GPS METEOROLOGY

Measurement of Precipitable Water Vapor Using the MET4 or MET4A Meteorological Measurement System and Global Positioning System Radio Signals

Water vapor is the engine of the weather. The unusually large latent energy associated with water's phase changes significantly affects the vertical stability of the atmosphere, the structure and evolution of storm systems, and the meridional energy balance of the atmosphere. Hence, the distribution of water vapor plays a crucial role in weather and global climate.

What is GPS Meteorology?

Global Positioning System (GPS) Meteorology is the application of GPS data to the monitoring and analyses of atmospheric conditions. Atmospheric monitoring can be done by both ground-based and space-based GPS applications.

GPS satellites transmit radio signals that can be inverted to measure atmospheric profiles of refractivity. The refractivity profile can be transformed to profiles of tropospheric humidity given a temperature profile.

Ground-based GPS receivers at fixed locations can be used to gather data that can be used to determine integrated ***Precipitable Water Vapor (PWV).*** Atmospheric scientists have shown that GPS-determined PWV observations can significantly improve weather forecasting accuracy.

Why is the Measurement of PWV important?

The Global Positioning System (GPS) tracking network was established to provide high precision navigation and geodetic positioning. The system consists of satellites in orbit around the earth and a ground-based network of support stations to update the ephemeredes and clocks.

A constellation of GPS satellites transmit atomic-clock controlled L-band signals to receivers on the earth. Time delays of the signal travel paths from multiple satellites to a single receiver are used to establish the ground position of the receiver. Data recorded by GPS receivers at fixed locations will show signal path delays caused by a variety of effects.

One class of GPS-signal delays can be directly attributed to the passage of the signals through the Earth's ionosphere and atmosphere.

The ionospheric delay is dispersive (frequency dependent) and can be determined by observing both of the frequencies transmitted by the GPS satellites (L1 & L2) using a dual-band GPS receiver. These ionospheric delays can be eliminated without reference to observations recorded by other GPS receivers [1].

The remainder of the atmospheric delay, or neutral delay, is not dispersive and cannot be estimated from single station observations. However, it is possible to parameterize the neutral delays affecting each station in a network of GPS receivers and to estimate these parameters jointly as part of the overall geodetic inversion for the relative geometry of the network and the precise orbits of the satellites.[2] (Hoffman-Wellenhof et al., 1993). The physical basis for estimating the zenith delay parameters is that a GPS receiver is typically tracking 4 to 8 satellites simultaneously and over-determines the zenith delay parameters without regard to azimuth or elevation.

The neutral delay can be decomposed into a "hydrostatic delay" associated with the "dry" atmosphere and a "wet" delay associated with the permanent dipole moment of water vapor.

Accurate, frequent, and dense sampling of water vapor is needed for operational weather forecasting as well as for weather and climatic research. Given the present operational weather data system, inadequate resolution of the temporal and spatial variability of water vapor has been cited as the single greatest obstacle to improved short range precipitation forecasts. Mesoscale numerical model simulations have shown that when model-predicted precipitable water is relaxed toward an observed value, the model recovers the vertical structure of water vapor with an accuracy much greater than that from statistical retrieval based on climatology, leading to significantly improved short range precipitation forecasts. One can infer that GPS water vapor data will be similarly valuable to longer range and global numerical simulations.

For example, using the NCAR/PennState mesoscale weather model, Kuo et al., 1995, have shown that the combination of PWV and surface humidity data significantly benefits the numerical models. A 20% improvement in the numerical weather forecasting was achieved when PWV time-series constrained the model. An additional improvement was achieved when the surface humidity was included.

How is PWV estimated from GPS Receiver Data?

The zenith hydrostatic delay (ZHD) has a magnitude (equivalent GPS phase delay length) of about 2300 mm at sea level. It is possible to predict the ZHD to better than 1 mm given surface pressure measurements accurate to 0.3 hPa (millibar) or better.

The Zenith Wet Delay (ZWD) can vary from a few millimeters in desert conditions to more than 350 mm in very humid conditions. It is not possible to predict the wet delay with any useful degree of accuracy from surface measurements of pressure, temperature, and humidity. However, once the ZHD parameters have been estimated from the measured GPS neutral delay, it is possible to estimate ZWD by subtracting ZHD from the ZND where the ZHD is derived from the surface pressure readings.

The Zenith Wet Delay can then be transformed into an estimate of Precipitable Water Vapor by using either a numerical weather model or a statistical/analytical model of the vertical temperature distribution at the receiver site.

Calculation of PWV

The steps to estimate PWV from MET3/GPS measurements are:

1) Determine the total station delays (or zenith total delay integrated over all azimuths and elevations) from the GPS station network with each station tracking multiple GPS satellites.

Total Delay = Ionospheric Delay + Neutral Delay.

2) Measure the Ionospheric delay from comparison of the L1 and L2 GPS signals recorded with a dual-band GPS receiver, and calculate the Neutral Delay.

Neutral Delay = Total Delay - Ionospheric Delay.

3) Calculate the Zenith Hydrostatic Delay from the barometric pressure, temperature, and humidity as measured by the Paroscientific MET3.

Zenith Neutral Delay = Zenith Hydrostatic Delay + Zenith Wet Delay.

4) Calculate the Zenith Wet Delay.

Zenith Wet Delay = Zenith Neutral Delay - Zenith Hydrostatic Delay.

5) Estimate Precipitable Water Vapor from the Zenith Wet Delay. ***PWV*** can be estimated from either a numerical model or a statistical/analytical temperature model.

Conclusions

GPS Meteorology represents a milestone improvement in environmental sensing technology. More accurate prediction of storm systems will improve surface, coastal, and air travel safety. Agriculture and farming will greatly benefit from these models by improving crop yields and better understanding micro-climates.

The important ground-based measurements of barometric pressure, temperature, and humidity necessary to determine precipitable water vapor are made with the Paroscientific MET4 or MET4A Meteorological Measurement Systems. The MET4/4A is directly compatible with most GPS reference stations. And the ease of installation, high accuracy, and excellent reliability of both instruments makes then an ideal choice for critical installations where high quality data is necessary.

Typical GPS Reference Station Monument

The Paroscientific's MET4/4A are being deployed world-wide to supplement GPS data and provide accurate precipitable water vapor information. For more information about the MET4 and Fan-Aspirated MET4A, contact your local Paroscientific representative or our sales and applications engineers.

References:

[1] J. Duan, M. Bevis, P. Fang, Y. Bock, S. Chiswell, S. Businger, C. Rocken, F. Solheim, T. van Hove, R. Ware, S. McClusky, T. Heering, and R. King, 1996: *GPS Meteorology: Direct Estimation of the Absolute Value of Precipitable Water*

[2] S. Businger, S. Chiswell, M. Bevis, J. Duan, R. Anthes, C. Rocken, R. Ware, M. Exner, T. van Hove, and S. Solheim 1996 - *The Promise of GPS Atmospheric Monitoring*

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