

Simultaneous Troposphere Estimation with Precise Point Positioning (STEPPP)

Global Navigation Satellite Systems (GNSS) microwave signals are delayed in the troposphere. Almost 90% of these delays depend on the pressure, which can be determined accurately from empirical models or numerical weather prediction models. However, the remaining 10%, so called wet delay, depend mainly on the water vapour content, that changes rapidly over time and space. Therefore, for precise GNSS applications e.g., in geodesy and geophysics, site-specific troposphere wet delay has to be estimated together with other unknown parameters like coordinates, receiver clock offset and GNSS carrier phase ambiguities.

Although troposphere delay is treated as an error source in precise GNSS positioning, there is great potential of exploiting wet delay in meteorology. A better knowledge of the water vapour distribution is beneficial for various meteorological applications ranging from regional and global climate research, numerical weather prediction to global warming monitoring. Remote sensing of water vapour in the troposphere with GNSS, called GNSS meteorology, operates under all weather conditions and provides homogenous products of spatial and temporal resolutions higher than any other troposphere sensing technique. The 3-D distribution of water vapour can be also reconstructed with a tomographic approach using troposphere products, which were estimated from a network of GNSS ground stations, but neglecting the correlation of the wet refractivity among stations.

Nowadays we observe a very dynamic development of GNSS, that is a modernization of existing systems (US American GPS and Russian GLONASS) and deployment of new systems (European Galileo and Chinese BeiDou). Moreover, recent advances in multi-core CPU and GPU architectures provide now the base to handle and solve the equation systems which describe the mathematical and physical nature of complex physical problems. This creates the possibility to determine the water vapor distribution in an utmost consistent and self-controlled approach, using data combination on the observation level. In this project, we aim to develop a revolutionary method for the determination of 4D water vapor distribution, which we call the Simultaneous Troposphere Estimation with Precise Point Positioning (STEPPP). In this approach, a network of ground-based and moving GNSS receivers is used to process observations from four GNSS, based on the Precise Point Positioning (PPP) technique and, instead of estimating classical troposphere products, the estimation of the whole wet refractivity field in a grid space is performed. Contrary to GNSS tomography, STEPPP operates on raw observation data instead of products. Values of wet refractivity at grid nodes are estimated from all stations simultaneously, i.e. they appear as common parameters in PPP. Wet refractivity is further converted to water vapor density so that a complete 4-D water vapor distribution model is obtained

We will develop functional and stochastic models for the STEPPP approach, taking into account a variety of data sources (static and moving GNSS receivers, meteorological sensors, background information from a numerical weather prediction model) as well as spatio-temporal correlations of the refractivity field. We will study the structure (dimensions, irregularity) of the grid depending on the receivers' locations and algebraic/numerical limitations. We will develop a dedicated software-suite which implements STEPPP on a multi-threaded architecture. We will use simulated GNSS observations and sensor data to validate both the STEPPP model and the software. Then we will perform real-data experiments, using a dense network of receivers distributed in a challenging environment, e.g., an urban area. Refractivity field obtained with STEPPP will be validated against classical methods, i.e., GNSS tomography, GNSS radio occultation and water vapor radiometer.

We will explore the potential of low-cost GNSS receivers to replace or densify existing networks of high-grade GNSS equipment to support troposphere monitoring. For this purpose, we will manufacture 25 low-cost GNSS receivers and then deploy a network of them in Wroclaw (Poland) area. We will also investigate the impact of using STEPPP model on precise positioning, navigation and time transfer. Finally, together with atmosphere physicist, we will study the dynamics and distribution of water vapor at unprecedented spatio-temporal scales during the occurrence of atmospheric phenomena, in order to better understand of micro- and macro physical effects of water vapour.

The outcomes from STEPPP will not only stimulate atmospheric research and further strengthen the role of GNSS as a meteorological sensor, but it can be stated that approaches and algorithms will also act as precursors for the implementation phase of Global Geodetic Observing System (GGOS), which aims to combine data from different techniques on the observation level.