Soil moisture monitoring using GNSS

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Introduction

Soil moisture is key for understanding the flow of water and energy between the surface of the earth and atmosphere, predict floods and droughts and also optimizing agricultural management.

Obtaining soil moisture data at the field scale with currently available in-situ techniques is a challenge since continuous observations are generally required and the sampling volumes are small.

Method

Among these techniques we have the gravimetric method and the TDR method. The gravimetric method consists of taking a sample of soil and drying it in an oven to compare the original weight with the dried one to estimate water content. In the TDR (Time-domain reflectometry) method a sensor is inserted in the ground and, using a pulse generator, a signal is sent. Finally analyzing changes in the waveform soil moisture is obtained.

The use of data from the Global Navigation Satellite Systems (GNSS) for remote sensing, based on utilizing Earth reflected signals, was first proposed in a pioneering work by Martin-Neira (Vey et al. 2015). Most scientists used GNSS exclusively to measure position, however, it was found out that using reflected GNSS signals (also known as multipath) can contribute to data acquisition about soil moisture.

High-precision GPS receivers can sense soil moisture fluctuations using the dual-frequency GNSS signals, which are in the L-Band with wavelengths of 19.05 and 24.45 cm. The reflected signals cover an area of approximately 1000 square meters and thus are a potential source of data acquisition.

It is possible to estimate soil moisture with measurements from a standard single ground-based dual-frequency geodetic GNSS receiver (Larson 2008). The power of the GNSS signal is recorded as signal-to-noise ratio (SNR). This SNR is the ratio of the GNSS signal power to the measurement noise given in a logarithmic decibel (dB) or decibel-Hertz (dB-Hz) scale. In operational applications, the SNR is used to check the signal quality and characteristics of electromagnetic noise in the close environment of the GNSS station. The SNR mainly depends on the power of the signal transmitted by the GNSS satellite, the antenna gain pattern, the elevation angle of the satellite from the horizon and the tracking algorithm in the receiver.

The soil moisture retrieval algorithm is based on the analysis of power variations of the GNSS signals. The direct signal from the GNSS satellite and the signal reflected by the land surface are simultaneously received at the antenna, and their power is added with consideration of their phase difference. Due to the motion of the GNSS satellites, the simultaneous reception of the direct and coherently reflected signals causes an interference pattern in the received signal. This interference pattern depends on the height difference between the GNSS antenna and the reflection point, as well as on the elevation angle of the satellite and the GNSS frequency. If the soil is wet, the GNSS signal is reflected from a layer just below the land surface while for dry soil, the signal penetrates deeper into the soil and is reflected within a surface layer of up to 15 cm depth.

Case study

In a study held at the South African Astronomic Observatory in Sutherland, South Africa from December 2008 to September 2014, soil moisture estimates based on GNSS interferometric reflectometry where compared to TDR measurements carried out at 10 and 15 cm to validate the data obtained (Vey et al. 2015).

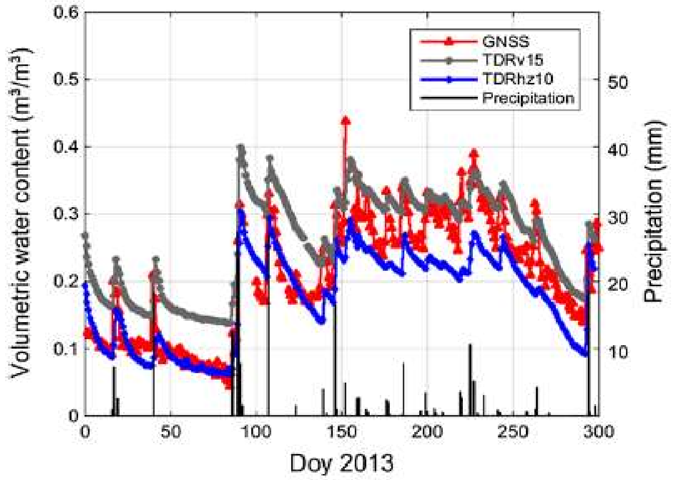

Figure 1. Comparison of daily soil moisture from GNSS data
and TDR sensors, with daily precipitation amounts on the right y-axis.

