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# Ground-based GNSS Remote Sensing for Near-surface Water Environmental Parameters

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## ABSTRACT

The expansion of research and application of the global navigation satellite systems (GNSS) has revealed more information. Tropospheric delay caused by atmospheric refraction and multipath error caused by reflected signals were thought to be two important errors in GNSS positioning. However, these refracted and reflected signals carry characteristic information of medium: the reflected signals can carry characteristic information of the reflecting surface (including sea level, snow depth, soil moisture, et al.); and the refracted signals can carry information of the atmospheric water vapor. Based on this information, some water environmental parameters such as water vapor, soil moisture, snow depth and sea level can be retrieved based on two ground-based GNSS remote sensing technologies - GNSS-Interferometry Reflectometry (GNSS-IR) and GNSS Precipitable Water Vapor (GNSS-PWV).

Chpater 1 gives an introduction to this thesis.

In Chpater 2 the principles of ground-based GNSS-PWV technique and GNSS-IR technique are briefly introduced.

Chpater 3 is devoted to analyze the spatial and the temporal characteristic of PWV. The data of 100 Global Positioning System (GPS) stations at Taiwan, China are chosen and the PWVs are retrieved based on GNSS-PWV technique. Then long and short time series of PWV retrievals are decomposed by Empirical Mode Decomposition and Wavelet Decomposition to obtain periodic oscillations of PWV. The physical causes of different periodic oscillations are also analyzed.

Chpater 4 presents an example of GNSS-IR technique applied to soil moisture retrieval. The fast Fourier transform method and the least-square method are used to acquire initial phase of signal-to-noise ratio (SNR) sequence. This phase parameter is used to retrieve soil moisture

Chpater 5 presents an example of GNSS-IR technique applied to snow depth retrieval. The results show a good correspondence between measured and retrieved snow depths. Also, considering the effect of terrain fluctuation, the theory and method of planarization of snow depth retrieval is proposed. This method is used to discover the anisotropic information hidden in SNR data and to provide plane information of environmental parameters, and then can correct the bias of snow depth retrieval caused by terrain fluctuation.

Chpater 6 presents an example of GNSS-IR technique applied to sea level retrieval. In Chpater 6, two important errors called tropospheric error and height variation error are corrected. Considering the noise in SNR data, a method based on wavelet decomposition

theory is proposed. It can reduce the noise and can avoid the appearance of false frequency peaks, leading a retrieval result with less gross error.

In Chpater 7, in order to improve the GNSS-IR resolution of the sea level retrieval, a method based on wavelet analysis is proposed to extract the instantaneous frequencies and retrieve based on these instantaneous frequencies. It can greatly increase the retrieval frequency and improve the effective utilization of SNR data. Also, in order to improve the accuracy of sea level retrieval, a combination algorithm based on multi-mode multi-frequency GNSS data is proposed. This algorithm is based on a sliding window and the least-square method, and it can achieve a retrieval accuracy less than 20 cm with a time resolution of 1 h. This combination algorithm is of great significance for advancing the application process of GNSS-IR for sea level retrieval.

Chapter 8 summarizes the thesis.

**Key words:** GNSS remote sensing, ground-based reflectometry, atmospheric water vapor, sea level, snow depth, soil moisture