UPPER-AIR RADIOSONDE INTERCOMPARISONS AND UNCERTAINTY ESTIMATION

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ABSTRACT

Atmospheric temperature and humidity profiles are important for weather prediction, but climate change has increased the interest in upper-air observations asking for very high quality reference measurements. The 8th WMO Intercomparison of High Quality Radiosonde Systems held in Yangjiang, China, in July 2010 showed the latest status of present-day radiosonde technology. GRUAN, the GCOS Reference Upper-Air Network on the other hand requests uncertainty values for upper-air parameters on each individual measurement. Solid individual calibration, traceable to SI reference standards, is a first important request for each specific radiosonde. Double and triple launches allow determining the reproducibility of a particular sonde. Specific experiments in the laboratory and in the air allow investigating radiation errors on temperature and humidity sensors. Uncertainty estimations on reference calibration, reproducibility- and radiation error experiments finally allow determining the total uncertainty of a particular radiosonde. However, intercomparisons between different radio-sondes are after all needed to test whether estimated uncertainties of different radiosondes are appropriate. Here, we show the different steps that were taken to determine the uncertainty of the Swiss SRS-C34 radiosonde and how well it compares to other radiosondes during several intercomparisons.

History of radiosonde comparisons

In 1942 some studies in Sweden were devoted to comparisons of air plane meteorographs and the Vaisala and an U.S. radiosonde type. Systematic and fairly large differences were found. As these results were of importance when using synoptic aerological charts it was suggested by the Swedish Meteorological and Hydrological Instituted that this question should be studied by the International Meteorological Organisation (I.M.O.). At the 1947 I.M.O. meeting in Toronto an international committee was appointed to investigate the different types of radiosondes. At the meeting of the R.A. VI in June 1949 in London the question was again pressed by the Swedish Institute, and a new Committee was organised to study the same problem. Dr. Lugeon from Switzerland, was elected president. He invited all members to cooperate at a meeting in Payerne, Switzerland, 8-26 May 1950, where all types of instruments should be compared. Representatives were sent there from ten countries, and six different types of instruments were compared, namely the Finnish, French, Swiss, USA, UK, and German types. In 1956 a second international radiosonde comparison was organized at Payerne with representatives from 16 countries comparing 14 different radiosondes from 13 countries. In 1968 a third comparison was held in Japan and in 1979 a forth comparison in the USA.

A new series of WMO radiosonde intercomparisons conducted under the auspices of CIMO took place in UK 1984, USA 1985, the former USSR 1989, Japan 1993, USA/Russian Federation 1995-7, Brazil 2001, Mauritius Island 2005, and China 2010 (Jeannet et al., 2008). While in the earlier comparisons the different parameters were measured up to 100 hPa, measurements are made up to 10 hPa since the 1980^{ies}. Figure 1 shows the temperature differences observed during the night at the different intercomparisons and the improvements made since 1984. The 1995-7 comparisons were mainly devoted to humidity measurements.

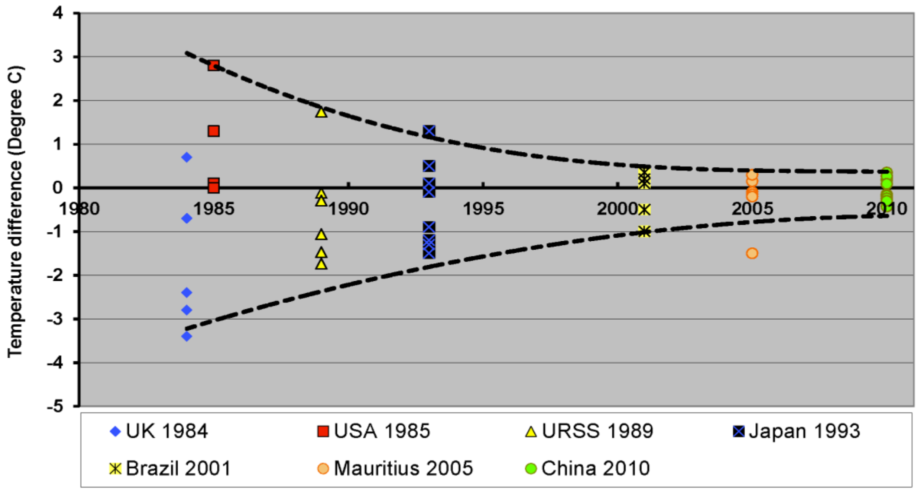

Figure 1: Mean temperature differences observed during the night at 10 hPa.

