GUIDE TO THE GCOS SURFACE NETWORK (GSN) AND GCOS UPPER-AIR NETWORK (GUAN)

(2024 Update of GCOS-144)

November 2010

GCOS - 144

(WMO/TD No. 1558)

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Note:

The GSN and GUAN networks are based mainly on stations which are included in the networks of the WMO World Weather Watch Global Observing System (GOS). For more general standards for observations at these stations, reference is made to the Manual on the Global Observing System (WMO-No. 544) and the Guide on the Global Observing System (WMO-No. 488), published by the WMO.

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Guide to the GCOS Surface Network (GSN) and GCOS Upper-Air Network (GUAN)

Preamble

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[1]. 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. However, there are three main exceptions: homogeneity of the data time-series relating to observing practices; representativeness of the environment; and homogeneity of the environment.

Homogeneity of data:

For climate research and analysis, it is very important that data be inter-comparable over the entire record. This holds in particular for data from the same location for different times. Problems for climate can be encountered over a long-period record through changes in observing practices, including instrumentation. For real-time use, such changes do not negatively affect the applications; in general they will improve operations. For climate research, however, and many applications, such changes can raise major problems. If no specific measures are taken, the value of a historical time series of observations can be severely reduced.

Representativeness of the environment:

Observing sites have been traditionally located at airports, in harbours, and in or near cities. The oldest observing sites can often be found along the seaside (and near the NMHS headquarters, in many cases in the capital city). This is not surprising, as maritime purposes were the first incentive for applications of meteorology. However, these sites do not necessarily provide the best representation for the climate in the area of concern. Current weather information and weather forecasts focus on locations where people are living and working; climate research has different criteria.

Homogeneity of the environment:

A vital requirement for time-series data is homogeneity, not only of observing practices and instrumentation (see above), but also of the environment in which the measurements are taken. Since observing sites are often established where people are living, the environment

[1] WMO manuals and guides listed under 'Selected Bibliography' give detailed guidance to Members in this regard and should be used in conjunction with this Guide.

Commented [TO2]: Not historical but closer to real-time.

Commented [TO3]: Update? Reference to WIGOS and GBON

Commented [TO4]: Much more so these days, especially with the reanalysis advances.

Commented [TO5]: Are these all not applicable to the other communities? I would have thought representativeness of the environment was applicable to all user communities

has a tendency to change continuously. Stations that have been established with climate in mind are sparse. While there are indeed stations on mountain tops and slopes, on sparsely inhabited islands, in deserts, in icy regions, in national parks, and simply in rural areas, these stations are often not operating under NMHS responsibility and with WMO commitments. In many cases there is no organization which can guarantee the continuity of such a station even into the near future.

Considerations regarding the environment and changes are less crucial for upper-air observations than for surface measurements. Except for some influence in the boundary layer, radiosonde observations are generally not affected by an environmental change or even by moving a station over a distance of less than, say, 20 kilometres. On the other hand, a change or variability of observing instruments and launch schedules has a much larger impact. Methods of observing the meteorological conditions in the troposphere and lower stratosphere are developing rapidly, particularly in the case of remote-sensing systems (satellites, profilers). For highest-quality upper-air observations, implementation of the GCOS Reference Upper-Air Network (GRUAN)[2] has started in 2008 – building on and complementing GUAN. In any case, it is extremely important to prepare for a smooth transition that allows for comparison of the results of old and new data acquisition systems.

To date, no new system has proved to be competitive with the radiosonde system with regard to *in situ* accuracy and consistency. The latter has been operated since about 1950, 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 have been established as Global Climate Observing System (GCOS) Baseline Networks, mainly on the basis of existing GOS networks. These are:

- the GCOS Surface Network (GSN) (1022~~1028~~ stations as of June 2023~~01/01/2010~~)
- the GCOS Upper-Air Network (GUAN) (178169 stations as of June 2023~~01/01/2010~~)

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 organization of the GSN and GUAN and the implications for stations that are included are described in the following sections.

[2] http://www.gruan.org

1. SCOPE AND PURPOSE OF THE NETWORKS

1.1 GSN

The GSN is intended to comprise the best possible set of land stations with a spacing of 2.5 to 5 degrees of latitude, thereby allowing coarse-mesh horizontal analyses for some basic parameters (primarily Temperature and Precipitation). The criteria for selection include:

- Commitments by NMHSs with regard to continuity;
- Geographical representativeness of observations;
- Length and quality of historical time series;
- Available parameters;

It is recognized that the coarse network density limits the applicability for some applications. For parameters having smaller-scale horizontal variability (e.g., precipitation), it is accepted that the network data generally should be supplemented by those from networks with a finer mesh.

The purposes of the GSN are the following:

- To establish national commitments for the preservation of a set of valuable climate 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;
- To create a baseline and benchmark data set for more enhanced regional and subregional climate networks and for newly-developed observing systems, including remote-sensing systems.

Please see Annex B for submitting GSN data and metadata to the GSN Archive Centre.

1.2 GUAN

The scope of the GUAN is somewhat different from the GSN in that the relation to the surface environment is not of major importance. For this reason, and also for practical reasons, the spacing is 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 formal restrictions.

Please see Annex D on submitting GUAN data and metadata to the GUAN Archive Centre.

