# GLOBAL CLIMATE OBSERVING SYSTEM-REQUIREMENTS AND REALITIES OF PROVIDING OVERLAPPING RADIOSONDE FLIGHT SERIES DATA FOR LONG TERM CLIMATE CONTINUITY

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ABSTRACT

The GCOS recommends that upper-air stations use a particular model radiosonde for as long as is feasible and if change is necessary that an overlapping flight series of old and new radiosondes be conducted at representative sites. The overlapping flights enable the formulation of bias transfer functions. These functions are then applied to the new data sets. This is to ensure a consistent historical data series suitable for long-term climate trends analysis by the climate community.

There are 163 GUAN radiosonde sites from over 67 countries using radiosondes from six providers. Forty percent of these GUAN sites are launching one or less radiosondes per day either because of operational forecasting requirements or because of the costs of radiosonde flights. Next generation radiosondes and technical adjustments to existing radiosondes used in the GUAN network are taking place, and a significant portion of the GUAN network is obsolete and no longer supportable. New systems are being introduced and the existing systems are continually introducing technology improvements. To satisfy the GCOS literal recommendation for overlapping radiosonde flight series requires a major financial commitment by GCOS quality radiosonde flights providers that is cost prohibitive. An internationally acceptable approach is needed to satisfy the GUAN climate continuity needs and at the same mitigate the expenses for establishing bias corrections for various radiosonde types by the countries providing GUAN network radiosonde measurements. This paper will outline an approach for selecting a climatologically representative subset from the GUAN for acquiring overlapping flight data to establish bias transfer functions from new radiosonde sensor suites. It will also explore approaches to determine if changes in radiosondes require establishment of new bias determinations. Finally, a consortium approach will be outlined for countries with only one to several radiosonde stations.

## Background

National Weather Service Upper-air data are used for short-term forecasts and warnings and are also the basis for long-term historical information for climate monitoring, analysis, and study. A-periodically, the NWS will replace or modify instruments or algorithms either as a normal life-cycle change of equipment or to take advantage of new technology. Each of these changes can yield unique performance characteristics which may impact the long-term climate record. In recognizing the importance of long term records stability and the needs of the climate for overlapping intercomparison measurements (WMO 2003), the NWS implemented a policy to conduct intercomparison studies as new instruments are introduced for the purpose of determining transfer functions to account for differences between old and new sensors. The differences needed to be determined under different operational weather conditions and locations to establish the differences brought on by sensor changes and those attributable to spatial differences (NWS 2003). At the conference that led to the development of the United States Climate Continuity Strategy (Peterson 2002), there was discussion about how well one could interpolate the results to other climate stations. The general opinion of the dozen or more experts was that it would be most reliable to treat each station individually and then reduce them in a fairly logical fashion. The reduction strategy will, however, have to be based on interpolation. The problem is that the inhomogeneities caused by changing radiosondes can be related to a wide variety of factors. These are primarily related to radiative and sensible heat transfer, which in turn are related to both solar angle (latitude, longitude, time of year, and time of day) and climate related factors such as cloudiness and humidity. The regions of optimal interpolation were, therefore subjectively drawn trying to balance many different factors. Ultimately, the individual station approach was reduced to a subset of the GCOS upper-air network. Figure 1 is a global depiction of the radiosonde sites comprising the

GUAN and the semi-gridded spatial separation of the sites.

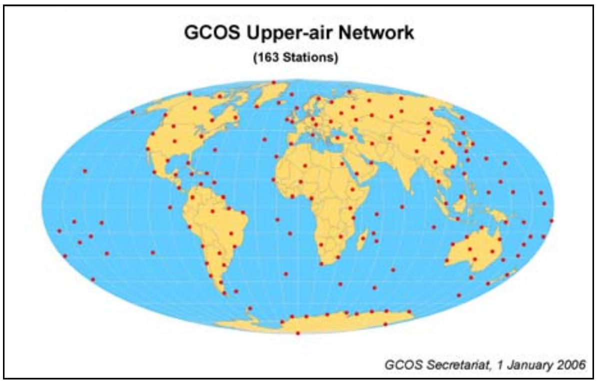


Figure 1. GCOS Upper-air Network (GUAN)

It was felt that the GUAN sites represented the overall network. The National Weather Service stations that constitute 17 of the GUAN sites are shown in Figure 2. These sites encompass sites from the Equatorial Tropics, Mid-latitudes and Arctic Regions.

