GCOS Upper Air Network (GUAN) Radiosonde Observations
Past, Present and Future

Introduction

It is well understood that meteorological observations are vital for both immediate needs such as weather forecasting and early warning systems, and longer-term needs such as supporting and planning adaptation to climate change and ensuring sustainable development. These twin needs were recognised by the United Nations Framework Convention on Climate Change (UNFCCC). The Paris Agreement calls for strengthening scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making. In 2016, the UNFCCC emphasized “the need to maintain, strengthen and build capacities for climate observations…” while the need for support in the least developed countries (LDCs) and small island developing States (SIDs) was also highlighted.

A recent joint Global Climate Observing System (GCOS) and WMO Integrated Global Observing System (WIGOS) regional workshop in the South Pacific agreed that the most important observation gap across the region is in upper air observations. Upper air (radiosonde) observations are very important for global numerical weather predictions, both regionally and globally, and therefore seasonal forecasts and climate models. The impact of these observations can reach planetary scale. For example, ECMWF has thus stated that better upper air observations in the south Pacific are of significant benefit for extended range forecasts over Europe. Isolated radiosonde observations in the Pacific are routinely shown to have the one of the highest impact of all observations on the skill of global NWP models.

Upper-air observations from radiosonde have been available for more than 70 years, with the more modern ‘automated’ systems that we are familiar with today being introduced in the early 1980’s. Despite the significant increase in the availability of observations from other in-situ systems (i.e. aircraft and remote sensing) and the satellite observations, the radiosonde measurements continue to be one of the underpinning observations for most applications. However, with the now normal pressures to reduce the costs of observations, the operation and maintenance of the radiosonde stations/networks to meet the agreed national, regional and international requirements are an ongoing challenge.

The comprehensive radiosonde network (Taken from the 2015 GCOS Status Report[1])

The World Meteorological Office (WMO), World Weather Watch (WWW)/Global Observing System (GOS), through the National Meteorological and Hydrological Services (NMHS), provides the comprehensive global radiosonde network. Figure 1 shows the geographical distribution of stations providing data and categorizes the annual number of soundings received, based on data holdings accumulated operationally by ECMWF for the 1 years 2002 and 2013. Small differences in data receipt and archiving may occur between operational centres due to the vagaries of the working of the Global Telecommunication System and data decoding issues but these are insignificant from the viewpoint of an overall assessment. Figure 1 shows notable increases from 2002 to 2013 in the frequency of data provided over Russia, South America and the islands of Southeast Asia and the tropical West Pacific. Coverage has remained poor over much of Africa despite some local improvements in reporting frequency. Of the countries and regions with a decline in reporting, that over Europe is from a particularly high level in 2002. Overall, there is a net increase of 10% in the number of radiosondes reporting a 500hPa temperature from 2002 to 2013. Corresponding increases are 12% for dew point and 13% for wind. This is accounted for mostly by the overall increase in reporting frequency, although coverage has improved slightly, at least in terms of the evenness of the distribution of observations. In 2018 there were approximately 800 radiosonde stations routinely reporting over the Global Telecommunication System (GTS)