2. COMMITMENTS BY STATION OPERATORS

Inclusion of a station in the networks requires that certain commitments be made by the WMO Member concerned (normally represented by the responsible NMHS). These commitments are:

(i) The NMHS shall make its best efforts to continue the operation of the station at the required performance level for the foreseeable future.
(ii) The NMHS shall operate the station in accordance with the observation requirements as described in Section 3.
(iii) The NMHS shall provide for the dissemination of the required reports (BUFR?? CLIMAT, SYNOP and TEMP, as appropriate) in accordance with WMO WWW Regulations.
(iv) The NMHS shall provide for the transfer of historical data to the World Data Centre for Meteorology - Asheville (National Climatic Data Center, Asheville, USA) in the required formats (see Annex B and D).
(v) The NMHS shall provide for the transfer of metadata (station location and altitude, description of environment, exposure, observation practices and instrumentation, past changes) to the World Data Centre - Asheville in the required formats (see Annex B and D).
(vi) The NMHS shall ensure that the information on the station as recorded in ~~WMO Publication No. 9, Volume A~~ WMO OSCAR/Surface (https://oscar.wmo.int/surface/#/), is correct.
(vii) The NMHS shall endorse the classification of all data provided under this commitment as "Essential" in the context of Resolution 40 of the twelfth World Meteorological Congress (Geneva, 1995).
(viii) The NMHS shall nominate a focal point within the Service for direct contact at the working level with the GCOS Secretariat, the ~~CBS~~ Lead Centres for GCOS, the Monitoring and Analysis Centres, and the GCOS/AOPC. ~~Advisory Group on the GSN and GUAN (AGG).~~

Notes:

Normally the GSN will be made up of stations drawn from the WMO Global Observing System (GOS) Regional Basic Climatological Networks (RBCN) which are designated though the WMO Regional Associations.

A summary of 'Best Practices' involved in discharging these commitments is included in the WMO Manual on the WIGOS~~Global Observing System~~ and reproduced in Annex A of this guide. Also included there are the GCOS Climate Monitoring Principles, which have been adopted by the Conference of the Parties (COP) to the UN Framework Convention on Climate Change (UNFCCC) and to which all GCOS systems are expected to adhere.

Commented [TO6]: This should be replaced with WMO OSCAR/Surface metadata base.

Commented [TO7]: Needs to reference Resolution 1

Commented [TO8]: RBC has been deprecated so needs to reference RBON

3. OBSERVATION REQUIREMENTS FOR STATIONS

The criteria for inclusion of stations in the networks are defined at two levels:

- Target Requirements (TRQs) are those that are ideally to be satisfied. Stations meeting all the TRQs shall have priority over stations that are deficient in that respect in some way.
- Minimum Requirements (MRQs) are the bare minimum that must be satisfied for inclusion.

The "required performance level" in commitment 2 (i) refers to the Target Requirements.

3.1 Statement of commitment

A written statement of commitment by the responsible NMHS to operate the station on a long-term basis, and to provide data and metadata as documented below, is a Target Requirement.

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3.2 Observed parameters

(i) For the GSN, the requirements are as follows:

MRQs:

- Monthly means of daily maximum, minimum and mean temperature.
- Monthly precipitation amounts.
- DAYCLI??

TRQs (in addition to the MRQs):

- Pressure: monthly mean values, station level and mean sea level.
- Daily precipitation amounts
- Precipitation: number of days with precipitation if daily precipitation amounts are not provided.
- Temperature: daily mean, minimum and maximum.
- Pressure: daily mean, station level and mean sea level.
- Subdaily data: historical and real-time synoptic or hourly reports, with all the data normally reported in synoptic transmissions, for the full period of record for the station.

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If only monthly values are available, the number of days used in the calculation should be provided as a Minimum Requirement.

Note:
Generating a monthly CLIMAT report is a Minimum Requirement for stations. CLIMAT reports are defined in WMO-No 306 (The Manual on Codes) as FM-71-XII CLIMAT. All sections of CLIMAT reports should be prepared and distributed, e.g. via the GTS. Further guidance on the preparation of the CLIMAT report can be found in the publication WMO/TD-No. 1188 and in GCOS-127[3]. For best quality, the CLIMAT reports should be prepared by the station operations staff. (Adherence to the rules for dissemination of monthly CLIMAT

[3] GCOS (2009):*Practical Help for Compiling CLIMAT Reports*. GCOS-127 (WMO/TD-No. 1477), http://www.wmo.int/pages/prog/gcos/Publications/GCOS-127_EN.pdf

reports and individual-ascent TEMP reports includes the assignment of a WMO block and index number to the station.)

For those GSN stations producing SYNOP reports, providing the maximum and minimum temperature and total rainfall sections of the SYNOP reports is a Target Requirement. SYNOP reports are defined in WMO-No 306 (The Manual on Codes) as FM-12-XII Ext. SYNOP.

(ii) For the GUAN, the requirements should be interpreted such that every month at least one observation on each of at least 25 days should attain the MRQs. The observing frequency (1 or 2 per day) in itself is not a criterion, although the Target Requirement for observation frequency is 2 per day, in accordance with WWW regulations for radiosonde observations. Where possible, priority should be accorded to night-time ascents because these are less susceptible to radiative biases.

MRQs:

- Temperature up to 30hPa.
- Humidity up to the tropopause.
- Wind direction and speed up to 30 hPa.

TRQs (in addition to the MRQs):

- Temperature and wind up as high as possible.

Note:
Generating TEMP reports is a Minimum Requirement for stations. TEMP reports are defined in WMO-No 306 (The Manual on Codes[4], Part A, FM 35-XI Ext. TEMP) and all relevant sections should be prepared and distributed, e.g. via the GTS. Only radiosondes that have participated in WMO sponsored intercomparisons should be used.

With migration to BUFR format, transmission of the equivalent information as included at present in CLIMAT, TEMP and SYNOP reports will be required. BUFR reports are defined in WMO-No. 306 (The Manual on Codes[2], Part B, FM 94-XIII Ext. BUFR).

3.3 Accuracy of observations

(i) For the GSN and GUAN, the accuracy criteria are identical to the WWW requirements for synoptic observations as found in the Guide to Meteorological Instruments and Methods of Observations WMO-No 8 ('CIMO Guide')[5].

