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ON THE USE OF THE IGS REPRO1 TROPOSPHERIC PRODUCT FOR CLIMATE CHANGE ANALYSIS: AN IWV INTER-TECHNIQUE COMPARISON STUDY

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BACKGROUND

Being the most important greenhouse gas in the Earth's atmosphere, water vapour plays a key role in the climate change debate. However, observing the atmospheric water vapour over climatological timescales in an homogeneous and consistent manner is challenging. To this end, water vapour estimations derived from reprocessing campaigns of continuously-operating ground-based Global Navigation Satellite System (GNSS) observation networks are very promising. In particular, the IGS troposphere products from the REPRO1 campaign ([3], [4]) provide climate researchers access to a world-wide dataset of continuous GPS-based Integrated Water Vapour (IWV) observations spanning over the last 15+ years. The AErosol RObotic NETwork (AERONET) also provides such long-term and continuous ground-based observations of the IWV performed with standardized and well-calibrated sun photometers.

OBJECTIVES

The purpose of this study is to compare GPS-based IWV time series derived from the IGS REPRO1/final troposphere products with simultaneous IWV measurements from collocated ground-based (sun photometer), in-situ (radiosonde) and satellite-based (GOME/GOME2/SCIAMACHY) techniques (1) to evaluate the quality and the consistency between the techniques and (2) to assess the applicability of GPS-based reprocessed IWV data for time series analysis and climate trend detection.

INSTRUMENTS, IWV DATASETS AND COLLOCATION

We searched for collocation between 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, 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, GOME2 & SCIAMACHY crossings at those selected sites. The IWV datasets 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: 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.

INSTRUMENTS:

2 Ground-Based Instruments

1 In-Situ Instrument

3 Satellite-Based Instruments

GLOBAL NAVIGATION SATELLITE SYSTEMS | RADIOSONDES | CIMEL SUN PHOTOMETERS | GOME (2) / 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.

