The GCOS Reference Upper Air Network: Quantifying the value of complementary observations for GRUAN operations

F. Madonna[1], D. Cimini[1], B. Demoz[2], J. Güldner[3], S. Gutman[4], R. Kivi[5], and G. Pappalardo[1]

(1) Istituto di Metodologie per l'Analisi Ambientale, Consiglio Nazionale delle Ricerche, Tito Scalo, Potenza, Italy

(2) Howard University, Department of Physics and Astronomy, Washington, DC, USA

(3) Deutscher Wetterdienst, Richard-Assmann-Observatorium, Lindenberg, Germany

(4) NOAA Earth System Research Laboratory (ESRL), Boulder, CO, USA

(5) Finnish Meteorological Institute Arctic Research, Sodankylä, Finland

Strategy

This research aims at quantifying the error reduction resulting from increasing redundancy of measurements of both temperature and moisture using data from highly-instrumented GRUAN sites (e.g., ARM site, Beltsville, Lindenberg, Payerne, Potenza) and from sensors synergies.

The investigation is carried out focusing mainly on water vapour and on the most common instruments available at the GRUAN sites: radiosoundings, Raman lidars, microwave profilers and GPS receivers.

The aim of the investigation is to suggest a recommendations of an optimal observation strategy related to GRUAN phase 1 and 2 measurements, increasing accuracy of measured parameters and reducing uncertainties through redundancy. Moreover, recommendations for the type of equipment to operate/acquire at the GRUAN sites will also be made.

Redundancy

Cross-checking of redundant measurements for consistency is an essential part of the GRUAN quality assurance procedures.

Richard-Assmann-Observatorium, Lindenberg, Germany – Year 2008
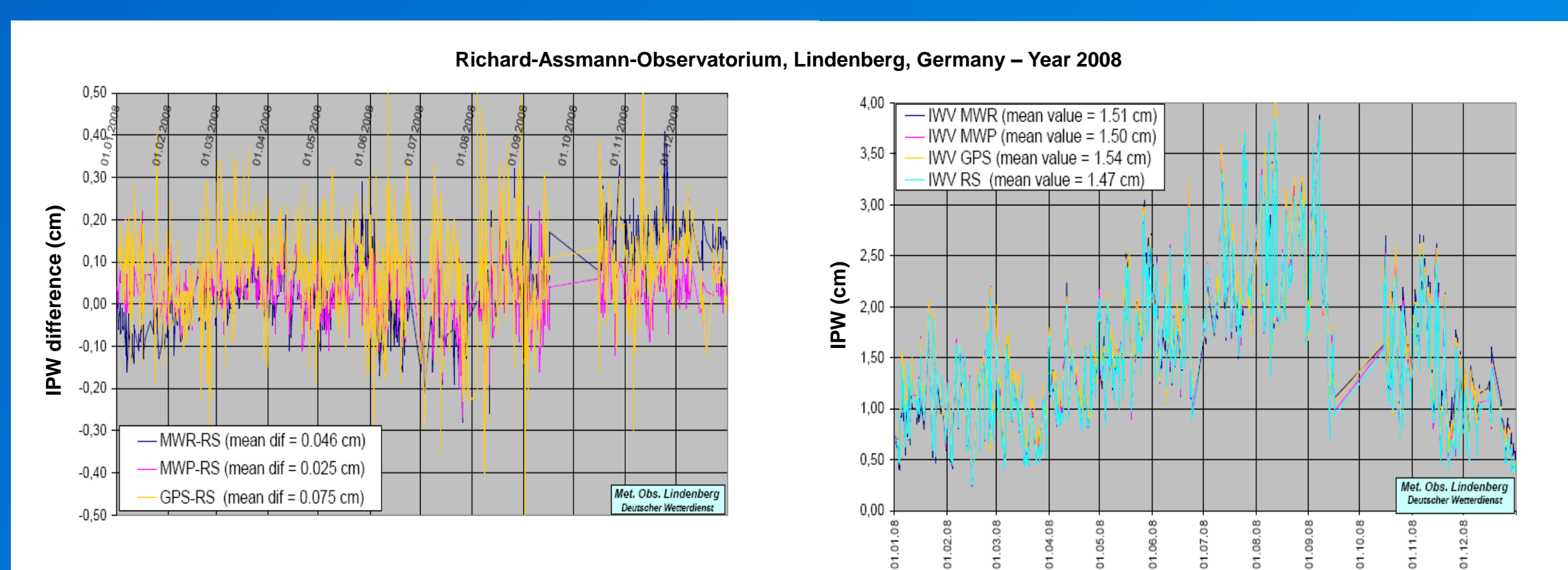
Comparison of Integrated Water Vapor (IPW) derived operationally from observations of GPS, radiosondes, dual channel microwave radiometer (MWR) and microwave profiler (MWP). The deviations (or differences or discrepancies) of IPW with respect to radiosondes (left panel) and the corresponding time series (right panel) during 2008 in Lindenberg (Germany) are shown.

