Validation of GPS-derived long-term trend in the atmospheric water vapor using homogenized radiosonde data

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Motivation

- Measurements of the atmospheric water vapor are of high interest for applications to both weather forecasting and climate research.
- With a relatively high temporal resolution, continuously improved spatial density, and less expensive receivers, ground-based GPS measurements have been identified as a useful technique to monitor long-term variations in the atmospheric integrated water vapor (IWV).

Objective

This study will focus on investigating uncertainties of long-term IWV trends obtained from the NCAR global, 2-hourly ground-based GPS IWV dataset. The IWV trends were estimated for 48 GPS sites covering the time period from 1997 to 2011. The GPS-derived IWV trends will be validated against those derived from co-located and homogenized NCAR radiosonde dataset.

Estimate IWV From the GPS Data

The water vapor reduce the velocity of radio signals from GPS satellites. The refractive index in the atmosphere is larger than one. Due to the fact that the refractive index depends on the humidity, it is possible to infer the atmospheric IWV, from estimates of these propagation delays (or the excess propagation path which is often expressed in units of length). A schematic for the estimates of the IWV from the GPS data is given in Fig. 1.

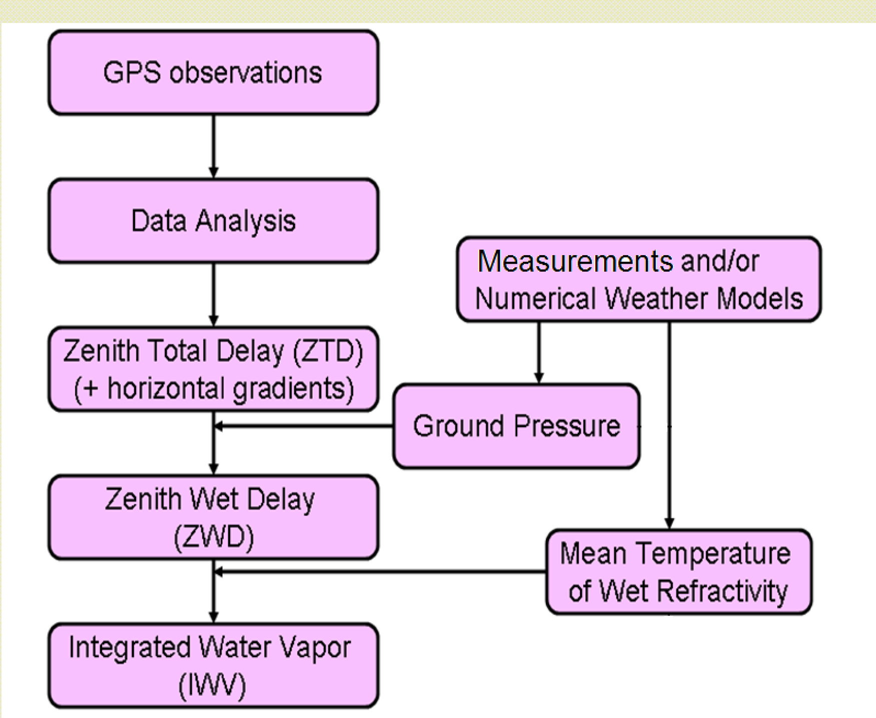

Fig 1: The schematic for estimating IWV from GPS observations.

Acknowledgement

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IWV Trends From the GPS Data

Linear trends in the IWV were estimated using the model:

$$Y = Y0 + A1\cdot t + A2\cdot\sin(2\pi t) + A3\cdot\cos(2\pi t) + A4\cdot\sin(4\pi t) + A5\cdot\cos(4\pi t)$$

where *Y* and *t* are the IWV and the time in years (from 1 Jan. 1997 at UTC 0:00 to 31 Dec. 2011 at UTC 24:00), respectively. The unknown coefficients *Y0*, *A1*, *A2*, *A3*, *A4*, and *A5* were determined through the method of least squares. Two examples the estimated linear trend for two GPS sites: REYK and GUAM are shown in Fig. 2.