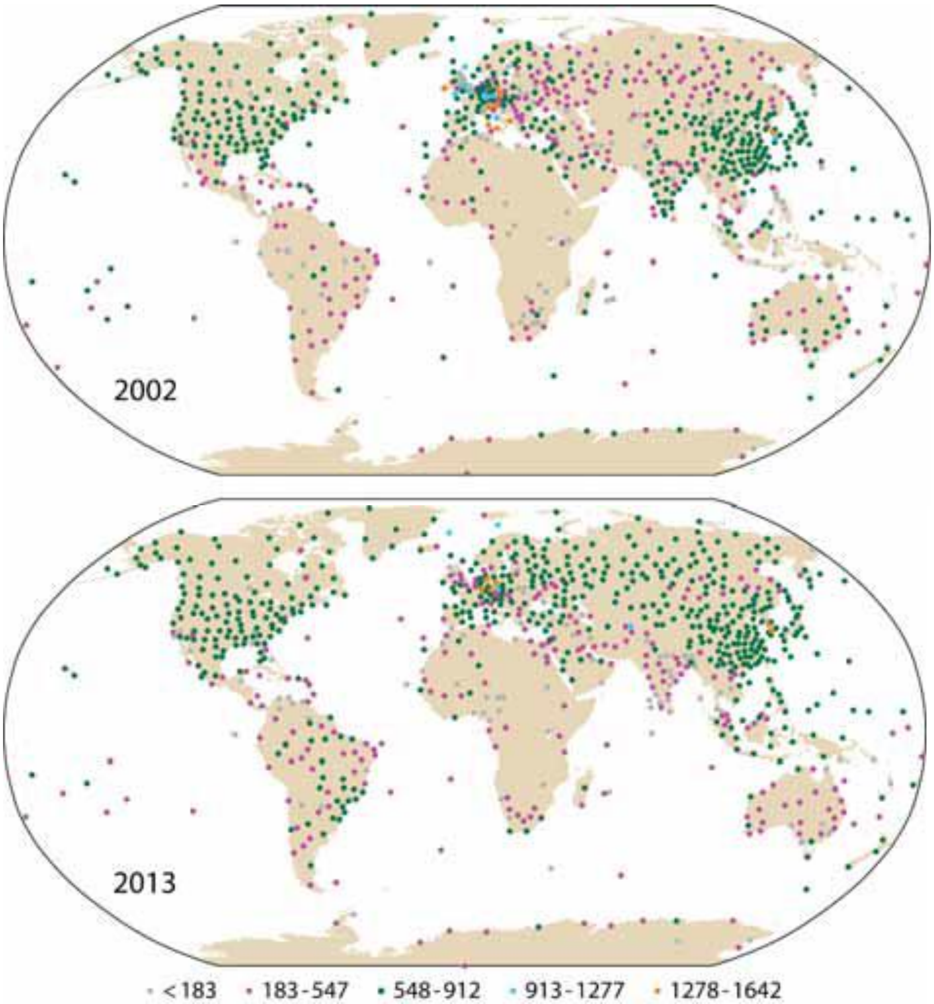

Figure 1: Annual counts of radiosonde reports from fixed land stations received operationally by ECMWF for 2002 and 2013. Plots are based on temperature data received for the 500hPa level;counts for humidity and winds at this level differ by less than 5% in 2002 and 2% in 2013.

GCOS Upper Air Network (GUAN) (Taken from the GCOS 144[2])

Climate and climate change research and applications require historical observational data from sources well distributed across the globe. In particular, it is of major importance that data from different locations and times are comparable or can be made comparable. In practice, meteorological measurements are made at thousands of places all over the world, more or less regularly. The most essential subset of these observing stations is operating under the regime coordinated by the World Meteorological Organization (WMO), involving clear commitments regarding the site, the exposure of instruments, error handling, units of measurement, coding and exchange of reports. In practice, this WMO Global Observing System (GOS) is implemented by National Meteorological and Hydrological Services (NMHSs) of WMO Members. The original prime purpose of the system was the provision of data in support of weather observation and forecasting, but it of course serves many other potential users particularly in this case climate and climate change research.

Many requirements for climate applications and research are satisfied very well by the GOS. The needs of the climatological and the synoptic communities have much in parallel. In most situations where climate research notes shortcomings in the available data sets, synoptic meteorology suffers from the same problem. To date, no new system has proved to be competitive with the radiosonde system with regards to accuracy, vertical resolution/range and consistency. They also provide main meteorological variables (temperature, wind and humidity) all together. Radiosondes have been operated since about 1940, and the results should remain valuable for climate research in future. This implies that a minimum configuration of stations should be preserved well into the 21st century, at least until about 20 years after other new systems may have taken over the basic tasks. Even in that case, this minimum configuration may be useful for a longer time for calibration and validation procedures.

In order to serve specifically the needs of global climate applications, two networks of observing stations were established in 1995 as Global Climate Observing System (GCOS) Baseline Networks, mainly on the basis of existing GOS networks. These are:

- the GCOS Surface Network (GSN) (1023 stations as of 01/01/2018)
- the GCOS Upper-Air Network (GUAN) (177 stations as of 01/01/2018, see figure 2)

These networks form a minimum configuration required for global applications. Regional climatic needs can be much more extensive, and it is anticipated that such needs will be served by more dense networks on a regional basis, possibly with more extensive requirements for observing programmes and specifications.

The scope of the GUAN is for a spacing set at 5 to 10 degrees latitude, sufficient to resolve synoptic-scale waves. The desired parameters are temperature, pressure (geopotential height), wind, and humidity (at least in the troposphere). The inclusion criteria are:

- Commitment by NMHSs with regard to continuity;
- Length and quality of historical time series;
- Current measurement quality.