Dual channel microwave radiometer IPW is retrieved using a physical retrieval while the microwave profiler IWV is retrieved using a regression method.

The use of microwave radiometers is crucial for GRUAN both for redundancy and for providing a reference estimation of IPW . The last point needs further consideration about the use of such instruments for a climate network.

Sonde-MODIS-ECMWF-MW radiometer IPW correlations
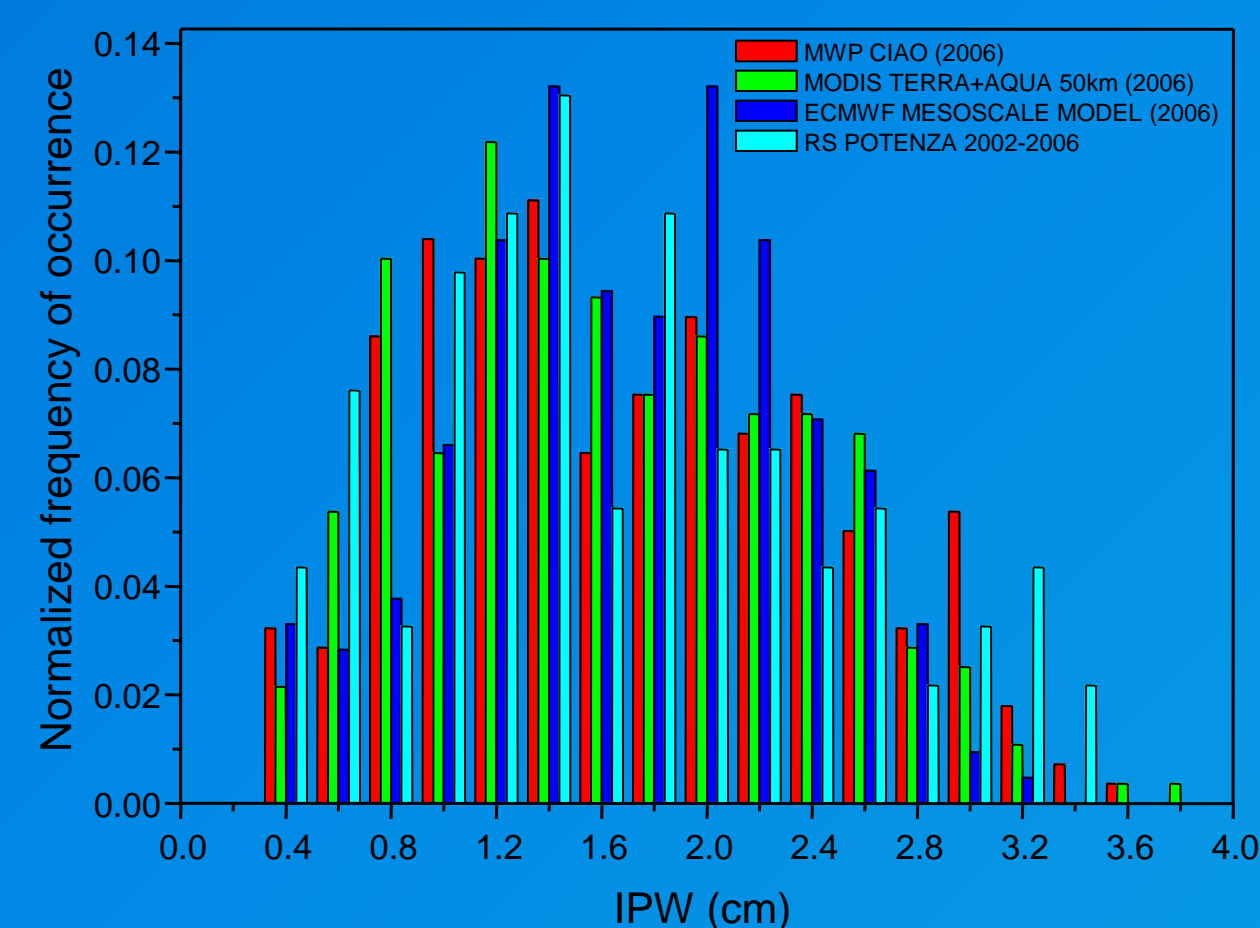
2006 cumulative distribution of IPW obtained from MWP operational at Potenza (Italy), from the 2002-2006 radiosounding climatology, from MODIS Terra-Aqua and ECMWF operational mesoscale model.