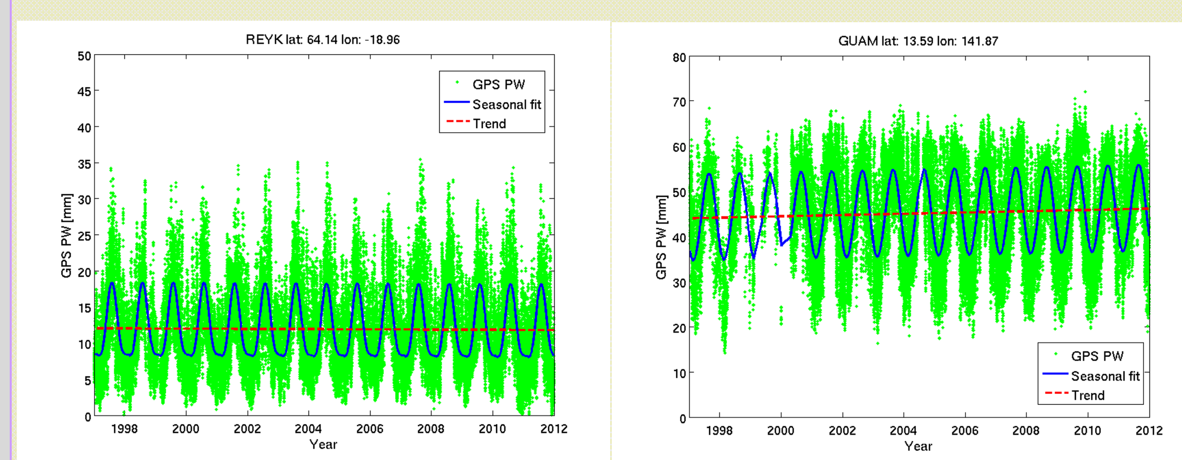

Fig 2: IWV time series, with the estimated seasonal and trend components, for two GPS sites: REYK and GUAM. The red straight line is the linear trend and the blue line is the seasonal components.

Uncertainty of the IWV Trend

The estimated linear trends have rather large uncertainties caused by the true short term variation (the natural variability of the weather) which are not described by the model. This phenomena means that trends, as well as their uncertainties, are typically larger for short time periods, and as time periods become longer both the trends and their uncertainties will decrease. Fig. 3 depicts such short term variations which were estimated from the residuals after fitting the IWV to the model.

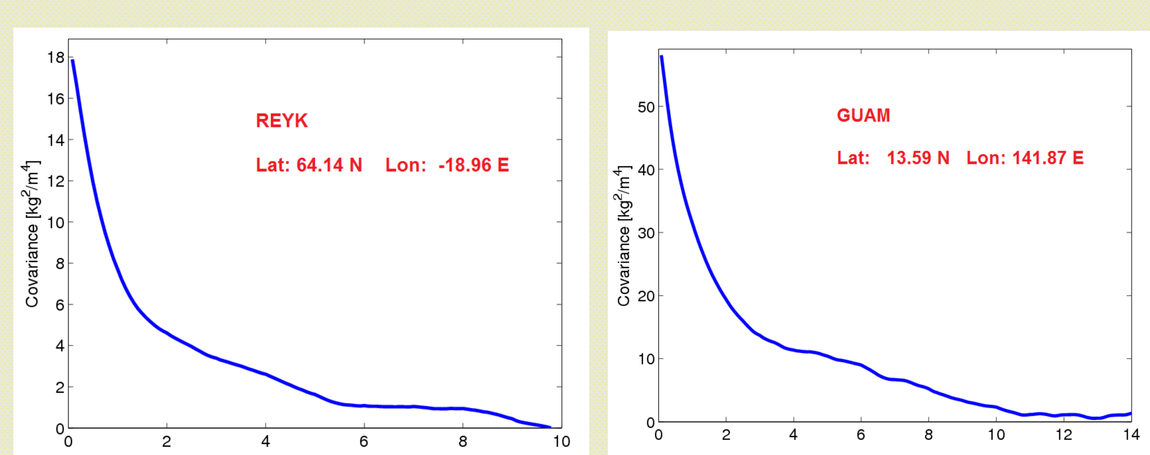

Fig 3: Short term variations in IWV for two GPS sites: REYK and GUAM.