The purposes of the GUAN are the following:

- 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 restrictions.

GCOS has assigned a dedicated network manager to monitor the performance of the GUAN. Regional lead centres assigned through the WMO Commission on Basic Systems (CBS) support this work, along with several global monitoring centres who provide specialised statistics. The European Centre for Medium Range Forecasting (ECMWF) provide monthly plots of data availability, an example of which is shown in figure 3. Here it can been seen that whilst the majority of the GUAN is meeting the minimum requirements (green squares) there are significant regions where this is not the case (i.e. Africa and the South Pacific), with the red squares showing stations which were inactive during the month.

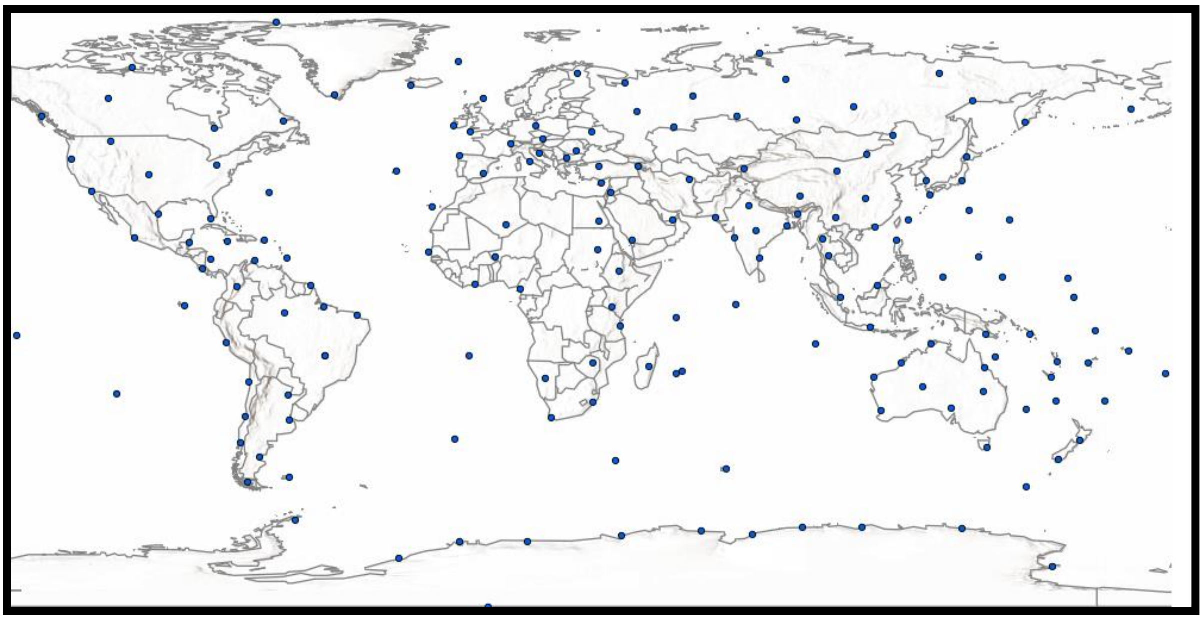

Figure 2 2018 - GCOS Upper-Air Network (GUAN) – 177 stations

Monitoring of the GUAN

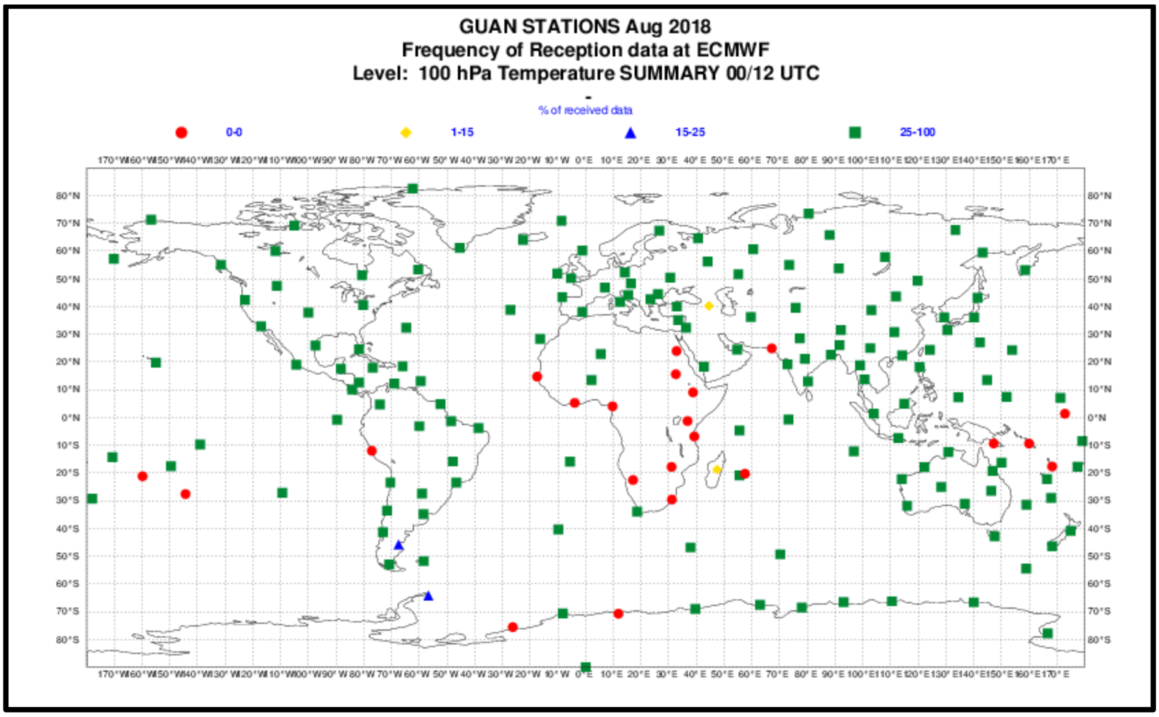

Figure 3 – ECMWF GUAN Monitoring August 2018

The following table is the 2017 summary for the GUAN monitoring against the GCOS minimum requirements (25 daily soundings to 30hPa per month) for each region, according to the monthly statistics provided by the National Centre for Environmental Prediction (NCEP). In brackets are the same statistics for 2016, 2015, 2014, 2013, 2012 and 2011.

Region	Number of GUAN stations	% meeting minimum GCOS requirements in 2017 (% for 2016, 2015, 2014, 2013, 2012 and 2011)
