Case study of windstorm effects on zenith tropospheric delay for RTK networking in northern Germany

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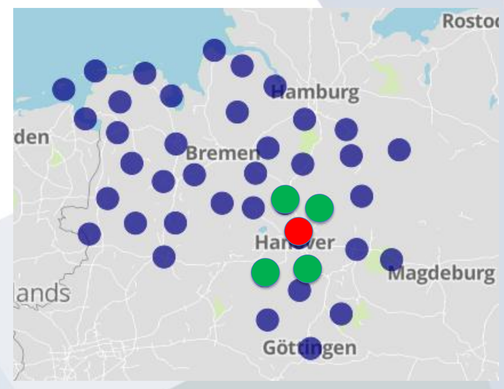
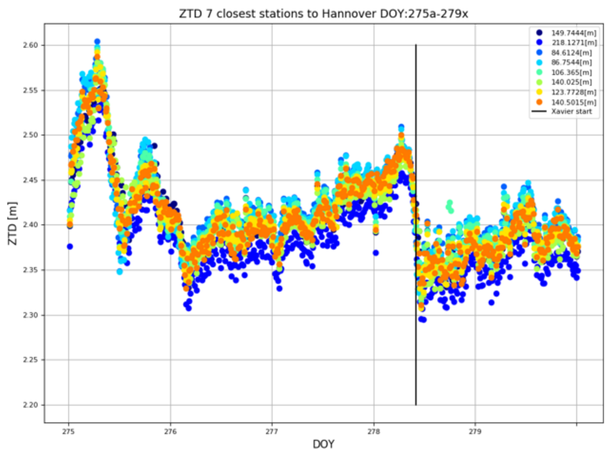


INTRODUCTION

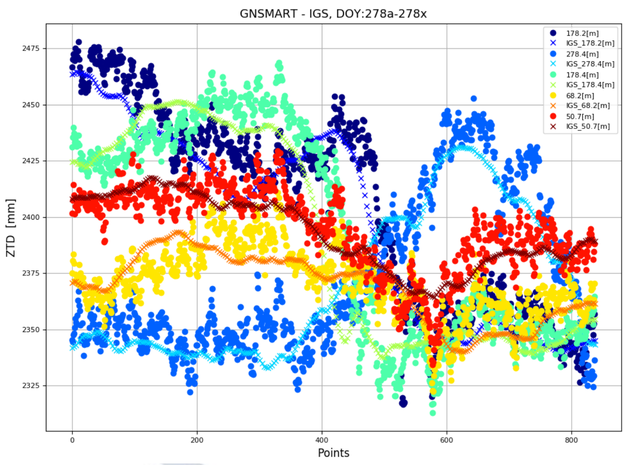
Tropospheric refraction is one of the major error sources in satellite-based positioning. The dependency of the troposphere on physical quantities such as temperature, pressure and humidity makes troposphere modeling challenging in severe weather conditions. One such severe weather event was the Xavier windstorm that occurred in northern Germany at the beginning of October 2017. 41 GNSS stations of the LGLN-SAPOS network in Lower Saxony are used for the analysis which is based on the tropospheric products of the Geo++® GNSMART (GNSS - State Monitoring And Representation Technique) software. The variations of the Zenith Tropospheric Delay (ZTD) are compared with the variation of published weather data of DWD and with ZTDs obtained from integration of the physical quantities available from the ECMWF data archive. Different approaches for interpolation of ZTDs between reference stations have been analyzed, including a utilization of the estimated horizontal gradients. The quality of the interpolation has been evaluated by rover tests, performed with GNSMART RTK modules .

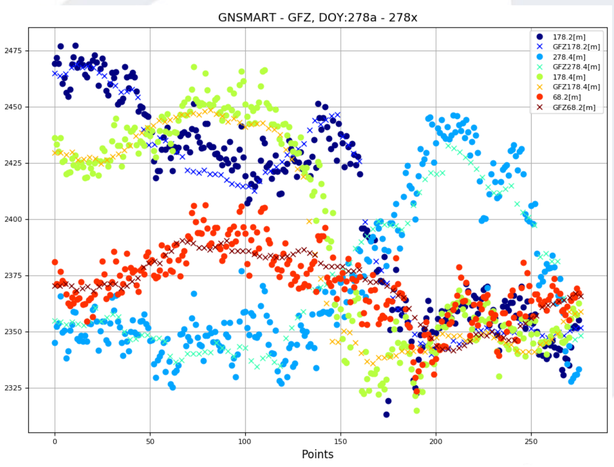
ZENITH TROPOSPHERIC DELAY (ZTD)



