INTER-TECHNIQUE COMPARISON OF INTEGRATED WATER VAPOUR MEASUREMENTS FOR CLIMATE CHANGE ANALYSIS

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GOAL

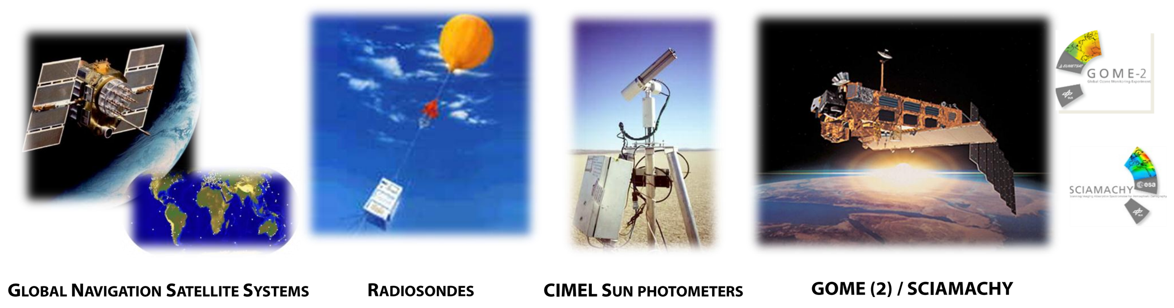
Water vapour plays a dominant role in the climate change debate. However, observing water vapour for a climatological time period in a consistent and homogeneous manner is a challenging task. To this end, water vapour estimations derived from ground-based observations of **Global Navigation Satellite System (GNSS)** receiver networks such as the International GNSS Service (IGS) network are very promising, with continuous observations spanning over the last 15+ years. In addition, the **AErosol RObotic NETwork (AERONET)** also provides long-term and continuous ground-based observations of the total water vapour content performed with standardized and well-calibrated sun photometers.

The present study aims to assess the applicability of either datasets for **water vapour time series analysis**. Therefore, we compare the Integrated Water Vapour (IWV) measurements retrieved from these two techniques, focusing on a selection of almost 30 sites worldwide. Furthermore, we **compare** the **GNSS** and **sun photometer** IWV values with simultaneous and co-located **radiosonde** and satellite-based IWV measurements (**GOME(2)** and **SCIAMACHY**) and we investigate 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



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.

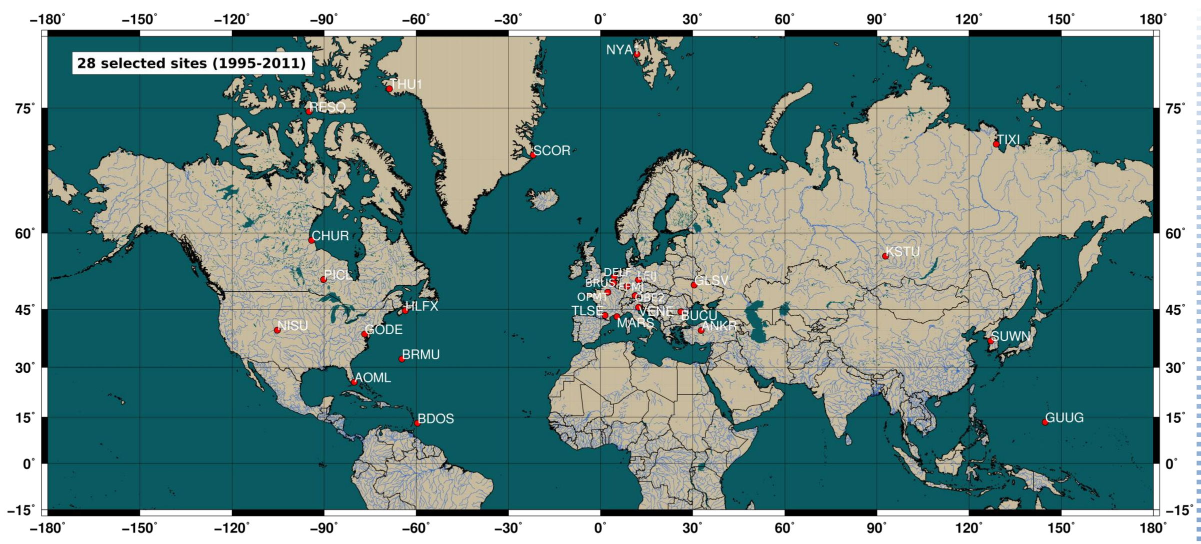


Fig. 1: Map of the selected sites that host at least 2 of the considered instruments.

