Trends in the atmospheric water vapour estimated using different elevation-angle-dependent parameters in the GPS data processing

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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.
- IWV obtained from a lower elevation cutoff angle solution may suffer from larger multipath effects.
- A higher elevation cutoff angle may be desired for the IWV trend estimation due to the lower multipath impact combined with the fact the that the formal stochastic error of the individual IWV estimates is not the limiting factor for trend uncertainties *(Ning and Elgered, 2012)*.

The data sets

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

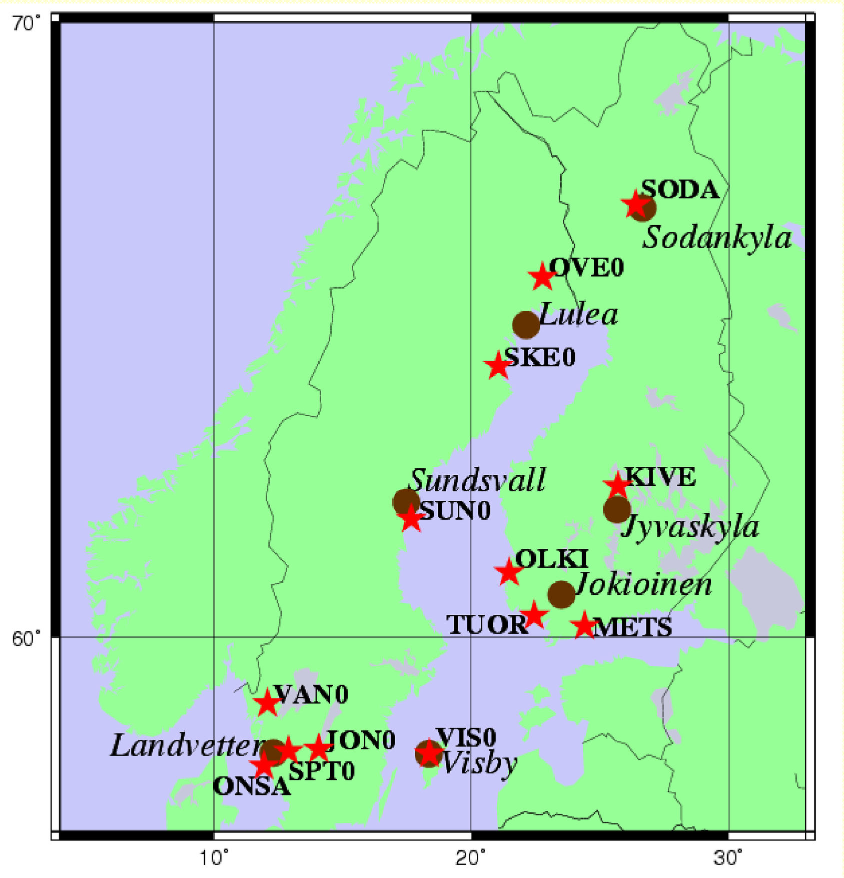

Fig. 1: The 13 GPS sites (red stars) and the 7 radiosonde sites (brown dots).

GPS data processing

We have processed GPS data using two different elevation cutoff angles 10º and 25º, to estimate the atmospheric IWV. We have tested three additional elevation-angle-dependent parameters in the GPS data processing, i.e., (1) two different mapping functions, (2) with or without second order corrections for ionospheric effects, and (3) with or without elevation dependent data weighting.

Model / Parameter	
GPS processing software	GIPSY v6.2
Strategy	Precise Point Positioning
Mapping function	Vienna 1 2006 (VMF1)
Elevation cutoff angles	10° and 25°
Elevation-angle-dependent weighting	No
Ocean tide loading	FES2004
Antenna PCV	igs08_1740.atx
Ambiguity resolution	Yes

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

For further information

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Interventions in GPS time series

Any known interventions in GPS observations due to, e.g., antenna changes and/or radome changes, need to be corrected for before we compare the GPS-derived IWV to the ones obtained from radiosondes and ERA-Interim. There are in total 6 GPS sites which have known hardware changes over the investigated time period. These changes are listed in Table 2 while 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.