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3.4 Recommended procedure in case of transmission failures

Regular submission of all reports (CLIMAT, SYNOP, TEMP, as appropriate) is a Minimum Requirement. Global distribution of submitted reports can e.g. be achieved through the GTS. In case of GTS failures, other means (mail, facsimile, electronic mail, etc.) should be used.

[4] http://www.wmo.int/pages/prog/www/WMOCodes.html
[5] http://www.wmo.int/pages/prog/www/IMOP/publications/CIMO-Guide/CIMO_Guide-7th_Edition-2008.html

3.5 Historical record

For the GSN, the Minimum Requirements relate to Temperature and Precipitation, for which historical daily series should have a length of at least 20 years. The Target Requirements for all parameters are set at 50 years. The time series should be homogeneous, or should allow for homogenisation through the provision of appropriate metadata.

The GUAN criteria are defined through numbers of individual observations. The Minimum Requirement is 5,000 upper-air observations, equivalent to about 15 years of 1 observation per day (or 7.5 years at 2 per day). The Target Requirement is 15,000 observations.

3.6 Submission of historical data

This refers mainly to the GSN historical data, since most historical GUAN data are already available in the World Data Centres (WDCs). However, as many of the historical GUAN data were received through sometimes unreliable telecommunication, a TRQ is to replace them by nationally-digitized and quality-controlled data.

The provision of the complete record of historical daily data for parameters identified under 3.2 "MRQs" is a Minimum Requirement. Provision of other daily data is a Target Requirement. Submission should be made following the format requested by the World Data Centre for Meteorology-Asheville (see Annex B) if possible, but other formats will be accepted if necessary.

In addition to historical data sets containing the original observations at a GSN station, some Members may have produced a homogenized or adjusted data set. In such cases, Members are requested to provide both the original and modified data set along with appropriate documentation. Knowledge about processing that has already been done on a data set is important to understanding the data.

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3.7 Spacing criteria

The following criteria have been agreed when the initial GSN was designed in 1997:

- The network stations should be well distributed over the globe.
- Additional value was placed on neighbouring GSN stations with large differences in elevation.
- Spacing considerations should take account of the fact that interannual and longer-term climate variations show strong spatial patterns in middle latitudes.

For the GSN, the horizontal distance between two network stations should not be less than the length of 2.5 degrees of longitude at that location (278 km at the equator). For stations beyond 60 degrees latitude (north or south) the minimum distance is fixed at the length of 2.5 degrees of longitude at 60 degrees latitude (139 km). Consequently, the minimum spacing varies from 278 km at the equator to 139 km in the polar regions.

An exception is made in cases where the difference in elevation of two stations is at least 1000 metres, in which case the criteria for minimum horizontal distance are not applicable. A further exception is made to allow inclusion of an individual GSN station from a geographically small nation.

Note that in the original selection of GSN stations (Peterson et al. 1997), a more sophisticated approach was used. In a small number of cases, selected stations do not meet

the above criteria. In these cases, the new spacing rules are not applied rigorously. Since 1997, the composition of the GSN has altered considerably mainly in response to the needs and commitments of operators and from requests to operators by the Advisory Group on the GSN and GUAN (AGG) of the Atmospheric Observation Panel for Climate (AOPC) of GCOS.

3.8 Location criteria

A Target Requirement is that the location of GSN stations should not be subject to major changes in the environment, nor to human activities influencing the local climate. In practice this implies a strong preference for stations in rural areas.

The focus of the GSN is on stations with long periods of record. However, the long-term data criteria are relaxed in the case of new stations installed in previously unobserved locations such as in extreme northern Canada.

4. MONITORING, ANALYSIS AND ARCHIVING ACTIVITIES

Commented [TO13]: This section needs to be updated to reflect current practices, and any changes to the monitoring and analyses processes

The broad responsibilities of the GSN and GUAN monitoring, analysis and archiving facilities are outlined in Annex C of this Guide.

The provision by the station operators of monthly CLIMAT and daily TEMP reports, and the submission of historical data, will be monitored on a regular basis. In particular, the criteria for inclusion in the networks will be addressed clearly in the monitoring activities.

The following centres have been assigned responsibility in the framework of these activities.

4.1 Monitoring of near-real-time data (monthly CLIMAT and daily TEMP reports)

GSN Monitoring Centre (DWD and JMA):

Routine monitoring of CLIMAT reports will be done jointly by the Deutscher Wetterdienst (DWD) in Offenbach, Germany (for Precipitation) and the Japan Meteorological Agency (JMA) in Tokyo, Japan (for Temperature) in their capacity as the GSN Monitoring Centre (GSN MC). The results reported will include the degree of availability of monthly reports and a breakdown to identify incorrectly coded and formatted reports, as well as the basic quality of the values for temperature and precipitation.

GUAN Monitoring Centre (ECMWF):

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). The reports on TEMPs will include availability of messages and a breakdown indicating reports attaining certain critical levels of height (100 and 10 hPa), as well as RMS departures of observed values from the model initial guess field values.

Monitoring Reports:

The information from the Monitoring Centres is presented in monthly or semi-annual reports. Monitoring results will include all stations which are in the GSN and GUAN lists.

Since the initial completion of the networks, CBS has initiated 9 Regional Lead Centres (http://www.wmo.int/pages/prog/gcos/index.php?name=cbsleadcentres). One of the

purposes of these Lead Centres is to improve links between the NMHS focal points and the GCOS Implementation Manager and the AGG.

4.2 Data analysis and archiving

GSN Analysis Centre (NCDC) and GSN Archive (WDC-Asheville):

The US National Climatic Data Center (NCDC) in Asheville, USA, will examine the quality of the GSN data and carry out analyses in its capacity as the GSN Analysis Centre (GSN AC).

