Royal Meteorological Institute of Belgium
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Max Planck Institute for Chemistry
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Solar-Terrestrial Centre of Excellence
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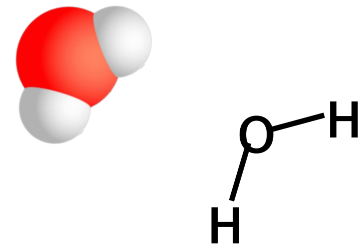
An integrated water vapour trends analysis based on more than 15 years of world-wide GPS and GOME/SCHIAMACHY/GOME-2 retrievals.

R. Van Malderen[1,5], E. Pottiaux[2,5], **H. Brenot**[3,5], S. Beirle[4], T. Wagner[4], H. De Backer[1], and C. Bruyninx[2,5]

NORS/NDAAC/GAW meeting, Brussels, 2014/11/5-7

Motivation

Water vapour



H_2O

- most important greenhouse gas, as it absorbs and emits radiation across the entire longwave spectrum
- dominant feedback mechanism in the climate system
- provides main source of moisture for precipitation

Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC, WG3)

http://gnss4swec.knmi.nl

Outline

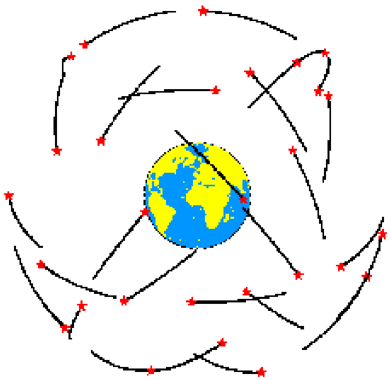
GNSS technique and Integrated Water Vapour content (IWV)

IWV techniques intercomparison (28 IGS GPS stations selected)

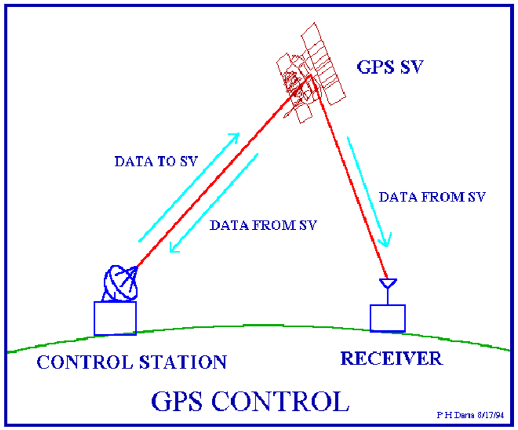
IWV database for climatology (101 IGS GPS stations selected)

Preliminary results of IWV trends (1995 - 2011)

Outlook



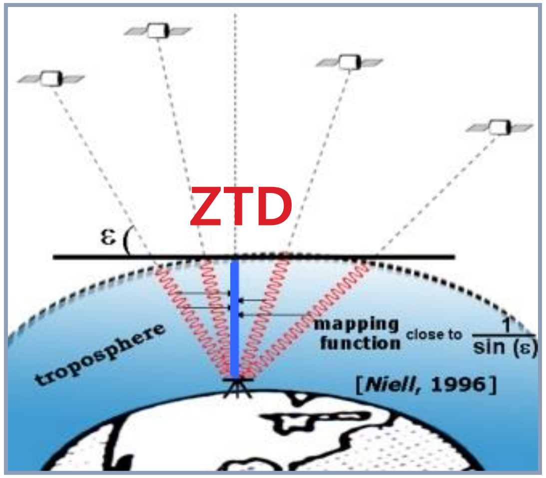
- **Architecture of Global Navigation Satellite Systems (GNSS)**
  - spatial segment (constellation of satellites)
  - control segment (network of bases)
  - user segment (antennae & receivers)
- **Example of GNSS: the Global Positioning System (GPS)**

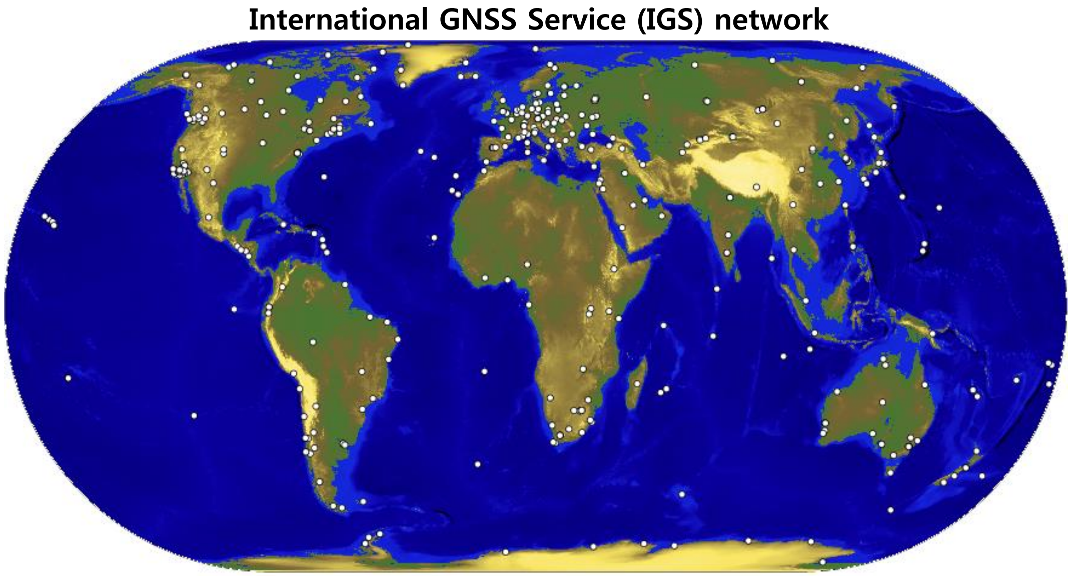


BRUS GPS station (ROB).

