Using ground-based GPS to quantify surface moisture

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Motivation

Within the data evaluation process of global satellite navigation systems (e.g. GPS) one has to handle all limiting factors with care in order to guarantee a highly precise and accurate determination of point positions. The factors, which are affecting GPS positioning, are normally classified as satellite-related, atmospheric, and site-specific. The most important and most critical limiting site-specific factors are receiver antenna modelling and multipath effects.

Site-specific factors can be mitigated on the one hand by means of a correct and complete functional and stochastical modelling within the data evaluation process (e.g. receiver antenna modelling), on the other hand one has to avoid difficult to model factors by choosing an appropriate location (e.g. multipath effects).

The error source multipath effect results from reflections of the original GPS signals, consisting of an electrical and an coupled magnetic component, on surfaces situated in the vicinity of the GPS antenna. GPS signals are polarised and due to the reflections the polarisation is changed. The reflected signals interact with the direct, not reflected signals and deteriorate the signal quality resp. the signal strength. As a measure of the signal quality the so-called signal-to-noise-ratio (SNR) is often used.

In the framework of a cooperation between the Geodetic Institute, the Institute for Meteorology and Climate Research of the University of Karlsruhe (TH), and the Department of Electrical Engineering (University of Applied Sciences, Mannheim) the feasibility of using ground-reflected signals of standard two-frequency geodetic GPS instrumentations as sensors in order to determine surface moisture variations is checked.

Fundamental Idea & First Experiment

If the existence of a significant correlation between the soil resp. surface moisture and the penetration depth of the received, ground-reflected GPS signals is assumed, investigations can be carried out concerning the usability of GPS as a soil resp. surface moisture sensor by means of analysing the signal strength of the received GPS signals.

A preliminary investigation was carried out at two carefully selected locations (line of sight: south; left: dry field, rough surface; right: calm lake). Within this test series a rotated GPS antenna was used as sensor. The direct GPS signals were shielded, thus only ground-reflected signals could be received from the antenna phase center. The evaluation of the GPS data showed significantly different SNR values: $SNR_{lake} > SNR_{field}$.

MESMERISE

Together with partners from neighbouring research disciplines such as geophysics, soil and electrical engineering a project called MESMERISE (Meteorological Soil Moisture Experiment Series; http://www.imk.uni-karlsruhe.de/seite_1932.php) was initiated.

MESMERISE had the aim to compare different innovative methods of wide-area soil moisture determination with respect to their temporal and spatial resolution and their usability for meteorological applications.

Therefore an observation campaign (5 days in July 2004) was carried out on a military training area close to Karlsruhe. In addition to a GPS soil resp. surface moisture experiment a large number of different approaches including atmospheric energy and moisture balance measurements, radiosoundings, electrical resistivity tomography (ERT), time-domain reflectometry (TDR), ground-penetrating radar (GPR), gravimetric soil moisture measurements, and measurements along free transmission lines were applied.

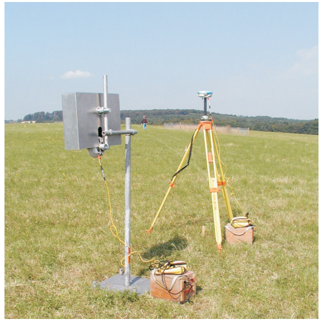
The data evaluation strategy of the GPS observations was based on the repetition of the geometrical situation defined by satellite positions, reflector resp. surface, and GPS antenna.

The constellation of the GPS satellites within the space segment is repeated approximately every $11^h\ 58^m\ 2^s$ satellite position correction manoeuvres excluded. Therefore the geometrical situation is repeated nearly every day, due to the Earth's rotation. The so-called sidereal time difference amounts approx. to $3^m\ 56^s$. This value is not constant, but satellite-dependent.

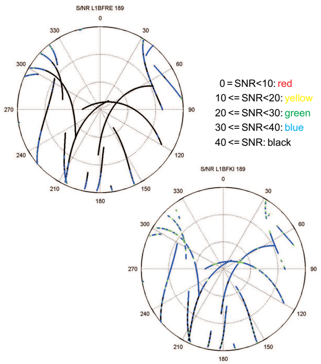
If it is assumed that the position of the GPS antenna does not change within the experiment, and it is also assumed that the characteristics of the reflector is only affected by variations of surface moisture, then one is able to determine sidereal signal strength differences. Assuming additionally, that the surface moisture is the only varied parameter (e.g. neglecting atmospheric variations due to ionosphere or neutrosphere), signal strength variations could be correlated with moisture variations.

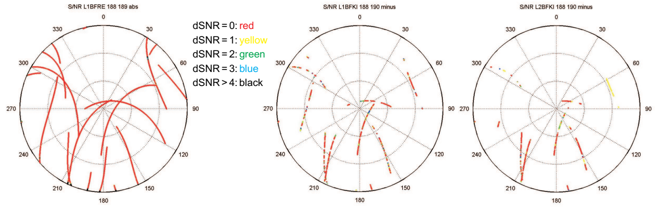
SNR values are depending on the manufacturer as well as on the series ("Arbitrary" Manufacturer Units (AMU)). In case of undisturbed reception the used instrumentation provides maximum values of 52 for the L1 frequency. L2 signals are characterised by a poorer quality, therefore they were not taken into account within the data evaluation.

As an example the sky plots of the SNR values of the L1 signal of DOY 189 of the reference antenna (top) and tilted antenna (bottom) are presented. The larger values of the non-rotated reference antenna are clearly visable.



Set-up of the GPS experiment of Mesmerise: Simultaneous registration of GPS observations at a reference antenna (Trimble 5800) and a tilted (90°) antenna (Trimble 5800); the tilted antenna receives only ground-reflected GPS signals due to a metal shielding box (line of sight: south-west). In order to compare, verify and normalize the data quality of the ground-reflected and received GPS signals the SNR values of the reference antenna could be used.





The MESMERISE data evaluation was carried out under the assumption: All satellites have an identical and constant constellation repetition period.

By means of the analysis of the sidereal differences of the SNR values of the reference antenna one is able to detect external effects (left figure).

Based on the analysis of changes of the SNR values one is able to give a preliminary answer of the question "Is ground-based GPS able to monitor surface moisture?".

In the forefront and within the first two days of MESMERISE no rain fall was registered. In the early morning hours of July 8th (DOY 190) heavy rain fell down on the parched soil.

Thus the SNR values of DOY 190 should differ significantly from the SNR values of DOY 188 (middle figure) resp. DOY 189 (right figure).

This variation is weakly significant for the L1 signal (higher SNR values of DOY 190), thus the fundamental idea could not be rejected.

Long-Term Test Series

- Long-term experiment: 16 days (October 24th - November 8th 2005)
- Carried out under controlled meteorological conditions (registration of rain, sprinkler irrigation)
- Test run for data on-line registration
- Data resolution increasing (1 AMU ⟶ 0.25 AMU); important due to little SNR differences
- Satellite-specific analysis: The sidereal time offset is calculated by means of a cross-correlation approach of the satellite positions
- First results show weakly significant SNR differences only in case of very different surface moisture characteristics

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