The World Data Centre for Meteorology-Asheville (at NCDC) will serve as the archive for all GSN data, both historical and those regularly submitted by Members over the GTS. Archived results will include the degree of availability of data as well as the metadata. The data themselves will be made available through the following data sets: High resolution subdaily data through the Integrated Surface Data (http://www.ncdc.noaa.gov/oa/climate/isd/index.php). Daily data via the Global Historical Climate Network (GHCN) – Daily (http://www.ncdc.noaa.gov/oa/climate/ghcn-daily/) and Monthly data via GHCN – Monthly (http://www.ncdc.noaa.gov/ghcnm/).

GUAN Analysis Centre (NOAA/NCDC) and Archive (WDC-Asheville):

Analysis of GUAN data will be performed by NOAA/NCDC in their capacity as the GUAN Analysis Centre. The Analysis Centre will provide an annual report.

WDC-Asheville will act 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/).

5. COMPOSITION OF THE NETWORKS

The lists of GSN and GUAN stations are available via the GCOS website at http://www.wmo.int/pages/prog/gcos/index.php?name=networks, as well as being published in the regular monitoring reports. While it is inevitable that some changes in the networks will occur due to circumstances beyond the control of the station operator, it is a fundamental obligation of the station operators to keep changes to an absolute minimum. When minor modifications to stations are made, WMO will be notified in the normal manner. Requests for additions to, or deletions from, the networks should be made to GCOS through the WMO. Such requests will be considered by the AGG of AOPC in the context of the networks as a whole. The AGG can also initiate requests for network modifications to the attention of station operators. All AGG recommendations will subsequently be harmonized with the Regional Basic Climatological Network (RBCN) available at http://www.wmo.int/pages/prog/www/ois/rbsn-rbcn/rbsn-rbcn-home.htm through the Presidents of the WMO Regional Associations concerned.

Commented [TO14]: Needs updating to mention OSCAR/Surface, and other changes

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Commented [TO15]: Check and update

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GCOS-34 (WMO/TD-No. 799) Initial Selection of a GCOS Surface Network, February 1997

GCOS-35 (WMO/TD-No. 839) Report of the second Joint CCl/CBS Meeting on the GCOS Surface Network (De Bilt, The Netherlands, June 25-27, 1997)

GCOS-53 (WMO/TD-No. 958) GCOS Surface Network (GSN) Monitoring Centre Implementation Meeting (Offenbach, Germany, January 19-20, 1999)

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GCOS-127 Practical Help for Compiling CLIMAT Reports, March 2009 (WMO/TD-No. 1447)

(all available at http://gcos.wmo.int : Publications)

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Wallis, T.W.R.: A Subset of Core Stations from the Comprehensive Aerological Reference Data Set (COADS), Journal of Climate **11**, February 1998, pp. 272-282.

ANNEXES

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Annex A

Best Practices and Principles

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A1: Best practices for GSN stations (Manual on the Global Observing System, WMO-No. 544, 2.3.1.3, 2.3.1.4, 2.3.1.6, 2.9, 3.2.4)

- Long-term continuity should be provided for each GSN station. This requires the provision of the necessary resources, including well-trained staff, and keeping changes of location to a minimum.

- In case of significant changes in sensor devices or station location, Members should provide for a sufficiently long period of overlap (at least one, but preferably two years) with dual operation of old and new systems to enable comparisons to be made and the identification of inhomogeneities and other measurement characteristics.

- In the case of automation of the site, overlapping measurements should be undertaken for a period of at least two years.

- CLIMAT data should be provided in an accurate and timely manner. CLIMAT reports should be transmitted by the fifth day of the month but not later than the eighth day of the month [see also GCOS-127].

- Regarding surface synoptic observations: the main standard times shall be 0000, 0600, 1200 and 1800 UTC. The intermediate standard times shall be 0300, 0900, 1500 and 2100 UTC. Every effort should be made to obtain surface synoptic observations four times daily at the main standard times, with priority being given to the 0000 and 1200 UTC observations required for global exchanges.

- Rigorous quality control should be exercised on the measurements and their message encoding. Coding should be consistent with FM-12, FM-35, FM-71 and GCOS-127. CLIMAT reports require quality control of the measurements themselves and their message encoding to ensure their accurate transmission to national, regional and world centres for their use. Quality control checks should be made on site and at a central location designed to detect equipment faults at the earliest stage possible. The Guide to Instruments and Methods of Observation (WMO-No. 8) provides the appropriate recommendations.

- The site layout should follow the recommended form (Guide on the GOS, WMO-No. 488).

- The site and instruments should be inspected regularly and maintained according to WMO recommended practices (Guide to Instruments and Methods of Observation, WMO-No. 8). As part of the maintenance, the necessary calibration practices should be traceable to the standards provided by the Guide. Management of change at sites needs to be accompanied by appropriate periods of overlap when transitioning to new systems, regular calibration activities and correction of biases introduced by changes in station surroundings.

- A national plan should be developed to archive daily data and metadata pertaining to each climate station. Metadata should include data concerning a station's establishment, subsequent maintenance, and changes in exposure, instrumentation and staff. Photographs from north, south, east and west are desirable and should be updated if the environment of the station changes. The data and metadata should be in their original form as well as in digital format. Further details are provided in Annex B.

- Detailed metadata and historical climate data for each GSN station should be provided to the GSN Archive (see Annex B). Both data and metadata should be up-to-date.