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	Antennae	−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

Table 2: Known GPS station-related changes and the corresponding estimated mean IWV differences caused by the intervention.

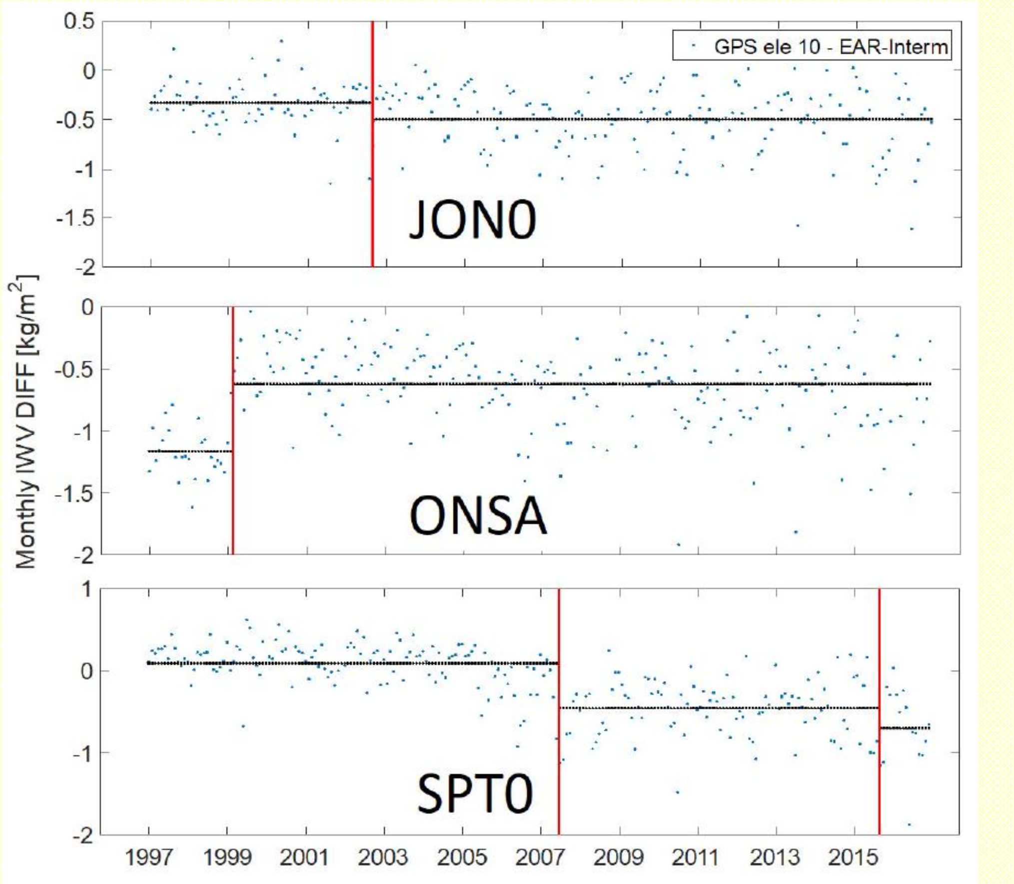

Fig. 2: Time series of the monthly mean IWV difference (GPS–ERA-Interim) for three sites: JON0, ONSA, and SPT0. Dark lines are the mean of IWV difference, and red lines indicate the date of the interventions.

Results I

- Table 3 presents the estimated trends together with the corresponding uncertainties. Offset corrections were implemented for all GPS sites with interventions. An overall result is that all estimated trends are positive (except one with a very small negative value). It is clear that the estimated IWV trends are comparable to the trend uncertainties, varying from 0.20 to 0.26 kg/(m^2·decade), for all techniques. In addition we observe that the trend differences between the GPS data and the radiosonde data show no clear correlation to the site separation.
- Table 3 also shows standard deviation (SD) of the trends (from 0.11 to 0.21 kg/(m^2·decade)) over all sites. The values given by *Ning and Elgered* (2012) were 0.33, 0.41, and 0.44 kg/(m$_2$decade) for the GPS elevation 10º solution, the elevation 25º solution, and radiosondes. The less consistence of the trends (large SD values) shown in *Ning and Elgered* (2012) is because of the shorter time period of the data (14 years) meaning that the trend shows more sensitivity to deviations from the model especially in the beginning and in the end of the selected time series.