GNSS technique and IWV contents

- **Architecture of Global Navigation Satellite Systems (GNSS)**
  - spatial segment (constellation of satellites)
  - control segment (network of bases)
  - user segment (antennae & receivers)
- **Example of obs. network: the International GNSS Service (IGS) network**





453 GPS stations available, some since the 90's
(actually 387 active stations)

Zenith Total Delay of the neutral atmosphere (ZTD)

ZTD = ZHD + ZWD

"hydrostatic" delay

induced by all the neutral atmosphere (dry and wet)

"wet" delay

Specific additional contribution of the wet atmosphere

Integrated Water Vapour content (IWV)

ZTD_{GNSS}

$P(ground)$ and $T(ground)$

hydrostatic formulation
[*Saastamoinen*, 1972]
[*Davis et al.*, 1985]

$ZHD_P = f\,(P(ground), lat, alt)$

conversion factor
[*Askne and Nordius*, 1987]
[*Bevis et al.*, 1992}

$$ZWD_{GNSS} = ZTD_{GNSS} - ZHD_P$$

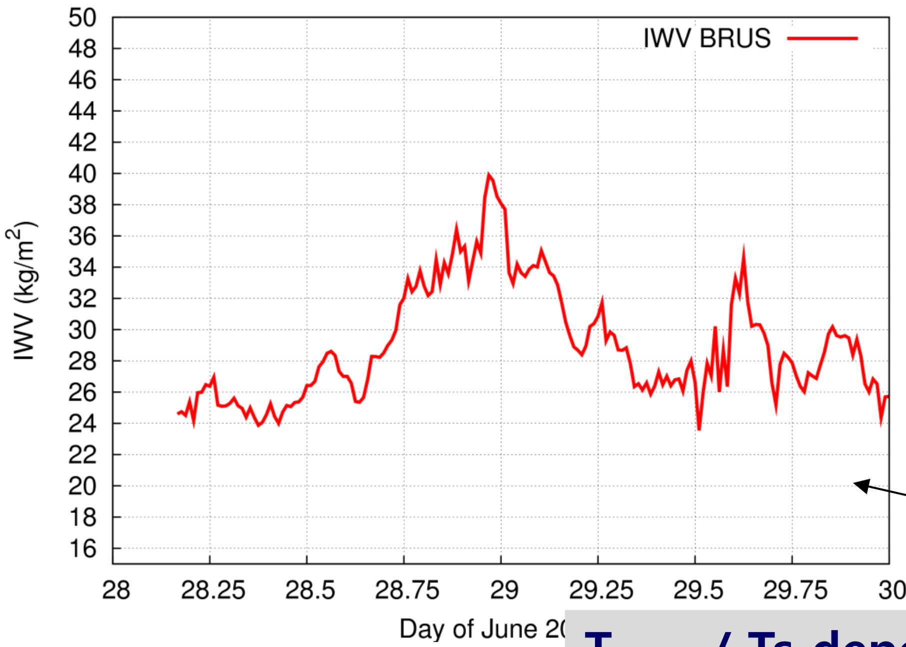
$$\kappa = \kappa\,(T_{mean})$$

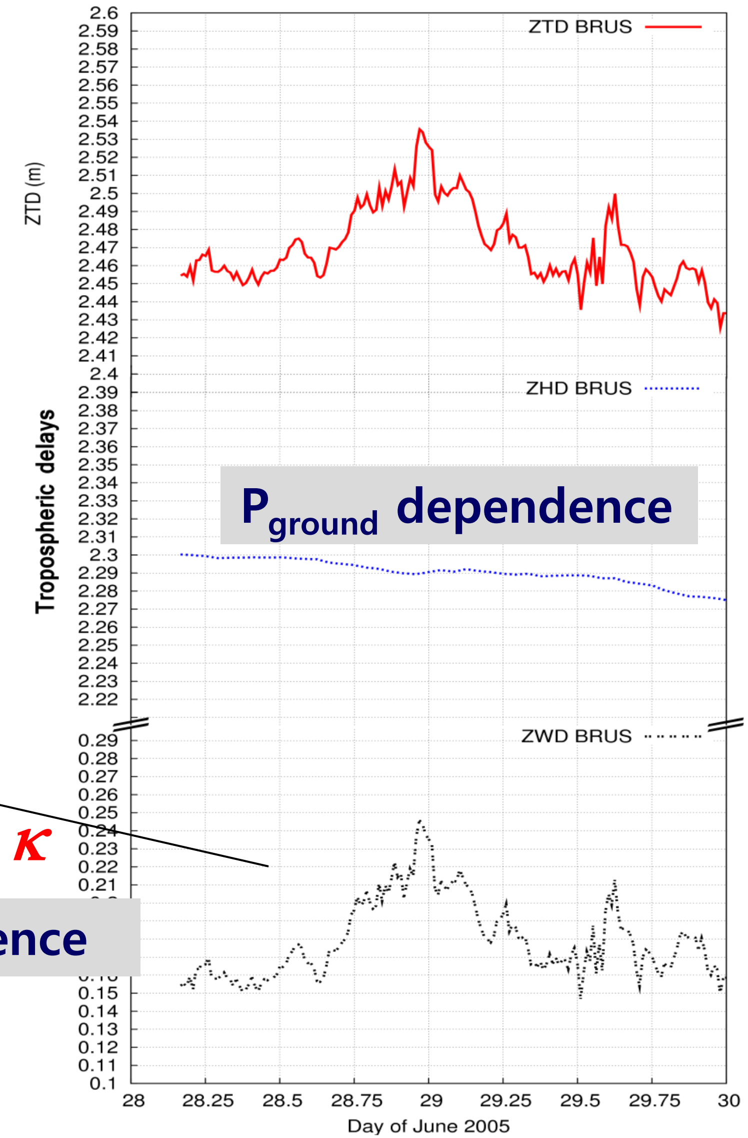
Can be approx. by using Tground

$$IWV_{GNSS} = \int \rho_v \mathrm{dz} \approx \kappa \,.\, ZWD_{GNSS}$$

Water vapour density

Integrated Water Vapour (IWV) equivalent to precipitable water





