally informed the breakout discussions. A map of the GUAN can be found in Annex 4.

Peter Thorne had presented a view arising from participants at the 6th GCOS Reference Upper-Air Network (GRUAN) Implementation and Coordination Meeting (ICM-6)<sup>1</sup>. This was further articulated in a supporting document (Annex 6). This called for strengthening GUAN together with a clear distinction from the soundings typically performed in the WMO Global Observing System (GOS) as a whole in terms of the data and metadata delivered and the active monitoring of performance. This would make it intermediate between GRUAN and GOS operations.

Tom Peterson had suggested that GUAN had exceeded its useful lifetime and advocated against further investment of time or resource on scientific grounds. He argued that

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<sup>1</sup> The ICM-6 report is available under: [http://www.wmo.int/pages/prog/gcos/Publications/gcos\\_180.pdf](http://www.wmo.int/pages/prog/gcos/Publications/gcos_180.pdf)

radiosondes were an expensive, old technology and that it was possible that sondes would be seen as redundant in the medium term with technological advances and increased profile data from commercial aircraft operations and remote sensing (both ground- and space-based). He also raised the issue of environmental littering that is inevitable with single-use consumables. Finally, he had highlighted the danger when trying to encourage countries by supplying sondes that this might have the opposite effect, leading to dependency on external funding of supplies to continue operations.

In plenary discussions arising, the point was made by participants that at the current time, radiosondes have the highest per-observation impact on NWP performance in Observing System Experiments (OSEs). It was not foreseen that this situation was likely to change, at least in the near-term. On the other hand, a recent cost benefit study based on forecast sensitivity to observations does not give radiosondes a very high impact compared with aircraft profiles.

Participants discussed targeted observations. It was stressed that launching sondes only at special situations in future would only work if one could be confident that the forecasting system captured every severe weather event. Currently, this is not the case. Furthermore, it would have deleterious impacts upon long-term climate record continuity, if launches were solely to occur 'on demand'. Finally, training of operators is an essential factor for measurement quality and might be a reason to maintain regular soundings. In discussions with GRUAN site operators, the desire to regularly make measurements to keep producing high-quality measurements has been highlighted by station operators.

Regarding the statement not to wait 10 to 15 years, knowing that the technology was likely to run out, Adrian Simmons, highlighted the need to fill the gaps in observations until new technologies are in place and proven. Furthermore, overlapping measurements were seen as one of the key GCOS principles.

In conclusion, while recognizing that a robust discussion had been healthy and nothing necessarily could or should last forever, the general feeling of plenary had been that modifying GUAN was the preferable course. This was also the strong consensus position of the breakout group members.

The breakout agreed that the high-level characteristics of a modified GUAN which would be pursued were to be as follows:

- GUAN should be about coverage, but also about data quality.
- GUAN data should be actively monitored for quality and adherence and that GUAN certification/designation should be applied to sites that meet GUAN requirements.
- GUAN data are defined by their measurement properties, so that they can be used with some confidence by data analysts and users, including for, but not limited to, climate analysis.

These reflect a realignment of purpose. In a nutshell GUAN 'membership' and data would mean something to the end-user be they intending to use the data for climate or for more near-real-time applications. GUAN measures would be able to be used with some confidence that they are likely to be fit for purpose.

Such realignment requires substantive changes to GUAN operations and guidance. Participants recognized that such changes would require consideration by other relevant bodies within both WMO and GCOS before they could be enacted. What follows are high-level initial recommendations. It is fully expected that these will be modified following discussion and consultation with relevant WMO Technical Commissions and programmes such as the WMO Integrated Global Observing System (WIGOS) prior to adoption.

## **2.1 Measurement Requirements for GRUAN**

Commensurate with the WMO regulatory practices, the breakout group considered requirements under two classes: “shall” and “should” (henceforth, these are italicized to highlight their intended meaning is commensurate with this guidance). The measurement *shalls* reflect minimum requirements which, if not met, would be deleterious to science applications and, therefore, below which it is not possible to claim GUAN status. Measurement *shoulds* reflect possible additional and relatively inexpensive capabilities which, if met, would substantially increase the value of the data to a broad range of users. GUAN stations are strongly encouraged to implement both all the *shalls* and all the *shoulds*.

### **GUAN operators *shall***

- Report full profile measurement in BUFR format, including full metadata (model, batch, ground checks, surface pressure etc.).
- Retain the raw data counts to allow future reprocessing. (The raw data is supposed to be archived locally; at a later stage a more routine distribution of these data might be implemented.)
- Use a balloon sufficient to get to 30 hPa at least 25 days a month.
- Meet the minimum observational requirements as stated for AOPC in the Observing Systems Capability Analysis and Review Tool (OSCAR) database<sup>2</sup> for temperature, humidity (up to at least 300 hPa) and winds.
- Meet all requirements of the Manual on the GOS related to GUAN stations.

### **GUAN operators *should***

- Undertake manufacturer independent ground checks and report these data.
- Use a balloon sufficient to get to 10h Pa at least 25 days a month.
- Archive the data from any radiosonde intercomparisons undertaken to improve metrological understanding of instruments.

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<sup>2</sup> The OSCAR database is available under: <http://www.wmo-sat.info/oscar/>

- Make the raw data available regularly to a designated GUAN archival centre at a minimum on an annual basis although more frequent sharing is encouraged.

## 2.2 Requirements for GUAN measurement scheduling

As is implicit in the GUAN *shalls* articulated above, GUAN stations *shall* launch at least once daily and at least 25 days each month. Furthermore, GUAN stations *should* launch twice daily. If they launch once daily it *should* be a night-time launch to minimize radiation-bias impacts on the instrumentation, which various peer-reviewed papers have shown to be a significant impediment to analysis (e.g. Sherwood et al., 2005). GUAN stations may undertake adaptive scheduling in support of process understanding, satellite overpass coincidence for satellite validation etc. However, recognizing that it is desirable not to alias in diurnal cycle noise into long-term monitoring, GUAN stations *shall* make sufficient launches at standard times (00 or 12 UTC – with a preference to whichever is in local night-time) to assure a long-term record. Several papers have been published on this subject looking at tropospheric temperature and humidity trend characterization (Seidel and Free, 2006; Whiteman et al., 2012) impacts of different scheduling. The robust finding is that launching at the same time every three days at standard times is enough to assure the long-term record. Going to longer gaps between repeat samples starts to have a significantly deleterious effect upon the time required to detect an emerging climate-change signal and hence must be avoided.

