WMO-CIMO Upper-Air Instrument Intercomparison
TT-UAII Report to WMO-CIMO

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1 Introduction

A Task Team Upper-Air Instrument Intercomparison (TT-UAII) was built in November 2014 to make a feasibility study for a future WMO-CIMO Instrument Intercomparison for upper-air measurements (UAII). The feasibility study for a next WMO-CIMO UAII was conducted over the last 12 month by the TT-UAII, and consists of a number of questions that were discussed and answered through email exchange and during a special session at the GRUAN-ICM7 meeting in Matera, Italy, in February 2015. The feasibility study was handed out to the WMO-CIMO secretariat for the CIMO Expert Team on instrument intercomparisons in March 2016. Their comments were then integrated in the current document.

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3 Feasibility study of next UAII

3.1 Background and scope of upper-air instrument intercomparisons

Radiosondes from different manufacturers are used worldwide at several hundred WMO upper-air stations. The accuracy of radiosondes and the homogeneity of the world upper air network was a matter of concern already more than 50 years ago, at the time of the first international intercomparison. Over the last decades, radiosonde intercomparisons conducted under the auspices of CIMO took place more or less every five years, with previous intercomparisons at Mauritius Island in 2005 , and at Yangjiang, China in 2010. Intercomparisons of radiosonde systems aim at improving the quality and cost-effectiveness of upper air observing systems by providing recommendations on system performances, improvements of instruments and methods of observation, and suitable working references to WMO Members and instrument manufacturers.

The Yangjiang, China intercomparison in 2010 brought together the highest number of radiosonde manufacturers with 11 companies participating in total, including for the first time three manufacturers from China. This intercomparison also advised GCOS on radiosondes and systems suitable for use in the GCOS Reference Upper Air Network (GRUAN).

The intercomparison in China in 2010 was very successful with respect to qualifying the eleven radiosonde systems that were participating in the campaign; however, radiosonde manufacturers from Russia and India, which constitute a significant share of the northern hemispheric radiosonde network, did not participate. This is considered a shortcoming of this campaign and therefore manufacturers from all major countries, including Russia and India, should especially be invited to participate.

This intercomparison also included an upper-air comparison between radiosondes and remote sensing instruments. Remote sensing data were only sparsely used in the final data analysis due to planning and staffing limitations. This point should be addressed in future UAII, which should allow the integration of remote sensing instruments for the benefit of in-situ radiosonde measurements and to broaden and extend upper-air investigations and measurements.

3.2 Questions raised and discussed by the TT-UAII

The task team discussed a number of principal questions with respect to a future UAII and came to the following answers:

- Do we need future WMO upper-air instrument intercomparisons?

All members of the task team unanimously agree that future UAIIs are needed. Radiosonde technology has substantially evolved since the last intercomparison generating the need for a re-evaluation of the currently available technology for upper air radiosonde observations.

- What are the reasons for having future WMO-UAIIs in a world of GRUAN activities?

The members of TT-UAII agree that GRUAN has specific goals focusing on long term climate observations. While GRUAN can address a number of important questions on the viability of radiosonde observations for climate, a good balance between weather prediction and climate issues with regard to upper air measurements is needed. Therefore a broader review of available radiosonde technology is needed, which should include the experiences both of the operational and the GRUAN community.

- Do future WMO-UAIIs need to be in the tropics or can they be made at higher latitudes?

The last three radiosonde intercomparisons were held at tropical sites. These regions exhibit a high and cold tropopause and warm and variable conditions in the lower and middle troposphere. At mid latitude the tropopause is lower and warmer and temperatures in the lower and middle troposphere generally not as warm. Therefore, tropical regions provide a larger range of atmospheric conditions, which may provide better conditions to probe the range of measurement uncertainties that the sensors may be faced with. Intercomparisons of temperature measurements at mid latitude may provide results equivalent to those in the tropics, since the largest challenge is temperature measurements near the balloon ceiling. Humidity measurements on the other hand are more challenging in the tropics, particularly since larger humidity values can be measured at higher altitudes and at low temperatures. Humidity measurements during the last intercomparison had considerable uncertainties on the different radiosondes and there is still a large potential for improvements.

However, logistical aspects may be easier for some mid latitude sites and operational aspects (including ground-based remote sensing possibilities) will need to be considered in the planning of the next campaign.

- Are WMO Intercomparisons for radiosondes only or also for remote sensing instruments?

Remote sensing instruments should be included as much as possible for the benefit of upper air measurements. However, the first priority goal of the intercomparison should be to intercompare radiosonde systems.

