Interpolation of tropospheric delays for high accuracy NRTK positioning

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Outline

- Objective and data-sets
- ZTD variation
- horizontal gradients
- ZTD interpolation
- results
- conclusions and future work

- the TREASURE project is a Marie Skłodowska-Curie Actions (MSCA) Innovative Training Network (ITN), funded through the European Union’s Horizon 2020 Research and Innovation Programme

- the project will concentrate on research that will pave the way for the development of a service that can ensure enhanced real-time high accuracy positioning
Objective and data-sets (1/2)

- investigation of interpolation of zenith tropospheric delay

- from the literature, ordinary Kriging interpolation and inverse distance weighted least squares are the most implemented interpolation techniques

- the rule of thumb 1:-3 between error in the interpolation of the ZTD and error in the height in the position domain

- ZTD interpolation is relevant for high accuracy positioning
### Objective and data-sets (2/2)

#### GNSS data

<table>
<thead>
<tr>
<th>LGLN-SAPOS network</th>
<th>Kadaster network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xavier windstorm October 2017</td>
<td>large weather fluctuations June 2017</td>
</tr>
<tr>
<td>Lower Saxony, Germany</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>41 GNSS stations</td>
<td>36 GNSS stations</td>
</tr>
<tr>
<td>average distance: ≈ 45 km</td>
<td>average distance: ≈ 40 km</td>
</tr>
<tr>
<td>Rinex 2.1, 1s time-step</td>
<td>Rinex 2.1, 1s time-step</td>
</tr>
</tbody>
</table>

#### Numerical Weather Model data*

<table>
<thead>
<tr>
<th>Global Forecast System (GFS)</th>
<th>Era-Interim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xavier windstorm October 2017</td>
<td>large weather fluctuations June 2017</td>
</tr>
<tr>
<td>Lower Saxony, Germany</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>time resolution: 3 h</td>
<td>time resolution: 3 h</td>
</tr>
<tr>
<td>spatial resolution: 0.25 deg</td>
<td>spatial resolution: 0.25 deg</td>
</tr>
</tbody>
</table>

* data provided by GFZ
ZTD variation

- Zenith total delay computed with the Geo++ software GNSMART
- Large spatial and temporal ZTD variations
- The effect of the height was corrected, the plot refers to stations at height = 0
Horizontal gradients

- ZTD computed from GNSS observations

- horizontal gradients retrieved from NWM

- good agreement between ZTD variation and horizontal gradients directions in both the days of large ZTD variations

- the variation of the ZTDs of the Kadaster data-set is more chaotic w.r.t. the LGLN data-set

* data provided by GFZ
ZTD interpolation (1/2)

- Four different interpolation approaches have been investigated:
  - ordinary Kriging (OK)
  - inverse distance weighted least squares (IDW2)
  - best fitting plane determined from weighted least squares with weight depending on the inverse of the distance elevated to the power of four (WLS4)
  - best fitting plane determined from weighted least squares with weight depending on the distance elevated to the power of four giving more weight to the stations perpendicular to the horizontal gradients retrieved from NWM (WLS4g)
ZTD interpolation (2/2)

- the interpolation has been investigated considering 7 distinct stations, 4 of the LGLN network and 3 of the Kadaster network

- these stations have been taken out from the networks and considered as user locations
Results
# Results (1/4)

1. RMS of the interpolation error w.r.t. reference value computed with GNSMART for the LGLN network.

<table>
<thead>
<tr>
<th>Technique</th>
<th>DOY 275 – 279 [mm]</th>
<th>DOY 275, hour 9 [mm]</th>
<th>DOY 278, hours 8-11 [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDW2</td>
<td>8</td>
<td>19</td>
<td>12</td>
</tr>
<tr>
<td>Kriging</td>
<td>7</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>WLS4</td>
<td>7</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>WLS4g</td>
<td>7</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

1 cm in the ZTD $\rightarrow$ 3 cm in the height

2. RMS of the interpolation error w.r.t. reference value computed with GNSMART for the Kadaster network.

<table>
<thead>
<tr>
<th>Technique</th>
<th>DOY 170-174, 177 [mm]</th>
<th>DOY 173, hour 17 [mm]</th>
<th>DOY 177, hours 15-18 [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDW2</td>
<td>39</td>
<td>24</td>
<td>9</td>
</tr>
<tr>
<td>Kriging</td>
<td>39</td>
<td>25</td>
<td>9</td>
</tr>
<tr>
<td>WLS4</td>
<td>39</td>
<td>24</td>
<td>9</td>
</tr>
<tr>
<td>WLS4g</td>
<td>39</td>
<td>25</td>
<td>7</td>
</tr>
</tbody>
</table>

2 mm in the ZTD $\rightarrow$ 0.6 cm in the height
Results (2/4)

- In 60% of the cases, the interpolation using the gradients gives the best interpolation quality.

- The results depend also on the position of the user within the network w.r.t. the current location of the weather event.

- Different interpolation quality between LGLN and Kadaster data-sets due to strong weather fluctuations.
Results (3/4)

- for each data-set the **cumulative error** shows **similar performance** for the techniques used.

- for the LGLN data-set the implementation of a different technique w.r.t. IDW2 increases the number of small errors.
• differences can be observed during particular hours involving weather fluctuations

• WLS4g marks an increment of the number of the errors below 1 cm w.r.t. IDW2
Conclusions and future work
Conclusions and future work

- the analysis indicates to **avoid inverse distance weighted least squares** for ZTD interpolation since the best fitting plane determined from weighted least squares and ordinary Kriging provide better performance

- during hours with **strong weather fluctuations** the use of the **gradients** (WLS4g) could **improve** up to **3 cm the error in the height** changing the error distribution

- further investigations are needed to define the criteria to decide **when to use** the WLS4g technique

- future work: implementation of WLS4g to see the effect in the **position domain** w.r.t. WLS4 in post-processing and a **real-time test** using horizontal gradients from NWM as external source
Thank you for your attention