## 2.3 Monitoring, quality assurance and certification

GUAN monitoring *shall* move from a “passive” monitoring, whereby the primary assessment was whether a sonde was launched, to more “active” monitoring, which considers the data quality. First and foremost GUAN monitoring centre(s) *shall* undertake BUFR ingest and monitoring. To move to active monitoring, the GUAN monitoring centre(s) in collaboration with relevant Numerical Weather Prediction (NWP), reanalysis and satellite agencies *shall* include measures of observation quality such as NWP / reanalysis observation-bias and satellite L2 data collocations within defined match-up windows. The monitoring centre(s) *shall* provide via appropriate GCOS and WIGOS mechanisms feedback quality information against the observational requirements to the sites on a regular basis. This information *shall* also be publicly available. GUAN sites *should* compare the provided analysis to their own assessment of quality and provide feedback to the monitoring centre(s).

GUAN sites *shall* be certified. Certification *shall* be commensurate upon meeting on a sustained basis the minimum stated measurement requirements. As such GCOS/WIGOS shall develop a set of criteria based upon:

- Meeting stated measurement *shalls* (and striving to meet all *shoulds*);
- Meeting objective quality assessments;
- Data stream continuity;

by which to certify stations. These criteria will be openly documented and appropriately applied.



All current GUAN sites will become *de facto* candidate sites for GUAN but need to be 'certified'. Recognizing that some time may be required by many current GUAN sites from adoption of new guidance to their implementation, these sites are to be given a **transition period of 5 years**<sup>3</sup> to meet the new *shalls*. These sites *should* apply as soon as they believe they meet the requirements. Other sites can apply to be certified as GUAN sites. Effectively, GUAN network membership *shall* mean that certain measurement standards are adhered to which provide value to applications, including but not limited to climate analysis. GUAN membership *shall* be dynamic. GUAN *shall* also aim to be a truly global network and support through mechanisms such as the GCOS Cooperation Mechanism (GCM), bilateral agreements, and Global Framework for Climate Services *shall* be targeted, to this end, toward ensuring capabilities in data sparse regions.

#### **2.4 Support for the GUAN network and identification of gaps**

Support from for instance the GCOS Cooperation Mechanism (GCM), or the Global Framework for Climate Services (GFCS) *shall* in the first instance look to address substantial capability gaps and spatial coverage gaps. Gaps should be assessed in the context of all aspects of the upper-air capabilities of the GOS (including but not limited to aircraft measures and various radiometers and techniques such as lidar, microwave radiometers, and Global Navigation Satellite System Precipitable Water (GNSS-PW)) and not from radiosonde capabilities in isolation. Gaps *should* be quantitatively assessed using inter-alia outcomes of the WMO Inter Programme Expert Team on the Observing System Design and Evolution (IPET-OSDE), published and grey literature, and expert solicitation via, e.g., reanalyses and NWP centres. AOPC *shall* have ultimate responsibility to determine the priorities for addressing gaps taking advice from relevant stakeholders into account.

#### **Decisions for the support of the network should also be informed by:**

- Measurement heritage and historical performance, recognizing that historically well performing stations may be more likely to perform well in future. This *shall* be informed by inferences from the existing climate analyses of the radiosonde station quality such as RICH (Haimberger et al., 2012), IUK (Sherwood et al., 2008), RATPAC (Free et al., 2006), HadAT (Thorne et al., 2005), and also comparison to reanalyses.
- Demonstrated stakeholder needs, either from the literature or direct requests, that arise to GCOS or other GUAN responsible parties.

#### **2.5 Capacity training and development**

GUAN sites *should* be staffed with and managed by technically expert operators. GRUAN and well equipped, functioning GUAN sites should act as regional centres of excellence to propagate best practices regionally within both GUAN and the broader regional GOS upper-air network with the Commission on Basic Systems (CBS) / the Commission for Instruments and Methods of Observation (CIMO) / GCOS / WIGOS regional centres. Consideration should be given to certification of GUAN operator expertise (in addition to station

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<sup>3</sup> Transition period starting from AOPC in 2015.

certification) through accredited programmes (e.g. CIMO, CBS or WIGOS certification of operator proficiency by taking part in an accredited training run by a competent NMHS). The presence of such certified operators may form a part of the site-assessment criteria.

## **2.6 Management of change**

GUAN sites *shall* advise GCOS and the monitoring centre(s) of a proposed change in practices before it is undertaken. GCOS and/or the monitoring centre *shall* provide scientific expert guidance making reference to inter-alia GRUAN, WIGOS, CIMO and other technical experts. GRUAN and GUAN sites together with WIGOS and CIMO *shall* pursue cost effective means to manage and quantify change that occurs across the network (e.g., sonde model change). Through coordinated assessment of change management, it is expected that no single organization bears the burden and that the change can be effectively managed in a way that benefits all tiers in the sonde network. As part of this coordinated effort, GUAN sites *should* where necessary undertake dual launches when a change occurs and archive that data.

## **2.7 GUAN network management**

WIGOS and GCOS (or their designates) *shall* actively manage the GUAN network. This interactive management *shall* be undertaken in a sustained manner and consider amongst others inter-alia network performance issues, network communications, and certification. The network *shall* be actively managed by an identified organization, which *shall* be assigned as the central GUAN Monitoring and Archival Facility and which *shall* be staffed at a level commensurate with the task. The Monitoring and Archival Centre *shall* provide annual reports to AOPC for their consideration and liaise with other relevant WMO bodies.

