GPS-derived trends in the atmospheric water vapour content: comparisons to other techniques and correlations with trends in the mean temperature

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Motivation

- Realistic and reliable Integrated Water Vapour (IWV) trends can only be obtained from homogeneous IWV time series.
- Systematic errors affecting the IWV time series, e.g. caused by multipath, may vary over time.
- A higher elevation cutoff angle may be desired for the IWV trend estimation due to the lower multipath impact combined with the fact that the formal stochastic error of the individual IWV estimates is not the limiting factor for trend uncertainties *(Ning and Elgered, 2012).*
- Assessment of the assumption about conservation of the relative humidity, implying a ratio between changes in the IWV and the temperature of 7 %/K (*Trenberth et al.*, 2003).

The data sets

- Time period of 20 years (Jan. 1997 to Dec. 2016)
- Observations acquired from 13 GPS and 7 radiosonde sites (the distance between the GPS site and the nearest radiosonde site vary from 1 km to 119 km).
- IWV obtained also from ECMWF (ERA-Interim) after a vertical interpolation to the GPS antenna height.

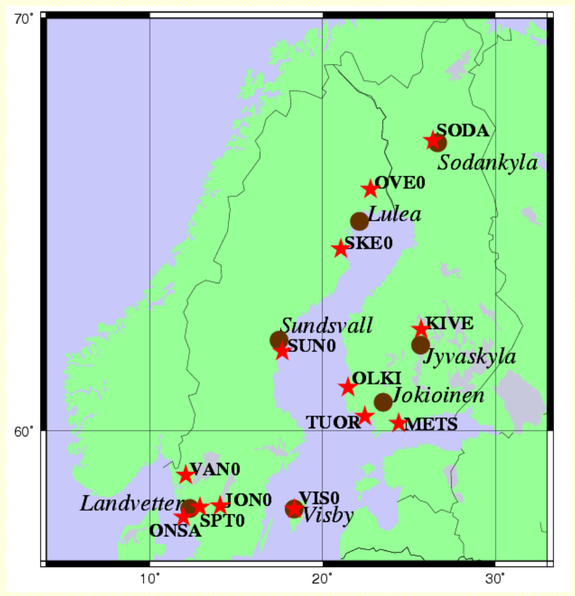

Fig. 1*: The 13 GPS sites (red stars) and the 7 radiosonde sites (brown filled circles).*

GPS data processing

We have processed GPS data using two different elevation cutoff angles 10° and 25°, to estimate the atmospheric IWV.

Table 1: *The models and parameters used for a standard GPS data processing.*

Model / Parameter	
GPS processing software	GIPSY v6.2 (*Webb and Zumberge, 1993*)
Strategy	Precise Point Positioning
Mapping function	VMF1 (*Boehm et al., 2006*)
Elevation cutoff angles	10° and 25°
Elevation-angle-dependent weighting	No
Ocean tide loading	FES2004 (*Lyard et al., 2006*)
Antenna PCV	igs08_1740.atx
Ambiguity resolution	Yes (*Bertiger et al., 2010*)

Reference

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For further information

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Interventions in GPS IWV time series

Any interventions in the GPS observations due to, e.g., antenna and/or radome changes, need to be corrected for before we estimated IWV trends using the GPS data. 6 GPS sites were found to have hardware changes over the investigated time period. Fig. 2 depicts the time series of monthly mean IWV difference for three sites in order to demonstrate the interventions in the GPS time series for JON0, ONSA and SPT0. The offset caused by each intervention was estimated as the mean difference in the GPS and ERA-Interim IWV difference time series before and after the occurrence of the intervention (see Table 2).

Table 2: *GPS site-related changes and the estimated mean IWV differences caused by the changes.*

Site	Date	Type of change	Mean difference for elevation 10° [kg/m^2]	Mean difference for elevation 25° [kg/m^2]
JON0	2002-08-23	Antenna	−0.16	−0.32
METS	2010-08-19	Antenna	0.29	−0.01
METS	2013-06-28	Antenna	−0.19	−0.22
ONSA	1999-02-02	Radome	0.63	−1.60
SKE0	2003-09-27	Antenna	−0.11	−0.04
SKE0	2008-03-14	Antenna	−0.27	−0.24
SPT0	2007-06-09	Absorber	−0.50	0.01
SPT0	2016-08-23	Antenna	−0.35	−1.40
VAN0	2003-03-30	Radome	−0.16	0.29
OLKI	2015-12-01	Radome	0.51	1.78