- GNSMART zenith tropospheric model: UNB3, based on the Saastamoinen model
- GNSMART slant delay model: Neill with DOY dependent mapping function

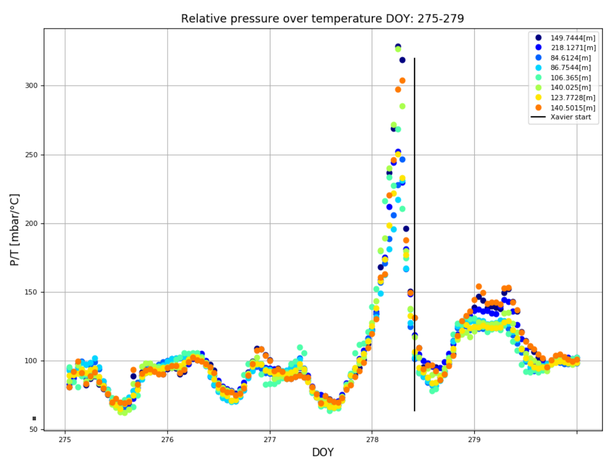
ZTD COMPARISON GNSMART, GFZ, IGS GREF STATIONS

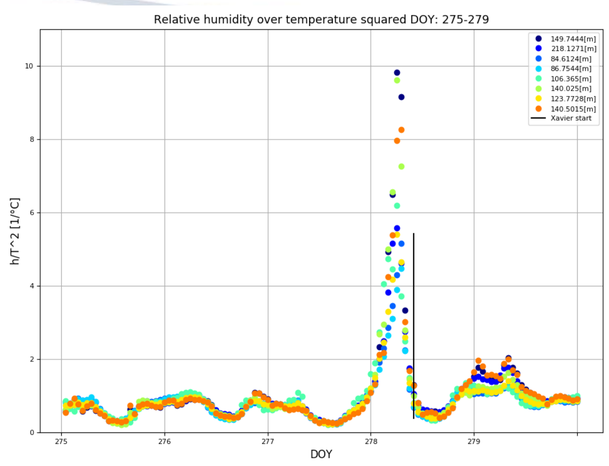




- good agreement in the ZTD variation but with differences up to 2.5 cm
- accurate comparison difficult due to different time-step and noise

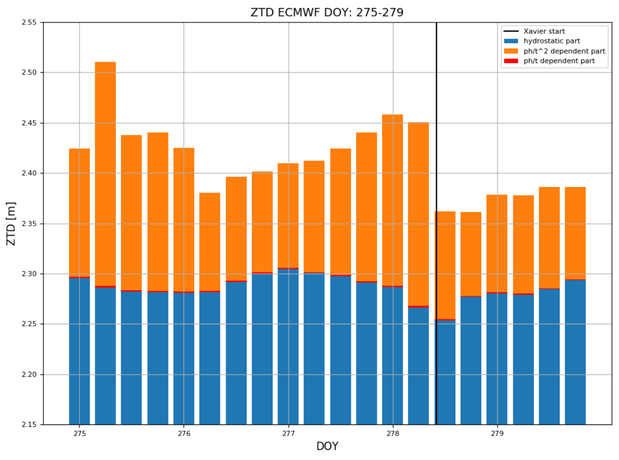
GROUND BASED WEATHER DATA





- surface based weather data fails to detect some significant ZTD changes
- information of atmospheric parameters at different heights is required

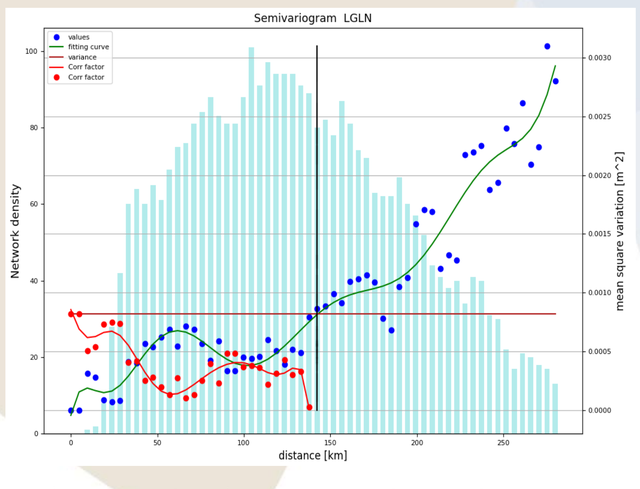
ECMWF NUMERICAL WEATHER MODEL (NWM)