## **3. GCOS Surface Network (GSN)**

The group decided to address six main topics that had emerged as issues during the earlier presentations and plenary discussions. The six were:

1. Reference Climate Networks and the concept of tiered surface networks (similar to GRUAN/GUAN/GOS for upper-air observations)
2. Raising the profile of, and compliance of, GCOS surface stations (those in the GSN)
3. Daily CLIMAT messages
4. Enhanced reporting statistics
5. Changes and modifications to the GSN
6. Data Rescue: how to best facilitate the digitisation of data still locked away in hard copy records, for important climate monitoring stations.

The final topic was subsequently moved to a separate breakout group.

The map of the GSN is attached in Annex 5.

### **3.1 Reference climate stations and tiers**

Starting from the premise that the original definition of GSN stations had been overly weighted towards length of record, and that to leave a legacy for the future (2050 and beyond), an improved set of high-quality reference stations was required, several countries already have such reference networks, e.g. Germany, Australia, and the USA. It was noted that not one of the USA's Climate Reference Network (CRN) of 114 stations is a current GSN site, but it was agreed that a Reference Climate Station need not be, and in many cases would not be, a GSN station.

It was agreed to dispense with the concept of a network altogether in favour of a concept for grading sets of stations, where "Tier 1" stations represented the Reference Climate Stations, analogous to GRUAN stations in the upper-air network, and the most suitable for long-term monitoring purposes. However, it was recognised that better definition of the capability and function of the various tiers should be undertaken.

Selection criteria for Tier 1 (and Tier 2 and 3 stations):

- It was agreed that a collaborative process, led by GCOS and the WMO Commission for Climatology (CCI) that also included consultation with the Commission of Atmospheric Sciences (CAS) and the Commission for Basic Systems (CBS), be established to set the selection criteria;
- The process should be guided by existing materials such as the Global Atmosphere Watch (GAW) process, CRNs, and aspects of the WIGOS network planning principles.
- It is as yet undecided whether the Reference Networks should be (a) established separately for different ECVs, or (b), be a set of stations that were of reference value for more than one parameter (at least temperature and precipitation). The danger with multiple-ECV sites is that geographical factors, for instance, might mean that some countries would face difficulty in achieving good quality on some variables despite good quality on others, at least not without significant commitment of resources. For instance, in dry countries like Australia, dust can significantly affect the reliability of measurements of atmospheric moisture.

It was decided that AOPC should be invited to consider establishing a working group to establish the selection criteria for Reference Climate Stations. Such a working group should take into account the guidance materials referred to above, and later discussions about the terms reference (Tier 1), baseline (Tier 2) and comprehensive (Tier 3). It is also important that the process should also be "socialized" among the climate monitoring community.

### 3.2 Compliance of GCOS surface stations

It was discussed how to raise the level of compliance on CLIMAT reporting (not just for the GSN, but for the WMO Regional Basic Climatological Networks (RBCN), as well) among member countries. A number of suggestions were made:

- Relatively simple actions such as certification of stations (as a reward and an incentive to National Meteorological and Hydrological Services (NMHSs));
- Educational/promotional activities to emphasise the scientific value of GCOS and its reporting (noting GCOS has already done this, but few NMHSs tend to be aware of it);
- Making CLIMAT compliance a “*shall*”, and having this formally reflected in WIGOS Regulatory Material and WMO Technical Regulations;
- By displaying compliance publicly, so that hopefully NMHSs would not wish to be embarrassed, and would make a greater effort to be compliant; but noting that there was an equal need to identify and address capability problems that prevented some NMHSs achieving compliance.

Further to the last point, it is important to diagnose what is preventing countries’ data being received in a timely fashion, and then address such issues. As one example, the CCI Expert Team on Climate Data Management Systems (ET-CDMS) will enable automation of the CLIMAT message generation and submission function by mandating that CDMSs being installed in developing countries include software to automatically generate CLIMAT messages.

It was also proposed that the next GCOS Implementation Plan should provide the scientific justification for the need of CLIMAT messages and underlying daily information.

### 3.3 Daily CLIMAT messages

An increasingly important aspect of climate change monitoring and service provision requires the provision of extra information necessary for monitoring extremes. The rationale for the development is discussed by van den Besselaar et al. (2012), where it is shown for Europe that consistent daily series of temperature and precipitation cannot be generated from daily SYNOP messages. A template for the receipt of this daily information in BUFR code is currently under development though requires testing. This concept needs endorsement by the sixteenth session of the Commission for Climatology (CCI-16), meeting from 3-8 July 2014 in Heidelberg, Germany. According to the draft template, it is intended that, at the end of each month, two separate messages be sent, one with the usual CLIMAT monthly summary, the other consisting of 28 to 31 separate lines containing for each day the minimum, maximum and mean temperature, along with precipitation, snowfall and snow depth (for the temperature and precipitation variables calculated using the same method and observation times as for the monthly CLIMAT message). There was discussion about the merits of sending one CLIMAT message each day instead of a consolidated message once a month, but counter arguments (including, among others, the greater opportunity for quality

check if the full set of daily submissions could be compared against the summary totals/averages) on balance favoured retention of the originally-proposed model.

Again, the potential difficulties with compliance could be greatly reduced if the process could be automated, e.g. using CDMSs, noting also the need for transmission of the messages in BUFR.

### **3.4 Extra reporting statistics**

It was noted that in many cases of so-called CLIMAT message non-compliance, the data were in fact available, but received outside the 21 day cut-off date. By reporting a second set of receipts, 3, 6 or 12 months later, it would be possible to get a better estimate of which stations were genuinely silent, versus those that were merely late, or who had sent messages only to have them stuck in bottlenecks somewhere in the Global Telecommunication System (GTS). Similarly, information on those stations that did not send CLIMAT, but did send SYNOP messages (and vice versa), would be useful for some purposes. Extra information of this kind (and extra graphs, maps, etc.) are necessary to properly diagnose many of the apparent problems in CLIMAT submission, leading to a better source of information for monitoring centres and CBS Lead Centres for GCOS on what and how to follow up with apparently non-compliant stations. Also discussed was the need to investigate the history of particular stations and regions based on data in their archives, as a lead to recovering missing data from earlier years.