Comparisons with models and satellite might represent a useful approach for the evaluation of measurement spatial representativeness.

GPS-MW profiler IPW correlations
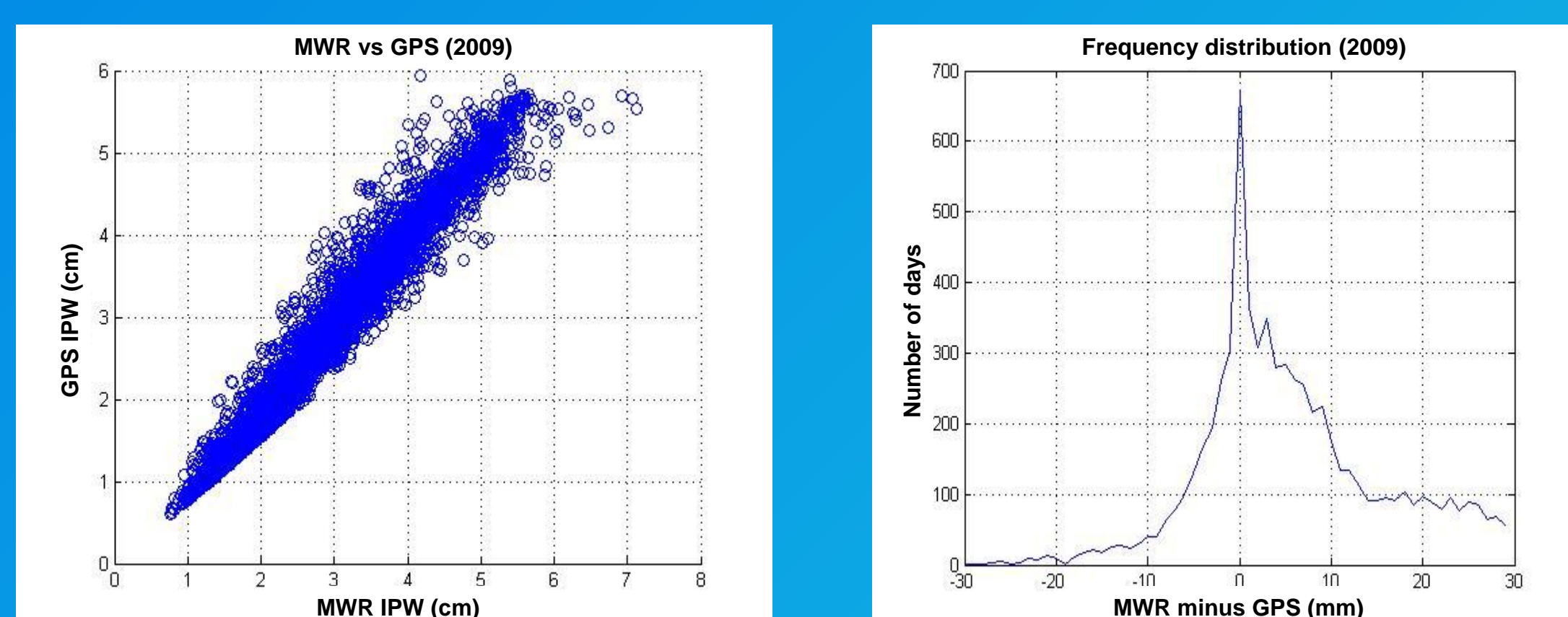
Comparison of the IPW from GPS and MWR operational in Beltsville (US) in 2009. In the left panel the comparison is reported while in the right panel the frequency distribution of the IPW difference.

Left panel shows that the majority of the days show little to no difference in IPW. The distribution drops quickly in the negative side (i.e. GPS wetter than MWR) than in the positive side, indicating that MWR measurements may be affected by rain or liquid water. Physics of the different instruments allows for identification of such issues.