A2: Best practices for GUAN stations (Manual on the Global Observing System, WMO-No. 544, 2.10)

Commented [TO17]: Now the Manual on WIGOS, check and update

- 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 twice a day; if this is impossible, night-time ascents should be given priority because these are less susceptible to radiative biases. Soundings should reach as high as possible, noting the GCOS requirements for ascents up to a minimum height of 30 hPa. Because climate data are needed in the stratosphere to monitor changes in the atmospheric circulation, composition and chemistry, every effort should be made to maintain soundings regularly up to a level as high as possible noting the above GCOS requirement.

- TEMP data should be provided in an accurate and timely manner: within 2 hours of the launch time as a target requirement.

- 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. Checks should also be made during and at the end of each sounding to enable correction of errors before transmission.

- Back-up radiosondes should be released in cases of failure in order to maintain the record from the GUAN station.

- Detailed metadata should be provided (cf. Annex D). 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 Archive 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.

A3: GCOS Climate Monitoring Principles

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Effective monitoring systems for climate should adhere to the following principles[6]*:*

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems should be required.
3. The results of calibration, validation and data homogeneity assessments, and assessments of algorithm changes, should be treated with the same care as data.
4. A capacity to routinely assess the quality and homogeneity of data on extreme events, including high-resolution data and related descriptive information, should be ensured.
5. Consideration of environmental climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Uninterrupted station operations and observing systems should be maintained.
7. A high priority should be given to additional observations in data-poor regions and regions sensitive to change.
8. Long-term requirements should be specified to network designers, operators and instrument engineers at the outset of new system design and implementation.
9. The carefully-planned conversion of research observing systems to long-term operations should be promoted.
10. Data management systems that facilitate access, use and interpretation should be included as essential elements of climate monitoring systems.

Furthermore, satellite systems for monitoring climate need to:

(a) Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and
(b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term interannual) changes can be resolved.

Thus satellite systems for climate monitoring should adhere to the following specific principles:

11. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.
12. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.
13. Continuity of satellite measurements (i.e., elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.

[6] *The ten basic principles were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP 5 in November 1999. The complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP 9 in December 2003.*

14. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.

15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.

16. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.

17. Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained.

18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on de-commissioned satellites.

19. Complementary *in situ* baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.

20. Random errors and time-dependent biases in satellite observations and derived products should be identified.

Annex B

Submission of Subdaily, Daily and Monthly GSN Historical Data and Metadata

Commented [TO19]: This needs checking and updating to current practices and procedures

Data Format and Supporting Documentation for WMO Members to Use when Providing Digital Historical Data and Metadata for GCOS Surface Network Sites to the World Data Centre for Meteorology – Asheville at the U. S. National Climatic Data Center

Meteorological Data:

Participating Members are asked to provide historical meteorological data in digital form from all GCOS Surface Network (GSN) stations. All parameters that can be made available for each station are requested. The historical data should be provided at one time and update periodically. Details of the subdaily, daily and monthly formats for the historical data as well as details of the station history format (metadata) are described below.

Meteorological data in a form that is not digital, such as an archive that is only on paper, cannot be processed at this time. However, if some observations are available only as non-digital data, information about this data is requested so that the potential for these data can be taken into account in assessing the GSN network potential. Copies of the data are also requested.

Subdaily Data:

Many GSN stations submit synoptic observational data in real-time over the Global Telecommunications System (GTS). In the interest of understanding changes in climate extremes and extreme events, for those GSN stations where such high-frequency data are available historically, Members are urged to submit historical synoptic observational data or other high-frequency synoptic data to the World Data Centre (WDC) for Meteorology Asheville (http://www.ncdc.noaa.gov/oa/wdc), in accordance with WMO Resolution 40 (Cg-XII, 1995). The Members are requested to provide all the meteorological variables that they normally include in synoptic reports.

Subdaily data format: The WDC will accept high-resolution data in one of three formats (in order of preference): (1) the format used for the Integrated Surface Database (http://www1.ncdc.noaa.gov/pub/data/ish/ish-format-document.pdf); (2) METAR, or (3) SYNOPTIC (avoiding the country specific groups). Please email GCOS.NCDC@noaa.gov as the first step in providing digital data to the GSN Archive.

Daily data:

Following is a list of the daily meteorological variables that participating Members are asked to provide.

1. Total daily precipitation
2. Daily maximum temperature
3. Daily minimum temperature
4. Daily mean temperature
5. Mean daily station pressure
6. Mean daily station pressure corrected to sea level

A “mean”, or average, is calculated by using the current method of the Member that operates the station. Each Member is asked to describe the method used.

“Daily” means each day of each month of each year that observations have been taken at a GSN station. It is all data days. In a similar way, “monthly” means each month of each year that observations have been taken at a GSN station.

If frozen precipitation is observed and will be included in the total precipitation, the water equivalent amount of frozen precipitation should be used.

Daily data format: It is important that all GCOS Surface Network data be converted into a single standard format. Please email GCOS.NCDC@noaa.gov as the first step in providing digital data to the GSN Archive. The preferred format is to have each file contain all the relevant daily data for one station with the file name indicating the station name or identifying number and that these are daily data (e.g., 70200Nome-dly.dat). A cross reference list between WMO identification numbers and any national identification numbers in use is also useful. Each day’s observations should be on one line with columns for each of the following values: year, month, day, and then each of the six variables listed above.

The units used in the data should be provided in the documentation along with a description of any code used to indicate trace precipitation, or other relevant measurement code.

Homogeneity Adjusted Data: In addition to data sets containing the original observations at a GSN station, some Members have produced a homogenized data set where the daily values have been adjusted to account for changes in the observing station. In such cases, Members are requested to provide both the original and adjusted data along with appropriate documentation. Knowledge about processing that has already been done on a data set is important to understanding the data.