The GCOS Implementation Manager will liaise with the National Climatic Data Centre (NCDC), the German Meteorological Service Deutscher Wetterdienst, (DWD) and the Japan Meteorological Agency (JMA) about producing the extra information.

### **3.5 Changes and modifications to the GSN**

While RBCNs, as well as GSNs, submit CLIMAT messages, currently RBCN CLIMATs are not monitored. There would be value in doing this, as CCI in particular would find the extra resolution afforded by the data from the full RBCN network (of which the GSN is a subset) of great value. Therefore, it was proposed to extend monitoring and reporting on CLIMAT by Lead Centres and Monitoring Centres to RBCNs. Implicit from the daily CLIMAT message discussion is that the RBCNs should be encouraged to submit the new daily message, as well.

## **4. Data rescue**

The need to recover the data locked away in paper-based climate records into accessible electronic formats through digitisation and imaging is well known. William Wright outlined CCI's proposal to establish an International Data Rescue Portal as a means of coordinating the many Data Rescue activities underway globally. Such a portal would also provide a means of determining gaps and priorities for digitization, provide information on best-practice techniques for data rescue, and encourage donors to fund data rescue projects and encourage new data rescue projects, including citizen-science digitization initiatives. A White

Paper on the initiative has been drafted, and is now being reviewed, with a view to presenting it for endorsement at the CCI-16 meeting in July 2014. A suggestion to circulate this paper to key potential partners ahead of this meeting was agreed.

There was discussion about obtaining seed funding to set up the portal and initially populate it, and a “kick-start” project approach was suggested. GCOS committed to supporting the project financially, on the basis that (a) it would be a way of ensuring that the full historical record of many GSN and RBCN stations be unlocked, (b) as a demonstration of how GCOS would support worthy projects of this sort, and (c) experience suggests that other parties, seeing GCOS’ lead, would follow suit. GCOS requested CCI to provide an overview of the project, outlining its benefits clearly, and an indicative costing. William Wright presented the proposed timeframes for the initiative, indicating that more detailed information on the project would follow the first meeting of the new CCI Expert Team on Data Rescue (ET-DARE), likely in September/October 2014.

## **5. Result of the discussion on network definitions**

This breakout group addressed the issue of terminology used to describe the different networks within GCOS. Plenary discussions had highlighted that the terms “baseline”, “reference” and “comprehensive” are used in different contexts in the different observing domains under GCOS’ auspices. The breakout group contained, in addition to AOPC expertise, expertise from the oceanic and terrestrial domains. Whilst the discussion highlighted the desirability of high-quality measurements and also a cascade of observing capabilities, it also highlighted stark areas of contention/disagreement which precluded a definitive outcome. In addition, participants recognized that not all necessary stakeholders were present. The breakout group recommended that further discussions be facilitated under an appropriate mechanism to further this issue e.g. in consultation with WIGOS.

It was agreed that the tier designation should be a function of demonstrable measurement qualities, such as traceability, metadata, comparability, data completeness, record longevity etc. Whilst far from complete or agreed, participants did alight on some text for the different tiers as they stand which was felt to be a useful starting point for substantive further discussion. This text was not unanimously agreed:

*Comprehensive observing networks:* include regional and national networks and, where appropriate, satellite data. The comprehensive networks provide observations at the detailed space and time scales required to fully describe the nature, variability and change of a specific climate variable.

*Global Baseline observing networks:* involve a subset of the comprehensive network at selected locations that is globally representative and provide long-term data records of sufficiently high quality to characterise global to regional variability and change. (metadata, meets the RRR, active management)

*Global Reference observing networks:* provide metrologically traceable observations with quantified uncertainty at a limited number of locations. (SI units, recognized standards, redundancy, metadata, active management)

Areas of significant concern that remained include, but were not limited to:

1. That alighted upon descriptions should be consistent with the Guide to Uncertainty in Measurements (GUM)<sup>4</sup> and use the language correctly regarding traceability, comparability etc.
2. That to be useful in addition to agreeing the terminology at a high level substantial background material would be required which:
  - a. More fully defined what in practical applications each tier means
  - b. Made clear the benefits of the posited system of systems architecture from a global climate observing system perspective, including such aspects as comparability and what research and technical infrastructure would be required to fully realize the benefits.
3. That even across the domains and programmes represented within the breakout group, the existing terms are used distinctly in many cases, which raises issues regarding potential renaming viz:
  - a. National programme funding may well entirely depend upon its continuing designation. For example, if a national programme is called a “reference” network, AOPC would not wish to place this at risk if it does not attain revised requirements because it doesn’t measure all the variables.
  - b. Existing users may well be confused if networks are renamed without adequate user engagement.
4. That the level definitions as currently used in many GCOS documents (reference, baseline, comprehensive) are potentially misleading. While the three levels is a useful context, their names should be revisited and revised in a manner which makes it less ambiguous.

## **6. Related Atmospheric Networks and Data Repositories**

The data and products provided by related atmospheric networks support the objectives of the GCOS programme. The Global Observing Systems Information Centre (GOSIC) portal should direct from the list of ECVs to the correspondent data repositories, e.g., the International Surface Temperature Initiative (ISTI) for surface temperature, the International Surface Pressure Databank (ISPD) for surface pressure, or the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) for marine data. For atmospheric composition observations, the GAW Station Information System (GAWSIS) also contains station characteristics. The measurement requirement for GAW global and regional stations can be found in the GAW Implementation Plan, which is not part of the WMO regulatory material.