P_{ground} dependence

κ

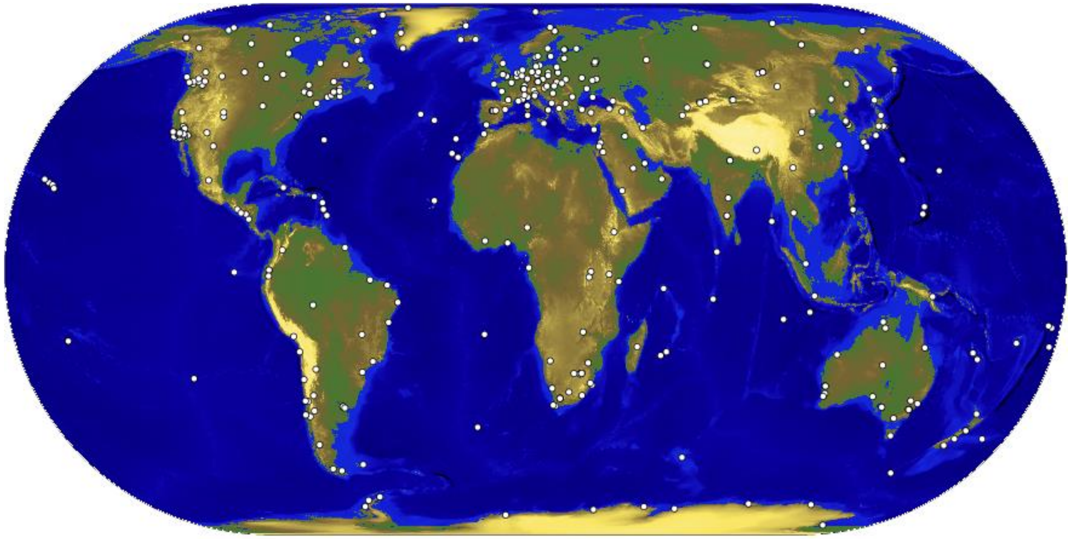
T_{mean} / Ts dependence

GNSS technique and IWV contents

GNSS/GPS Reprocessing Activities (mandatory for long-term trend analysis)

- International GNSS Service (IGS) database (homogeneous Reprocessing 1995-2011, GPS only)
- At all weather conditions, always
- High time frequency (every 5 minutes)
- T_{mean} and P_{ground} are needed: Zenith Total Delay → IWV conversion needed

International GNSS Service (IGS) network



453 GPS stations available, some since the 90's
(actually 387 active stations)

IWV techniques intercomparison

Van Malderen, R., Brenot, H., Pottiaux, E., Beirle, S., Hermans, C., De Mazière, M., Wagner, T., De Backer, H., and Bruyninx, C.: A multi-site intercomparison of integrated water vapour observations for climate change analysis, Atmos. Meas. Tech., 7, 2487-2512, doi:10.5194/amt-7-2487-2014, 2014.

GOME/SCIAMACHY/GOME-2

satellite

AIRS

NASA

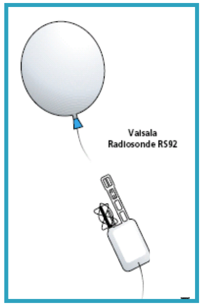
IWV ~ TCWV ~ PW

ground-based

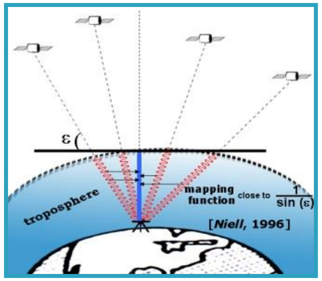
CIMEL sun photometer

radiosondes

In situ

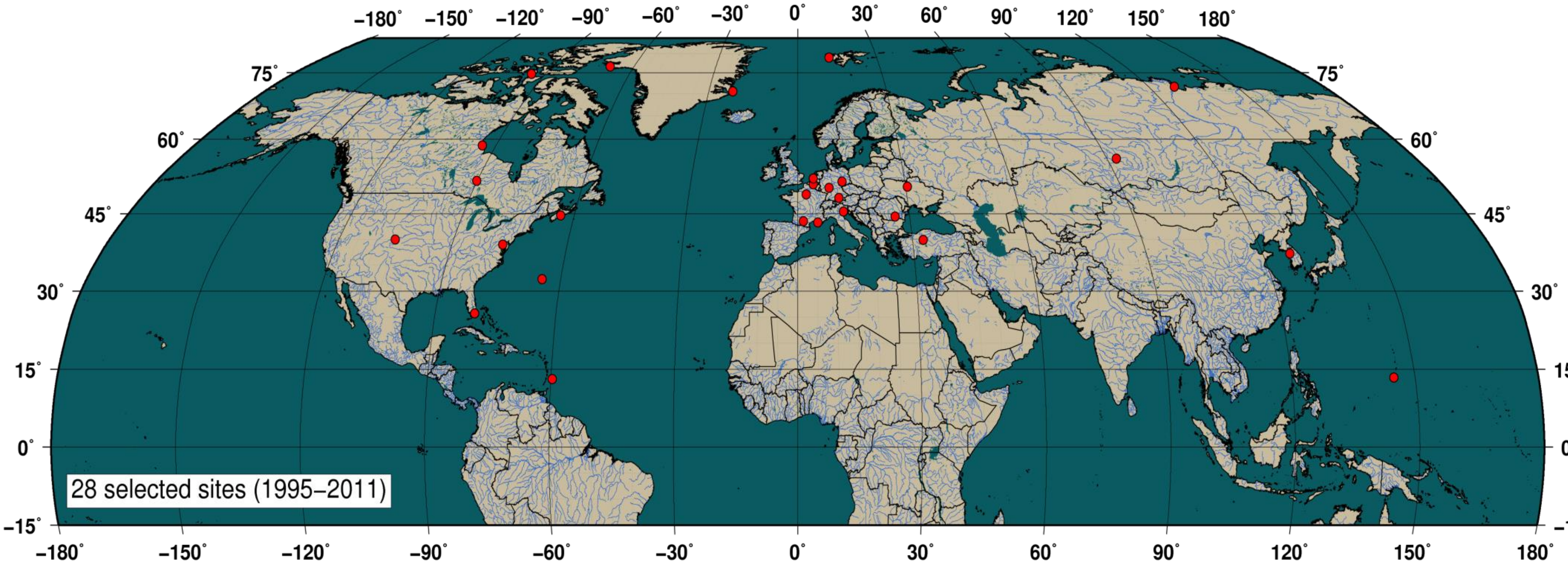


GPS (IGS)



