Weather monitoring Based on Collaborative Crowdsourcing

NAVISP Industry Days - ESTEC
Objectives and approach

GNSS receiver network

Collaborative crowdsourcing algorithms

Troposphere delays (ZWD) estimated for NWP

Troposphere
Content

1. Project summary

2. Organization

3. Results

4. Conclusion/recommendations

5. Perspectives
Introduction on troposphere

• Lowest part of the atmosphere, below ionosphere

• From the surface of the Earth to ~ 50km

• GNSS Slant Total Delay (STD) =

\[ \text{Slant Hydrostatic delay (SHD)} + \text{Slant Wet delay (SWD)} \]

\[ \Rightarrow \text{SWD contains troposphere water vapor content information} \]
Motivations

- Limited area NWP: AROME Model example

- Conventional sensors (radiometers)
  - Low spatial resolution

- Network of GNSS receivers
  - High spatial and temporal resolution

Accumulated precipitation (mm) on 19 July 2007 AROME forecast
Motivations

- **Objective of the project**

Conventional Observations → Limited area NWP → Forecast

GNSS smartphone receiver network

⇒ Collaborative crowdsourcing approach
Organization

Work steps

Task 1: review, trade off and preliminary design

Task 2.1: simulation test-bed detailed design

Task 2.2: simulation test-bed implementation/validation

Task 3: simulation test-bed operation and experimental study

Task 4: results analysis, conclusions and recommendations
Simulation test-bed
WMCC test-bed

- **Receiver error generator**

Measurement combination to extract and model:
- Receiver clock offset
- Noise+multipath effects

<table>
<thead>
<tr>
<th>Receiver grade</th>
<th>GNSS signal</th>
<th>Multipath environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smartphone (Samsung S8)</td>
<td>GPS L1, Galileo E1, GLONASS L1</td>
<td>Open sky + semi-urban</td>
</tr>
<tr>
<td>Medium (uBlox)</td>
<td></td>
<td></td>
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<tr>
<td>High grade (Septentrio)</td>
<td></td>
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Tropospheric delay estimator

• Estimate:
  - Tropospheric zenithal wet delays (ZTD)
  - Standard deviation of the estimation error

• Methodology:
  - Feed forward loop implementation of PPP and tomography
Results: Performance contributors

- GNSS receiver grade
- Frequency mode
- System performance
- Multipath environment
- Atmospheric conditions
- Receiver density
- Constellations

Atmospheric conditions
GNSS constellation impact on system performance

- The number of assimilated ZTD increases with the number of constellations.

**Local coverage, dual-frequency.** After tropospheric delay estimator. In red, the reference value.
Results: Optimal conditions

- 3 constellations
- Dual frequency receivers
- Near-future smartphones
- Open-sky environment
- ~ 1 smartphone / km²

Test bed algorithms

- ~ 10mm error
- Can be used in NWP
# Recommendations

## Configuration

<table>
<thead>
<tr>
<th>Configuration</th>
<th>GPS SF</th>
<th>GPS+GAL+GLO SF</th>
<th>GPS DF</th>
<th>GPS+GAL+GLO DF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recommended?</strong></td>
<td><strong>Red</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Remark</strong></td>
<td>ZTD estimation error &gt; 10 cm (*)</td>
<td>ZTD estimation error &lt; 10 cm (*)</td>
<td>Performance slightly better than multi-constellation in SF</td>
<td>In local coverage, ~1 cm (*) ZWD error</td>
</tr>
</tbody>
</table>

## Performance

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Network failures on every RCV</th>
<th>Semi-urban multipath environment</th>
<th>Duty cycles on 50% RCV</th>
<th>High residual ionospheric errors (SF)</th>
<th>Low-grade receiver</th>
</tr>
</thead>
<tbody>
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<td><strong>Recommended?</strong></td>
<td><strong>Red</strong></td>
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<td></td>
</tr>
<tr>
<td>Degradation of the number of ZTD assimilated in NWP w.r.t nominal conditions</td>
<td>70%</td>
<td>40%</td>
<td>30%</td>
<td>25%</td>
<td>20%</td>
</tr>
</tbody>
</table>

- **SF**: Single Frequency (L1 and E1)
- **DF**: Dual Frequency (L1/L2 for GPS and GLONASS, E1/E5a for GALILEO)
- **RCV**: Receiver

(*) before bias removal
Way forward

- **Consolidate system performance analyses**
  - Adapt to moving smartphones
  - Test on real data

- **Assess performance improvement on weather forecast**

- **Develop operating system**
  - Develop near-real time processing facility to support crowdsourcing algorithms
“Combinations of Measurements for Modeling Smartphone and Higher End GNSS Receiver Performance”. V. V. Lehtola, S. Söderholm, M. Koivisto, L. Montloin, MDPI, July 2019

“Towards Tropospheric Delay Estimation Using GNSS Smartphone Receiver Network”. Tiago Marques; Maija Makela; Leslie Montloin; Terhi Lehtola; Sarang Thombre; Ville Lehtola, proceedings of 7th ESA colloquium - Scientific and Fundamental aspects of GNSS, September 2019
Submitted to Special Issue on GNSS for Science of Elsevier - ASR

“Tropospheric tomography with a network of roving GNSS receivers”. Ville V. Lehtola, Maija Makela, Tiago Marques, Leslie Montloin, to be published this year
Back-up
Tropospheric delay generator

- **Objective:** Generate reference GNSS tropospheric slant total delays between smartphones and GNSS satellites
- **Constraint:** Need to represent **small-scale** and **short-term** tropospheric delay variations

Positions for which temperature, pressure and specific humidity are available from meteorological profile files

Spatial resolution of meteorological files (1.3km for AROME)

Positions for which IWVC are available from meteorological surface files

Receiver antenna positions (assumed to be on the ground)
Tropospheric delay generator

- **Methodology:**
  - 1st step: compute the reference ZTD by using a vertical integration of the high resolution AROME/ARPEGE meteo fields above the smartphone location
  - 2nd step: compute the wet and hydrostatic mapping functions VMF1 using tropospheric files (VMF1 parameter files from Vienna University)
  - 3rd step: compute the reference STD

- **Accuracy:**
  - IGS ZTD and AROME ZTD comparison => [mm] level accuracy of AROME ZTD
Frequency mode impact on system performance

Conclusions

- It is recommended to use dual frequency, the estimation of the ZTD error is significantly better comparing to single frequency mode.

- Number of assimilated points when using single frequency is too low.

Local coverage, GPS+GAL

Blue line: ZTD after tropospheric delay estimator
Blue cross: ZTD after data processor for assimilation
Red line: Reference value