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<sup>4</sup>The GUM is available under: <http://www.bipm.org/en/publications/guides/gum.html>

## 7. List of Actions

1. **Promoting and strengthening of the GSN and GUAN.** To make ‘membership’ and data of these dedicated networks more meaningful and distinct from the wider Global Observing System (GOS), the of purpose of the GSN and GUAN should be re-enforced. This would include, among others, coordinated assessment of change management, active performance and quality monitoring, fulfilling of requirements as stated in the Guide to the GSN and GUAN<sup>5</sup> and the OSCAR database. All current GUAN sites should become de facto candidate sites, but need to be ‘certified’ within a transition period of 5 years. The GCOS Secretariat is requested to take the steps necessary to get such changes reflected in the WMO regulatory material, specifically the Manual on the GOS, to be brought to Congress in 2015.
2. **Certification Criteria.** GCOS in cooperation with WIGOS shall develop a set of criteria by which to certify GSN and GUAN stations, based upon meeting stated measurement *shalls* (and striving to meet all *shoulds*), meeting objective quality assessments, and data stream continuity. In addition to station certification, consideration should be given to certification of GUAN operator expertise.
3. **GUAN Monitoring and Archival Facility.** GUAN monitoring shall move from a “passive” monitoring, whereby the primary assessment was whether a sonde was launched, to more “active” monitoring, which considers the data quality. The network shall be actively managed by an identified organization, which shall be assigned as the central GUAN Monitoring and Archival Facility.
4. **Reference Climate Stations.** AOPC should be invited to consider establishing a working group to establish the selection criteria for Reference Climate Stations. A collaborative process, led by GCOS and the WMO Commission for Climatology (CCI) that also included consultation with the Commission of Atmospheric Sciences (CAS) and the Commission for Basic Systems (CBS), be established to set the selection criteria.
5. **Scientific justification for CLIMAT messages.** The next GCOS Implementation Plan should provide the scientific justification for the need of CLIMAT messages and underlying daily information.
6. **Extended reporting statistics for GSN and GUAN monitoring.** The GCOS Implementation Manager will liaise with the National Climatic Data Centre (NCDC), the German Meteorological Service Deutscher Wetterdienst, (DWD) and the Japan Meteorological Agency (JMA) about producing the extra information.
7. **Monitoring and reporting on RBCNs.** CBS Lead Centres for GCOS should extend monitoring and reporting on CLIMAT to RBCNs. Once available, the RBCNs should be encouraged to submit the new daily CLIMAT message, as well.
8. **Portal on data rescue efforts.** GCOS committed to supporting the project financially of setting up an International Data Rescue Portal as a means of coordinating the many data rescue activities underway globally, on the basis that (a) it would be a way of ensuring

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<sup>5</sup> Guide to the GCOS Surface Network (GSN) and GCOS Upper-Air Network (GUAN) (2010 Update of GCOS-73), GCOS-144: [http://www.wmo.int/pages/prog/gcos/Publications/GCOS-144\\_en.pdf](http://www.wmo.int/pages/prog/gcos/Publications/GCOS-144_en.pdf)



that the full historical record of many GSN and RBCN stations be unlocked, (b) as a demonstration of how GCOS would support worthy projects of this sort, and (c) experience suggests that other parties, seeing GCOS' lead, would follow suit. GCOS requested CCI to provide an overview of the project, outlining its benefits clearly, and an indicative costing.

- 9. Network definitions.** The level definitions currently used in many GCOS documents (reference, baseline, comprehensive) are potentially misleading. While the three levels is a useful context, their names should be revisited and revised in a manner which makes it less ambiguous. Further discussions on network definitions be facilitated under an appropriate mechanism to further this issue e.g. in consultation with WIGOS.

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van den Besselaar, E.J.M. Klein Tank, A.M.G, van der Schrier, G. and Jones, P.D. (2012) Synoptic messages to extend climate data records. *Journal of Geophysical Research*, 117, D07101, doi:10.1029/2011JD1688.

Whiteman, D. N., K. C. Vermeesch, L. D. Oman, and E. C. Weatherhead (2011), The relative importance of random error and observation frequency in detecting trends in upper tropospheric water vapor. *J. Geophys. Res.*, 116, D21118, doi:10.1029/2011JD016610.

## Agenda

### Background

Following presentations and discussions at the 18<sup>th</sup> AOPC meeting (Geneva, April 2013) it was agreed to arrange a 2 day workshop to discuss the GSN/GUAN networks (see below) in advance of the 19<sup>th</sup> AOPC meeting.

### Discuss topics

- GSN/GUAN networks - Design and User Requirements. Tiered networks & GRUAN
- Other networks (i.e. GAW) – Priority/benefit to GCOS/ECV's.
- GCOS Network performance – Current status, practices and prioritization within the network
- Historical v Future – Sustainable networks, continuity, data-recovery, archives

### Structure of meeting

#### Day - 1

Welcome, Introduction, Background & Aims (0900)

Presentation (1) - History & requirements of GUAN/GSN (Phil Jones)

Presentation (2) - Performance/monitoring/maintaining of GUAN/GSN (Tim Oakley)

Presentation (3) - GRUAN and the implications of GUAN (Peter Thorne)

Presentation (4) – Do we need a GUAN? (Tom Peterson)

Presentation (5) - Climate archive (Jay Lawrimore)

Presentation (6) – GAW networks, requirements and operations (Oksana Tarasova)

(Presentations should be a maximum of 20 minutes)

Update discussion topics, agree break-out groups

Break-Out groups (Current requirements for the GSN & GUAN, 2 groups)

#### Day - 2

Break-Out groups (issues to be discussed: design, management, silent stations, reference surface network for climate (manual, automatic), etc.)

Feedback

Work plan & follow-up meeting(s)