Lidar-Sonde-MWR radiometer IPW correlations
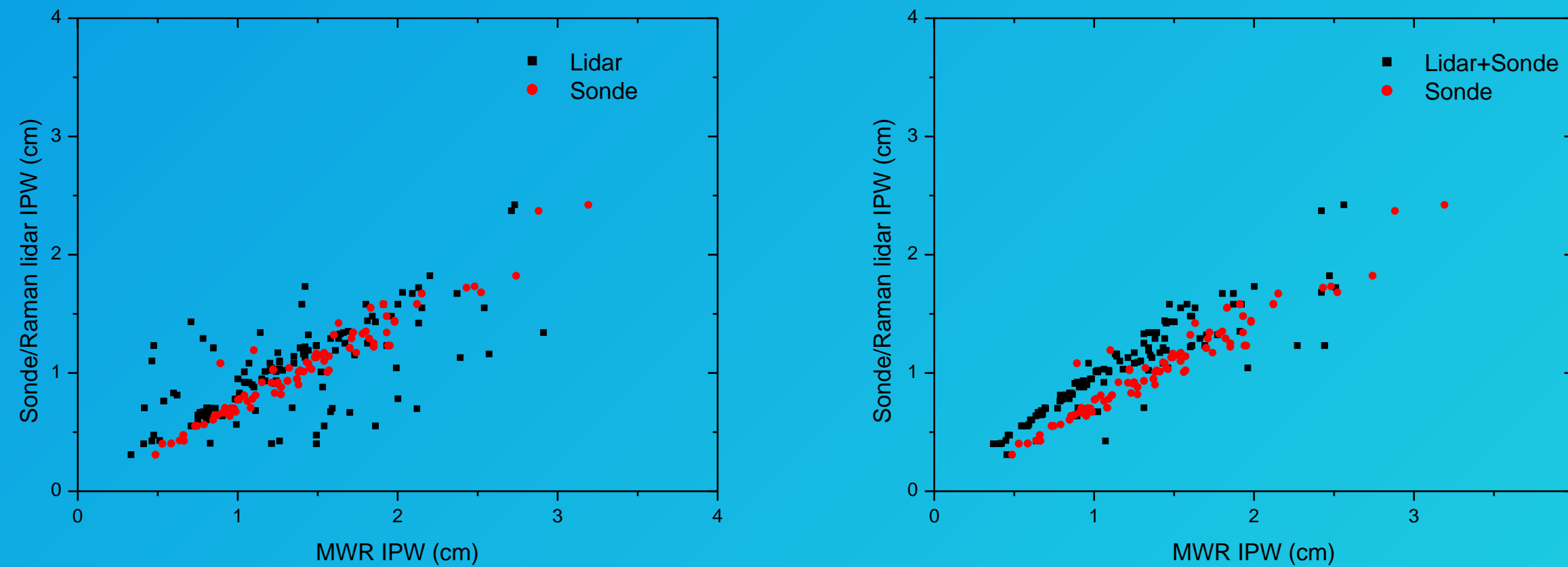
Left panel: comparison of IPW obtained from sondes and lidar at the Southern Great Plains (SGP) facility in 2010 compare with IPW retrieved by MWR; same as left panel but considering an hybrid lidar-sonde estimation obtained using the radiosonde profile as a top-up for the lidar water vapour mixing ratio profile from the lidar level where relative uncertainty exceeds 25%.
The use of an hybrid estimation is a possible solution for reducing the impact of radiosonde spatial representativeness on the measurements comparison.

Uncertainty

Error budget

As a whole the total uncertainty of a remote-sensing or in situ observation could be estimated as follows (Kitchen, Q. J. R. Meteorol. SOC. (1989), 115, pp. 673-700):

$$\Delta E = \sqrt{\Delta r^2 + \Delta s^2 + \Delta t^2 + \Delta i^2}$$

where the first term indicates the observation error, including all the error contributions due to statistical noise, sensor response functions, rounding errors; the second and the third term are related to the observation representativeness due to space and time co-location, respectively. The last term indicates the error related to the model used for comparison with observations.