Monthly data:

If daily data are available for the full period of record for which monthly data are available, Members providing daily data do not need to also provide monthly data. Where digital daily data are not available for the full period in which digital monthly data are, participating Members are asked to provide the following is a list of the monthly meteorological variables.

1. Total monthly precipitation
2. Mean monthly maximum temperature
3. Mean monthly minimum temperature
4. Mean monthly temperature
5. Mean monthly station pressure
6. Mean monthly station pressure corrected to sea level

A “mean”, or average, is calculated by using the current method of the Member that operates the station. Each Member is asked to describe the method used.

“Monthly” means each month of each year that observations have been taken at a GSN station.

If frozen precipitation is observed and will be included in the total precipitation, the water equivalent amount of frozen precipitation should be used.

Monthly data format: It is important that all GCOS Surface Network data be able to be converted into a single standard format. Please email GCOS.NCDC@noaa.gov as the first step in providing digital data to the GSN Archive. The preferred format is to have each file contain all the relevant monthly data for one station with the file name indicating the station name or identifying number along with an indication that these are monthly data (e.g.,

70200Nome-mon.dat). Each month's observations should be on one line with columns for each of the following values: year, month, and then each of the six variables listed above.

The units used in the data should be provided in the documentation along with a description of any code used to indicate trace precipitation.

Homogeneity Adjusted Data: In addition to data sets containing the original observations at a GSN station, some Members have produced a homogenized data set where the daily values have been adjusted to account for changes in the observing station. In such cases, Members are requested to provide both the original and adjusted data along with appropriate documentation. Knowledge about processing that has already been done on a data set is important to understanding the data.

Station History Data (Metadata):

Stations sometimes change location, instrumentation, environment, schedules, and other parameters. Knowledge about these parameters is important to understanding the meteorological data. Participating Members are asked to provide historical information about these station changes for the stations that they operate. This should include a time history of each site, with sufficient detail to assist in making adjustments to develop homogeneous time series (see the *Guidelines of Climate Metadata and Homogenization*, World Climate Data and Monitoring Programme, Report No. 52, 2003, WMO/TD-No. 1186).

Metadata describing the GSN station and its history should include, as a Minimum Requirement (MRQ), the following information:

- WMO Station identification number
- Station name
- WMO Member country
- Latitude (refers to plot on which observations are taken (position of raingauge, where available); as accurate as possible, at least to the nearest second)
- Longitude (refers to plot on which observations are taken (position of raingauge, where available); as accurate as possible, at least to the nearest second)
- Elevation (defined as the height above mean sea level of the ground on which the raingauge stands or, if there is no raingauge, the ground beneath the thermometer screen or, if there is neither raingauge nor thermometer, the average height of the terrain in the vicinity of the station; with 1m precision)
- Types of instruments used for observations (classes of instruments, e.g.: mercury-in-glass thermometer; storage gauge, psychrometer, automatic weather station)
- Observation schedule and procedures (UTC times of observations)
- Height of instruments above ground (with 0.1m precision)
- Methods used to calculate daily and monthly means
- Methods used to calculate sea level pressure from station pressure
- Dates when any station changes occurred (YYYY-MM-DD)

In addition, metadata describing the GSN station and its history should include, as a Target Requirement (TRQ), the following information:

- National station identification number
- Manufacturers and model numbers of instruments used for observations
- Methods used to calibrate instruments, and calibration schedule
- Description of the terrain and activities within 10km around the station
- Description of instrument field
- Short description of station changes for each date they occurred

- Photographs taken at the station, showing the environment in which the station is located (photos taken from north, south, east and west are desirable and should be updated if the environment of the station changes; see example given below)
- Photographs taken of the station, showing its layout and instrumentation (see example given below; for further guidance on station descriptions, see WMO-No. 8, Annex 1.C (Station Exposure Description))

Sending the Data/Metadata:

Station operators are kindly requested to send the historical data and related metadata from GSN stations to:

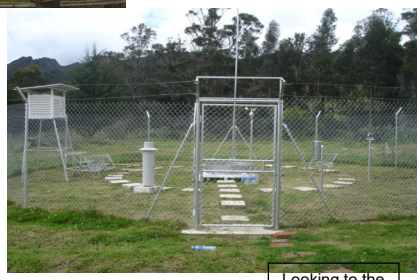
World Data Centre for Meteorology, Asheville
NOAA/National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, NC 28801-5001, U.S.A.
Telephone Number: +1 828 271 4800 ; +1 301 427 2475
Fax Number: +1 828 271 4876 ; +1 301 427 0033
Email: wdcamet@noaa.gov or GCOS.NCDC@noaa.gov

Example for photographing a GSN station: Loja/La Argelia, Ecuador (84270)

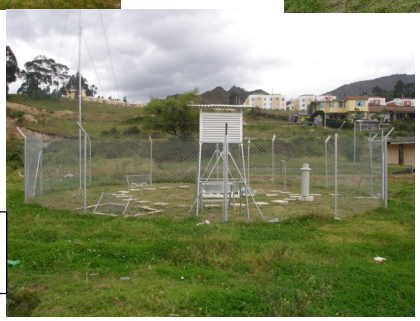
Photographs taken at the station, showing the environment in which the station is located:

Looking to the North (31 July 2008)

Looking to the West (31 July 2008)



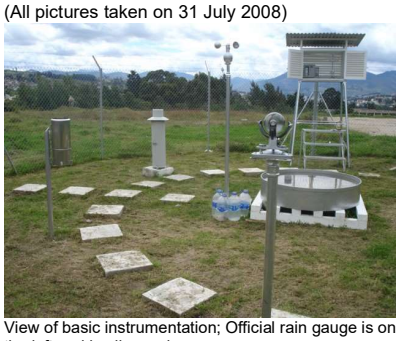
Looking to the East (31 July 2008)