Within a maximum separating distance of 30 km, **28 co-locations** are found **worldwide** between **IGS GNSS** sites and AERONET **CIMEL sun photometer** locations (see Fig. 1). Additionally, we looked for radiosonde launches and GOME(2) & SCIAMACHY crossings at those selected sites. 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 (*Byun and Bar-Sever* [2009,2010]) 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. Bevis et al. [1992], Saastamoinen [1972], Askne and Nordius [1987] and Davis et al. [1985]).
- **CIMEL**: IWV is obtained by measuring the (direct) sun radiance at a 940nm channel (centred on the 946nm 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 700nm.

The advantages and disadvantages of each technique are summarized in Table 1.

2. INTER-TECHNIQUE COMPARISONS

INSTRUMENT COLOCATION - STEP 1: 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: 10min) 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 the 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 candidate for reference device because of data every 10min (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.

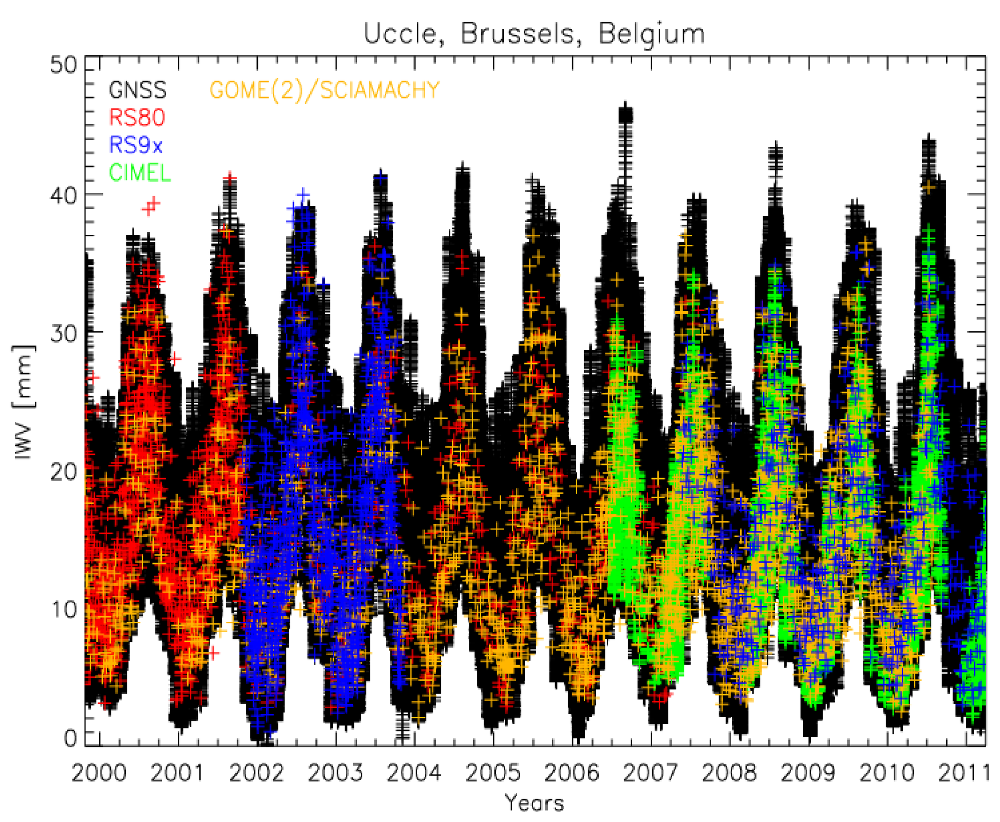


Fig. 2: Overview of all IWV data available at Uccle, Brussels.

EXPLOITATION OF THE IWV DATASETS @ BRUSSELS

We constructed scatter plots of simultaneous (Δt = 10min for CIMEL, Δt = 30min 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/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, especially for GNSS observations, compared to the simultaneous CIMEL measurements.