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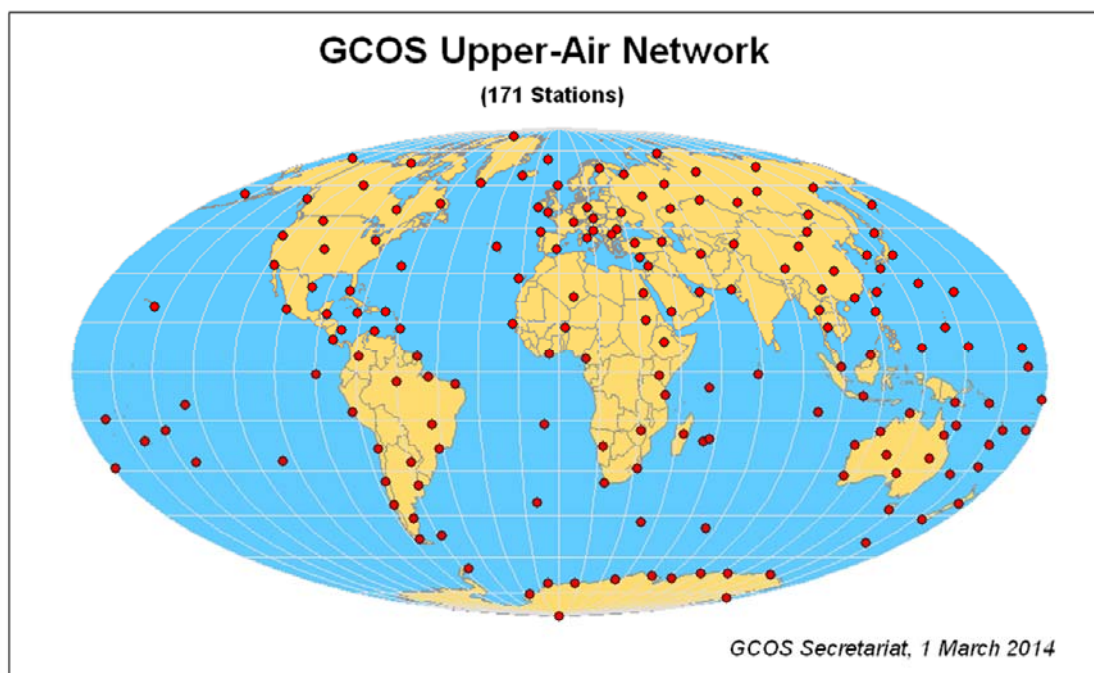


## CBS Lead Centres for GCOS

WMO Regional Association (RA)	WMO Member/ Host Institution of Lead Centre	Lead Centre Contact	Responsible for GSN and GUAN stations in
RA I (Africa)	Morocco (DMN)	<a href="#">Feddoul El Ouazzany</a>	Algeria, Benin, Burkina Faso, Cameroon, Comoros Islands, Cape Verde, Central African Republic, Chad, Congo, Côte d'Ivoire, Egypt, Gabon, Ghana, Gambia, Guinea, Guinea Bissau, Guinea Equatorial, Liberia, Libyan Arab Jamahiriya, Madagascar, Mali, Niger, Nigeria, Mauritania, Morocco, Senegal, Sierra Leone, Sao Tome and Principe, Sudan, Togo, Tunisia
RA I (Africa)	Mozambique (INM)	<a href="#">Jose Sequeira</a> <a href="#">Patricio Domingos</a>	Angola, Botswana, Burundi, Canary Island, Democratic Republic of the Congo, Djibouti, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mauritius, Mozambique, Namibia, the Ocean Islands (St. Helena Island, Ascension Island, Martin de Vivies, Iles Crozet, Iles Kerguelen), Rwanda, Seychelles, Somalia, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
RA II (Asia), RA VI (Europe)	Iran (IRIMO)	<a href="#">Mina Jabbari</a> <a href="#">Maryam Rازه Keisami</a>	Afghanistan, Armenia, Azerbaijan, Bahrain, India, Iran, Jordan, Kazakhstan, Kyrgyzstan, Maldives, Nepal, Oman, Pakistan, Qatar, Russian Federation, Saudi Arabia, Sri Lanka, Syria, Tajikistan, Turkey, United Arab Emirates, Yemen
RA II (Asia)	Japan (JMA)	<a href="#">Ayako Takeuchi</a>	Brunei, Cambodia, China, Japan, Laos, Malaysia, Mongolia, Myanmar, Philippines, Republic of Korea, Singapore, Thailand, Vietnam

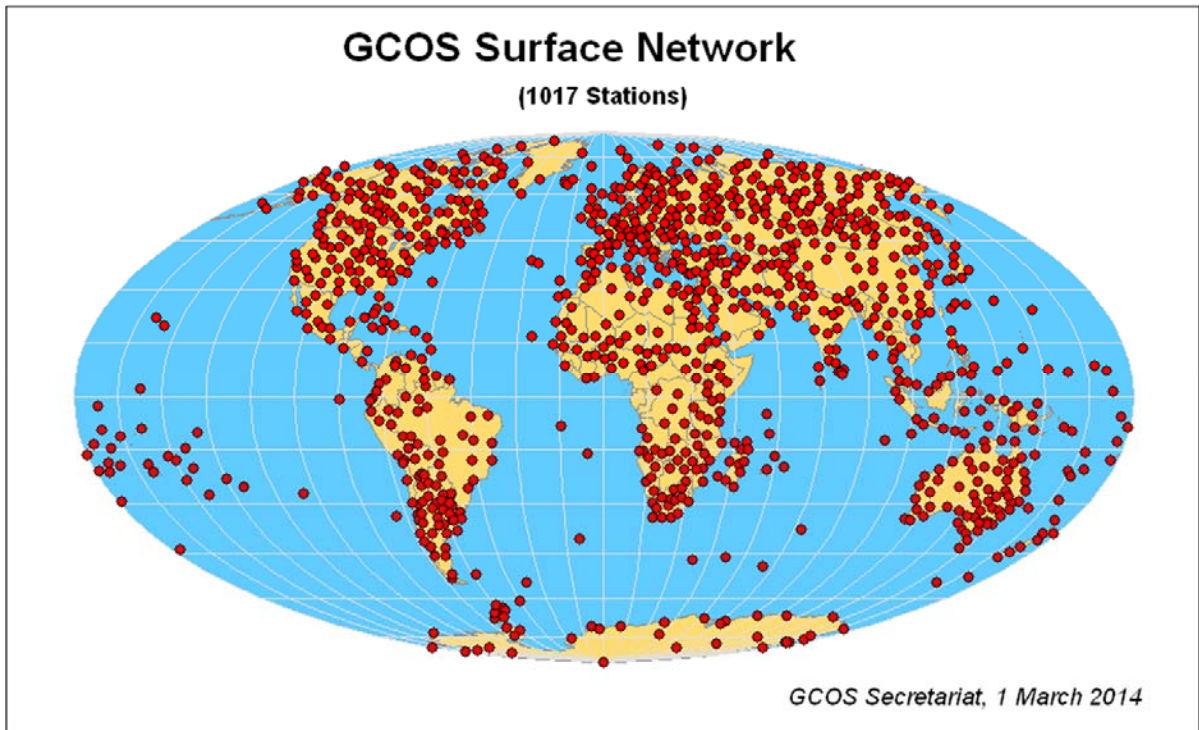
RA III (South America)	Chile (DMC)	<a href="#">Jorge Carrasco</a> <a href="#">Gaston Torres</a>	All of RA III (South America)
RA IV (North and Central America, Caribbean)	USA (NOAA NCDC)	<a href="#">Jay Lawrimore</a>	Most of RA IV (North and Central America, and the Caribbean) and Hawaii
RA V (South-West Pacific)	Australia (BOM)	<a href="#">Kevin Smith</a>	Most of RA V, except those areas noted for Japan and Hawaii
RA VI (Europe)	Germany (DWD)	<a href="#">Christiana Lefebvre</a>	Most of RA VI (Europe), except those countries noted for Iran
Antarctica	UK (BAS)	<a href="#">Steve Colwell</a>	All of Antarctica