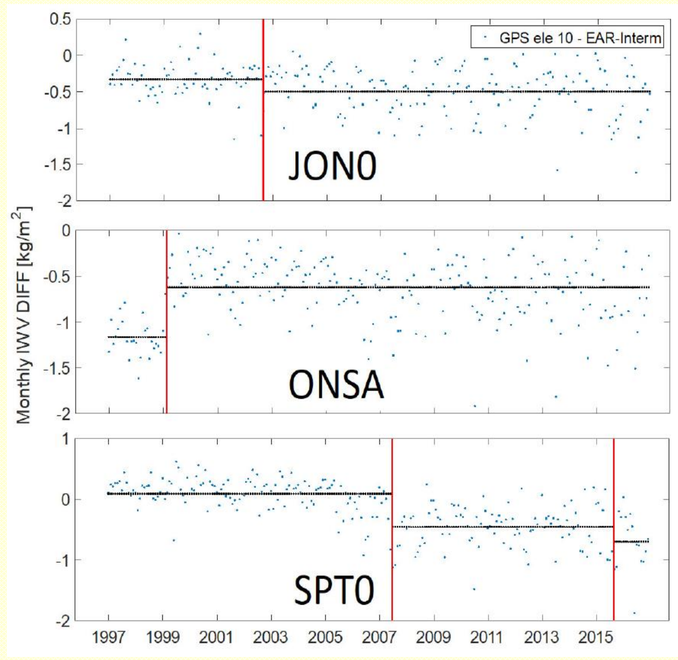

Fig. 2: *Time series of the monthly mean IWV difference (GPS– ERA-Interim). Dark lines are the mean of IWV difference, and red lines indicate the date of the interventions.*

Comparison to IWV trends from other techniques

We compared the GPS-derived IWV trends to the corresponding trends from the radiosonde data at 7 nearby sites and the trends inferred from ERA-Interim. As expected the lowest correlation (< 0.6) and larger RMS values (> 0.25 kg/(m^2·decade).) are given when we used the GPS data without offset corrections (see Fig. 3). The trend agreement is significantly improved when the GPS data were corrected for interventions (see Fig. 4) although we note that the data sets are no longer independent because we used the ERA-Interim time series to correct for the interventions. The results show a maximum increase in the correlation coefficient from 0.46 to 0.77 and a maximum decrease in the RMS difference from 0.31 to 0.14 kg/(m^2·decade). Furthermore the agreement of the trends between the two GPS solutions is also improved when the offset corrections were performed.

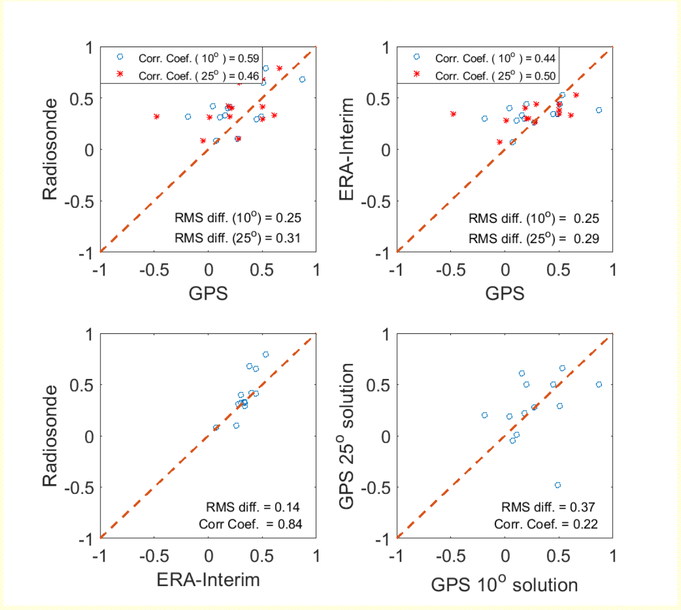

Fig. 3: *Correlations between the IWV trends (in kg/(m^2·decade)) from the two GPS solutions and the reference data sets. No offset corrections for the interventions were carried out in the GPS data. The dashed lines show the perfect agreement.*