Measurements representativeness
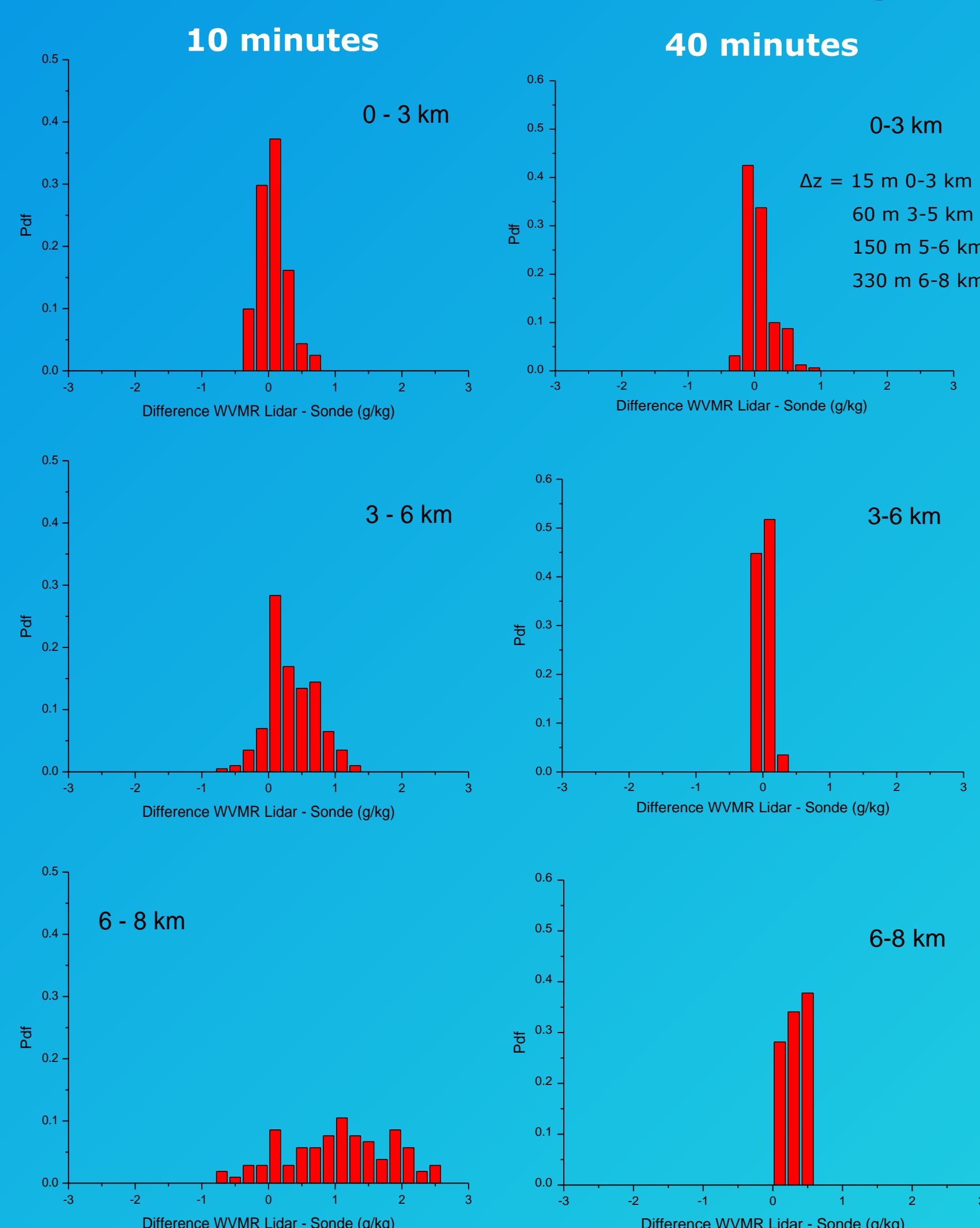
Normalized probability density functions (pdf) of the average difference between co-located and simultaneous Raman lidar and radiosonde water vapour mixing ratio profiles, as measured in 2004-2005 at Potenza (Italy).
Raman lidar calibration is based on the long term comparison with radiosondes in the range 1-2 km. Pdfs have been calculated averaging the lidar profiles over 10 (left) and 40 (right) minutes integration time

10 minutes			
Range (km)	Center	Width	Offset
0 - 3	0.046341	0.38319	0.07423
3 - 6	0.28763	0.73132	0.18708
6 - 8	1.1747	1.6293	-0.0525