GPS site	Radiosonde site	Distance [km]	Number of paired observations	Trend [kg/(m^2·decade)] GPS 10°	GPS 25°	Radiosonde	ERA-Interim
VIS0	Visby	1	11007	0.07±0.24	−0.05±0.24	0.08±0.25	0.07±0.23
SODA	Sodankylä	12	10756	0.45±0.21	0.50±0.23	0.29±0.22	0.34±0.21
SUN0	Sundsvall	35	15338	0.18±0.23	0.22±0.23	0.40±0.24	0.30±0.23
SPT0	Landvetter	37	11436	0.17±0.23	0.25±0.23	0.32±0.24	0.30±0.23
ONSA	Landvetter	37	11420	0.21±0.25	0.23±0.26	0.32±0.24	0.34±0.24
KIVE	Jyväskylä	47	9947	0.27±0.22	0.28±0.23	0.10±0.23	0.26±0.22
TUOR	Jokioinen	73	11644	0.53±0.26	0.66±0.26	0.79±0.25	0.53±0.25
METS	Jokioinen	83	12366	0.41±0.24	0.40±0.24	0.65±0.24	0.44±0.24
OVE0	Luleå	90	10805	0.20±0.20	0.50±0.20	0.41±0.23	0.44±0.20
SKE0	Luleå	90	10926	0.29±0.23	0.37±0.23	0.42±0.23	0.40±0.23
JON0	Landvetter	105	11636	0.23±0.23	0.24±0.23	0.31±0.24	0.28±0.23
VAN0	Landvetter	114	11584	0.28±0.23	0.40±0.24	0.33±0.24	0.33±0.23
OLKI	Jokioinen	119	10655	0.87±0.26	0.50±0.26	0.68±0.25	0.38±0.25
Mean trend				0.32	0.35	0.39	0.34
Standard deviation				0.21	0.18	0.21	0.11

Table 3: The estimated IWV trends from all data sets

Results II

- Fig.3 (a) depicts the comparison of the trends between the radiosonde data and the ones given by the GPS data for two different elevation cutoff angle solutions. Similar correlation coefficients (0.71 and 0.74) are observed for the 10º and 25º solutions, respectively. In addition, the 25º solution gives a slightly lower root-mean-square (RMS) difference (0.15 kg/(m^2·decade)). The GPS trends were also compared to the ones obtained from the ERA-Interim data (see Fig. 3(b)). A higher correlation coefficient (0.9) and a lower RMS difference (0.09 kg/(m^2·decade)) are seen for the elevation 25º solution than the ones (0.53 and 0.18 kg/(m^2·decade)) for the 10º solution.
- We also compared the GPS-derived IWV trends with a data weighting to the trends obtained from radiosondes and ERA-Interim. The results are shown in Fig.4 where the trend correlations and the RMS differences are in general slightly worse than using the GPS data without the elevation dependent weighting.

