Evaluating the potential of ground-based instruments to validate the quality of integrated water vapour data measured by satellite-based observing techniques

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Goal

The GlobVapour Project is developing multi-annual global water vapour data sets based on calibrated and inter-calibrated satellite radiances for long time series satellite observations. On the other hand, Integrated Water Vapour (IWV) estimations derived from ground-based **Global Navigation Satellite System** (**GNSS**) observation networks such as the International GNSS Service (IGS) network are also very promising, with continuous observations spanning over the last 15 years. Additionally, the **AErosol RObotic NETwork** (AERONET) also provides long-term and continuous ground-based observations of the IWV performed with standardized and well-calibrated sun photometers. Finally, **radiosonde** measurements offer long time series of IWV, but suffer from inhomogeneities due to changes in the used humidity sensors throughout time.

The aim of the present study is to set up an **inter-technique comparison of IWV measurements** from satellite devices (**GOME/SCIAMACHY/GOME2**) and the above mentioned ground-based and in-situ instruments. To this end, we selected 28 sites worldwide at which the GNSS observations were directly compared with simultaneous satellite IWV observations, together with sun photometer and/or radiosonde measurements, if available. In particular, we investigate the inter-technique biases, the influence of the presence of clouds on the IWV inter-technique comparison and the geographical dependency of the properties of the IWV scatter plots between all these different instruments.

1. Instruments and Datasets

Instruments:

- 2 Ground-Based Instruments
- 1 In-Situ Instrument
- 3 Satellite-Based Instruments

Global Navigation Satellite Systems | Radiosondes | CIMEL Sun photometers | GOME (II) / SCIAMACHY

Technique	Spatial Coverage	Temporal Resolution	Time Span	Tech. Costs	All Weather / All Directions	By Product of An Analysis
GNSS	± 350 IGS sites	every 5 minutes	1995-now	low	Yes / Yes	Yes
Radiosonde	± 1500 sites	on average twice/day	1950s-now	low to moderate	Yes / Vertical Profile	No
CIMEL Sun Photometers	± 300 sites	± 15 min, depending on weather conditions	1993-now	moderate	clear sky only / solar direction needed	No, but focus on aerosol properties retrieval
GOME(2)/SCIAMACHY	Global	maximum once/day	1996-now	very high	only if (almost) cloud free/nadir	No

Table 1 : Pros & cons per technique.

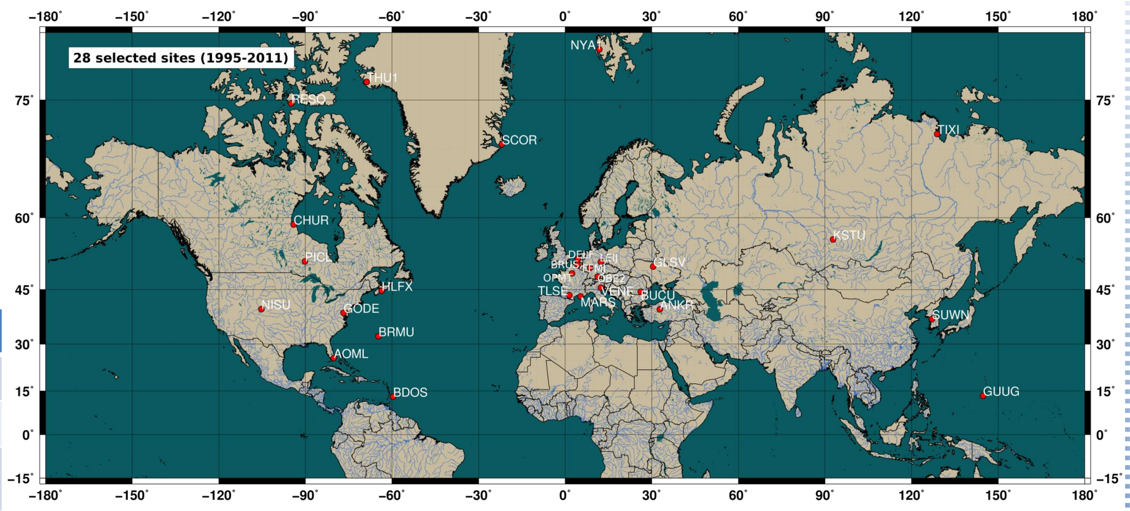

Fig. 1: Map of the selected sites that host at least 2 of the considered instruments.