Van Malderen et al., AMT, 2014

IWV techniques intercomparison

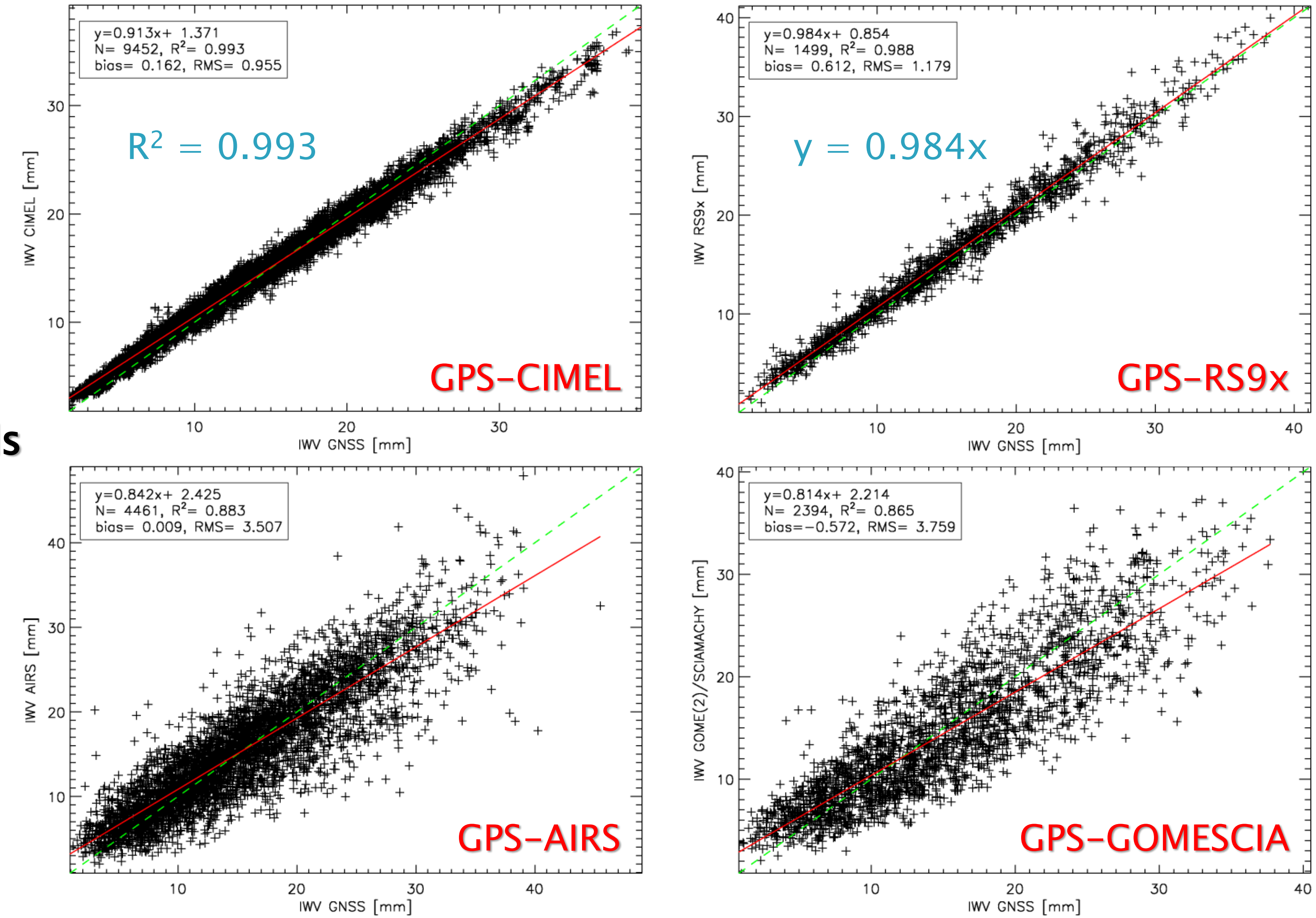


- selection of 28 sites world-wide (NH), with focus on CIMEL-GPS co-location and based on meteo data availability
- altitude correction between data (raw data, meteo data and IWV data) gathered at sites with different altitudes