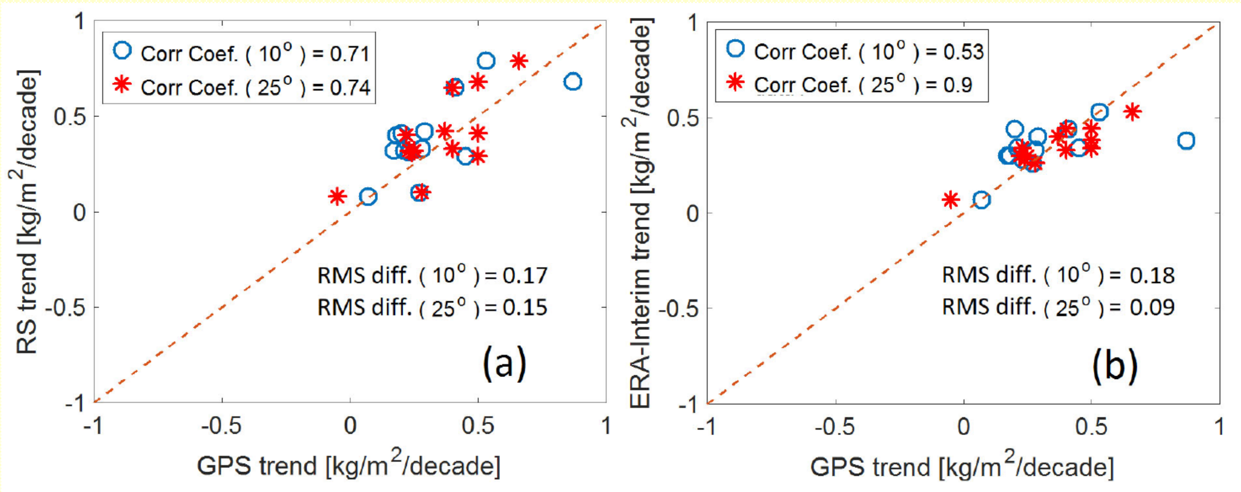

Fig. 3: Correlations between the IWV trends from the GPS and the radiosonde data (a), and the ERA-Interim data (b) for 10º and 25º elevation cutoff angles. The dash lines show the perfect agreement.

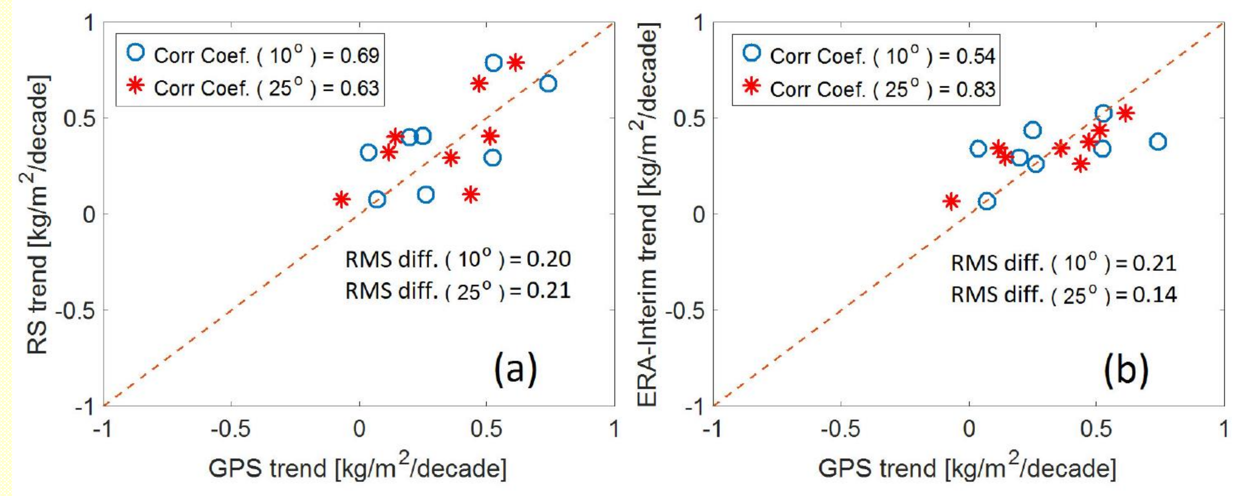

Fig. 4: Same as Fig. 3 but the GPS-derived trends were obtained from the data processing applying an elevation-angle-dependent weighting.

Reference

- Ning, T., and Elgered, G.: Trends in the atmospheric water vapor content from ground-based GPS: the impact of the elevation cutoff angle, *IEEE J-STARS*, *5(3)*, 744–751, doi:10.1109/JSTARS.2012.2191392, 2012.

Conclusions

- The selection of mapping function and the use of the second-order ionospheric corrections are not critical when using GPS-derived IWV for estimating linear trends over decades.
- Elevation dependent weighting does not improve the agreements and gives the same relative performance when comparing the solutions with the two different cutoff angles.
- Using different elevation cutoff angles is a valuable diagnostic tool that can be used for validation purposes and detection of possible site problems, such as multipath impacts.
- 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 significantly different cutoff angle elevation solutions should be the same if there is no significant long-term changes in the multipath impacts, or any other elevation dependent phenomena that affects the observations.

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