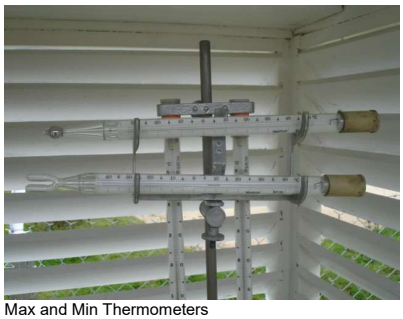
Looking to the South (31 July 2008)

EXAMPLE: Photographs taken of the station, showing its layout and instrumentation:

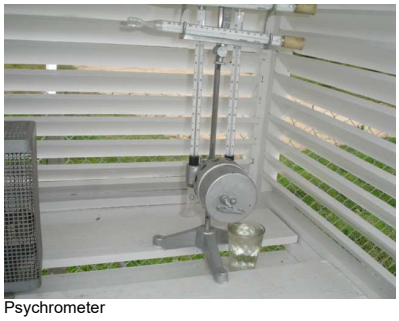
(All pictures taken on 31 July 2008)



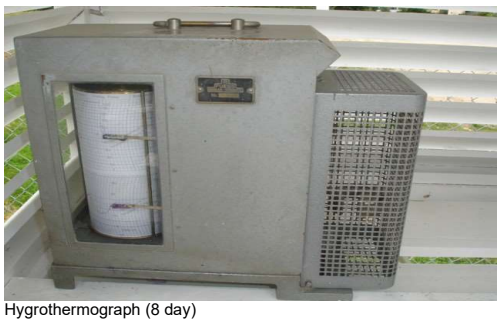
View of basic instrumentation; Official rain gauge is on the left and in silver colour



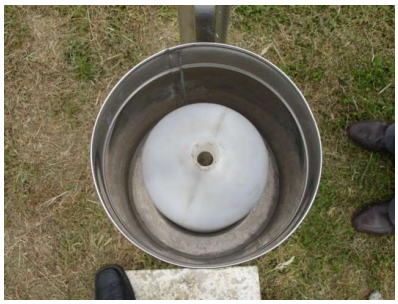
Max and Min Thermometers



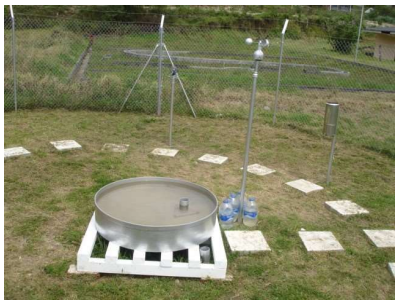
Psychrometer



Hygrothermograph (8 day)



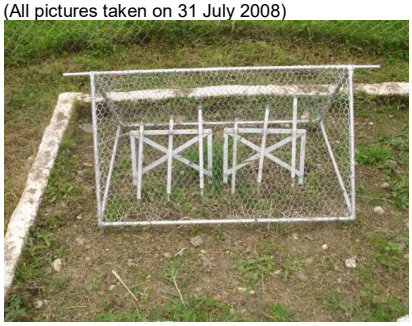
Inside official rain gauge



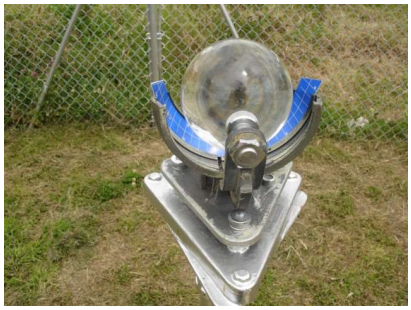
Evaporation Pan and Wind counter

EXAMPLE: Photographs taken of the station, showing its layout and instrumentation:

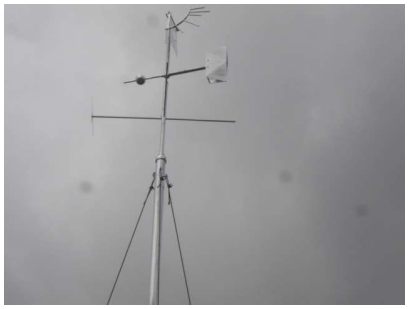
(All pictures taken on 31 July 2008)



Array of soil temperature instruments



Campbell Stokes sunshine recorder



Wind system

ANNEX C

GSN-GUAN Data Monitoring, Analysis and Archiving Centres

Commented [TO20]: Needs updating to new Terms of Reference for Lead Centers GCOS

The GSN-GUAN Data Monitoring, Analysis and Archiving Structure includes monitoring the availability of data, quality control, the analysis of the data, product development, and archiving of the final data sets. Detailed responsibilities of the individual components are given below.

A. GCOS Monitoring Centre (DWD and JMA for GSN; ECMWF for GUAN)

The tasks of a GCOS Monitoring Centre are to:

- Monitor the availability, timeliness and completeness of the incoming data and messages received via GTS or other communication medium with the objective of improving the performance of the network being monitored;
- Perform fundamental quality-control and assurance procedures on the incoming data and metadata to ensure the basic quality and completeness of the data set;
- Compile regular monthly network performance monitoring reports, and disseminate these reports to all GCOS National Focal Points through appropriate communication channels.
- Make basic quality-controlled data available to National Meteorological and Hydrological Services (NMHSs) and World Data Centres (WDCs) and others for their use in a variety of climate applications and products.

B. GCOS Analysis Centre (NCDC for GSN and GUAN)

A GCOS Analysis Centre will provide higher-level quality control of the GCOS network data.

- For historical data, this will include updating and quality-controlling the data, applying bias corrections where possible, calculating monthly statistics from the data, and providing the data, both original and homogeneity adjusted where available, metadata and products to users;
- The centre will also report on historical data and metadata reception.

