Kinematic GNSS experiment supported by precise augmented tropospheric model

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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

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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

Douša J, Eliaš M (2014) An improved model for calculating tropospheric wet delay, Geoph. Res. Letters 41(12): 4389-4397. doi: 10.1002/2014GL060271

  - 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

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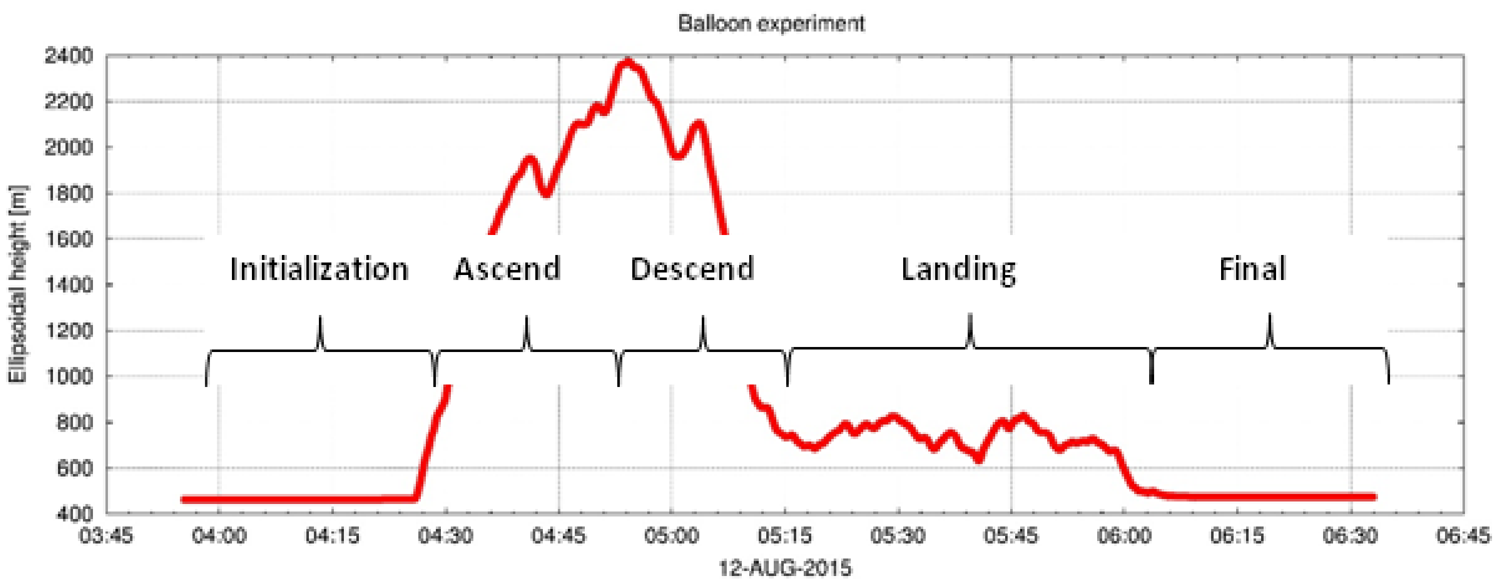
Data analyses

- 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.



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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)

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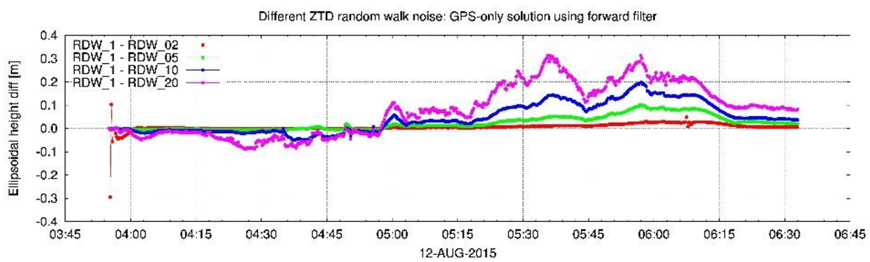
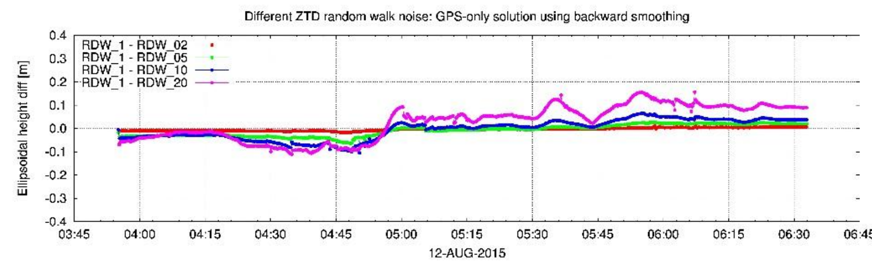
Data analyses

(ZTD estimated along other parameters)