## Map of GUAN



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## Map of GSN



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## **GRUAN input to AOPC discussion on the GRUAN-GUAN interface and the future of GUAN**

**WG-GRUAN**  
**27th March 2014**

**Submitted by Peter Thorne on behalf of WG-GRUAN**

### Synopsis

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, and hence how GUAN can benefit from GRUAN practices and expertise.

This document was prepared for the GRUAN 6<sup>th</sup> Implementation and Coordination Meeting (ICM-6) and has been subsequently revised to reflect the discussion of this issue at ICM-6. Participants were informed that all options for the future of GUAN were likely to be discussed in Ispra. ICM-6 participants represent many of both the GUAN data providers and the GUAN data users. Meeting participants at ICM-6 noted that GUAN has helped in several ways to maintain and enhance our understanding of upper-air climate change and variability.

Participants at ICM-6 further noted that the historical impacts of GUAN have varied on a country-by-country basis. Some countries have:

- saved stations because they are designated as belonging to GUAN;
- Used GUAN stations to access external support for operations;
- Used GUAN facilities as test beds for continuity studies;
- Ignored GUAN designations and done as they pleased.

This variable treatment by different countries of their designated GUAN sites starkly reflects both the value that GUAN has brought and potentially can bring and its potential weaknesses as currently constituted.

The consensus position of ICM-6 participants (and hence GRUAN) was that GUAN fulfills a valuable role within the Global Observing System (GOS) in the context of a system of systems approach and that the network should be retained and embedded within the emerging WMO Integrated Global Observing System (WIGOS) infrastructures. However, substantial changes in governance and operations were advocated to ensure GUAN is fit for 21<sup>st</sup> Century requirements and fills its intended niche.

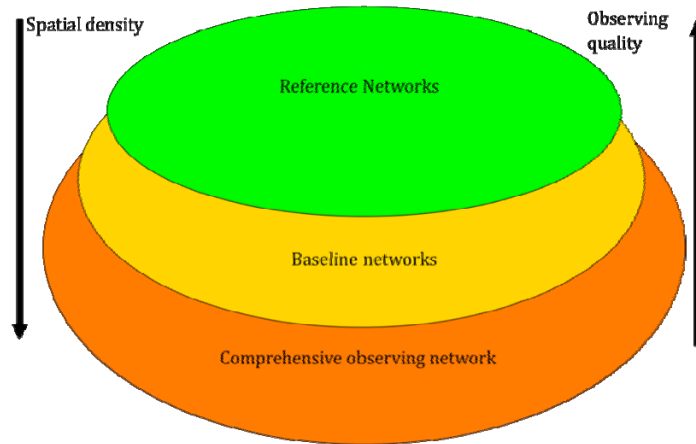


Figure 1. GUAN, GRUAN and the GOS fulfill distinct niches in a system of systems architecture. If realized then GUAN would form an intermediate data quality baseline network function which is distinct from both GOS sondes (comprehensive observing network capability) and GRUAN observations (reference quality network capability) and intermediate between the two. A core facet of the baseline network capability is its ability to robustly characterize global and hemispheric change.

This document is being submitted to the AOPC Network Meeting to provide specific recommendations 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 GUAN and to differentiate it from other upper-air stations of the Global Observing System (GOS).



## Recommendations

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 Appendix I. The suggestions are of varying complexity, cost, and benefit, and first estimates of values for these categories are given. Where possible these have been denoted in the sections ranking each low, medium or high. This ranking should be discussed by the Network Meeting. The recommendations are in no particular order.

### 1) Metadata collection and centralized data processing

Complexity: low/medium (dependent upon ambition)

Cost: low to high

Benefit: medium/high

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 that can be considered to improve this situation. The two extremes are outlined here.

At the simplest end is transmitting full reports in BUFR over the WMO Information System (WIS). To realize the full value, these reports would need to contain metadata (sonde model, batch number, ground check info etc.) that BUFR allows, as well as data and be collected and archived at one or more regional or global GUAN monitoring centres. Such centers could, for example, be regional GISCs (Global Information System Centers) or GFCS (Global Framework for Climate Services) centres. This would provide a step forward compared to current state of the art data collection and retention and substantively enhance the value of GUAN data to multiple users. It was noted by the representative of the Association of Hydro-Meteorological Equipment Industry (HMEI) that converting to send in BUFR for many modern sonde systems is a one-time single switch operation. Where possible both the raw data and the manufacturer processed data, should be transmitted. This would enable future reprocessing.

A more ambitious target would be to use a tool that collects raw data and metadata and submits them to a centralized data processing / archival facility before they are disseminated. This would significantly improve the scientific value of the GUAN data. Centralized data processing such as developed in GRUAN - while not transforming GUAN data into a full GRUAN product - would have the advantage of providing a comprehensive GUAN archive of data and metadata allowing users to more fully understand the GUAN data and provide more rigorous analyses to the data. This would also provide a clear point of difference between GUAN radiosonde data and radiosonde data from other sites in the GOS. It should be stressed that this would not be a facility that under current or envisaged resources can be extended from GRUAN to GUAN.