RA-I	**23**	***30%*** *(39%, 35%, 39%, 46%, 48%, 57%)*
RA-II	**38**	***89%*** *(87%, 87%, 87%, 87%, 87%, 87%)*
RA-III	**18**	***61%*** *(61%, 67%, 72%, 67%, 89%, 78%)*
RA-IV	**24**	***92%*** *(87%, 79%, 83%, 75%, 83%, 87%)*
RA-V	**38**	***79%*** *(84%, 79%, 76%, 74%, 84%, 87%)*
RA-VI	**24**	***87%*** *(87%, 87%, 87%, 83%, 92%, 87%)*
Antarctica	**12**	***67%*** *(58%, 67%, 58%, 58%, 83%, 83%)*

Eleven (11) of the GUAN stations (6%) were 'Silent' (zero reported TEMP observations) during 2017, which is the highest since this monitoring was started in 2011. In 2016 and 2015 it was seven (7), 2014 and 2013 it was three, four (4) in 2012 and five (5) in 2011.

Future Plans

In 2017, the GCOS Atmospheric Observations Panel on Climate (AOPC) agreed on the creation of a dedicated task-team to deliver progress upon a number of actions in the GCOS Implementation Plan related to the operation and monitoring of the GCOS Upper Air Network as follows:

- Reviewing the network requirements;
- Assessing and documenting the benefits of meeting stated requirements;
- How it contributes as a baseline network in the tiered network framework.

This task-team had its first meeting in Lindenberg, Germany in December 2017. Here expert participants were asked to present their, and that of their institution, feedback on the GUAN through a SWOT analysis (Strengths/Weaknesses/Opportunity/Threats), a summary of which is provided in figure 4 below.