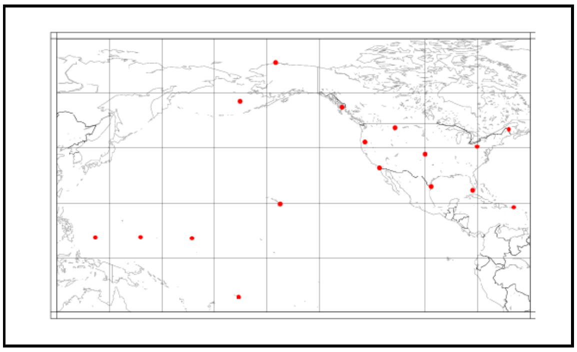

Figure 2. National Weather Service GUAN Sites

**Planning**

Biases stratification by variables such as location, time-of-day, season, and pressure level is required to apply meaningful adjustments to data time series. The recommendation from the climate community was that biases for the 0000 UTC and the 1200 UTC upper air data sets should be calculated separately for each season. The dual flights option at only selected climate stations was deemed the best option by the climate community meeting of experts in October 2002. The advantages were that spatial interpolation was not required, the potential for spatial interpolation would be available for spatial interpolation of analyses to added stations, the best stations would be used for the continuity analysis, stations not required for regional large scale climate averages would not be addressed, and finally, the number and distribution of NWS upper air sites used for continuity testing would likely be the same as the sites used for climate purposes.

Rosen et al. (2002) examined radiosonde station needs for detecting trends in the CONUS and for North America. The basis for the study was the use of reanalysis data interpolated to radiosonde station locations to evaluate 50-year trends in temperature. The conclusion from the study was that cutting the NWS network to the GCOS network produced trends that were not significantly different from those based on the full network.

**How many flights are enough**

The minimum error thresholds required for climate analysis continuity bias adjustments determine the number of dual flights performed for a given station. For the NWS CONUS network, for area averaging purposes for eight stations to determine the error in the discontinuity analysis would require 200 dual flights to get to the 95% confidence limit for a CONUS average discontinuity error caused by changing to the RRS that is less than 0.05 C. This represents 25 flights per bias assessment which means per each of four seasons per each of the 0000 and 1200 UTC.

Weatherhead (MacDonald 2005) used a 40-year database developed by the Forecast Systems Laboratory. Detailed vertical profiles of temperature change for nine stations from three different geographic areas over a 40 year period were determined. The nine stations were from three different regions in the CONUS. Three each were in Alaska, the Mountain West, and the Eastern United States. Of interest here is that these trends tend to be regional and exhibit remarkable similarity within a region, but are distinctly different across regions. The nine stations are shown in Figure 3.

Weatherhead (2002, 1998) has compiled data on an extensive number of upper air sites. The same regional groupings are also apparent over large areas. The noteworthy aspect of these analyses is that although temperatures from the different sites can show different mean and standard deviations by pressure levels, the radiosonde temperature trends from the troposphere through the stratosphere show very similar trends.

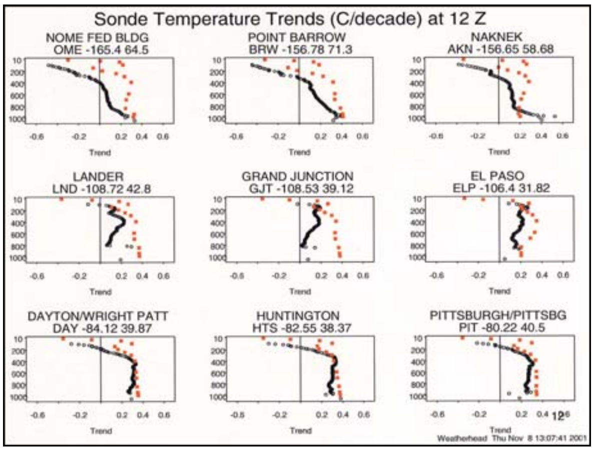


Figure 3. Forty-year (1956-96) radiosonde temperature trends.

**How often and how many**

The question of the optimal temporal frequency of upper air data for climate considerations was determined in a study by Weatherhead. Temperature trends determined for Washington (Sterling, Virginia), for 500 hPa level for a 40-year period of record are shown in Figure 4 where the trend using all of the soundings for the period of record is shown with the solid line. Data are systematically removed in increments of every other day, every third day, etc to determine how often soundings need to be flown to determine long-term climate trends (MacDonald 2005). For operational purposes, the number could be more. From the graph, for a given hour as few as 10 soundings per month would yield stable trends.

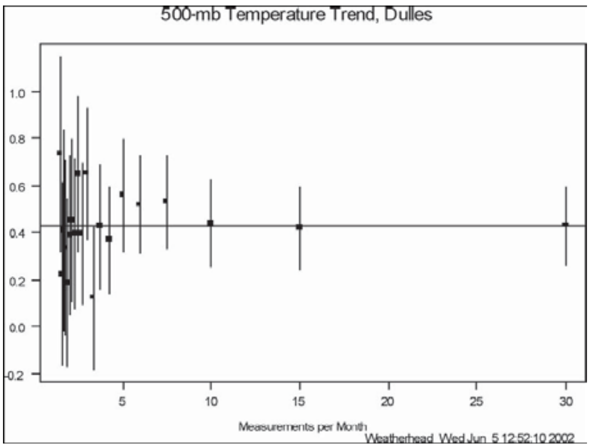


Figure 4. 500 hPa temperature trends for Washington (Sterling, Virginia). Vertical lines represent one standard deviation of the trend.