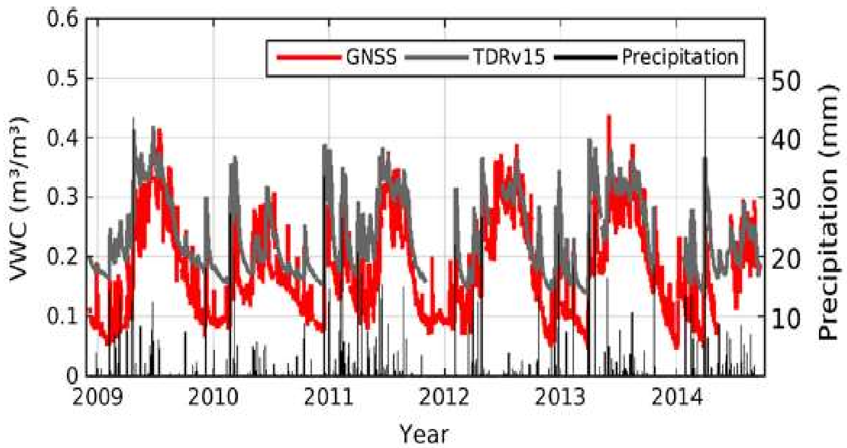

Figure 2. Comparison of yearly soil moisture from GNSS data
and TDR sensors at the depth of 10 cm.

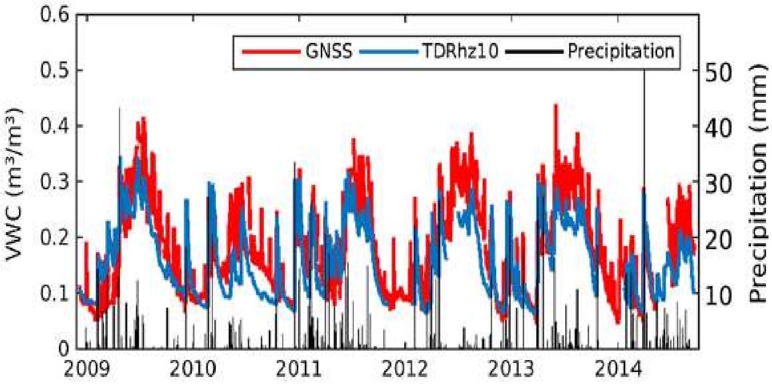

Figure 3. Comparison of yearly soil moisture from GNSS data and TDR sensors at the depth of 15 cm.

From this data it was concluded that the soil moisture obtained using GNSS correspond very well to the TDR observations, both on daily and seasonal scales. It was also observed that light rains events were detected by the GNSS but not by the TDR probes, indicating that water from small precipitation events was hardly infiltrated.

There exist some minor deviations between the GNSS and TDR datasets because TDR sensors are installed deep in the soil and moisture generally increases with depth. TDR sensors also become less sensitive to precipitation events with depth and this can cause a delayed response.

Finally the comparison between the three available methods in terms of spartial and temporal resolution, as well as Effort in data collection, is shown in Table 1.

Mehod	Spatial resolution	Temporal resolution	Effort in data collection
Gravimetric	Low	Low	High
TDR	Low	High	Low
GNSS	High	High	Low

Table 1. Comparison of methods to obtain soil moisture.

Conclusion

This case study proves the reliability of the soil moisture data obtained using GNSS by validating the data with the TDR observations. In future, soil moisture estimates based on GNSS signals could be the main descriptor of the state of the land surface and substitute current in-situ techniques. Furthermore the spatial resolution of this data can help to enhance weather predictions, agricultural management and the current knowledge about the water cycle in general.

References

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