Van Malderen et al., AMT, 2014

IWV techniques intercomparison

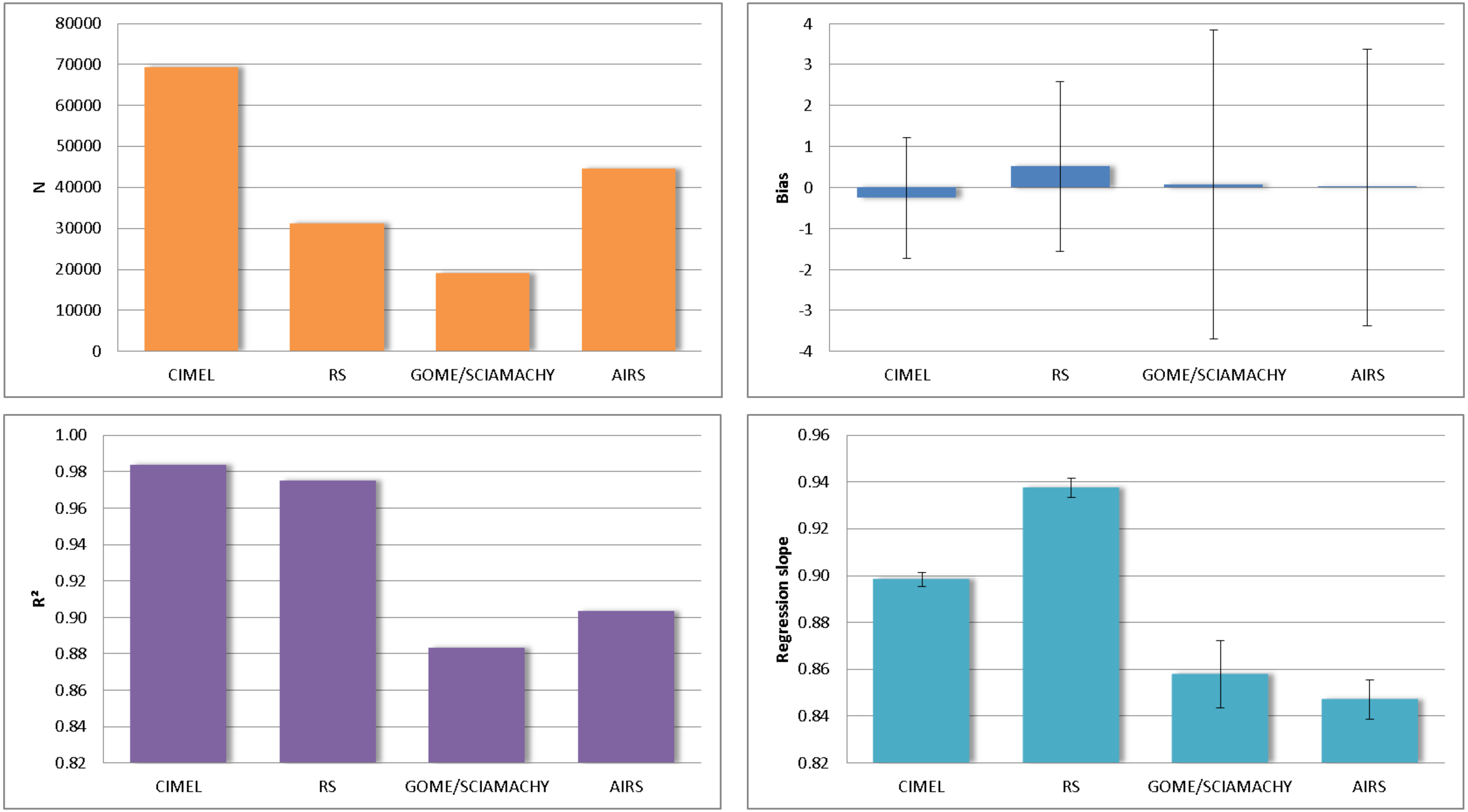
Brussels



- bias with GPS ranges between -0.6 mm and +0.6 mm

Van Malderen et al., AMT, 2014

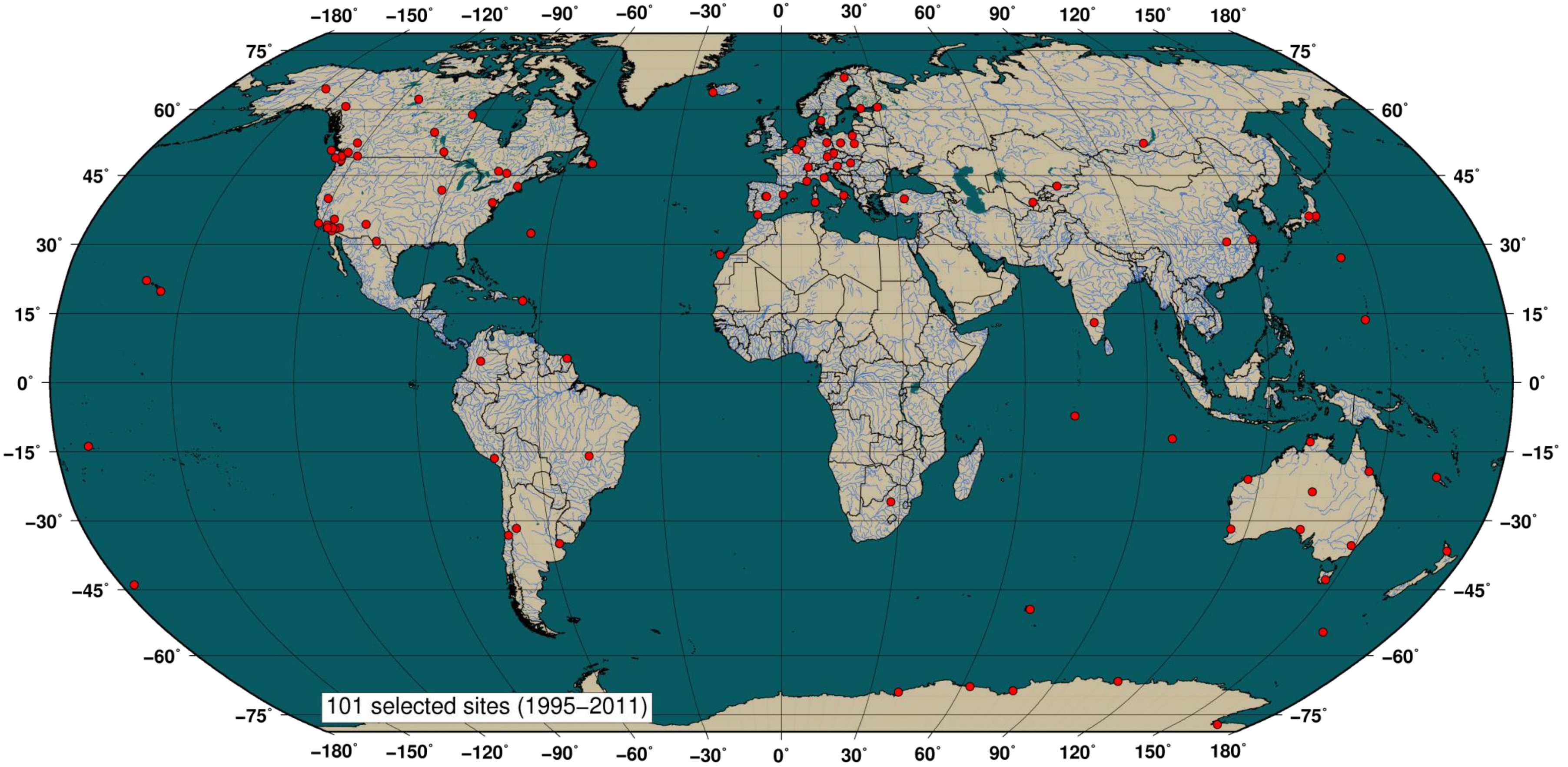
IWV techniques intercomparison



- scatter plot properties for the 28 co-locations, ordered with increasing latitute from left to right
- No geographical dependency

Van Malderen et al., AMT, 2014

IWV database for climatology



IGS station selected (homogenous processing for data since 1995 to 2011)

Establishment of GNSS IWV database:

