Kinematic GNSS experiment supported by precise augmented tropospheric model

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IAG Commission 4 Positioning and Applications Symposium

September 4-7, 2016, Wroclaw, Poland
Motivation

Experimental data collection

Processing strategy

Data analysis
  ◦ Positioning when ZTD is estimated
  ◦ Positioning using precise tropospheric model
  ◦ Simulation of reduced constellation

Conclusion
Motivation

- Collect kinematic GNSS and meteorological data with a vertically moving receiver reaching up to 2 km above the earth surface

- Evaluate different approaches of the troposphere modeling, particularly using GOP augmented tropospheric model, in high accuracy kinematic GNSS positioning
Experimental data collection
(*Hot air balloon flight campaign*)

- A balloon has been chosen for a simplicity of mounting GNSS antenna and other sensors
- Hardware equipment:
  - GNSS receiver/antenna - Trimble SPS855/TRM57970.00
  - Meteorological sensors - COMET T7410
    (temperature, pressure, humidity)
- Observation sampling rate
  - GNSS: 0.2s (5Hz), however, processed only 1s (1Hz) data
  - Meteo sensors: 10s
- Observed constellations: GPS, GLO, GAL, BDS
- The flight reached a maximum height of about 2000m above the earth surface.
Experimental data collection
( Hot air balloon flight campaign )

• The additional longer wooden board was used to minimize obstacles caused by the balloon and influences of the heating system
**Processing strategy**

Several strategies for GNSS processing have been set up:

- **Software:** G-Nut/Geb developed at the Geodetic Observatory Pecny
- **Estimation method (Precise Point Positioning - PPP)**
  - Forward Kalman filter
  - Forward Kalman filter improved by the backward smoothing
- **Precise Products for Orbits/clocks**
  - Real-time products: Centre National d’Etudes Spatiales (CNES)
- **Constellations**
  - Real-time processing: GPS, GLO
- **Tropospheric parameters**
  - Estimated: ZWD estimated, ZHD taken from the Saastamoinen as a priori using pressure from GPT
  - Fixed: ZTD parameter has been introduced from a tropospheric model
- **Observations:** undifferenced dual frequency ionosphere-free combination
**Processing strategy**

*(External tropospheric corrections)*

- GOP augmented tropospheric model
  - The tropospheric corrections (ZHD, ZWD) are based on numerical weather model (NWM) and algorithms developed at GOP


- Mesoscale weather forecasting model WRF has been operated in two domains (CZ and EU) by the Institute of Computer Sciences, Academy of Science of the Czech Republic.
  - Four forecasts per day - at 00, 06, 12 and 18 UTC
  - 1-hour time resolution in each forecast with 13-hour length of the forecast
Data analyses

- We divided the experimental campaign into the five sections
  - Initialization phase
  - Ascending phase
  - Descending phase
  - Landing maneuver
  - Final phase
- During the initialization and the final phases the rover receiver remained in a static position.
Data analyses
(ZTD estimated along other parameters)

- What is the impact of ZTD constraining on estimated height?
- Four approaches:
  - Kalman filter using GPS
  - Kalman filter + backward smoothing using GPS
  - Kalman filter using GPS+GLONASS
  - Kalman filter + backward smoothing using GPS+GLONASS
- Different ZTD random walk noises:
  - 1, 2, 5, 10, 20 mm/sqrt(hour)
- Reference solutions constrained with 1 mm/sqrt(hour)
Data analyses
(ZTD estimated along other parameters)

Kalman filter using GPS

Kalman filter + backward smoothing using GPS

Kalman filter using GPS+GLO

Kalman filter + backward smoothing using GPS+GLO
Data analyses

(ZTD estimated along other parameters)

- Heights estimated from the individual solutions differ due to a mutual correlation with the ZTD parameters.
- How can external troposphere stabilize the vertical positioning in studied approaches?
We set up a loose constraining ZTD (\(q = 20 \text{ mm}/\sqrt{\text{hour}}\))

Reference solution: ZTD estimated via the backward smoothing algorithm and using GPS+GLONASS

The positive impact (\(\approx 50\%\)) of precise tropospheric corrections in GPS-only real-time solution is similar to including GLONASS constellation.
Data analyses

*(Simulation of reduced constellation)*

- The most important aspect of the accurate estimation of the rover height during the vertical movement is the correlation with the zenith total delay.
- The satellite geometry strongly influence the correlation
- We investigated the impact of external tropospheric corrections depending on the number of satellites or the geometric dilution of precision (GDOP)
- First, we estimated coordinates using a full available GPS constellation; second, we excluded a few satellites to increase the GDOP value.
- Two scenarios were applied
  - ZTD was derived from the augmented tropospheric model
  - ZTD was estimated along with other parameters including coordinates
- Parameters were estimated using the backward smoothing to reach the best possible accuracy.
Data analyses
(Simulation of reduced constellation)

- Considered solutions
  - **EST_FULL**: All available GPS satellites, ZTD corrections estimated
  - **EST_RED**: Reduced GPS constellation, ZTD corrections estimated
  - **D01_FULL**: All available GPS satellites, ZWD + ZHD introduced from the GOP-ZWD tropospheric model using WRF-ICS data
  - **D01_RED**: Reduced GPS constellation, ZWD + ZHD introduced from the GOP-ZWD tropospheric model using WRF-ICS data

- Reference solution
  - **EST_GRxx**: All available GPS and GLONASS satellites, ZTD corrections estimated
Data analyses
(Simulation of reduced constellation)

- Receiver height estimation using all available GPS satellites or when a few satellites are excluded
Conclusions

- We collected and analyzed data from the flight experiment when the receiver reached 2000 m about the earth surface with averaged velocity of 2m/s.
- Receiver height and ZTD should be estimated loosely constrained when processing such vertical kinematic data. However, when estimating ZTDs with a higher noise, the parameters can absorb additional effects together with a part of the height component due to a strong mutual correlation.
- Processing multi-GNSS data resulted in significantly better satellite geometry and the lower correlation between ZTD and height.
- External information about troposphere improved real-time (Kalman filter) GPS-only height estimation in a similar way as including GLONASS satellites.
Conclusions

- Precise tropospheric corrections can improve height Sdev by the factor of 2 in real-time applications.
- The impact of external tropospheric corrections became significant with increasing GDOP.
- In general, we recommend utilizing precise augmentation tropospheric model in GNSS positioning whenever both height and ZTD have to be estimated almost unconstrained, e.g. during a vertical movement.

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better height-ZTD decorrelation

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increased robustness and stability of the solution
Thank you for your attention

The experimental data collection, processing and tropospheric model enhancement has been supported by

ESA project DARTMA

Initial tropospheric model development has been supported by

ESA project Trop4LAS

We further acknowledge:
IGS for providing final and real-time GNSS products

Disclaimer: The work reported in this paper has been performed under a contract of the European Space Agency in the frame of the Announcement of Opportunities on GNSS Science and Innovative Technology within the European GNSS Evolutions Programme. The views presented in the paper represent solely the opinion of the authors.