Analysis of tropospheric structure from multi-station PPP-analysis

Motivation and Introduction

Tropospheric Refraction
- Refractivity variations in Neutral Atmosphere form a significant error source for space-geodetic techniques such as Global Navigation Satellite Systems (GNSS) or Very Long Baseline Interferometry (VLBI).
- At the same time refraction variations are valuable signals which can be used to enhance the modelling of meteospheric refraction.
- Especially mesoscale meteorological phenomena (turbulent properties) are little studied and not yet considered in routine analysis, such as Reference Frame determination.

Purpose of this study
- Investigate the spatial structure of the troposphere from distributed space-geodetic observations at the Geodetic Observatory Wettzell, Germany, by means of geostatistics.
- Develop a strategy to find a suitable model to describe spatial structure by including observations of different periods of time.
- Check feasibility of estimating Zenith Wet Delay (ZWDs) for an arbitrary chosen epoch and line of sight (GPS or VLBI) from an interpolated surface of ZWDs.

Data
- GPS L3 carrier phase residuals and ZWDs from 4 stations at Wettzell Observatory (WTZ, WT27, WT33, and WT72) "where data from daily PPP Kalman Filter solution for 3 days in Feb., 2015 (set time: [Kube and Schön, 2016])
- VLBI (RTW) ZWDs ±30min
- Finally 18 hours of data on DoY 50 2015 from both techniques were used for this study.

Analysis steps and Methods

Preprocessing
- GPS residual estimation according to [Fuhrmann et al., 2015] in order to reduce the multipath influence. Since permanent GPS observations at the Geodetic Observatory Wettzell, Germany, are available for WT33 and WT27, multipath reduction was only possible for WTZ7 and WT27.
- Reduction of VLBI and GPS ZWDs to common height and removing trend and offset from residual ZWD time series.
- Computation of GPS Equidistant ZWDs (EZWDs) by mapping the residuals to the zenith and adding the ZWD, see Fig. 1(a) - residuals contain mainly turbulence, since all other remaining effects are carefully modelled in our PPP algorithm, see Fig. 1(a).
- Choosing VLBI ZWD epochs (36 epochs ±30min) as reference epochs.
- Projecting GPS EZWDs and VLBI ZWD to plane 1000m above Wettzell, see Fig. 3(a) and 3(b).

Variogram Computation and Fitting
- Setting up empirical variograms by computing semivariances \( \gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left( z(x_i) - z(x_i + h) \right)^2 \), where \( h \) denotes the difference between two points in plane, \( z(x) \) is the coordinate in the plane. Plotting the empirical semivariances against the distance shows the spatial variability of EZWDs, see squares in Fig. 4(b) and 4(c).
- Fitting variogram models to the data [Stein, 1999] by means of least squares fit: Linear Model (1), Exponential Model (2), Matern Model with Exponent \( \nu = \frac{1}{2} \) (3).
- Comparing the spatial variability, e.g. the variogram parameter range \( a \) and sill \( b \) of a sample epoch by varying the number of epochs included in the variogram computation, see Fig. 4(a) and 4(b). Nugget variance \( c_0 \) is omitted in this study.
- Evaluating the quality of variogram fitting by computing the root mean squared error (RMSE) and correlation coefficient of the residuals.

Ordinary Kringing Interpolation
- Surface estimation of EZWD by means of Ordinary Kringing, which uses the mathematical function specified with the variogram model, see Fig. 5.
- Evaluating the Surface by cross-validation (leave-one-out): remove one GPS data location and predict the associated data using the data at the rest of the locations and compare predicted and measured values by means of RMSE and mean absolute error (MAE).

Results and Findings

- Number and distribution of EZWDs in a single epoch is not meaningful for fitting a variogram, thus changing the number of epochs included in the variogram for the current epoch: 1s, 5s, 10s, 30s, 1min, 10min, 30min, 1h.
- Empirical variogram gets smoother the more epochs are included, but small-scale variations get lost, see Fig. 6.
- Then selected variogram models show similar behaviour, no significant difference either in the RMSE of the variogram residuals, the correlation coefficient, see Fig. 7, or the estimated variogram parameters, see Fig. 8.
- Including more epochs in the variogram computation reduces the RMSE of the variogram residuals and increases the correlation between empirical values and selected model, see Fig. 7.
- Decrease the estimated range parameter and increase the estimated sill parameter, see Fig. 8 for the majority of investigated epochs.

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References