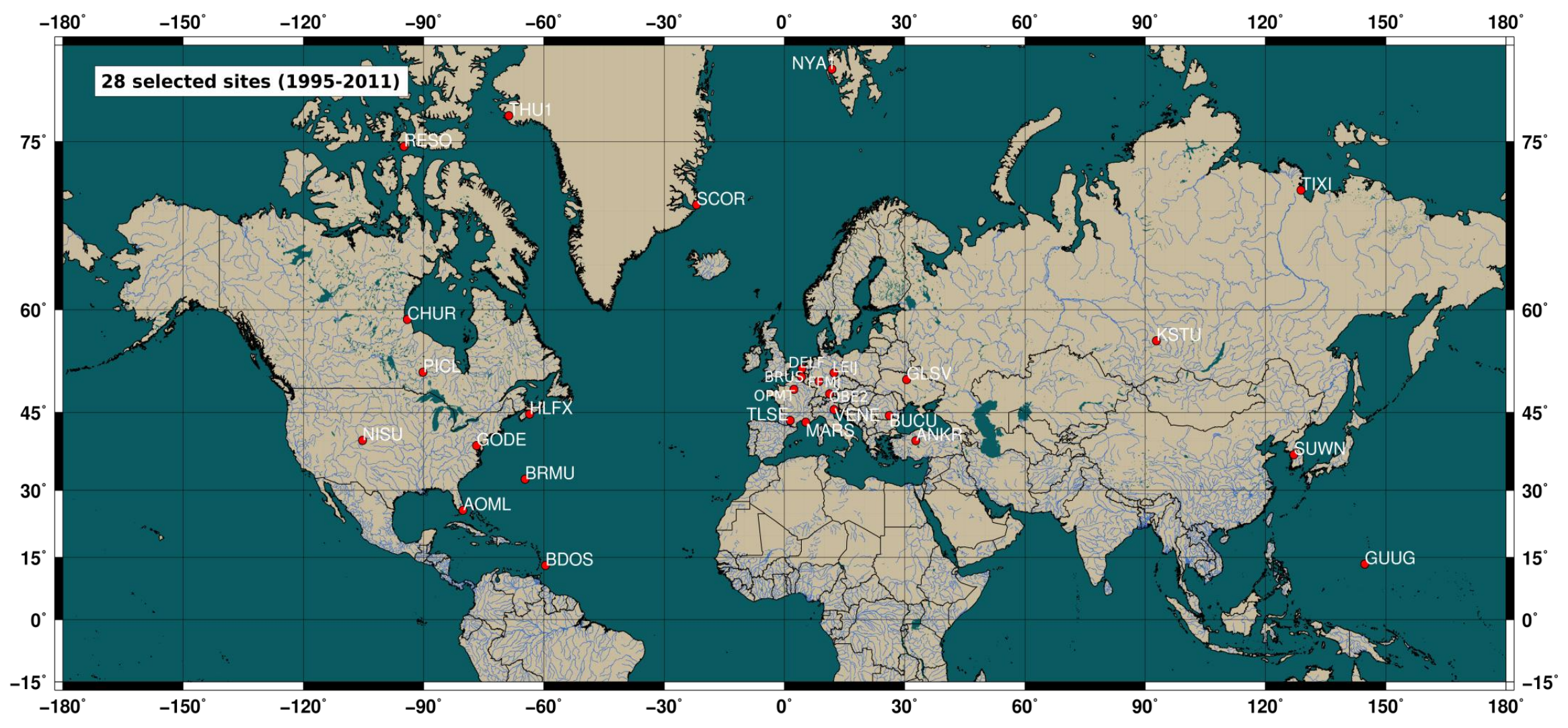

Fig. 1: Map of the selected sites that host at least 2 of the considered instruments.

THE IWV INTER-TECHNIQUE COMPARISON

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: 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 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-based IGS IWV is 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.

