An Evaluation of Slant Water Vapor Using a High Resolution Numerical Weather Model

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Abstract

The integral amount of water vapor along a path through the atmosphere is called a measurement of slant water vapor (SW). A ground based GPS station is able to simultaneously measure SW in the direction of all GPS satellites that are visible. A GPS station is typically able to track between six and twelve satellites at any time, with each satellite having a different elevation and azimuth direction with respect to the station. A previous comparison (Braun et al., 2003) of SW measured both by GPS and a pointing microwave radiometer showed a root mean square difference between the two techniques of 1.3 mm integrated water vapor. We have investigated the errors associated with GPS derived SW by evaluating how well the standard processing technique was able to retrieve SW from simulated observations created from a high resolution (3 kilometer horizontal resolution) numerical weather model. This simulation depicted the development and movement of a squall line that passed over a large portion of the United States Southern Great Plains region and represents a time period when SW from a network of GPS stations should be more valuable for characterizing the distribution of water vapor in the atmosphere than any integrated quantities of water vapor. This simulation provided the opportunity to study realistic systematic and random errors on the technique used to retrieve SW. Using this simulation, we determined that SW provides precise measurements of the spatial variation of water vapor, while sometimes containing systematic errors that affect the accuracy of GPS derived SW. Nevertheless, this simulation illustrates the value of SW measurements in multiple directions when compared to a single zenith integrated quantity.

Model Fields from Simulation

Model Observations from Simulation

What is Slant Water Vapor?

Slant water vapor (SW) is defined as the integral amount of water vapor between a GPS station and satellite. It is a term that evolved from the more common observation of precipitable water vapor (PW). PW is the vertically integrated amount of water vapor along a path through the atmosphere called a measurement of precipitable water vapor (PW). PW is the vertically integrated amount of water vapor above a station. GPS can be used to estimate PW by observing the amount of water vapor in the direction of multiple satellites over time periods of between 2 and 30 minutes. In this simulation, PW is modeled as a horizontally homogeneous parameter. If this model does not accurately describe the atmosphere the estimate of PW will be inaccurate and the residuals from this estimation will contain information regarding the atmospheric isothermogenities. If the PW estimate is combined with the retrieved residual (S), then this new value will represent the amount of water vapor between the GPS station and an individual satellite, in other words SW:

\[ SW = m \cdot PW + S \]

Errors in the PW estimate and uncorrelated errors in the residuals (such as multipath or station position errors) will degrade the accuracy of the retrieved SW. This investigation was conducted to assess the errors that are introduced during standard GPS processing.

Description

Using a previously analyzed storm (Ha et al., 2002), a simulation was conducted to determine how well SW observations could be retrieved using a network of ground based GPS stations. The figures above show the 3 km MMS model run which was used to create the simulated SW observations. Sea level pressure and temperature are in the top row, vertically integrated precipitable water vapor is shown in the middle row, and one hour accumulated rainfall is in the bottom row. Realistic satellite geometry and station locations were used. The network of GPS stations is shown in the figure to the right. After these simulation SW values were computed they were included in a GPS simulator program that recreated GPS observations. These observations were then processed in the same manner that actual GPS observations are processed. The retrieved SW values were compared against the values computed directly from the MMS run to assess what effect the GPS processing had on the SW values.

Simulated vs Retrieved SW

Summary

The figures above compare the simulated SW (thinner red lines) values to the retrieved ones (thinner blue lines) for individual station satellite pairs. These results are expressed as units of delay instead of integrated water vapor. The scale factor relating delay to water vapor is approximately 0.15. The zenith delay estimates are shown as blue diamonds. The half hour averages of the simulated observations are plotted as red diamonds. The difference between each half hour average and the corresponding zenith estimate is an error common to all retrieved values. It is caused by both the mismodelling of the atmosphere using a single isotropic zenith term and the associated non-gaussian errors in this model. This error is systematic in nature and is common to both PW and SW estimates. All atmospheric parameters derived from GPS are subject to this type of error. Comparisons of GPS PW to other instruments (microwave water vapor radiometers) indicates that the RMSE of this type of error might be as large as 1.5 mm. This magnitude of error would be smaller than the azimuthal variations in the atmosphere. In addition, the SW values capture this variability in a precise relative sense because the dominant error is common to all SW observations. The two figures below illustrate this point. The figure on the left compares the retrieved zenith term to the original slant values (black diamonds). The red diamonds compare the retrieved slant values to the original ones. In the figure on the right, the error in the slant retrieval that is common to all satellites for a station has been removed. It is clear from this comparison that the dominant error originates in the isotropic zenith term.

References