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Robust GNSS and InSAR tomography of neutrospheric refractivity using a Compressive Sensing approach

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Motivation:

An accurate knowledge of the 3D distribution of water vapor in the atmosphere is a key element for weather forecasting and climate research. In addition, a precise determination of water vapor is also required for accurate positioning and deformation monitoring using Global Navigation Satellite Systems (GNSS) and Interferometric Synthetic Aperture Radar (InSAR). Several approaches for 3D tomographic water vapor reconstruction from GNSS-based Slant Wet Delay (SWD) estimates using the least squares (LSQ) adjustment exist. However, the tomographic system is in general ill-conditioned and its solution is unstable. Therefore, additional information or constraints need to be added in order to regularize the system.

Goal of this work:

In this work, we analyze the potential of Compressive Sensing (CS) for robustly reconstructing neutrospheric refractivity from GNSS SWD estimates. Moreover, the benefit of adding InSAR SWD estimates into the tomographic system is studied.

Approach:

A sparse representation of the refractivity field is obtained using a dictionary composed of Discrete Cosine Transforms (DCT) in longitude and latitude direction and of an Euler transform in height direction. This sparsity of the signal can be used as a prior for regularization and the CS inversion is solved by minimizing the number of non-zero entries of the sparse solution in the DCT-Euler domain. No other regularization constraints or prior knowledge is applied.

The tomographic reconstruction relies on total SWD estimates from GNSS Precise Point Positioning (PPP) and Persistent Scatterer (PS) InSAR. On the one hand, GNSS PPP SWD estimates are included into the system of equations. On the other hand, 2D ZWD maps are obtained by a combination of point-wise estimates of the wet delay using GNSS observations and partial InSAR wet delay maps. These ZWD estimates are aggregated to derive realistic wet delay input data at given points as if corresponding to GNSS sites within the study area. The made-up ZWD values can be mapped into different elevation and azimuth angles.

Moreover, using the same observation geometry as in the case of the GNSS and InSAR data, a synthetic set of SWD values was generated based on WRF simulations.

Results:

The CS approach shows particular strength in the case of a small number of SWD estimates. When compared to LSQ, the sparse reconstruction is much more robust. In the case of a low density of GNSS sites, adding InSAR SWD estimates improves the reconstruction accuracy for both LSQ and CS.

Based on a synthetic SWD dataset generated using WRF simulations of wet refractivity, the CS based solution of the tomographic system is validated. In the vertical direction, the refractivity distribution deduced from GNSS and InSAR SWD estimates is compared to a tropospheric humidity data set provided by EUMETSAT

consisting of daily mean values of specific humidity given on six pressure levels between 1000 hPa and 200 hPa.

Study area:

The Upper Rhine Graben (URG) characterized by negligible surface deformations is chosen as study area. A network of seven permanent GNSS receivers is used for this study, and a total number of 17 SAR images, acquired by ENVISAT ASAR is available.