- Use this dataset to study the sensitivity of IWV data and trends to cloudy conditions
- Study the sensitivity of the IWV conversion algorithms to different T_{mean}, T_{ground}, P_{ground} datasets (e.g. ERAinterim, NCEPNCAR, SYNOP) – impact on IWV biases and trends
- Screening and detection of outliers/breaking points is mandatory
- Homogenisation:

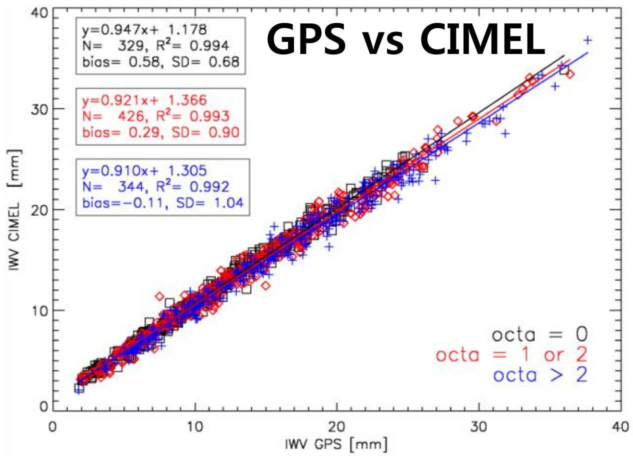
  - detection of change points looking at the difference between GPS-based and model-based IWV datasets (e.g. GPS versus ERAinterim)

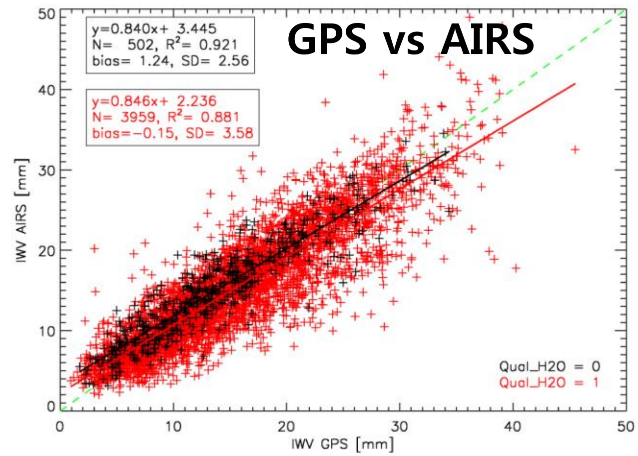
  - consistency in the ZTD → IWV conversion for any worldwide station

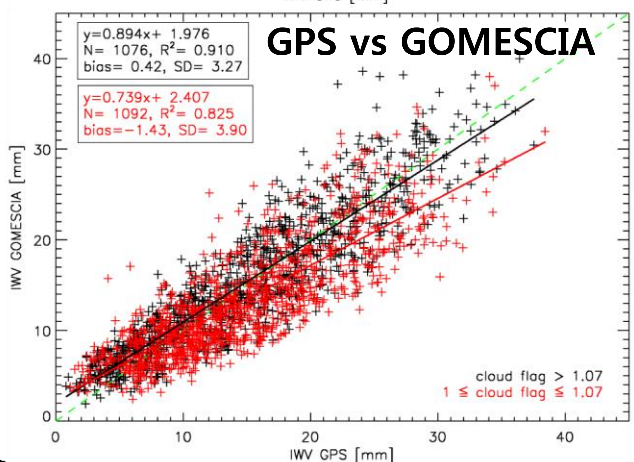
    ➔ use of P_{ground} and T_{mean} from model (ERAinterim & NCEPNCAR)

IWV database for climatology

- Sensitivity of IWV data and trends to cloudy conditions (preliminary results based on the 28 IGS site. Will be extended to the 101 IGS sites)







- cloud cover ↗ → regression slopes ↘ and correlation coefficients ↘
- GPS measurements incorporate contribution from clouds in directions towards satellites
- GOMESCIA and AIRS measurements inaccurate in cloudy conditions

➔ **clear sky/low cloud cover is the optimal condition**

Van Malderen et al., AMT, 2014

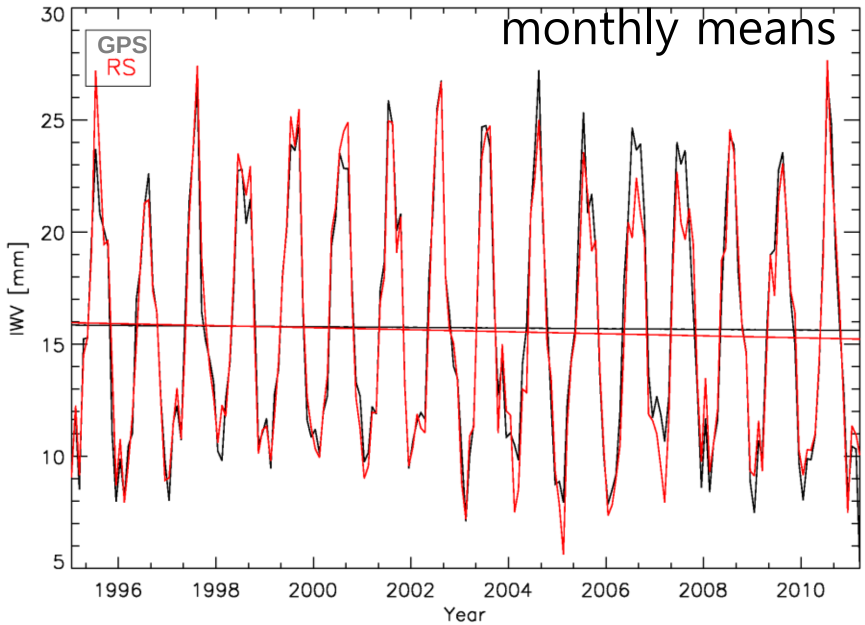
IWV database from other techniques:

- IGRA Radiosonde sites (systematic observational error)
- AERONET sun photometer measurements (regular instrument calibration)
- GOME-SCIAMACHY-GOME2 [UV-vis]] (partly clear sky needed)

