NEAR REAL, TIME ESTIMATES 011 PRECIPITABLE WATER VAPOR USING THE GLOBAL. POSITIONING SYSTEM

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The Global Positioning System (GPS) was conceived and developed primarily as a point positioning system for military use. It has nevertheless spawned a great number of civilian uses that go far beyond the original point positioning application. While most 01 these applications remain in the area of positioning or distance measurement, there has recently been much interest in using the signals broadcast by the GPS satellites to probe atmospheric properties. in particular, it has been proposed to use the GPS to estimate the amount of precipitable water vapor (PWV) in the atmosphere at the receiver location. This is possible because of the relatively strong effect of atmospheric water vapor on the transmission of GPS signals. In practice, these effects must be included in the observational model that is used when GPS data are processed to estimate geodetic parameters. These effects are usually modeled as an effective zenith signal "delay" on the time of arrival of the GPS signals, By using surface measurements of atmospheric pressure and temperature, it is possible to remove the effects of the. dry troposphere from these total delay estimates and recover the so called zenith "wet delay" due to water vapor alone. The PWV is directly proportional to this zenith delay.

With the advent of rapidly expanding networks of continuously operating GPS receivers, there has been growing interest in using the. data recorded by these receivers to provide routine estimates of precipitable water vapor. This has been the impetus for a number of studies comparing the estimates of this quantity derived from GPS data with those obtained from radiosondes 01 water vapor radiometers. The results of these studies have generally shown that GPS-based estimates of precipitable water vapor are of comparable accuracy to those derived from these more conventional techniques.

One of the most advantageous aspects of a GPS-based system for PWV estimation is the potential for producing accurate estimates of 1'WV in near real time (~1-3 hour delay). Precipitable water vapor data over land, for use in numerical weather prediction, are now obtained from a network of twice daily radiosonde launches. Assimilation of more frequent PWV data from GPS- based observations might significantly improve forecast accuracy for certain weather conditions. Because of their autonomous operation, GPS-based PWV systems can also be located in remote regions where regular radiosonde launches are not practical.

There are three main components of a near real time system for obtaining GPS-based estimates of PWV. These include:

1. A means of reliably transferring both the GPS and surface meteorological data from remote sites to a central processing facility. This data transfer should occur automatically at predesignated intervals. It is preferred that both the GPS and surface meteorology data be combined within the same data stream.

2. A data handling system, located at the central processing facility, that will format the. data, perform initial quality checks, and make the data available for the analysis stage where the PWV values will be estimated. This part Of the system also controls the timing of the data transfer from the remote sites.

3. A data analysis system that can provide accurate estimates of 1'WV immediately after GPS and surface meteorology data arrive. at the central processing facility. '1 he most essential component of this part of the system is a means of obtaining accurate GPS satellite orbits.

The first two components of this system can be adapted with 1 ittle or no modification from the infrast - ture that has been established for the existing, global networks of GPS receivers. Although these networks were dc.signed sole.ly for geodetic applications, only the addition of relatively inexpensive su rface meteorology sensors at the receiver locations is required to add the capability for production of near real time PWV estimates.

The third component of this system requires an alternate approach to the processing of the GPS data than is now used in the operational system designed for geodetic applications. The standard method used in geodetic analyses, as it is presently implemented, requires a long delay time (- I 8 hours) to allow processing of GPS data from a globally distributed set of receivers to estimate precise GPS orbits. These orbits are then used to process data from all othe I sites. Because of the long delay time required for orbit estimation, such a system is unsuitable for generating near real time estimates of PWV. A near real time system requires that GPS orbits of sufficient accuracy be available at the time that data arrive at the processing center. Unfortunately, the broadcast orbits that are recorded by the GPS receivers do not have sufficient accuracy to provide useful PWV estimates.

We are investigating two alternative approaches to the standard geodetic processing of GPS data that can provide near real time PWV estimates. The first of these uses "predicted" GPS orbits to estimate 1'WV from the GPS and surface meteorological data. The predicted orbits are obtained by propagating forward in time the equations of motion of the GPS satellites using the most recent estimated orbits as initial conditions. Since predicted orbits can be obtained at any time, without the need for further GPS data processing, they are well suited for use in a near real time PWV estimation system. There are two principal drawbacks in using predicted orbits for GPS-based PWV estimation. The first of these results from degradation in the orbital accuracy that occurs as the length of the prediction period increases. Because the accuracy of the PWV estimates is directly related to the orbital accuracy, the accuracy of the resulting PWV estimates is also degraded. This degradat ion can be alleviated by reducing the predict ion period through improvements in the efficiency of the orbit estimation process

Another difficulty with using predicted orbits in this application is due to the absence of satellite clock information in the predicted orbits. Because of the random nature of the satellite clock drift, it is not possible to propa gate the GPS satellite clock parameters forward in time. For this reason it is necessary to eliminate tile satellite clocks by forming di fferenced observations with data from another site that has observed the same set of satellites. This procedure complicates the development of tile overall PWV estimation system by requiring transfer of data from a second site, and because of the mutual visibility requirement, places further restrictions on the available site locations.

An alternative to predicted orbits is simultaneous estimation of both PWV values and GPS orbits in near real time. This technique is being developed independently as an alternative to the wide area augmentation system (WA AS) for commercial aircraft landing. To apply this technique to a near real time PWV estimation system simply requires the installation of surface meteorology sensors at the desired receiver locations. The primary advantage of this technique over the use of predicted orbits is increased accuracy of the PWV estimates. The primary drawback results from the added complexity in the analysis when GPS orbits are estimated along with the I'W\' values. To obtain accurate orbits in near real time will also require transfer of data in real time from a n etwork of receivers that covers a significant geographical area. 1 lowever, it is just such a net work that w ould be necessary for assimilation of GPS-based PWV estimates into numerical weather prediction and climate models.

wc will show results that establish the accuracy of GPS-based PWV estimates by comparison with those obtained from a state of the art water wiper radiometer(WVR). We will show the effect of using predicted GPS orbits on the accuracy of the resulting PWV estimates. The potent ial of generating simultaneous GPS orbits and PWV values in real time is discussed and the basic elements of such a system are presented.