Radiation Error on Temperature Measurements

The report on the 8th WMO intercomparison in Yangjiang, China best describes the quality of present-day operational radiosondes (*Nash et al.*, 2011). With respect to temperature profile measurements at night, most radiosonde systems were found to provide suitable quality for both weather and climate application. In the day however, a rather large spread was found between the results of the individual sondes particularly at high altitudes, with biases of almost 1 °C at 32 km (~10 hPa). A relatively large cold bias of -0.8 °C at high altitude was found for the Meteolabor SRS-C34 radiosonde, which uses a large day time radiation error correction (-1.8 °C at 32 km) that is based on laboratory experiments and on statistical analyses of day-night differences (*Ruffieux and Joss*, 2003).

The large differences on day temperature measurements observed during the 2010 WMO intercomparison led us to reanalyse the radiation error of the Meteolabor SRS-C34 radiosonde. We measured solar shortwave and thermal longwave radiation profiles through the atmosphere with radiosondes, which allow relating radiation errors on temperature sensors to the radiative fluxes (*Philipona et al.*, 2012). We developed an experimental method allowing direct measurements of the radiation error by using several thermocouples on the same sonde, which simultaneously measure air temperature under sun shaded and unshaded conditions. We further measured the radiation error of thermocouple temperature sensors in a vacuum chamber at the Observatory of Lindenberg (DWD) at different pressure levels using an artificial light source. These in flight and laboratory measurements allowed determining a new radiation error correction curve shown in Figure 2, which was then applied to the SRS-C34 radiosonde. We finally used the data of the 2010 WMO Intercomparison to analyse and compare night and day measurement differences between the SRS-C34 and the 10 other internationally used radiosonde systems (*Philipona et al.*, 2013).

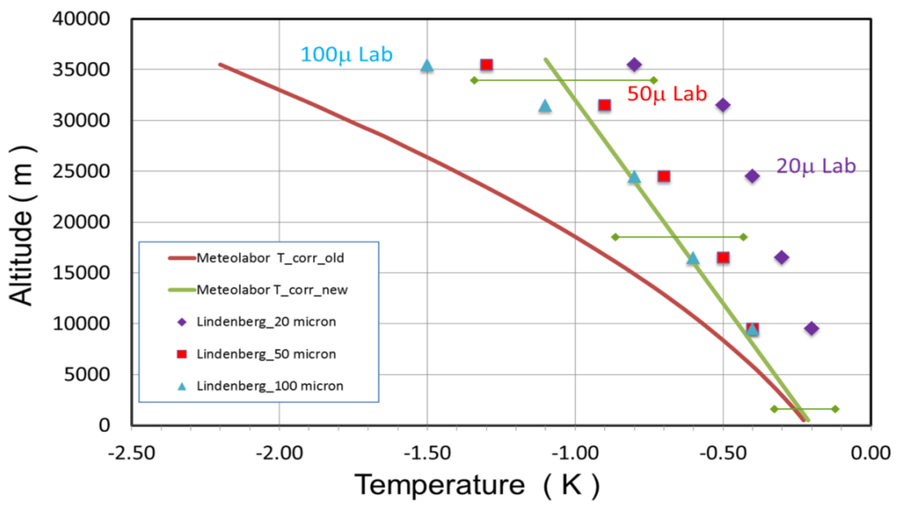

Figure 2: Old (red) and new (green) radiation error curve. The green curve is experimentally determined in flight with 50 micron thermocouples under shaded and unshaded conditions. The purple, red and blue marks are measured in the vacuum chamber using 20, 50 and 100 micron thermocouple sensors.

Upper-Air Radiosonde Uncertainty

Beside reliable measurements, GRUAN standards now request uncertainty estimates for all upper-air parameters on each individual measurement. Solid individual calibration, traceable to SI reference standards, is a first important request for each radiosonde. Specific experiments in flight and in the laboratory allow investigating radiation errors on temperature and humidity sensors. Double and triple launches allow determining the reproducibility of a particular sonde type. Uncertainty estimations on reference calibration, radiation error and reproducibility- experiments allow determining the total uncertainty of a particular radiosonde.