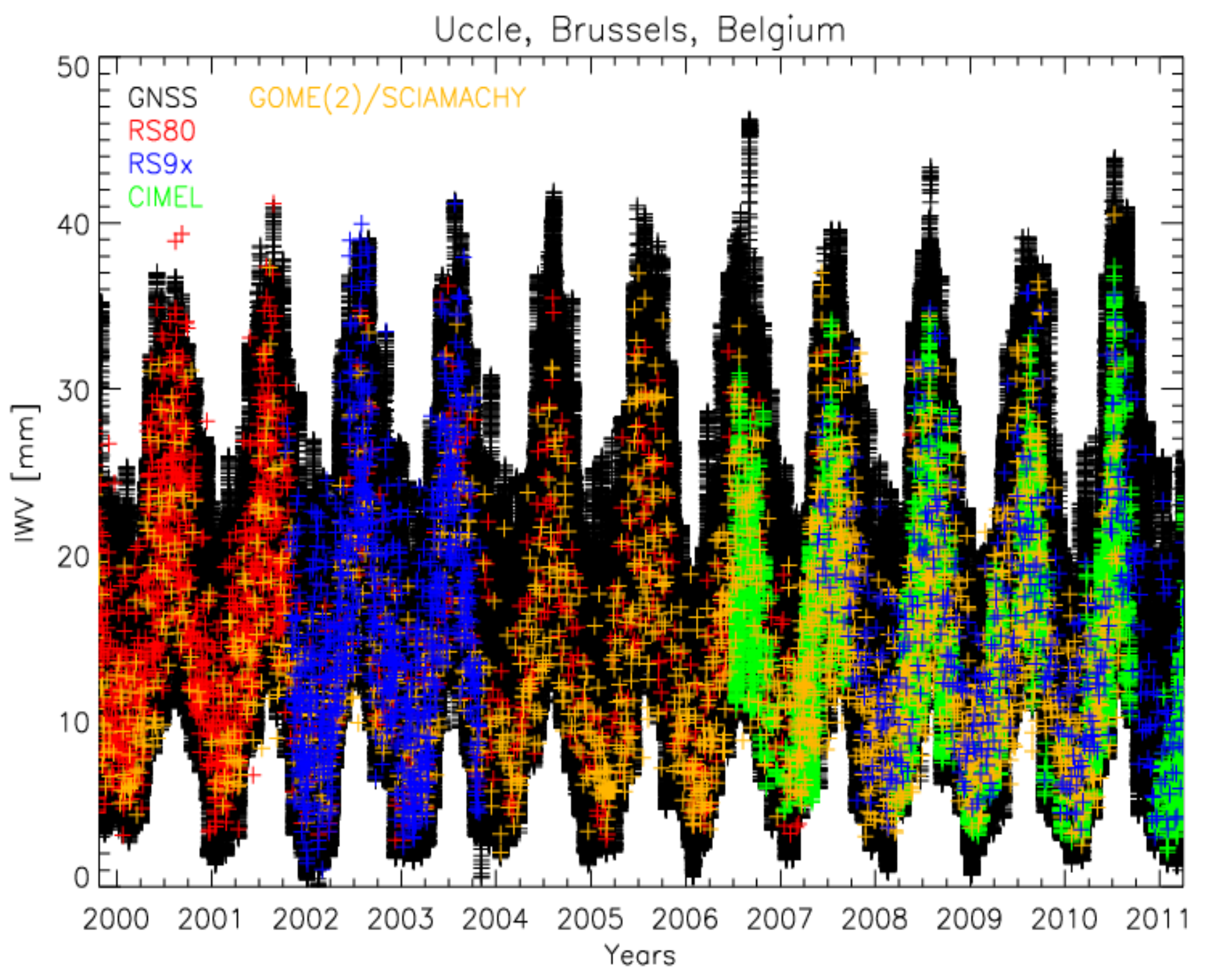

Fig. 2: Overview of all IWV data available at Uccle, Brussels.

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.

