A Permanent GPS Ground Network for Atmospheric Research on Taiwan

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Abstract: The purpose of establishing GPS networks of continuously operating reference stations (CORS) is aimed to assist land surveying or crustal deformation in the early stage. However, with a fast evolving and improving path the GPS technique has been extended to accurately measure atmospheric precipitable water vapor as a core objective of many projects developed in many countries and regions such as the SuomiNet (U.S., UNAVCO), COST716 (European, COST), GEONET (Japan, GSI), …etc. In this paper, we present the current progress of the being-set-up GPS network in Taiwan whose atmospheric profile observations mainly count on the traditional radiosonde soundings as typically seen in any other part of the world. The GPS data collected from the Taiwan dense GPS network primarily supported by Central Weather Bureau are processed using the Bernese software version 4.2. Precipitable water vapor is then derived with the auxiliary surface meteorological measurements. Time series of precipitable water are examined and analyzed. A focus on the extreme weather cases is shown as an example.

Keywords: GPS, GPS network, Atmosphere

1. Introduction

The Global Positioning System (GPS) has been applied in a wide range of applications in Taiwan. For the ground-based approach, the island-wide GPS network of 16 receivers was first established in 1989 as shown in Figure 1, and has been continuously providing measurements since 1990. After the destructive 1999 Chi-Chi earthquake (Mw 7.5), the number of GPS permanent network stations has been constantly and rapidly increased at a rate of roughly 30 GPS receivers per year. At the time of the publication of this report, there are about 120 permanent station receivers around the island, while the number is expected to reach 200 in 2005. The network will become the densest (roughly one station per 180 km^2) in the world after its setup is completed.

In recent years, it is been proved that the total delay of GPS signals due to the atmosphere can be computed from the signal of GPS. In Taiwan, the method had been used by resolving the single baseline before.

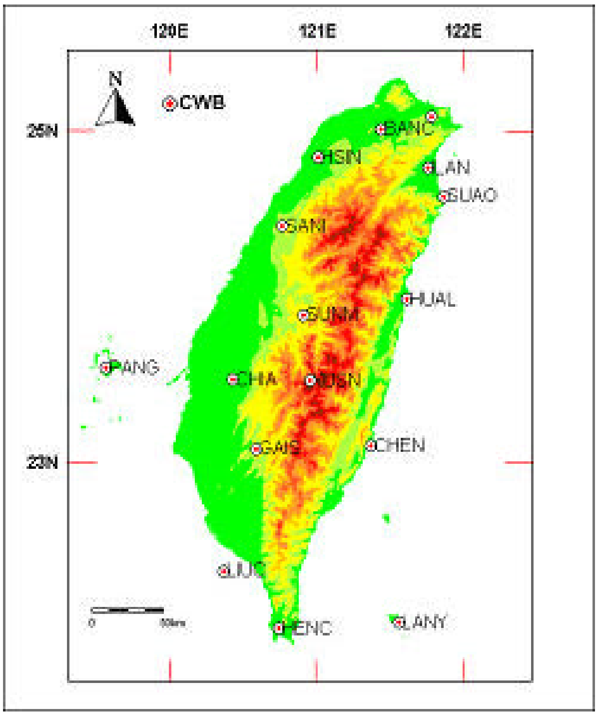

Fig. 1. Taiwanese GPS Network in 1989

2. Precipitable Water

The sensing of precipitable water (PW) by ground-based GPS receivers is one of the most recently developed observing schemes [1][2][3][4][5]. Ware et al. (1997) demonstrated the sensing of integrated slant-path water vapor along ray paths between GPS satellites and receivers. Rocken et al. (1997) presented near real-time GPS sensing of PW for assimilation in numerical weather models [7]. Kuo et al. (1997) showed the impact of GPS/Met data on the prediction of an extratropical cyclone [8]. As the GPS approach becomes reliable in sensing PW, its role in advancing our knowledge to improve forecasts for severe weather systems becomes increasingly important.

Well-developed countries have invested significant resources in GPS technology over the past 20 years. For example, Japan is leading the world in application of GPS to earthquake research. Their network is growing from initial 1,000 receivers established for deformation studies and is now expanded to a network of 1300 receivers. Many of the new sites will be focused on atmospheric research. In USA, the National Science Foundation awarded funds to UCAR to purchase 100 state-of the art GPS receivers for real time atmospheric sensing. In light of the tremendous potential of GPS in atmospheric and geodetic research and education, Central Weather Bureau (CWB) of Taiwan is planning to set up 200 GPS sites over the island. Forty-five GPS sites are currently deployed by CWB, Department of Interior, and Academic Sinica of Taiwan.

3. GPS Sensing of PW

Three typical steps are performed to acquire PW from GPS observations. First, total path delay is derived from GPS observations. Second, zenith wet delay (ZWD) is obtained by subtracting surface pressure-estimated dry delay from the total path delay. Finally, PW is derived from ZWD through a surface temperature-dependent conversion factor [9] [10]. Following our previous work [4][5], we estimate hourly ZWD at eight of CWB's GPS sites using the Bernese GPS software version 4.0 developed by the University of Berne [11]. L1 and L2 carrier phase observations are used in data reductions, and the precise GPS ephemeris is obtained from the International GPS Service for Geodynamics. A satellite elevation cutoff angle of 10 degrees is used in the data processing. A threshold of 1 cm in the ZWD solution standard deviation (SD) is set to assure good quality in GPS estimates of ZWD. Causes to large SD are discussed by Liou and Huang (2000) [12]

4. GPS Met Applications in Taiwan

The Center for Space and Remote Sensing Research (CSRSR) at National Central University is leading in the research of GPS Meteorology on Taiwan. The Center maintains two permanent GPS sites, which, together with the Central Weather Bureau’ s GPS stations provide the observation data essential for the investigation in the GPS Meteorology. There are Trimble 4700 GPS receiver and Paroscientific Met3A Meteorological Measurement System installed by the research center. The Met3A system measures surface temperature, relative humidity, and pressure at high precision accuracy. Two major fields of the research efforts conducted by the Center are addressed below.