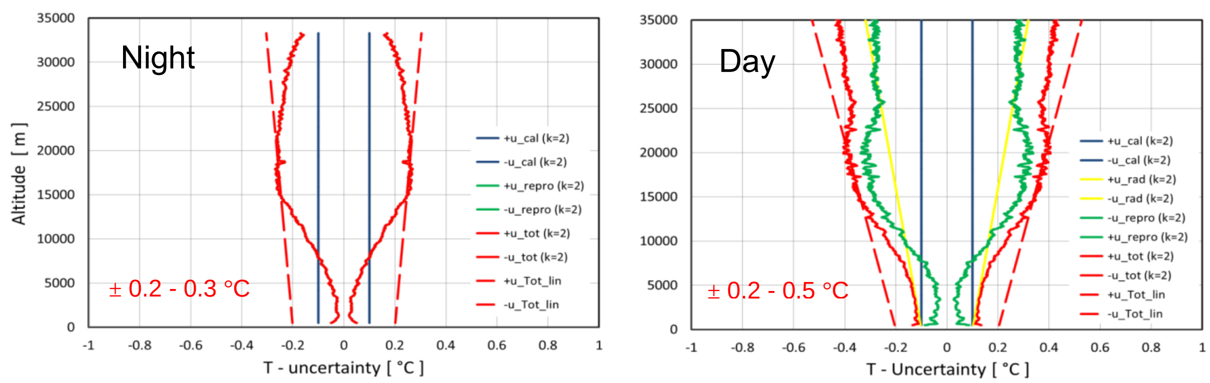

Figure 3: Night and day uncertainty estimates for SRS-C34 radiosonde temperature measurements

Thermocouple temperature sensors of SRS-C34 radiosondes are referenced to a copper resistor that guaranties an absolute uncertainty of ±0.1°C within the measurement range of -100 to +50 °C. Double and triple launches show that the reproducibility during night and day is always below that ±0.1°C limit in the first 5000 meters. However, higher up a divergence is observed during night and day, which is likely related to differential cooling of the radiosonde electronics. For daytime measurements the radiation error correction adds an uncertainty of ±0.1°C at the surface, which linearly increases to ±0.3°C at 32'000 meters (see Fig. 2). A total uncertainty (k=2) is finally calculated (*Immler et al*., 2010), and a linear function is used to express the final uncertainty for night and day measurements as shown in Figure 3.

Future Radiosonde Intercomparisons

Radiosonde intercomparisons so far primarily addressed the overall performance of individual sondes and there agreement between different operational radiosonde systems. However, a better understanding of performances of radiosondes is very important, especially with regard to climate change and the variability of temperature and humidity in the lower atmosphere. Radiosonde measurements are also key for anchoring satellite observations, which are the main source of information for NWP models, and play a very important role in investigating and understanding the performances of other remote-sensing technologies. The demand for clear information on uncertainty estimates for each individual measurement asks for advanced information on calibration, systematic error analyses and reproducibility tests. Sensor calibration is usually performed by the manufacturer in collaboration with metrological institutions. Radiation and time lag errors are investigated for individual sondes in flight or in the laboratory. Reproducibility tests on the other hand can be made for particular sonde types or during intercomparisons of several radiosonde systems, providing at the same time uncertainty information on the individual sondes as well as an overview on radiosondes measurement uncertainty as a whole.

With new operational radiosonde designs appearing on the market, periodic quality checks and intercomparisons by independent organizations are needed. Double soundings should be made in future intercomparisons for all radiosonde types, to test reproducibility and to determine measurement uncertainty of individual sondes in a common way. Intercomparing different (new) radiosonde types is necessary to evaluate the overall uncertainty of all measured upper-air parameters (altitude, pressure, temperature, relative humidity, wind direction and speed). Comparisons with scientific sounding instruments is particularly beneficial for humidity measurements in the upper troposphere and lower stratosphere. Remote sensing instruments are a further source of accurate humidity measurements at high altitude and allow, among other things, investigating spatial effects of drifting radiosondes. High time resolution of remote sensing instruments also enable connecting different radio-sonde flights, while low uncertainty in-situ radiosonde measurements allow accurate calibre-tion of remote sensing instruments in the troposphere. Feasibility studies for various tests on comparisons are made at Payerne during bilateral campaigns with different manufacturers.

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