The uncertainty of the IWV trend with a much smaller amplitude is caused by systematic errors in the GPS data, such as elevation-angle-dependent errors and changes of the GPS antenna and horizon mask. A comparison with the IWV trend estimated from homogenized radiosonde data acquired during the same time period will help us to quantify this type of uncertainty, since the expected differences should be significantly smaller.

Results

GPS 15 yr trends v.s. Radiosonde >30 yr trends:

The GPS data were obtained from the NCAR global, 2-hourly ground-based GPS IWV data set. The IWV trends were estimated for 48 GPS sites covering the time period from 1997 to 2011.

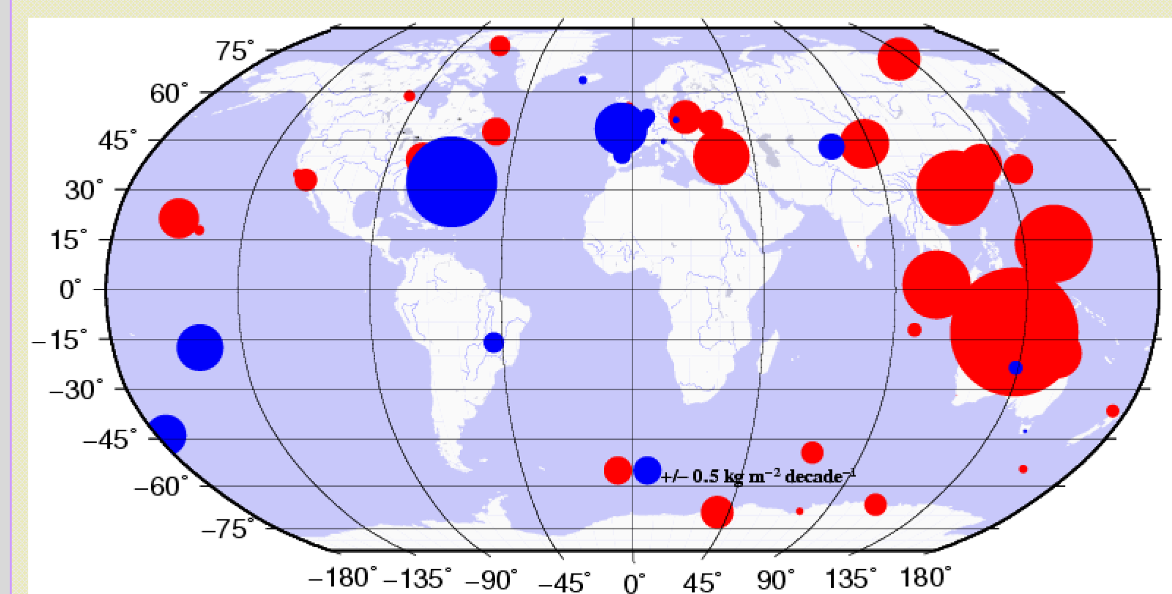

Fig 4: Estimated linear IWV trends (kg/(m^2·year)) for 48 GPS sites.

The IWV trends were also estimated for 101 radiosonde sites, using NCAR homogenized daily data, with a time period over 30 years (1973–2011).