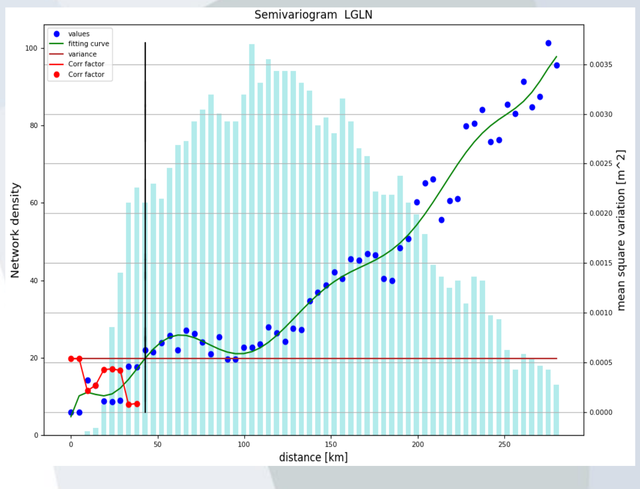


- good agreement between variation of the reconstructed ZTD from NWM and GNSMART products
- the shape of the variation is mostly given by the contribution depending on h/T^2
- here, p is the atmospheric pressure, T the absolute temperature and h the specific humidity

$$\boldsymbol{ZTD} = \mathbf{10^{-6}} \int_s^r \left(\mathbf{77.6}\frac{p}{T} - \mathbf{12.81}\frac{p}{T}\frac{h}{\mathbf{0.622}} + \mathbf{377600}\frac{p}{T^2}\frac{h}{\mathbf{0.622}} \right)$$