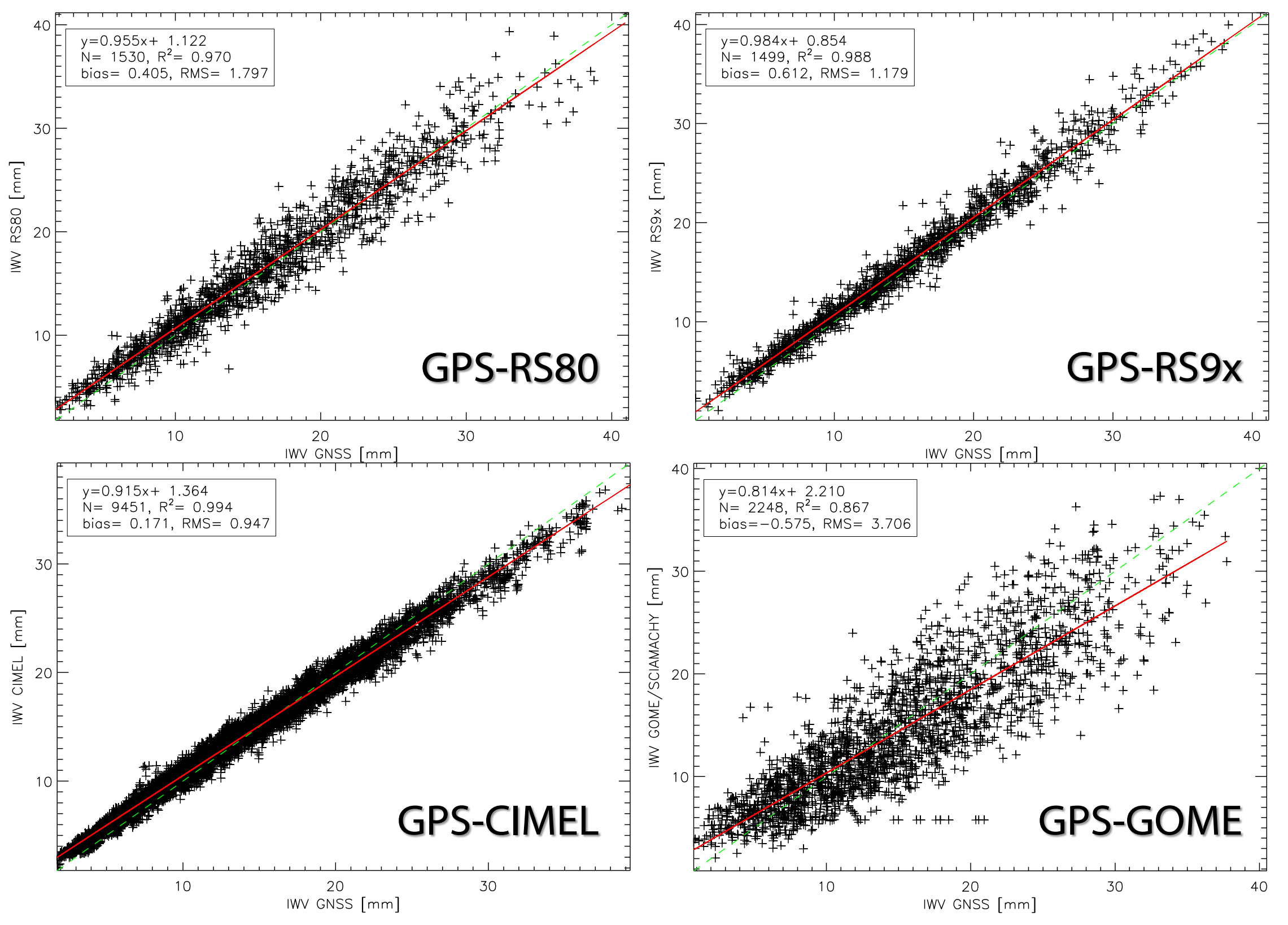

Fig. 3: Scatter plots of simultaneous IWV measurements of the different instruments with respect to the GNSS device.

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 Fig. 4 and Fig. 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.