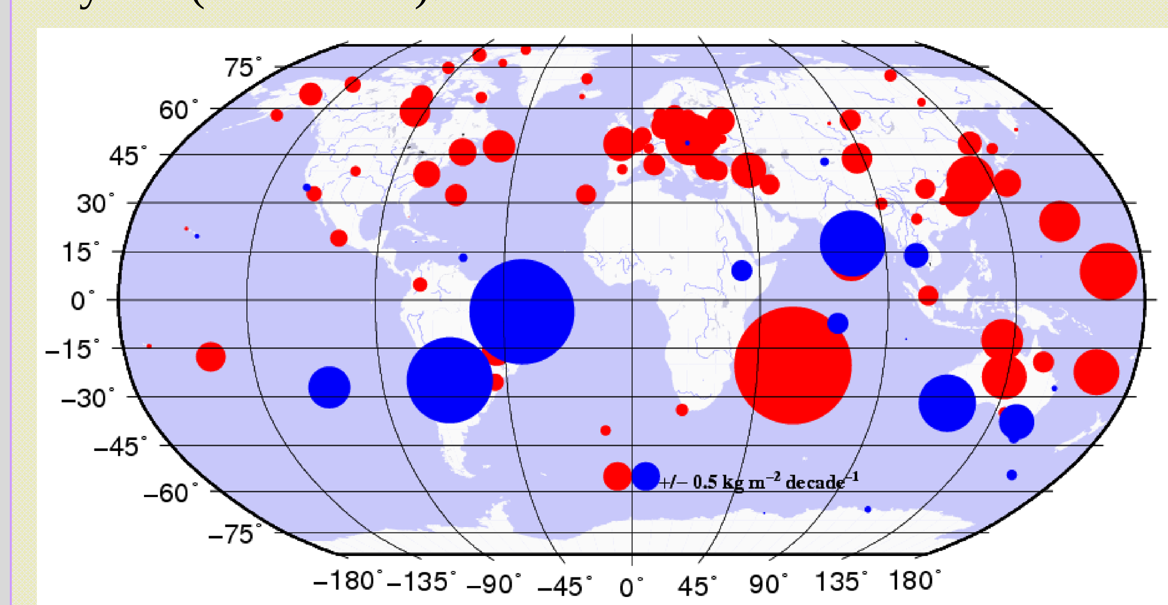

Fig 5: Estimated IWV trends (kg/(m^2·year)) for 101 radiosonde sites.

Trend Uncertainty:

The uncertainty of the radiosonde-derived trend is much smaller due to the longer time period used for trend estimation. The amplitude of the uncertainty is clearly latitude dependent.