We searched for co-location between the different techniques: 2 ground-based, one in-situ and 3 satellite-based. The main advantages and disadvantages of each technique are summarized in Table 1. Within a maximum separating distance of 30 km for the ground-based and in-situ instruments, **28 co-locations** are found **worldwide** between at least 3 of those different devices (see Fig. 1). The IWV data sets from the different instruments are retrieved as follows:

- **GNSS**: GPS-based Zenith Total Delay (ZTD) from the IGS Final/re-processed tropospheric product ([3], [4]) is converted into IWV by using surface measurements of temperature and pressure, gathered at synoptic stations at a horizontal distance of maximum 50 km from the GNSS station (more details in e.g. [1], [2], [5] and [6]).
- **CIMEL sun photometers**: IWV is obtained by measuring the (direct) sun radiance at a 940 nm channel (centred on the 946 nm water vapour absorption line).
- **Radiosondes**: IWV is calculated through integration of the vertical profiles of temperature and relative humidity.
- **GOME(2)/SCIAMACHY**: IWV is retrieved by applying the so-called Air Mass Corrected Differential Optical Absorption Spectroscopy method to nadir measurements around 700 nm. .

2. Inter-Technique Comparisons

Instrument co-location: focus on Brussels

As a first step, this study focused on Uccle, Brussels, Belgium (50°48'N, 4°21'E, 100m asl) presenting the following advantages:

- The different ground-based and in-situ instruments and the automatic weather station (time resolution: 10 min) are really located at the same site, so that the horizontal and vertical separation of the different devices is not an issue.
- All techniques are available for this site.
- We dispose of all metadata of the different instruments, so that we are aware of any instrumental change that might give rise to an inhomogeneity of the instrument's data series.
- The availability of auxiliary weather data is a major advantage.

From Fig. 2, we note:

- The different instruments have different observation periods.
- We have 2 radiosonde types: Vaisala's RS80 and RS90/RS92 (=RS9x).
- The GPS IGS IWV is a good candidate for reference device because of data every 10 min (since 1999*), only minor data gaps, homogeneous data (re)-processing by IGS.

* We dispose of weather data with 10 minutes of time resolution only since 1999.

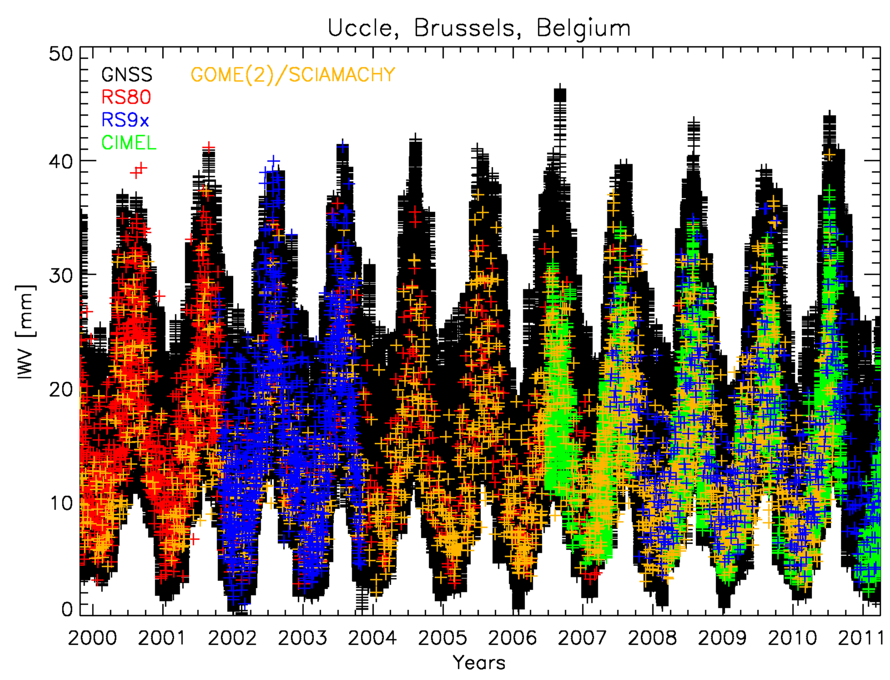

Fig. 2: Overview of all IWV data available at Uccle, Brussels, since the installation of the automatic weather station