Faced with the costs of doing a continuity series on all 17 GCOS upper air sites in the NWS network and with the long term stability issues, the NWS is in the process of down-selecting sites from the initial sites from the GUAN network.

Information from several climate workshops on requirements for a baseline network and on the recognition that there are inherent stability problems with radiosonde sensor suites as well as providers of radiosondes, has provided an opportunity to reevaluate our continuity strategy. Weatherhead's work suggests that if properly selected, individual radiosonde sites can accurately characterize climate trends over large geographically similar areas.

The question is this: How does one select a representative site? One likely distinguishing characteristic of sites having similar historic trends from uninterrupted radiosonde flight series is perhaps common air masses. In reviewing the Weatherhead results and comparing them to principal air mass types for common regions, it appears there is a relationship on the issues of air mass types and shapes of climate trends by altitude. A review of the NWS radisonde network against air mass types found that the network is encompassed by six major air mass types. Five of the major types are shown for North America in Figure 5. An additional air mass type is Equatorial Tropical which encompasses the NWS upper air locations in the Pacific.

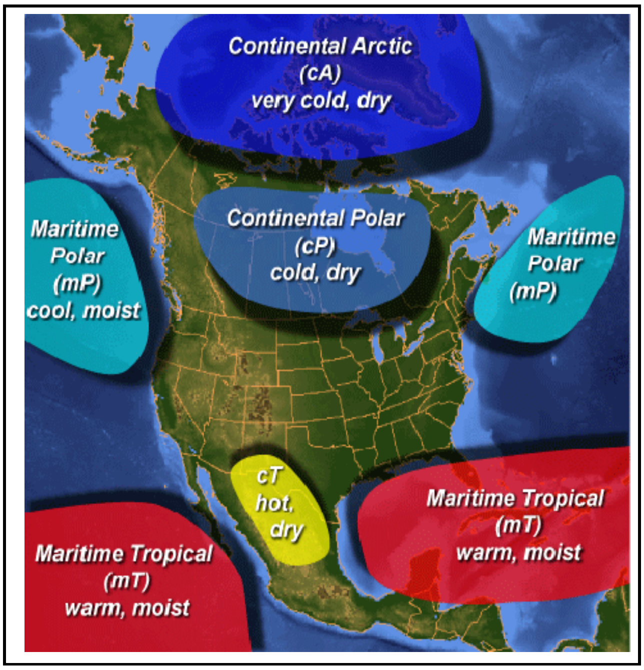


Figure 5. Major North American Air Mass types.

Having studied the air mass approach for looking for similar upper air climate regions, the NWS GUAN network was reviewed to see how the network would align with various air mass areas. Figure 6 is a chart of the NWS network of GUAN stations with the stations depicted in the individual rectangles being GUAN stations, and the station in each rectangle with the small green square is the station selected as representative of the air mass type or climate region. Essentially, six major air mass types are encompassed with the station selection. These are Arctic, Continental Polar, Maritime polar, Continental Tropical, Maritime Tropical, and Equatorial Tropical.

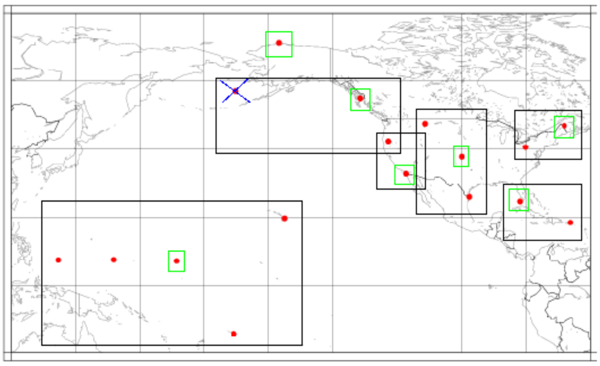

Figure 6. NWS GUAN network with air mass areas defining common overarching characteristics.

**International Continuity Testing**

Radiosonde continuity testing globally is a challenging if not. insurmountable task. When one considers the number of providers of radiosondes and the distribution by WMO Regions it is difficult to come up with a cost effective continuity testing strategy. Table 1. shows the number of GUAN sites by WMO region and the type of radiosonde they are using.