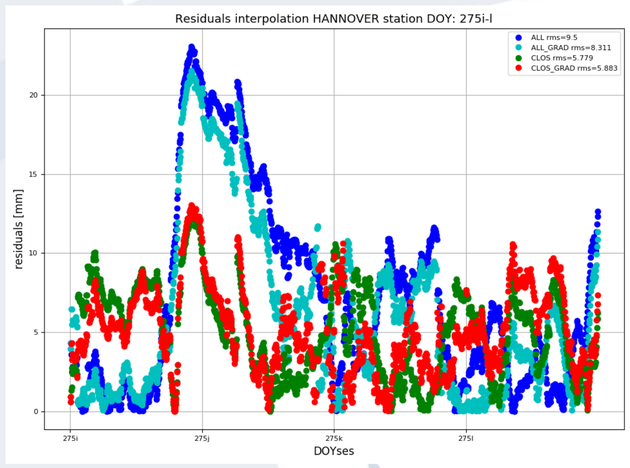
SPATIAL CORRELATION

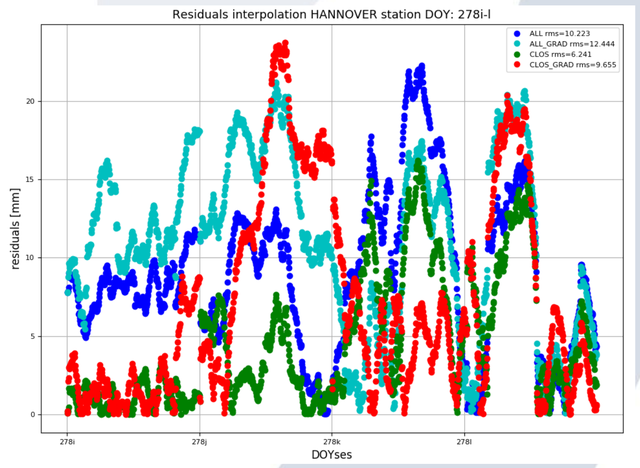




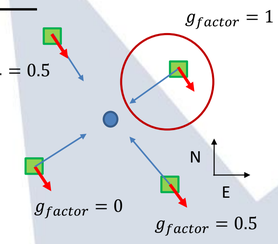
- hypotesis: the process is stationary
- semivariogram: $\boldsymbol{v(r)} = \frac{\mathbf{1}}{\mathbf{2}}\left\langle [\boldsymbol{ZTD(x+r)} - \boldsymbol{ZTD(x)}]^2 \right\rangle$
- covariogram: $\boldsymbol{C(r)} = \boldsymbol{\sigma^2} - \boldsymbol{v(r)}$
- considering all the days: max correlation length $\boldsymbol{r_{max} \cong 142\ km}$
- considering only DOY 275 (with high ZTD variations): max correlation length $\boldsymbol{r_{max} \cong 43\ km}$
- correlation with the impact of humidity contribution on the ZTD variation

INTERPOLATION OF ZTD REDUCTED TO HEIGHT=0





$$g_{factor} = \frac{\frac{(\boldsymbol{R}\vec{g}) \cdot \vec{n}}{gn} + 1}{2}$$

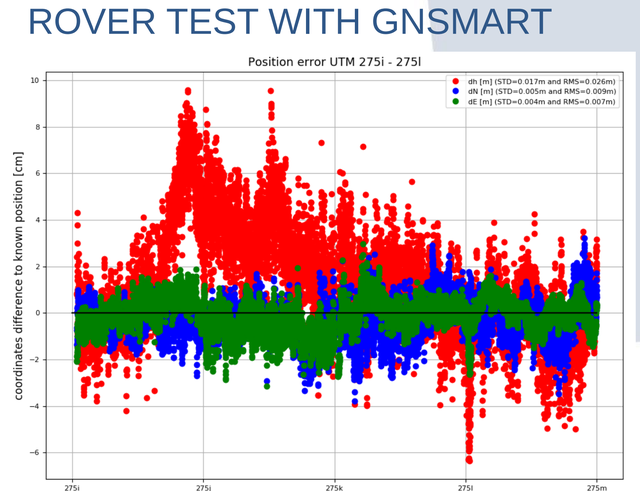


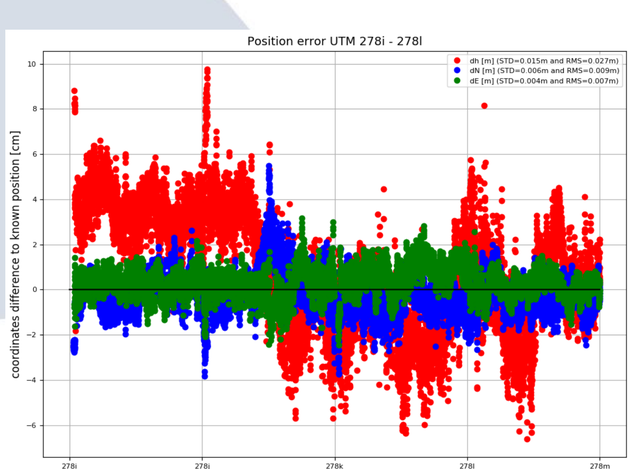
where:

- $\vec{g}$ is the tropospheric gradient (N,E)
- $\vec{n}$ is the distance vector in the 2D plane (N,E)
- $\boldsymbol{R}$ is a clockwise rotation matrix of 90°
- t is the interpolation time
- $t - x$ is the reference time of the gradients

- Kalman filter used for the interpolation with four different ways to interpolate changing:
1. number of stations, all or stations within a maximum distance of 43 km
2. the weight, $\frac{1}{d^2}$ or $\frac{g_{factor}}{d^2}$
- the use of the closest stations might improve the interpolation performance
- the info from the gradients seem to be valuable when there is a weather front

ROVER TEST WITH GNSMART





- DOY considered with the two large slants in ZTD
- larger effect before the windstorm: there is no evident impact on the positioning during the windstorm

SUMMARY AND FUTURE WORKS

- ZTD information cannot reliably be extracted from surface weather data alone
- variation of ZTD reconstructed from ECMWF is in good agreement with GNSS ZTD variation
- during periods with large ZTD variation, interpolation should only consider stations close to the interpolation point improving the performance up to 1cm
- gradients information might be valuable only during a weather front improving the interpolation up to 7mm
- implementation of the closest stations interpolation in GNSMART
- use of NWM to predict when to use the gradients into the interpolation process

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