Exploitation of the IWV Datasets @ Brussels

We constructed scatter plots of simultaneous (Δt = 10 min for CIMEL, Δt = 30 min for RS and GOME(2)/SCIAMACHY) IWV measurements between the different devices (using the GNSS as reference, see Fig. 3). These plots show that:

- The **mean bias** between the different techniques varies between **-0.6 mm** (GOME(2)/SCIAMACHY) **to 0.6 mm** (RS9x).
- The **best correlation and lowest dispersion** of the data points are reached for the **CIMEL vs. GNSS** comparison.
- Vaisala's state-of-the-art radiosonde type (RS9x) compares better w.r.t. GNSS data than the preceding RS80 type.
- The **slopes of regression lines w.r.t. GNSS are closer to 1 for other all-weather devices (RS) than for instruments demanding a partly clear sky** (CIMEL, GOME(2)/SCIAMACHY). A small study incorporating the available cloud cover data demonstrated that the presence of clouds leads to higher IWV values, in particular for the GNSS observations, compared to the simul-taneous CIMEL measurements.

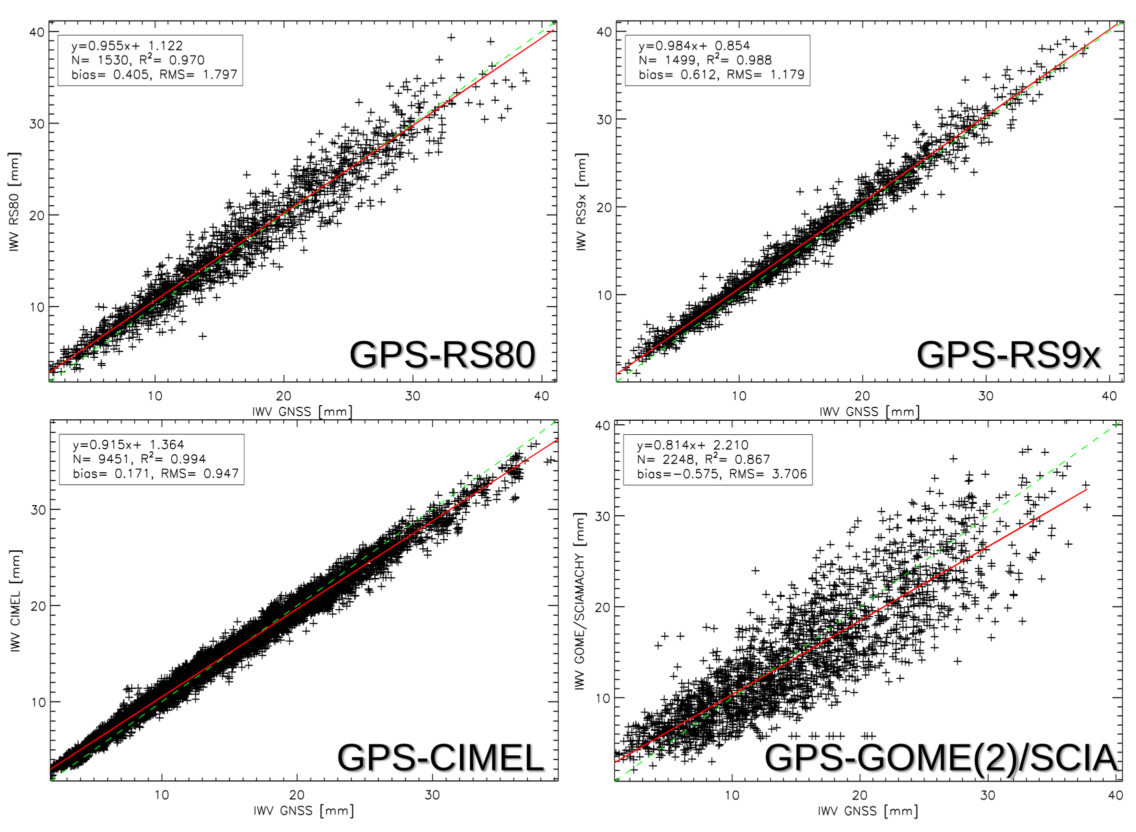

Fig. 3: Scatter plots of simultaneous IWV measurements of the different instruments with respect to the GNSS device.