40 minutes			
Range (km)	Center	Width	Offset
0 - 3	-0.01362	0.24275	0.47609
3 - 6	0.013204	0.22619	-0.0941
6 - 8	0.33787	0.32503	-0.1631

The contribution of space and time measurement representativeness to error budget may largely exceed the contribution related to the observation error. A trade-off between signal-to-noise of remote sensing and the impact of space and time co-location mismatch at all altitude levels has to be found before the comparison or combination of different sensors, in-situ and remote sensing.
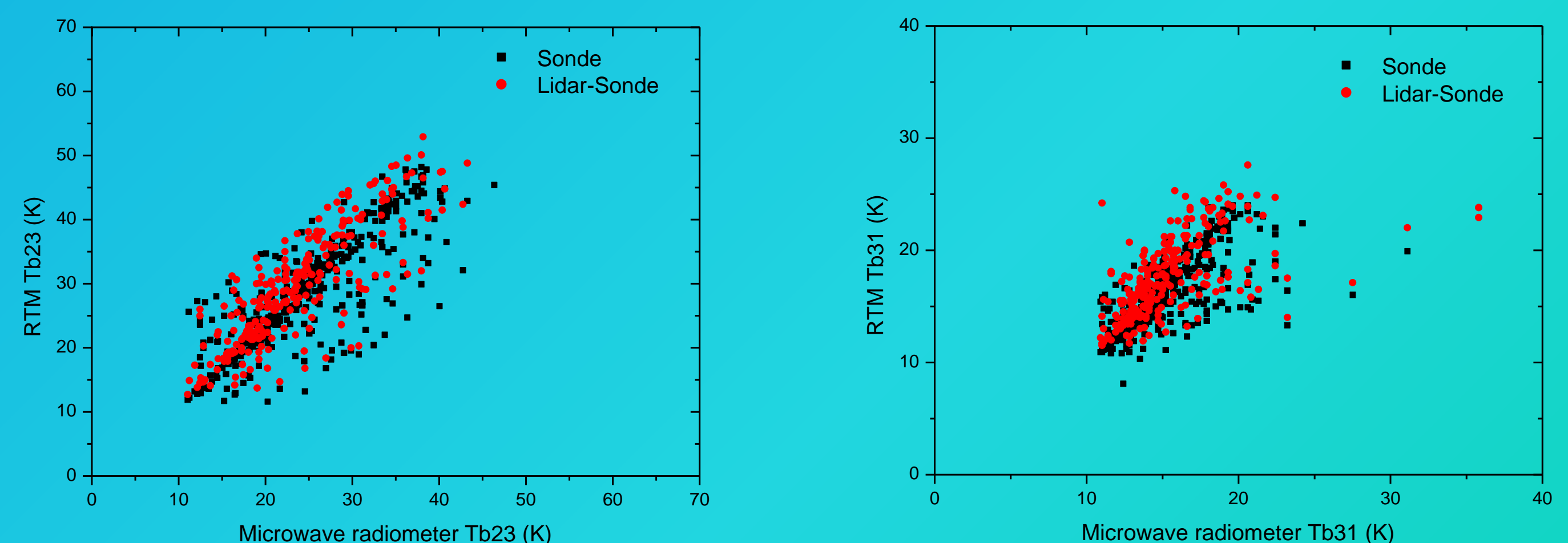
Left panel: comparison of brightness temperatures at 23.8 GHz modeled using Rosenkranz98 radiative transfer model and considering as input profile of water vapour mixing ratio obtained by the sonde profile or the hybrid lidar-sonde profile. The observations are referred to the 2010 dataset collected at the Southern Great Plains (SGP) facility; in the right panel, same as left but for brightness temperatures at 31.4 GHz.

As mentioned above, the use of an hybrid estimation might be considered as a possible solution for reducing the impact of radiosonde spatial representativeness on radiative transfer models.

Under investigation

At present, the work is oriented in the elaboration of a scheme for uncertainty reduction using the concept of total and conditional uncertainty, that will be also a possible solution to be implemented in the so-called "Site Atmospheric State Best Estimation (SASBE), under discussion in cooperation with GRUAN TT5.

Acknowledgement

ARM data is made available through the U.S. Department of Energy as part of the Atmospheric Radiation Measurement Program. Cloudnet project (European Union contract EVK2-2000-00611) for providing the water vapour mixing ratio profiles on the ECMWF model.

GCOS — GLOBAL CLIMATE OBSERVING SYSTEM