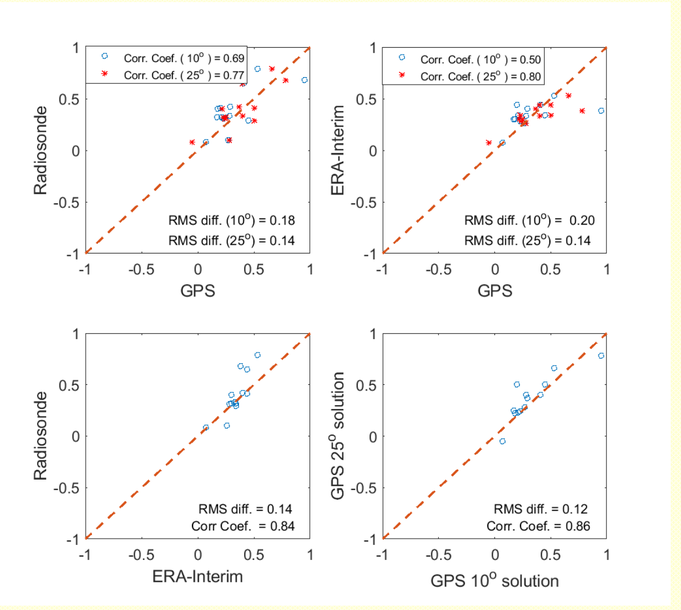

Fig. 4: *Correlations between the IWV trends (in kg/(m^2·decade)) from the two GPS solutions and the reference data sets. GPS data were corrected for interventions. The dashed lines show the perfect agreement.*

Comparison to trends in the mean temperature

The relative IWV trends from GPS, in percentage, are expected to be correlated with trends in the mean temperature, calculated from ERA-Interim. The mean temperature, T_m, of the wet refractivity in the atmosphere is calculated from the vertical profiles of the partial pressure of water vapour, p_w, and the physical temperature, T:

$$\int_S \frac{p_{\mathrm{w}}(s)}{T(s)}\mathrm{d}s = T_{\mathrm{m}} \int_S \frac{p_{\mathrm{w}}(s)}{T(s)^2}\mathrm{d}s$$

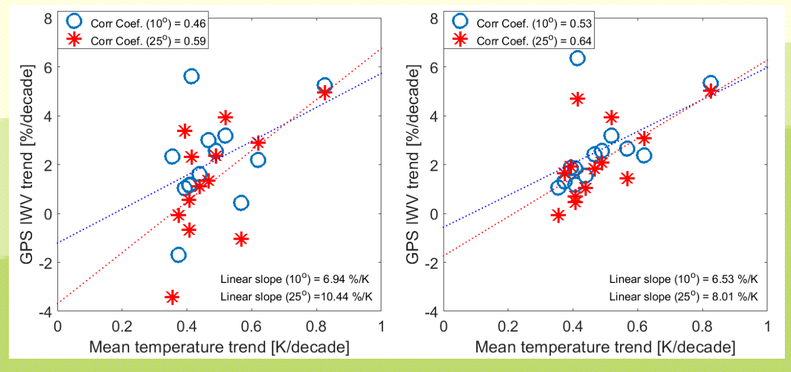

Fig. 6: *The correlation of the IWV trends from the GPS data, without offset corrections (left) and with offset corrections (right) to the corresponding trends in the mean temperature given by the ERA-Interim data.*

Conclusions

- Using different elevation cutoff angles is a valuable diagnostic tool that can be used to validate the homogeneity of the IWV time series.
- When we use the GPS data to monitor the long-term change in the IWV, e.g., as linear trends, it is recommended to apply at least two different elevation cutoff angles in the data processing. Ideally the IWV trends obtained from the two solutions with significantly different cutoff angle elevations should be the same if there are no significant systematic errors in the time series, or any other elevation dependent phenomena that affects the observations.
- The ratios of IWV and temperature trends in Fig. 6 have large uncertainties because of the small dynamical range and that we only have 13 data points. Therefore we calculate the mean values of the trends in the IWV and of the trends in the mean temperature for all sites. These ratios − representative for the specific area and time period − are 5.40 %/K and 4.44 %/K for the GPS 10° and 25° solutions, respectively

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