World-wide Exploitation of IWV Datasets

In a second step, we extended our study worldwide. We created scatter plots similar to Fig. 3 for the selected 28 sites for which we found instrumental co-location. Results are summarised in Figs. 4 and 5 and show that:

- The **CIMEL instrument compares best with the GNSS** technique for the IWV measurements (best correlation, lowest scatter).
- The **regression slopes** are for almost all instrument comparisons at all stations **smaller than 1**.
- At sites where different CIMELs can be compared with one IGS GNSS station (e.g. BRMU, NISU, TLSE, BUCU, VENE, OBE2, OPMT), significant differences exist between the regression slopes of the respective scatter plots → geographical dependency or remaining CIMEL calibration issues?
- There is **neither latitudinal nor longitudinal dependency** of the scatter plots properties.

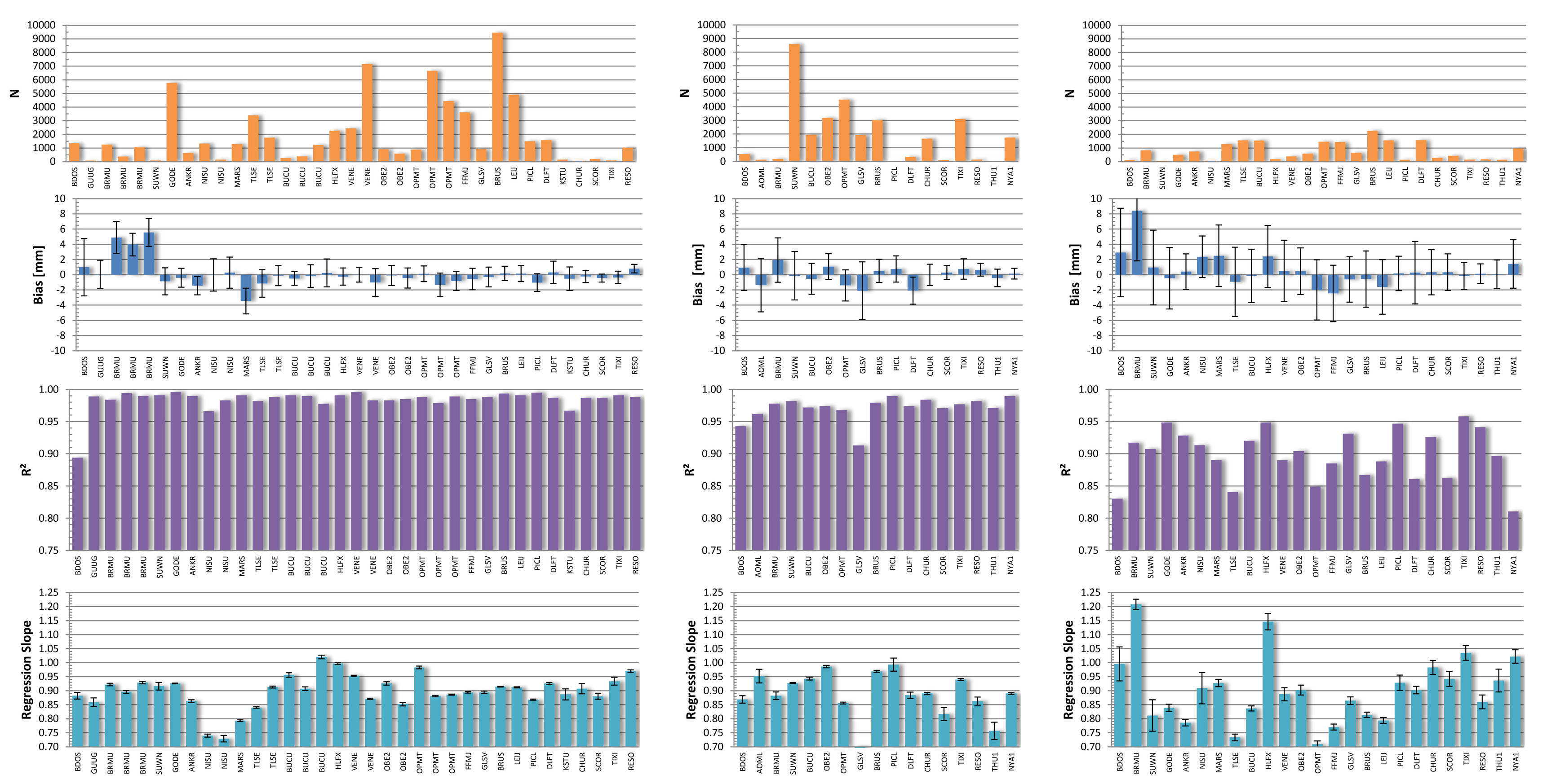

Fig. 4: Column bar plots of scatter plot properties (count N, bias, R² and regression slope) of the different instruments versus GNSS for the selected sites worldwide. Sites are ordered with increasing latitude. The error bars represent the RMS (bias) and the standard deviation (regression slope).

