Geophysical Research Abstracts
Vol. 13, EGU2011-4046, 2011
EGU General Assembly 2011
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PPP-derived High-frequency Tropospheric Delays as a Measure of Atmospheric Turbulence

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Electromagnetic waves, such as GNSS signals are affected by atmospheric attenuation, fluctuations, and delay. Especially the long-periodic components of the tropospheric delay significantly contribute to the error budget of GNSS observations. Consequently, several deterministic models have been developed to account for these effects. Usually the 'dry' component of the tropospheric delay can be modelled, while the 'wet' component is estimated together with other geophysical parameters. Besides these long periodic effects, GNSS carrier signals are also affected by high-frequency variations of the refractivity index which are generated by thermodynamically unstable air (and thus water vapor) on different scales. As a consequence, tropospheric delays show both annual to hourly long-periodic variations and short periodic variations in the range of minutes to seconds (and even below). Thus, on the one hand, these dynamical processes in the atmosphere induce correlated wave propagation effects on GNSS signals which should be properly accounted for in the stochastic model. On the other hand, these phase fluctuations reveal important information about the turbulent media through which the signal has travelled.

Using high-frequency (1 Hz or more) GNSS carrier phase observations in a PPP analysis, atmospheric turbulence can be studied in various steps/at various levels of the analysis process: For example, prefit residuals (or 'observed minus computed (O-C)' values) of carrier phase observations show short-periodic variations whose temporal and spatial stochastic behaviour agrees with the power-law behaviour predicted by the Kolmogorov turbulence model (assuming low receiver noise and no multipath effects).

In this presentation, data of two dedicated GPS-networks is used to analyse the temporal and spatial impact of atmospheric turbulence on both prefit residuals and estimated high-frequency tropospheric delays. The first network consists of six equally equipped GPS-stations located along a straight line with interstation distances between 1 and 16 km. PPP-derived zenith tropospheric delays show the theoretically predicted temporal power-law behaviour with initial exponents of 5/3 for the first approximately 2000 s. The spatial behaviour of zenith tropospheric delays shows a 2/3 power-law behaviour and thus indicates two-dimensional turbulence processes.

In order to study the impact of the receiver clock noise and local multipath, data from a second network is analysed. It consists of a short baseline of approximately 4 m with two identical receivers connected to a common frequency standard (H-Maser) and operated in a temperature stabilised laboratory. The temporal signature of atmospheric turbulence is analysed in terms of the power-law behaviour of prefit-residuals and zenith tropospheric delays for a 14 day measurement campaign. In addition, the impact of a common ultra-stable frequency standard for the separation of clock and tropospheric fluctuations is discussed.