IWV trends for all IGS stations starting in 1995

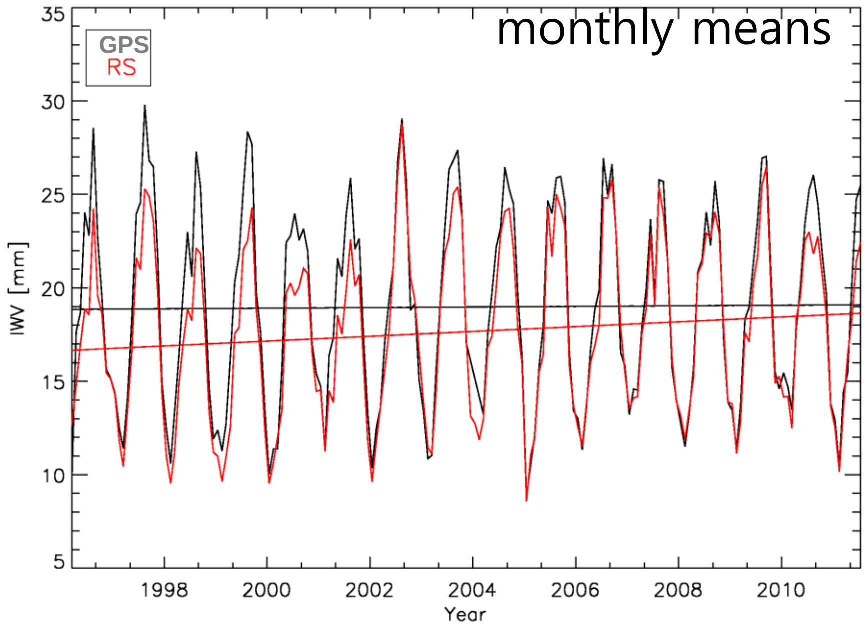
Comparison of trends with other techniques

Brussels (Belgium)



- although overall good agreement, small difference in trend slope between GPS and radiosonde time series (-0.15 vs. -0.45 mm/decade)

Cagliari (Italy)

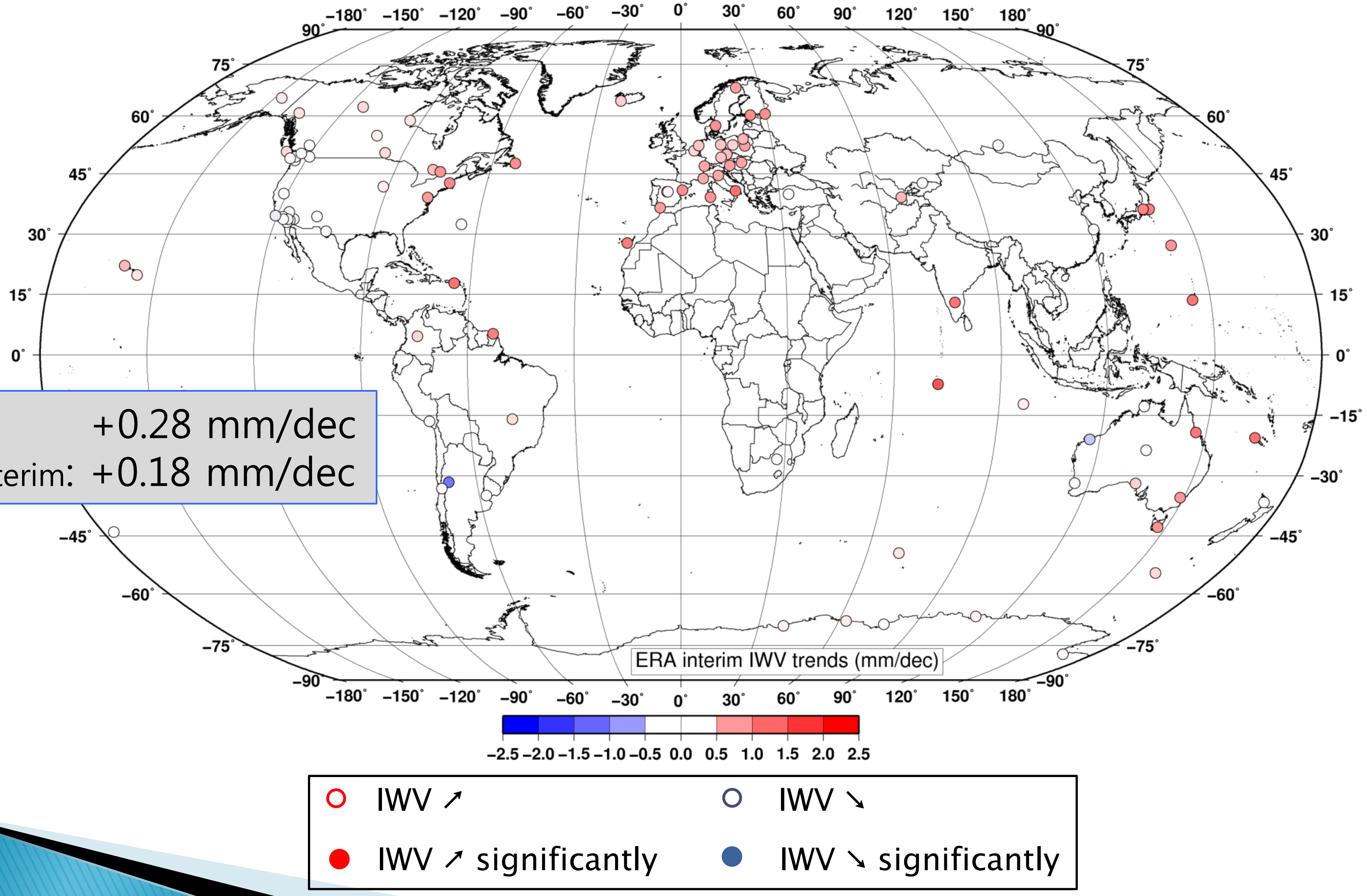


- RS IWV < GPS IWV in early years: instrumentation change for RS?
- Large difference in IWV trends (0.16 vs. 1.29 mm/decade)