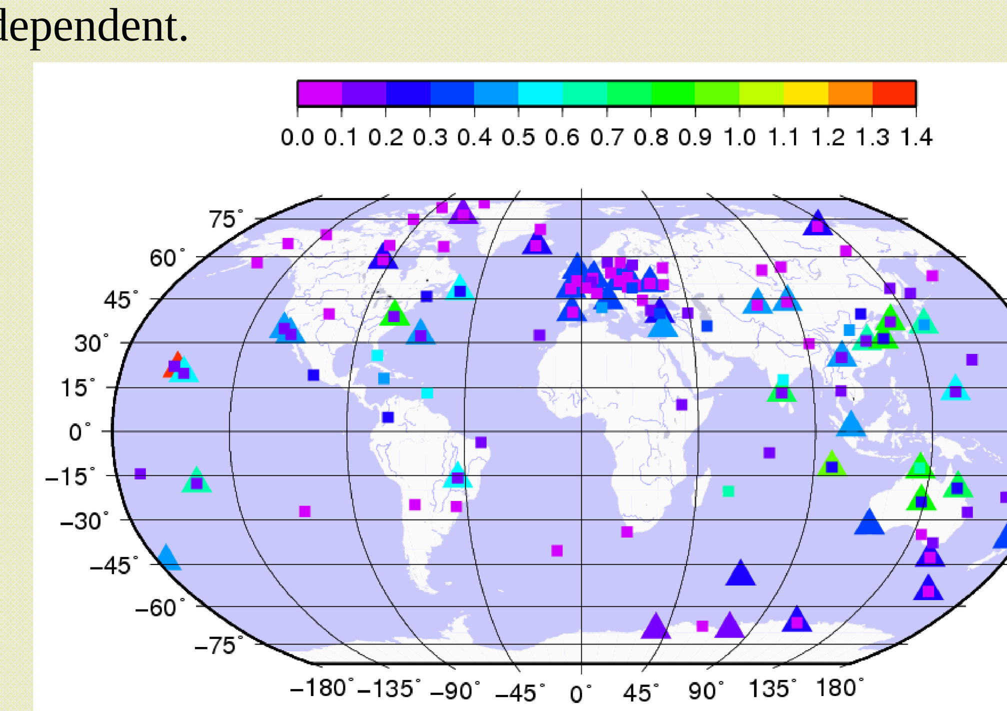

Fig 6: Trend uncertainties after taking the short-term variation of IWV into account for the GPS (triangles) and the radiosonde data (squares).

Results

GPS 15 yr trends v.s. Radiosonde 15 yr trends:

41 radiosonde sites, co-located to GPS sites with a horizontal distance smaller than 50 km and a height difference smaller than 100 m, were used. After synchronizing the radiosonde data to the GPS data, IWV trends were estimated for 15 years (1997–2011). The differences between the radiosonde-dervied and the GPS-dervied IWV trends are shown in Fig. 7. Larger trend differences are seen for some sites in the tropics, e.g. BRAZ and GUAM, are due to the large intra-annual IWV variations and the short time period studied.