C. GCOS Archive (WDC-Asheville for GSN and GUAN)

The GCOS Archive is located at NCDC, Asheville (WDC-A).

- It archives GSN and GUAN data and metadata for each station.
- A GCOS archive will make all GCOS data and products available to all potential users on a free and unrestricted basis.
- The GCOS data in the Archives may come from data specifically provided to the GCOS Archive by participating Members or, where those data are unavailable, from any other source of data for GCOS stations that have been made available to the Archive centre via the Monitoring Centres, transmissions on the GTS, bilateral data exchanges or any other source openly available to the archive for unrestricted further distribution.
- The GCOS Archive centre will work with Regional Centres in seeking out historical GCOS data and metadata. This will include providing information on data gaps.

D. CBS Lead Centres for GCOS in WMO Regions

The Terms of Reference for the CBS Lead Centres for GCOS are as follows[7]:

1. Diagnose problems in the GSN and GUAN by using the monitoring reports produced by the GCOS Monitoring and Analysis Centres;

2. Liaise with nominated National Focal Points for GCOS and related Climatological Data, and other responsible officials, to improve data and meta data availability and quality;

3. Co-ordinate activities with other GCOS Centres and/or other centres as appropriate;

4. Monitor and report to CBS and GCOS on actions taken, progress achieved, concerns and recommendations on a yearly basis in a time frame that corresponds to planned AOPC and CBS meetings;

5. Assist AOPC in the revisions of GSN and GUAN stations;

6. Assist the WMO Secretariat in maintaining the list of National Focal Points for GCOS and related Climatological Data.

As of the writing of this document, the CBS Lead Centres for GCOS and their areas of responsibility are[8]:

1. WMO Regional Association I: Morocco (DMN)
GSN and GUAN Stations in : Algeria, Benin, Burkina Faso, Cameroon, 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.

2. WMO Regional Association II: Mozambique (INM)
GSN and GUAN Stations in: Angola, Botswana , Burundi, Canary Island, Comoros 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 Kerquelen), Rwanda, Seychelles, Somalia, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, Zimbabwe.

3. WMO Regional Association II and part of VI: Iran (IRIMO)
GSN and GUAN stations in: 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.

4. WMO Regional Association II: Japan (JMA)
GSN and GUAN stations in: Brunei, Cambodia, China, Japan, Laos, Malaysia, Mongolia, Myanmar, Philippines, Republic of Korea, Singapore, Thailand, Vietnam.

5. WMO Regional Association III: Chile (DMC)
All GSN and GUAN stations in RA III.

6. WMO Regional Association IV: USA (NCDC)
GSN and GUAN stations in: most of WMO RA IV plus Hawaii.

[7] WMO (2007) : *CBS Lead Centres for GCOS Coordination Meeting/Workshop – Final Report*, Annex III.
[8] See also http://www.wmo.int/pages/prog/gcos/index.php?name=CBSLeadCentres

7. WMO Regional Association V: Australia (BoM)
GSN and GUAN stations in the most of RA V, except those countries noted for Japan and Hawaii (USA).

8. WMO Regional Association VI: Germany (DWD)
GSN and GUAN stations in the most of RA VI, except those countries noted for Iran.

9. Antarctica: UK (British Antarctic Survey).
All GSN and GUAN stations in: Antarctica.

ANNEX D

Format for Submission of Historical GUAN Data and Metadata

Commented [TO21]: Is this still valid?

Data format:

GUAN data have historically been transmitted over the Global Telecommunications System (GTS) in TEMP reports. Generally, if the available data have been transmitted via GTS, no further submission is necessary. Should historical GUAN data have not been transmitted over the GTS or if data are missing from the GUAN Archive, the data should be sent to World Data Centre for Meteorology – Asheville. The preference for the data format is the format in the IGRA database (see http://www1.ncdc.noaa.gov/pub/data/igra/readme.txt) or standard TEMP format would be appropriate. Please contact GCOS.NCDC@noaa.gov to coordinate the data transfer.

Metadata format:

Metadata describing the GUAN station and its history should include, as a Minimum Requirement (MRQ), the following information:

- WMO Station identification number
- Station name
- WMO Member country
- Latitude (refers to plot on which observations are taken; as accurate as possible, at least to the nearest second)
- Longitude (refers to plot on which observations are taken; as accurate as possible, at least to the nearest second)
- Elevation (defined as the height above mean sea level of the zero point of the barometer; if there is no barometer, the average height above mean sea level of the terrain in the vicinity of the station; with 1m precision)
- Observation schedule and procedures (UTC times of observations)
- Types of instruments used for observations (radiosonde type)
- Dates when any changes occurred (YYYY-MM-DD)

In addition, metadata describing the GUAN station and its history should include, as a Target Requirement (TRQ), the following information:

- National station identification number
- Methods of prelaunch check
- Description of the terrain and activities within 10km around the station
- Description of instrument field
- Short description of station changes for each date they occurred

Sending the Data/Metadata:

Station operators are kindly requested to send the historical data and related metadata from GSN stations to:

World Data Centre for Meteorology, Asheville
NOAA/National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, NC 28801-5001, U.S.A.
Telephone Number: +1 828 271 4800 ; +1 301 427 2475
Fax Number: +1 828 271 4876 ; +1 301 427 0033
Email: wdcamet@noaa.gov or GCOS.NCDC@noaa.gov

GCOS Secretariat
Global Climate Observing System
c/o World Meteorological Organization
7 *bis,* Avenue de la Paix
P.O. Box No. 2300
CH-1211 Geneva 2, Switzerland
Tel: +41 22 730 8275/8067
Fax: +41 22 730 8052
Email: gcosjpo@wmo.int
Web: http://gcos.wmo.int