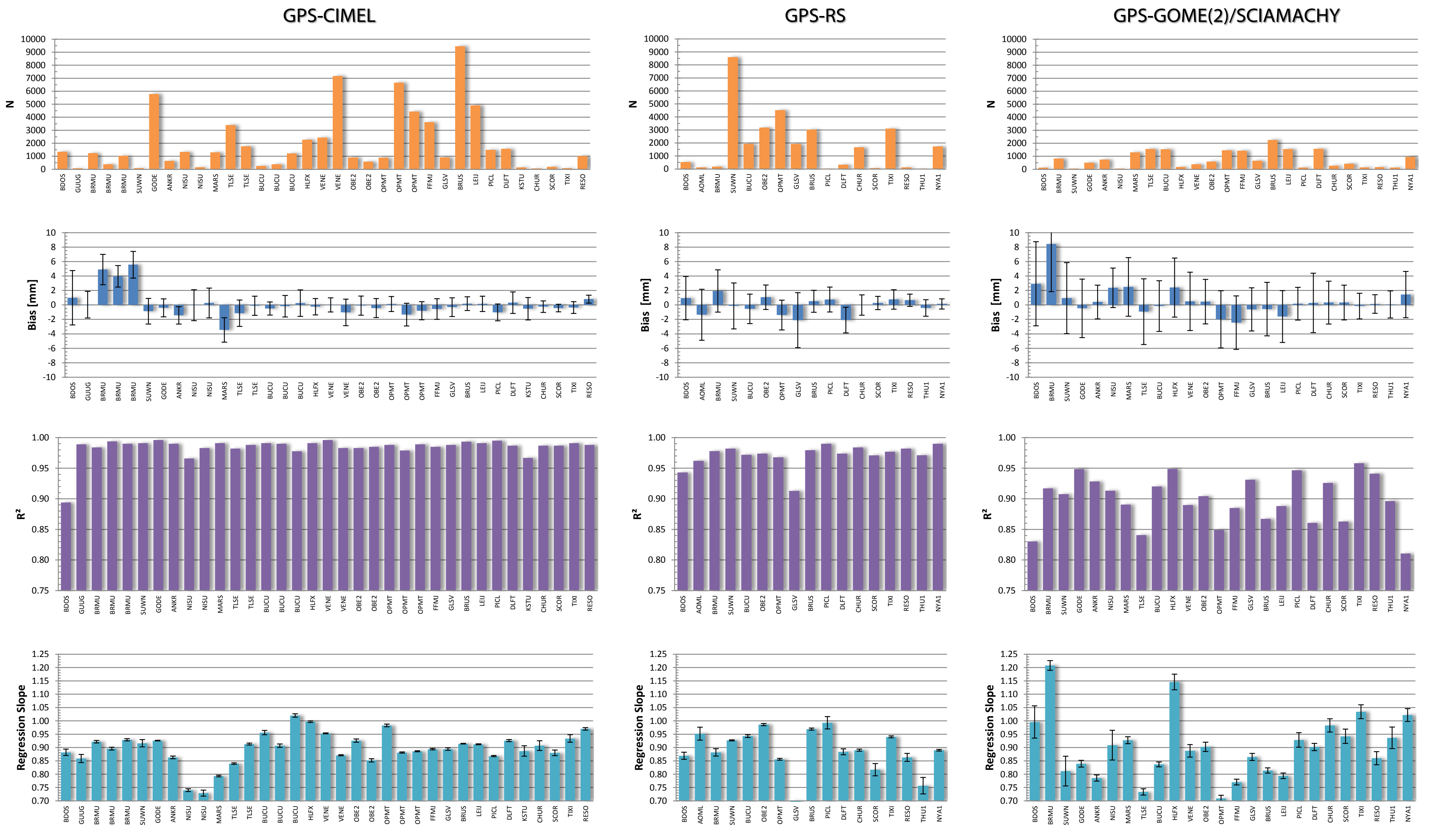

Fig. 4: Column bar plots of scatter plot properties (count N, bias, R^2 and regression slope) of the different instruments versus GNSS for the selected sites worldwide. Sites are ordered with increasing latitude. The error bars represent the RMS (bias) and the standard deviation (regression slope).

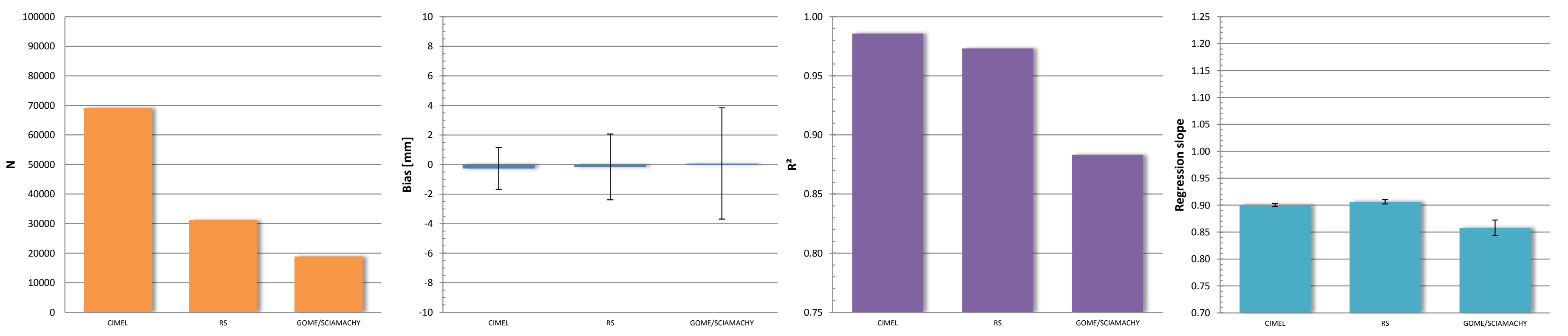

Fig. 5: Column bar plots of scatter plot properties (count N, bias, R^2 and regression slope) of the different instruments versus GNSS averaged over all stations included in the inter-technique comparison. Error bars: see Fig. 4.

CONCLUSIONS AND PERSPECTIVES

Conclusions:

- Ground-based and in-situ IWV measurements techniques typically agree at the level of 0.3 mm ± 2mm of IWV. However, different radiosonde types compare differently to the co-located GNSS instrument (different biases, larger scatter when different RS types are launched in time). Comparisons with satellite-based techniques show slightly higher biases and more variability (~ 4 mm of IWV).
- Influence of the clouds: for large IWV values, GNSS measures higher values than CIMEL does. Sun photometers require clear sky in the direction of the sun. But the larger the IWV values, the higher the probability to have clouds ; the latest contributing directly to the GNSS, but not to the CIMEL observations. GOME(2)/SCIAMACHY IWV measurements are susceptible to a similar observation bias.
- No clear geographical pattern (e.g. w.r.t. climate type) was found out of our inter-technique comparison. Satellite-based techniques show the largest (but apparently random) geographical variability (w.r.t. the collocated GNSS).
- CIMEL sun photometers and GNSS are thus very valuable techniques to measure IWV and are the most promising to build up long time series for climate applications (data homogeneity guaranteed thanks to regular calibration and homogeneous reprocessing).

Perspectives :

- Exploit the full potential of the IGS network (~ 110 stations with 15+ year observations) by using the IGS reprocessed tropospheric product to investigate climate trends and variability (+ cross-validate with CIMEL sun photometer and radiosonde observations).
- Further exploit the IGS reprocessed tropospheric product to 1) quantify systematic bias in satellite-based IWV products (e.g. cloud cover or calibration) and 2) validate these satellite-based IWV products and their influence on the analysis of climate trends in the IWV time series.

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