The use of a raw and metadata 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 WIS where restrictions and coding errors can cause those data not being 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).

Centralized processing of the raw and metadata 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 climate studies from that of the remainder of the global radiosonde network by allowing the potential for periodic reprocessing. This would require significant resourcing and network operator buy-in.

## 2) Establishing a scientific basis for the design of GUAN

Complexity: low

Cost: low

Benefit: low/medium

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 are:

- 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 attribution.
- ii) *The satellite community*: GRUAN and GUAN data products are regularly 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 regularly monitored as part of NOAA retrieval validations within its Products Validation System (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 makes profile measurements at vertical resolutions much higher than can be retrieved from satellites, it provides 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. An assessment of the value that GUAN has brought to these four user

communities since its inception would be valuable in this regard. 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 their 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 useful 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 decisions could be based, in part, on the recommendations of this report and the methodologies explained therein at least as a starting point for further consideration of the issue of network design.

### 3) Measurement resolution

Complexity: low

Cost: low/medium

Benefit: high

GUAN should aim to collect and process 6-second resolution (or better 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 - a new SPARC (Stratosphere-troposphere Processes And their Role in Climate) activity is currently being proposed to capitalize in the scientific value of HVRRD. Studies have been made of the fine-scale structure of the tropical and extra-tropical tropopause on climatological and regional bases with subsequent analysis of the abilities of General Circulation Models (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 this network from the remainder of the GOS by demonstrating greater 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, as proposed above, may ameliorate technical issues associated with data transmission although BUFR should be able to transmit this data also.

#### 4) Implementation of inexpensive ground-checks

Complexity: low/medium

Cost: low/medium

Benefit: high

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). GRUAN 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.

#### 5) Transitioning from passive performance monitoring to active performance monitoring

Complexity: medium

Cost: low/medium

Benefit: medium

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 the Guide to GSN and GUAN [GCOS-144] that analysis of GUAN data will be performed by the NOAA National Climatic Data Centre (NCDC) in their capacity as the GUAN Analysis Centre. In practice NCDC provides an annual report of data receipt frequencies. The World Data Centre (WDC)-Asheville acts as the archive for all GUAN data and makes them available through the Integrated Global Radiosonde Archive (IGRA)<sup>6</sup>. While there is some activity at the national level in monitoring the quality of the submitted data, this information is not shared. Therefore, at the global network level, 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 go deeper than simply logging data presence / absence.

1. ECMWF and other data assimilation centres could provide observation minus background time series for GUAN sites.

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<sup>6</sup> <http://www.ncdc.noaa.gov/oa/climate/igra/>

2. NOAA through its NPROVS facility could provide similar statistics for departures between GUAN profiles and L2 retrievals from polar orbiter overpass measurements within temporal and spatial coincidence criteria.

Monthly summaries of statistics would:

- Allow the GCOS Implementation Manager to alert stations which are launching but providing poor quality data to address data-quality issues.
- Be able to be sent to the site operators as a means of providing quality assurance feedback and providing extra value and incentive to operators undertaking GUAN operations (the stations both give and get rather than just give).
- Provide a cleaner toolset to identify resourcing and data quality based decision priorities at annual meetings of the Advisory Group on GSN and GUAN (AGG).

#### 6) Making GUAN membership mean something through an improved assessment and certification scheme

Complexity: low/medium

Cost: low

Benefit: medium

Within GRUAN a site certification procedure<sup>7</sup> 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 similarly intensive certification process is unlikely to be tractable under current resourcing of GCOS for the much larger GUAN, 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 tractable and would certainly be useful. For example, there is currently no mechanism to convince National Meteorological and Hydrological Services (NMHSs) to change to better sondes, even if the equipment in use is known to be of inferior quality and NMHSs 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. If there are no consequences for poor performance of a site within a network, this generally degrades the operational integrity and scientific utility of the network as a whole. Therefore, 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.

A more formal process for GUAN site certification would also support the creation of a GUAN 'community'. GUAN does not have an established community or steering mechanism - regular meetings of representatives from GUAN sites, or representatives from GUAN sites in regions, are not held. Rather, GUAN is overseen by a small group(s) via AOPC and the WMO Commission for Basic Systems (CBS). The creation of a community of GUAN site representatives, or regional GUAN site representatives, would foster greater sharing of skills, expertise and operating experience across the network.

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<sup>7</sup> 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].

## 7) Measurement redundancy and intercomparisons

Complexity: low to high

Cost: high

Benefit: high

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 GUAN 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 activities of this nature at GUAN sites may help distinguish their value from the remainder of GOS sondes.

Several approaches exist here:

- Where possible measure, on a routine basis, parameters redundantly. For example, 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 design.
- 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.
- Periodic multi-instrument payload launches at a subset of GUAN/GRUAN sites and in conjunction with the Commission for Instruments and Methods of Observations (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.

## 8) Training and capacity building

Complexity: low/medium

Cost: low/medium

Benefit: high

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 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, CBS and the NMHSs.

## 9) Adding value through pairing of GRUAN and GUAN sites

Complexity: medium

Cost: low/medium

Benefit: high

Improving collaboration between geographically close (or even not so geographically close as attested to by Payernne and Nairobi) GRUAN and GUAN sites is likely to lead to a flow of value from GRUAN to GUAN in the form of improved operating standards, access to expertise in reference quality measurements, instrument calibration, and the use of measurements standards for establishing traceability of measurement uncertainties.

If at all possible, where a GRUAN and GUAN site are operating in close proximity, but where the GRUAN site is not also a GUAN site and not currently launching at least twice daily balloons, consideration should be given to relocating the GUAN operations to the GRUAN site.

### References

GCOS-144, Guide to the GCOS Surface Network (GSN) and GCOS Upper-Air Network (GUAN) (2010 Update of GCOS-73)

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.

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