Strengths	Weaknesses
GUAN is a well known brand. It is regarded as high-quality Radiosonde observations. (even if this is only a perception) Common practices and an underpinning standard. Has documented governance through WMO technical regulations and GCOS documents.	The aims, requirements and user needs of GUAN are not known and/or have just been forgotten. No NMHS 'buy-in'. Passive not Active management (i.e. poor performance is not addressed) Little difference between GUAN and the Comprehensive network No auditing of GUAN and little outreach between GUAN operators Requirements and guidance has not been updated to reflect the change in technology and user needs
Opportunities	**Threats**
GUAN best practices and outreach can support the comprehensive network Utilised improved tools for Quality Management & Visualisation Healthy competition in industry for the prestige of suppling GUAN stations Better alignment of GRAUN and GUAN, for example GRUAN products from GUAN stations.	Budget cuts and resource priorities are often targeted at radiosonde system consumables The pollution aspect of radiosondes Lack of clarity on the difference between GRUAN and GUAN might cause competition for resources

Figure 4 – SWOT analysis of GUAN (1st task-team meeting in Lindenberg, Dec 2018)

The key findings from the meeting were as follows:

- Continuing under its current requirements is not an option for a baseline network
- New focus on a guaranteed quality of observational data, according to updated requirements
- A subset of the comprehensive network based on quality assurance rather than a fixed network of stations. Adopting a tiered-network approach (Comprehensive-GUAN-GRUAN), as described by GAIA-CLIM
- Actively managed through a lead-centre, with a certification process, real-time monitoring and validated station list for the user community
- Process to identify gaps in global/regional networks, both in data sparse areas and least develop countries, to allow targeted support projects, using relevant cooperation and funding mechanisms (i.e. GCM, GCF, national bi-lateral programmes).

An example of improved quality of GUAN observations was the mandatory requirement that all GUAN stations reported high-resolution BUFR messages. (see figure 5 below)

The task team has agreed a work plan to develop the proposal for an updated GUAN, with revised requirements, a focus on guaranteed quality as a baseline network and improved active management.

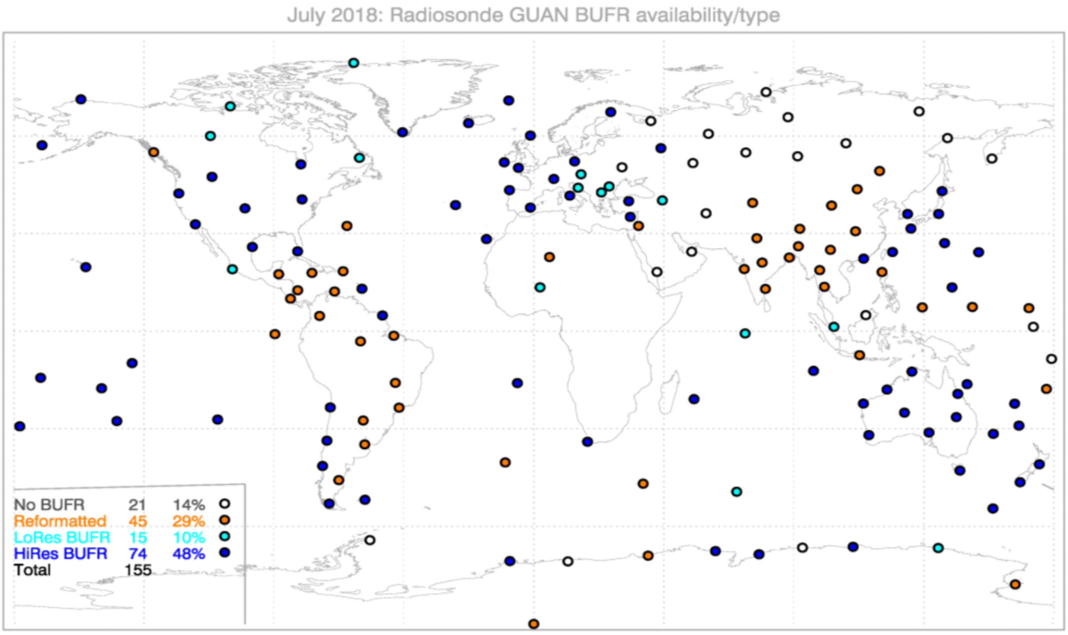

Figure 5 – Example of improved GUAN monitoring (ECMWF July 2018)
"Blue dots show native BUFR reports (dark blue high resolution), open circles indicate no BUFR reports, orange circles indicate BUFR reports reformatted from alphanumeric TEMP reports - most of which do not meet the BUFR coding regulations." [3]

References

1 - Status of the Global Observing System for Climate WMO Pub No. GCOS - 195

2 - GCOS, 144. Guide to the GCOS Surface Network (GSN) and GCOS Upper-Air Network (GUAN) World Meteorological Organization (WMO)

3 – High Resolution BUFR data. Ingleby et al (2016, BAMS)