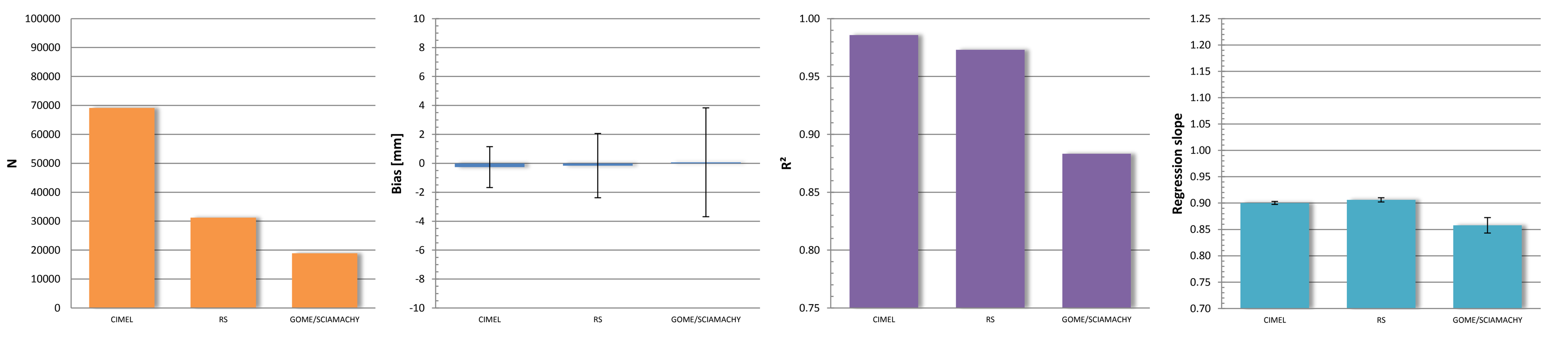

Fig. 5: Column bar plots of scatter plot properties (count N, bias, R² and regression slope) of the different instruments versus GNSS averaged over all stations included in the inter-technique comparison. Error bars: see Fig. 5.

3. Conclusions and Perspectives

- **CIMEL sun photometers and GNSS** are very valuable ground-based techniques and therefore good candidates to evaluate/calibrate the long-term IWV datasets provided by satellite devices: they correlate very well (their mean R² is 0.984) and **typically agree at the level of 0.3 mm ± 1.5mm of IWV**.
- **Influence of clouds**: for large IWV values, the GNSS instrument measures higher amounts of IWV than the CIMEL does. This can at least partly be explained by the observation bias of the CIMEL instrument: it requires a clear sky in the direction of the sun. But the larger the IWV values, the higher the probability to have clouds, which contribute directly to the GNSS observations, but not to the CIMEL IWV observations.
- Both ground-based techniques are very **promising to build up long time series for climate applications**, as long as the data homogeneity can be guaranteed. For the CIMEL photometers belonging to the AERONET, a regular calibration of the instrument is required. IGS GNSS data were (re)processed homogeneously from 1994 on to mid-April 2011.
- As a first example, we evaluated the **GOME(2)/SCIAMACHY** satellite IWV dataset. The GOME(2)/SCIAMACHY IWV measurements are susceptible to a similar observation bias as the CIMEL (almost cloud free skies are needed), which is also reflected in the low mean value of the regression line slope. For these satellite data, the **largest (but apparently random) geographical variability** of the IWV measurements relative to the co-located GNSS observations is obtained.
- At this point of our research, there is **no clear geographical pattern** (e.g. related to the climate type) in the inter-technique comparisons at the selected sites worldwide.
- This research might be **extended to other (e.g. IR) satellite devices** measuring IWV.

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AERONET Aerosol Robotic Network — NASA Goddard Space Flight Center

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