Kalman filter using GPS

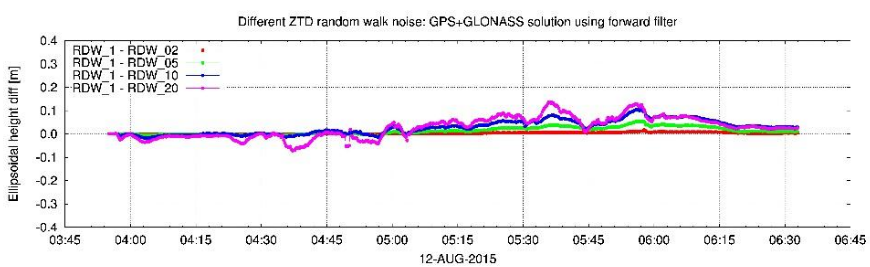
Kalman filter + backward smoothing using GPS

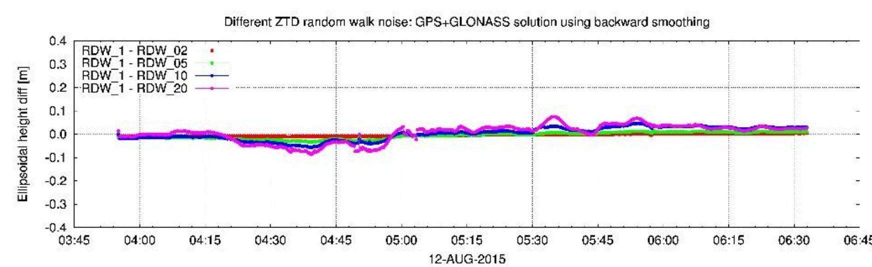




Kalman filter using GPS+GLO

Kalman filter + backward smoothing using GPS+GLO





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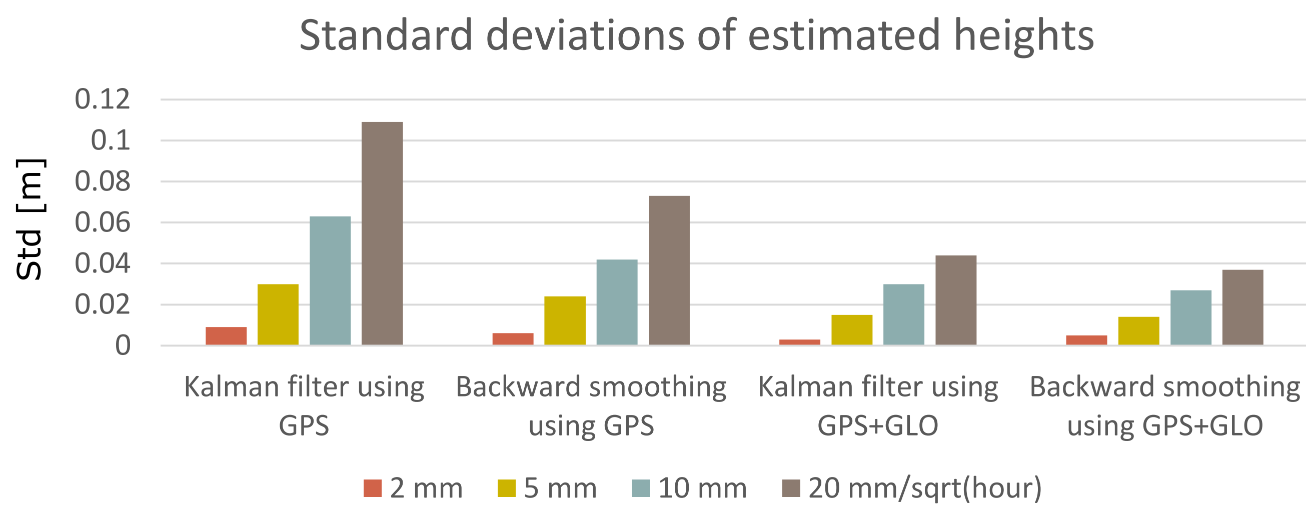
Data analyses

(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?

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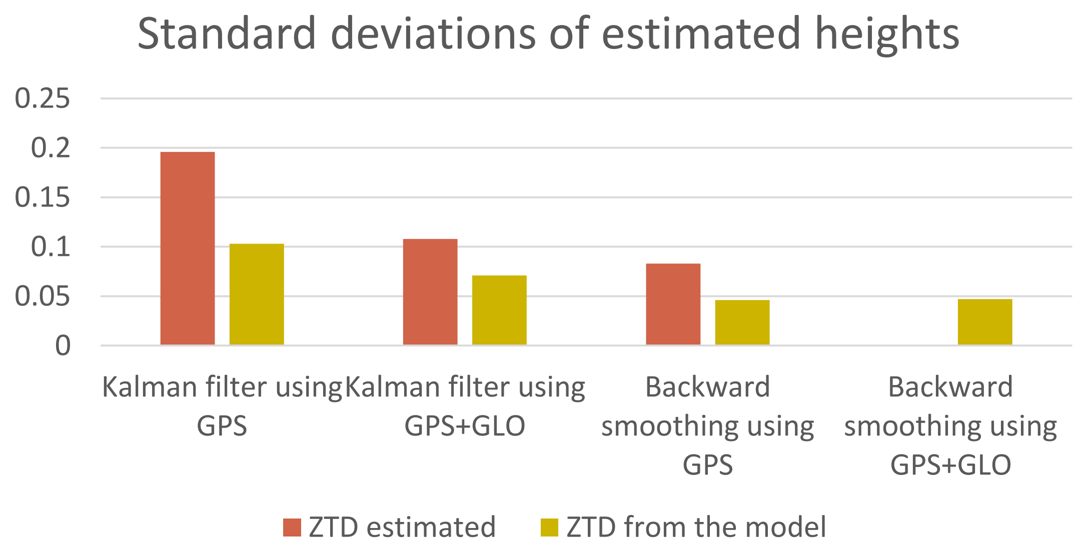
Data analyses