Table 1. GUAN site radiosonde vendors by WMO Region.

| Radiosonde | Africa | Asia | South America | North and Central Am | Southwest Pacific | Europe | Antarctic | Total |
|---|---|---|---|---|---|---|---|---|
| Vaisala | 19 | 6 | 13 | 8 | 30 | 14 | 8 | 98 |
| Sippican | 2 | 1 | 4 | 15 | 4 | | | 26 |
| Modem | 3 | | 1 | | 4 | | 1 | 9 |
| Shanghai | | 7 | | | | | | 7 |
| Meir | | 4 | | | | | 1 | 5 |
| Mrz | | 11 | | | | 2 | 1 | 15 |
| Unknown | | | | | | | | |
| Total | 24 | 31 | 18 | 23 | 39 | 16 | 12 | 163 |

Many of these sites/Regions have not had an opportunity nor were they able to do overlapping continuity studies, particularly for the newer Vaisala RS92 and the Modem systems that have been installed in many locations. Nash (2004) recognized the need for a meaningful means of acquiring overlapping continuity data for climate purposes. He proposed that the WMO Regional Instrument Centers (RICs) perform the flight comparisons. Heretofore, the majority of testing has been carried out in test sites in Western Europe and North America. Tests need to be carried out in their representative conditions if climate monitoring needs are to be satisfied. The current RICs do not have the infrastructure to carry out these tests in terms of equipment and personnel. Additionally, the locations of the RICs may not be good locations for doing intercomparison flights in that they are not locations that would adequately represent major air mass regions for the purpose of determining bias functions. Mt Washington, New Hampshire, in Region 4 is a good example. A list of the RICS and the climate region they are situated in are shown in Table 2. A minimum number of locations world wide would be at least one RIC each in an Arctic Region, a Polar Region, a sub-tropical Region, and an Equatorial region, preferably located at an existing GUAN location. This initial four region breakdown would need to be doubled in size to allow for continental influences and island/ocean influences.

Table2. WMO Regional Instrumentation Centers.

| World Meteorological Organization Regional Instrumentation Centers | |
|---|---|
| Region | Location |
| 1 Africa | Oran, Algeria<br>Gaborone, Botswana<br>Cairo, Egypt<br>Nairobi, Kenya |
| 2 Asia | Beijing, China<br>Tsukuba, Japan |
| 3 South America | Meteorological Laboratory and Workshop of the National Meteorological Service of Argentina |
| 4 North and Central America | Mt Washington, New Hampshire<br>The Caribbean Meteorological Institute of Barbados<br>RMTC, San Jose, Costa Rica |
| 5 Southwest Pacific | Melbourne, Australia (Regional Radiation Center) |
| 6 Europe | Service des equipments et des techniques instrumentals de la meteorology, Trappes, France |

A global map showing major air mass regions is shown in Figure 7. Many of these regions are repetitive as a function of latitude and longitude. If only representative regions are used as test sites, an intercomparison strategy would have to include asynoptic flights as well so that bias results from a test site in one air-mass region could be transferred to similar regions.

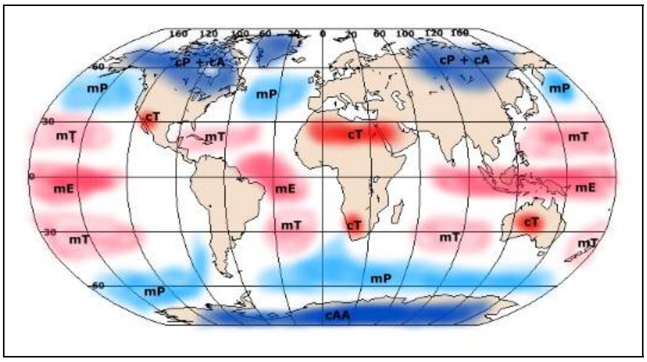


Figure 7. World map with major air-mass regions identified by the two letter indicators maritime (m) and continental (c) and the added indicators of Polar (P), Tropical (T), and Arctic/Antarctic (A).

**Conclusions**

The recommendation that upper air stations in the GCOS GUAN upper air network carry out intercomparison flights for as much as a year (WMO 2003) anytime radiosonde sensors, algorithms, or radiosonde manufacturers change is a hard requirement to satisfy. Even with a given radiosonde manufacturer, improvements are being made continuously that may impact long-term climate continuity records. The requirement that only representative sites from the 163-station GUAN network still makes this a daunting task.

Over 67 countries make GUAN flights using radiosondes from six radiosonde providers. The cost to do flights by these countries for the purpose of climate continuity is not feasible for many of the countries.

The combinations of radiosonde types and regions where they are flown would require a substantial investment that individual countries would find cost prohibitive.

The concept of having RICs equipped to carry out the intercomparisons for upper air and to be funded by the climate community to the maximum extent possible would help ensure that data are available for the determination of data bias transfer functions. RIC locations might have to be increased to adequately encompass the air-mass climate regions of greatest interest to the long-term climate community working on global climate change.

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