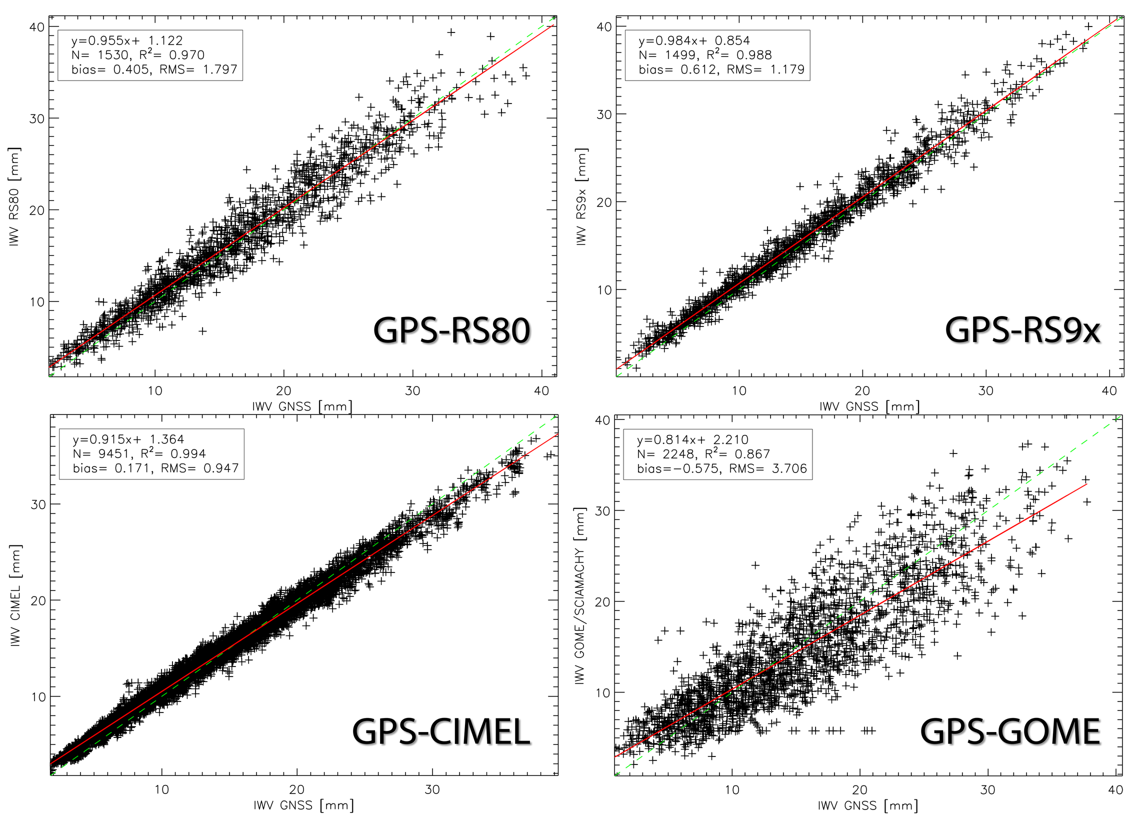


Fig. 3: Scatter plots of simultaneous IWV measurements of the different instruments with respect to the GNSS device.

INSTRUMENT COLOCATION - STEP2: 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 → site location influence 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, R^2 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).

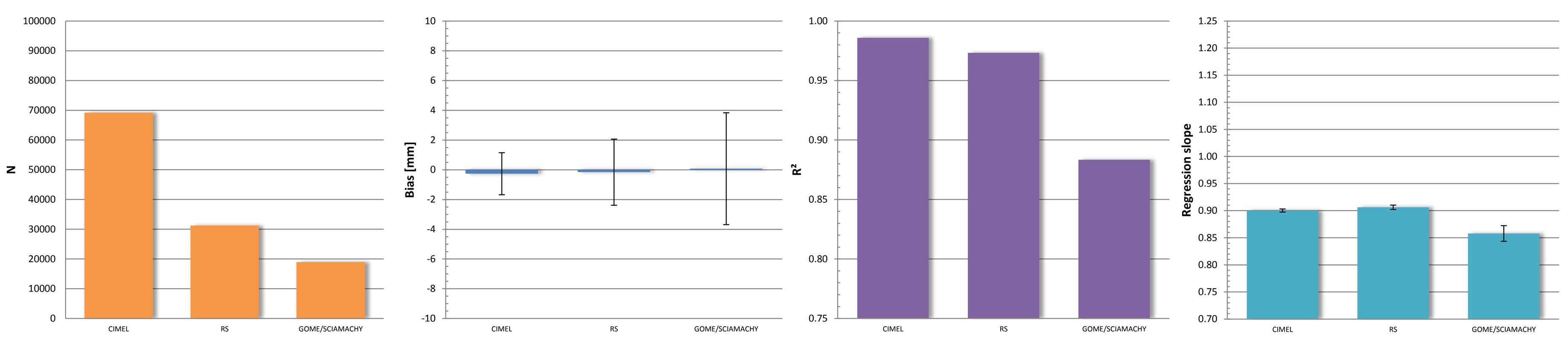


Fig. 5: Column bar plots of scatter plot properties (count N, bias, R^2 and regression slope) of the different instruments versus GNSS averaged over all stations included in the inter-technique comparison. Error bars: see Fig. 5.

3. CONCLUSIONS AND PERSPECTIVES

- CIMEL sun photometers and GNSS are very valuable techniques to measure IWV and are the most promising to built 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 tropospheric products were (re)processed homogeneously from 1994 on to mid-April 2011.
- 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.
- Radiosondes are launched in all weather conditions, but different radiosonde types compare differently for the IWV measurements to the co-located GNSS instrument (demonstrated by the Uccle case study), giving rise to a larger IWV scatter w.r.t. GNSS for RS stations having launched different types in time.
- 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.
- A possible future perspective is to analyse to which extent the different instrumental properties (and hence observation biases) influence the trends in the IWV time series.

REFERENCES AND ACKNOWLEDGEMENTS

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