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New scientific and operational application with real-time GNSS monitoring of atmosphere

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GPS has been widely used as new unique sensor for accurate atmospheric sensing. The method is based on the measurement of the atmospheric delay of the phase of a microwave transmitted from a GPS satellite and received at a GPS antenna. This time delay is determined by comparing the observed propagation delay with the computed vacuum delay based on the know positions of transmitting and receiving antennas. The primary part of the delay is caused by the ionosphere, and its contribution can be corrected (observed) with dual frequency observations due to the nature of dispersion of the ionosphere. We can retrieve the integrated refractivity of the neutral atmosphere after removing the contribution of the ionospheric delay.

Improvements in the GNSS processing strategy, geophysical/instrumental models, and satellite orbit/clock products has led to improved GNSS atmospheric sensing. Availability of real-time data has made true real-time solutions that are available within a few seconds of data collection possible. For GPS Earth Observation NETwork (GEONET) in Japan, the most antennas and receivers were replaced around 2003, and real-time data streaming of 1Hz data has been implemented since then. Many other global GPS networks with real-time data streaming have also come on line. Such real-time GPS networks enable new GPS application of monitoring the atmosphere in true real-time and make previous near-real-time (NRT) applications obsolete.

The primary GNSS product in the neutral atmosphere is the zenith tropospheric delay (ZTD). ZTD can be mapped to represent the averaged precipitable water vapor (PWV) in the surrounding of the GPS antenna. NRT ZTD and PWV have been used for operational numerical weather forecast, and the impact of ZTD data has been reported for many severe storm cases globally. The primary impact of real-time PWV can be seen in short-term forecasts with frequent updates. It has also been shown to provide useful information for nowcasting of precipitation. Real-time slant path delay which contains information on the inhomogeneity of the water vapor distribution in active weather conditions can be used for water vapor tomography. All the products mentioned above are now available also for moving platform such as ships and buoys with kinematic processing. Such products can be helpful to improve precipitation forecast if the observation data are transmitted in real-time from ocean platforms. A new application of GNSS environmental monitoring is the determination of soil moisture. This is done by analyzing S/N ratios which fluctuate due to multipath reflections from the ground near the GNSS station. These S/N fluctuations are affected by soil moisture and we attempt to use GEONET data for soil moisture monitoring. The data are potentially useful for farming, as input to flood models and for research of the water cycle.

Monitoring of the ionosphere is also possible under the assumptions of a thin ionospheric layer and stable differential code biases in the GPS receivers on the order of a few days. The vertical and slant total electron content (TEC) is used for monitoring of space weather and ionospheric disturbances. With real-time capability, it is possible to monitor the current status of ionosphere to issue warning, and detect tsunami and rocket launches. We can also use ionospheric model generated from dual frequency network for processing of relatively low cost L1 receiver network to get denser information on water vapor and slant path delay.

The paper briefly introduces the background of neutral and ionized atmospheric sensing with GPS, and reviews the current status of global and Japanese GNSS research on atmospheric sensing. It then introduces new real-time application of GNSS for atmospheric research, and concludes with a near future perspective of GNSS meteorology under consideration of Japan's QZSS and radio occultation.

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