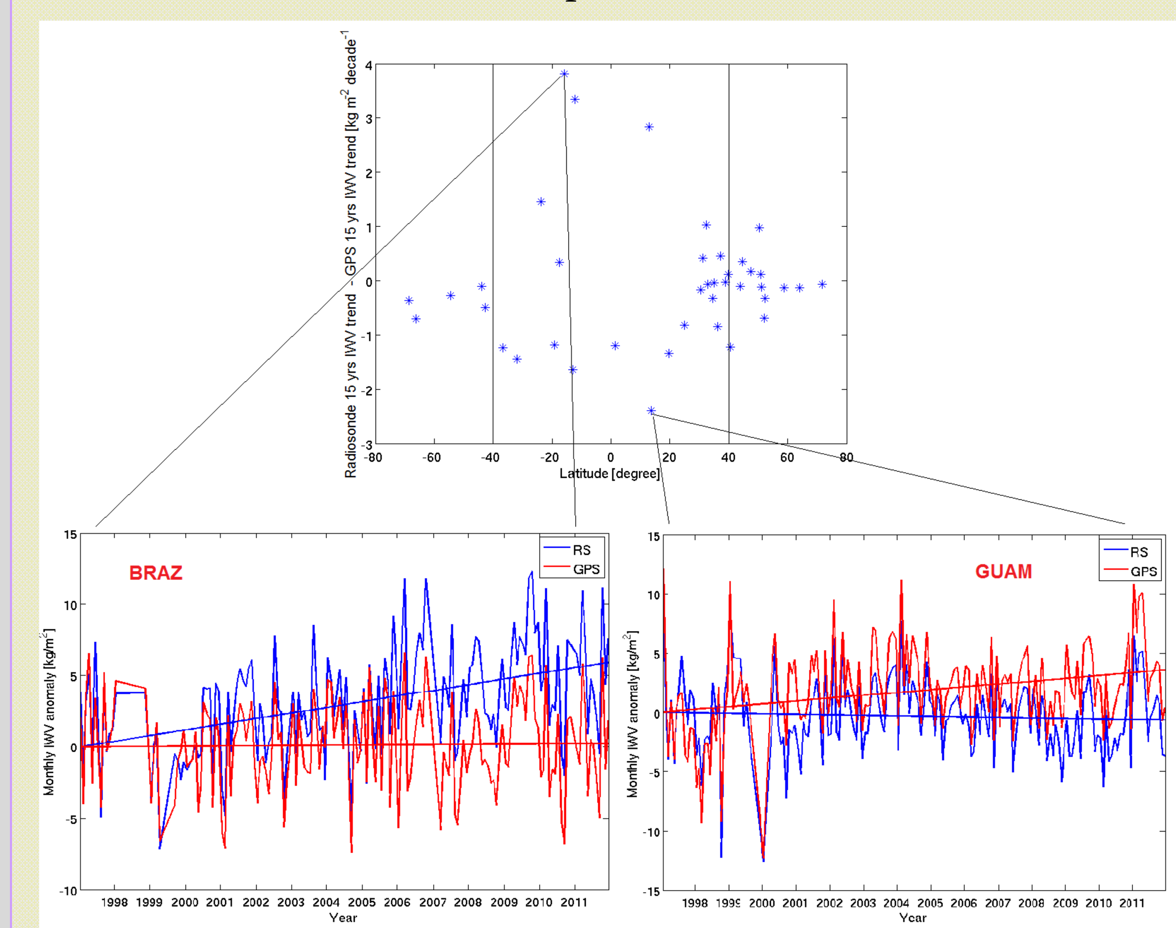

Fig 7: Trend differences between the GPS and radiosonde data. Also shown are the time series of monthly IWV anomaly for two sites (BRAZ and GUAM) with large trend differences.

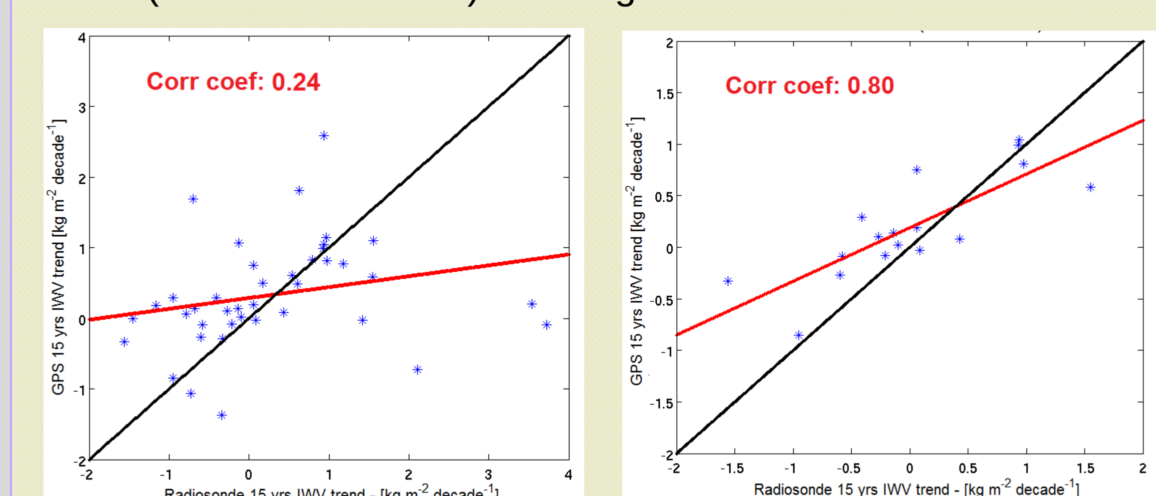

Fig 8: Correlations in the IWV trends for all 41 sites (left) and for sites North of 40º N. The solid line shows the perfect agreement

Conclusions

- IWV trends estiamted from the GPS data vary from –1.7 to 2.3 kg/(m^2 decade) for the last 15 years, which are different from the radiosonde trends using over 30 years data.
- The uncertainty of the GPS-dervied trend varies from 0.2 to 1.4 kg/(m^2 decade) depending on the latitude of the site.
- A good correlation seen in the IWV trends between the GPS and the radiosonde 15 years data for the sites North of 40º N.