(ZTD introduced from the tropospheric model)

- We set up a loose constraining ZTD (q = 20 mm/sqrt(hour))
- Reference solution: ZTD estimated via the backward smoothing algorithm and using GPS+GLONASS



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

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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.

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Data analyses

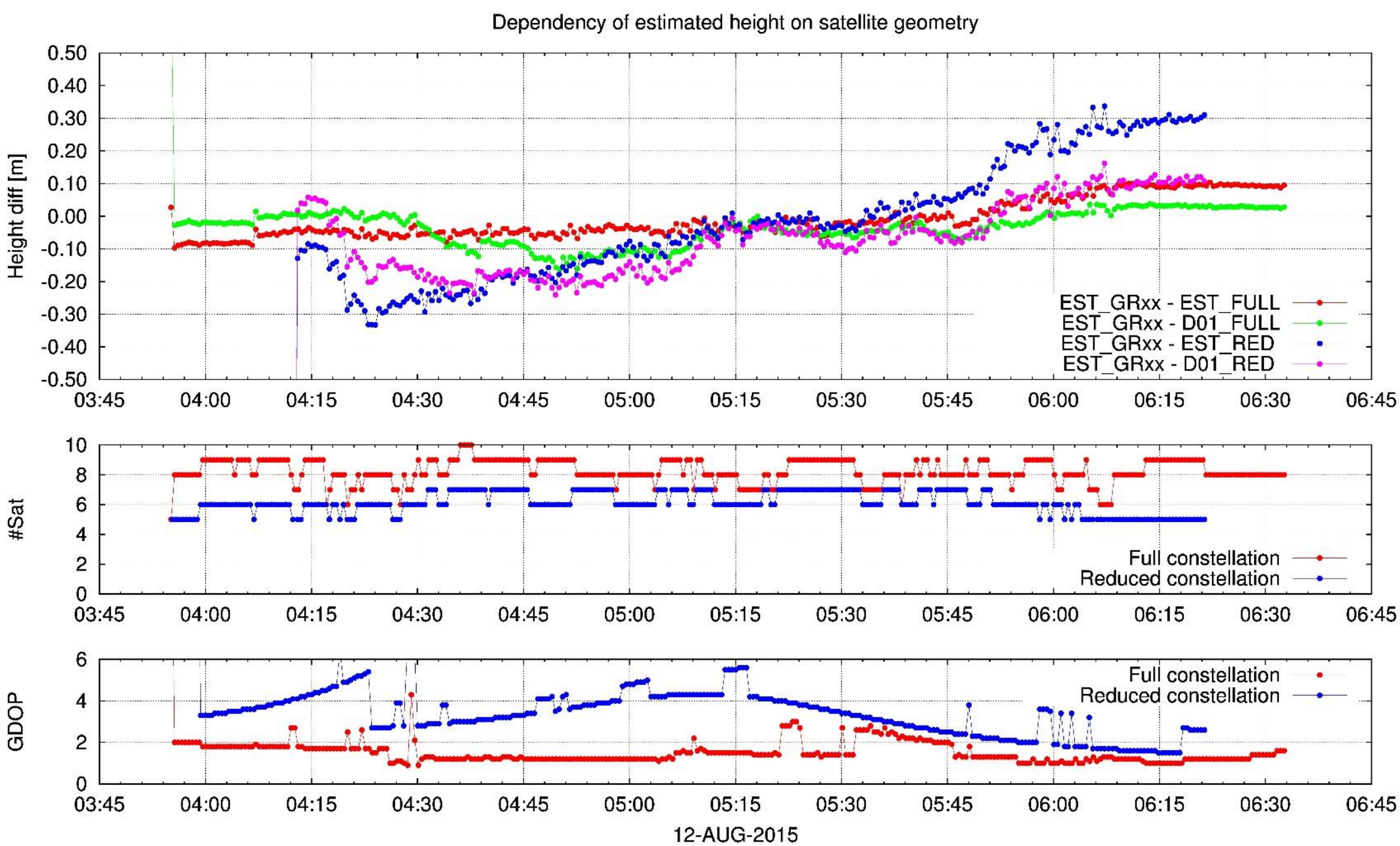
(Simulation of reduced constellation)

- 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



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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.

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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

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