1) Estimating Water Vapor from GPS Data

Radio signals emitted by the GPS satellites are delayed by the atmosphere before they are received on the ground. The delay due to the wet component of the troposphere provides the opportunity for sensing water vapor with ground-based GPS. The data are processed using the GPS data processing software developed by the University of Berne to solve the carrier phase observables for excess optical path length [11]. Zenith wet delay was subsequently derived by subtracting zenith hydrostatic delay from the excess OPL, and mapped onto PW by a linear conversion scheme proposed by Bevis et al. (1994) where MET3A measurements are needed to derive the wet delay and perform the conversion. The magnitude of the conversion factor ranges from 0.160 in winter to 0.167 in summer based on calculations from 10-year (1988-1997) radiosonde measurements [4].

Later, we examined three factors that would influence the accuracy of the sensing of PW using the GPS in the near tropics. The three factors are the baseline between any two GPS sites, the cutoff angle, and the total water vapor with a vertical column of the atmosphere [5]. It was concluded that the rms difference between GPS and water vapor radiometer (WVR) observed PW scales with the variability of the total water vapor burden (PW); and accurate absolute PW estimates from the GPS data may be obtained for baseline lengths between 1,500 and 3,000 km at a cutoff angle near 12 degrees.

2) Monitor Water Vapor Dynamics During the Passage of Severe Weather Systems

GPS water vapor sensing is used to monitor the dynamics of the water vapor during severe weather systems [12]. Typhoon Zeb, which caused serious damage in the Philippines, Taiwan, and Japan in mid-October 1998, is used as an example. It took 39 lives, destroyed 30 buildings, and caused agricultural loss of US$170 million in Taiwan. GPS data are analyzed from the CWB’ s three weather stations in Taiwan, and from a site in Tsukuba, Japan. Figure 2 shows the GPS-observed PW time series [12]. The trend of the GPS-observed PW matches well with those from MM5 simulations and radiosonde observations. The figure demonstrates that PW is, in general, high before and during the occurrence of the typhoon, and low after the typhoon. PW increased from about 5 cm on DoY 285 (October 13) to near 8 cm or so on DoY288 (October 16) when the typhoon was striking Taiwan, and, then, decreased to 2-3 cm after passage of the typhoon. In addition, GPS-observed PW depletion from 8 cm on DoY 288 to about 3 cm on DoY 290 is found to be consistent with radiosonde observations acquired at the Taipei weather station.

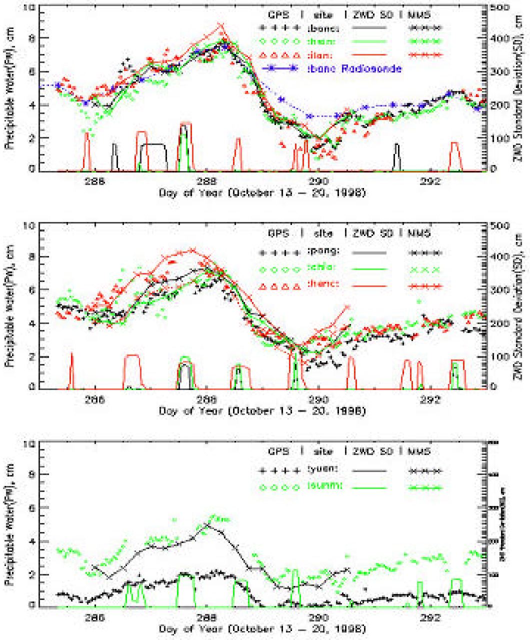

Fig. 2. GPS-observed PW time series [12]

5. Conclusions

In light of the tremendous potential of GPS in atmospheric and geodetic research and education, National Science Council (NSC) of Taiwan initiated a project to set up a 200 GPS sites network in year 2000. Major funding to support the network comes from Central Weather Bureau (CWB), Department of Interior, Academic Sinica, and NSC. Up to date, there are in total more than 100 GPS sites are completed. In this paper, we present the signatures of atmospheric water vapor observed by the GPS receivers during the passage of typhoon. Atmospheric water vapor is a key variable in the atmospheric radiation budget and global hydrological cycles. Traditionally, its diurnal variation is primarily examined using the observations from radiosonde soundings, which are typically launched twice daily and, hence, insufficient to capture the representative characteristics of the diurnal water vapor variation. Recently, the GPS observations that provide continuous measurements of atmospheric water vapor were used to study its diurnal variations in USA. We are investigating the diurnal variation of water vapor based on the GPS observations in Taiwan whose climatology dramatically differs from that in the Northern America. The differences are primarily due to the fact that Taiwan is located in the boundary of the sub-tropical and tropical regions with much more abundant of water vapor in the atmosphere in addition to its fast changing topography surrounding by the oceans.

Acknowledgment

This work is supported by grant from National Science Council of Taiwan. The authors thank the Central Weather Bureau of Taiwan for providing GPS data.

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