3.3 UAIIs and ground-based remote sensing instruments

In a future UAII ground-based remote sensing instruments shall be included to assist the upper-air intercomparison and to assess the quality of remote sensing measurements versus a widely accepted reference. These intercomparisons shall also be used to develop methods to compare remote sensing and in-situ observations given the differences in the observed volume (representativeness). This would be a major outcome of the combined campaign and shall set the standard for comparisons considering representativeness and atmospheric variability. Established and emerging remote sensing technologies

for meteorological or climatological observations of temperature, humidity and wind profiles shall be considered; however only a subset of all available remote sensing instruments should be invited. We propose Doppler lidar and radar windprofilers for wind measurements, Raman lidar for water vapor observations, microwave radiometers for temperature and water vapor observations, and GPS receivers for integrated water vapor observations. Data analysis including ground-based remote sensing instruments is expected to be very laborious. A very careful planning of the combined measurement campaign is advised and the available financial and staff resources for the instrument groups and coordinating team must be carefully evaluated. A feasibility analysis should be performed as soon as a list of potential candidate instruments has been compiled to make sure that the data can be evaluated to their full potential. The final list of ground-based remote sensing devices at the candidate location will be an important point to consider, the idea being to optimize the financial and human resources costs by choosing a location with already as many as possible ground-based remote sensing systems available.

The integration of ground-based remote sensing instruments will benefit in-situ radiosonde measurements by giving information on the upper atmospheric conditions, as well as by comparing remote sensing instruments to the in-situ reference for quality and uncertainty evaluation.

3.4 Goals for a future WMO-UAII

Following the discussions above the TT-UAII decided on four goals for a future UAII.

1. Invite all major radiosonde manufacturers (including Russian and Indian manufacturers).
2. Characterize individual radiosondes with respect to their **Reproducibility** and to determine the **Uncertainty** of the different measured parameters.
3. Compare the different radiosonde systems to an agreed upon "**Reference**". One option for this reference is a combination of different radiosondes or one radiosonde, similar to previous intercomparisons.
4. Include ground-based remote sensing instruments for the benefit of upper air measurements.

3.5 Strategy to reach the four goals

Goal 1: The aim of an international upper-air intercomparison is to evaluate radiosonde systems that are used operationally by member countries and to provide guidance on their performance relative to each other. This campaign should not be used to test new prototypes. Due to the absence of manufacturers from important member countries in recent campaigns, efforts should be undertaken to also include systems from these manufacturers.
Goal 2: The radiosonde reproducibility should be tested. One way is to fly two radiosondes of one system in the same flight. A given number of double flights allow calculation the random uncertainty of a system.
Goal 3: Previous radiosonde intercomparisons were made without a reference since there is no World reference radiosonde. The choice of the reference system or a combination of some of the available systems (for instance 3) still needs to be made.
Goal 4: Ground-based remote sensing instruments shall be included with the following objectives:

(i) support the planning of the radiosonde intercomparison campaign giving information on the upper atmospheric conditions,
(ii) compare remote sensing instruments to the in-situ reference to evaluate measurement quality and uncertainty, and

(iii) develop adequate methods to compare remote sensing with in-situ measurements considering sampling strategies and atmospheric variability (representativeness).

3.6 Sounding requirements for the next UAII

The organization of the campaign as well as the number of necessary flights will be defined in such a manner to fulfill the main goals described in 3.5. The final schedule needs to be discussed with the participating manufacturers.

3.7 Estimations of costs and time

The cost of the campaign should include a financial participation of the various manufacturers in addition to the participation of the hosting laboratory/meteorological service. Supplementary fund could be found in laboratories/meteorological services willing to participate in a more active manner to the campaign.

4 Evaluation and results

Compared to previous upper air intercomparison the next UAII should include all the major radiosonde systems that are used by WMO members in the World. Double sounding will allow investigating the individual systems with respect to reproducibility and allow to calculate the random uncertainty of each system. The use of a reference will make comparisons between different flights more representative and will allow to better compare the individual systems. A study of systematic uncertainty sources, for instance by reviewing studies in the literature could also be included in the analysis (remote sensing data can also help for this).

Remote sensing data will be used to identify favorable upper atmospheric conditions at launch time and to support so the radiosonde campaign. Uncertainty and quality of remote sensing data will be evaluated through intercomparisons with the in-situ reference. Finally, a standard method will be developed to compare remote sensing with in-situ measurements considering different sampling strategies and atmospheric variability.

The results will be published similar as in 2010 in a WMO report that presents a good overview of the quality and uncertainty of WMO radiosondes as a whole and the individual systems in particular. Further, the standard method to compare in-situ with remote sensing data will be described and first results on the quality of remote sensing instruments will be presented.

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