➔ different databases give different trends

IWV trends for all IGS stations starting in 1995

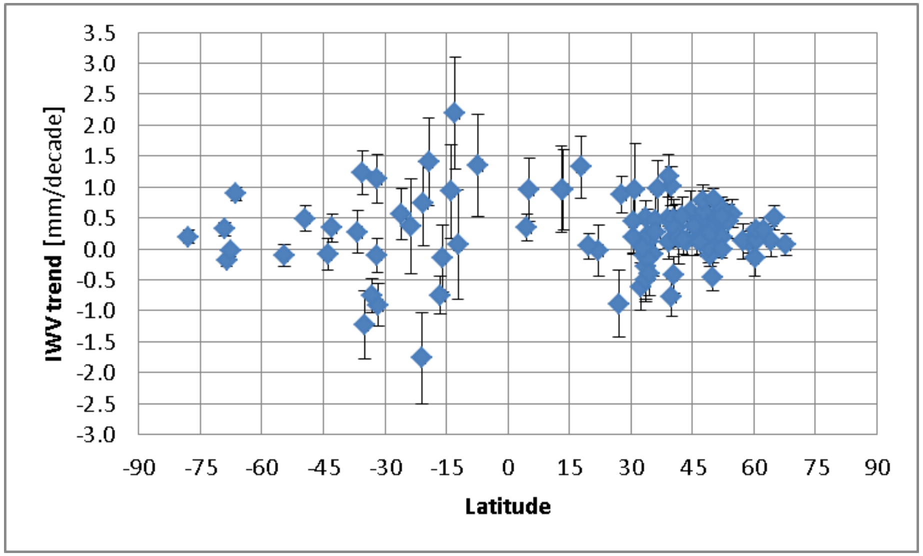
Comparison of trends with ERAinterim

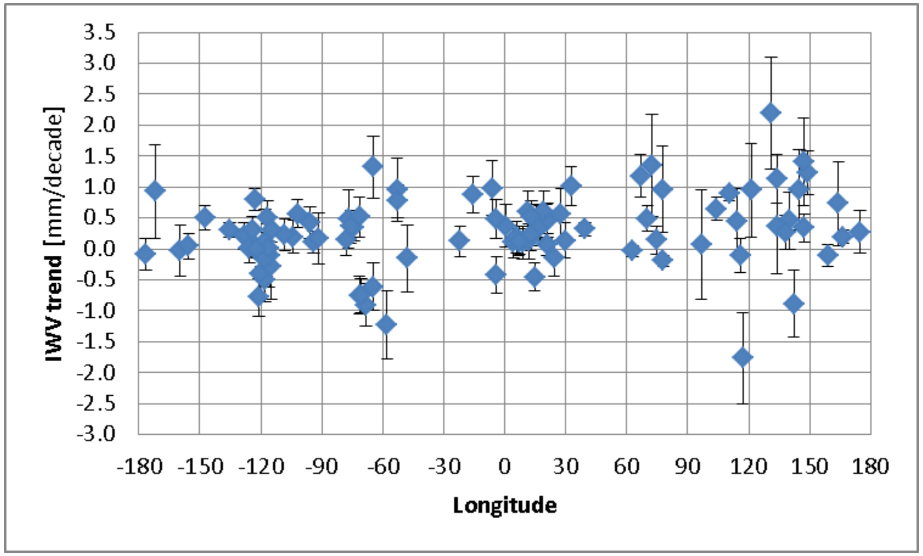


GPS: +0.28 mm/dec
ERAinterim: +0.18 mm/dec

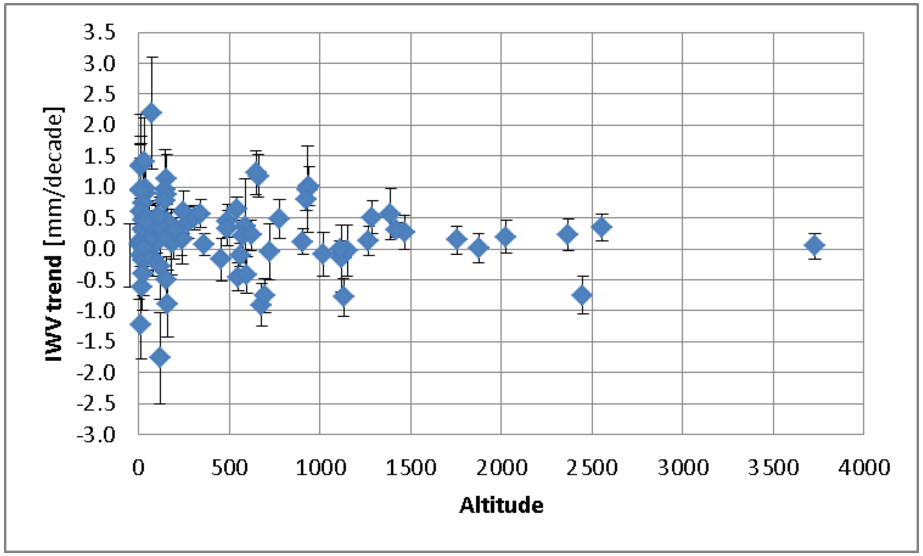
IWV trends for all IGS stations starting in 1995

Geographical dependency of the IWV trends





- smaller trends for higher latitudes?
- no longitudinal dependency
- larger variability in the trends for lower altitude stations



Outlook

- Preliminary results seems to indicate a global wetting as observed by the GPS IWV trends

- The region with the largest variability in the trends (30°N-30°S) is exactly the region where the strongest relation with (sea) surface temperature is expected/observed.

- At first sight, GPS IWV trends are not too strongly affected by the used meteorological dataset

  → the trends are really in the Zenith Total Delay data

Outlook

- Compare the IWV trends given by the satellite devices (GOME/SCIAMACHY/GOME2) to the GPS IWV trends at the 101 IGS stations

- Is there a day-time night-time difference and a geographical dependency for the different methodologies?

- Sensitivity of trends according to ZTD → IWV conversion?

- Impact of the cloud cover on trends? E.g. extend to the 101 IGS sites.

- Verification of "Water holding capacity" (relation IWV / temperature trends)? Does the relationship better holds for GPS IWVs or ERAinterim IWVs?

  A basic physical law (the Clausius-Clapeyron equation) tells us that the water holding capacity of the atmosphere goes up at about 7% per degree Celsius increase in temperature.

- Relationship IWV / pressure trends?

Thank you!