Numerical Weather Predictions for GPS Positioning

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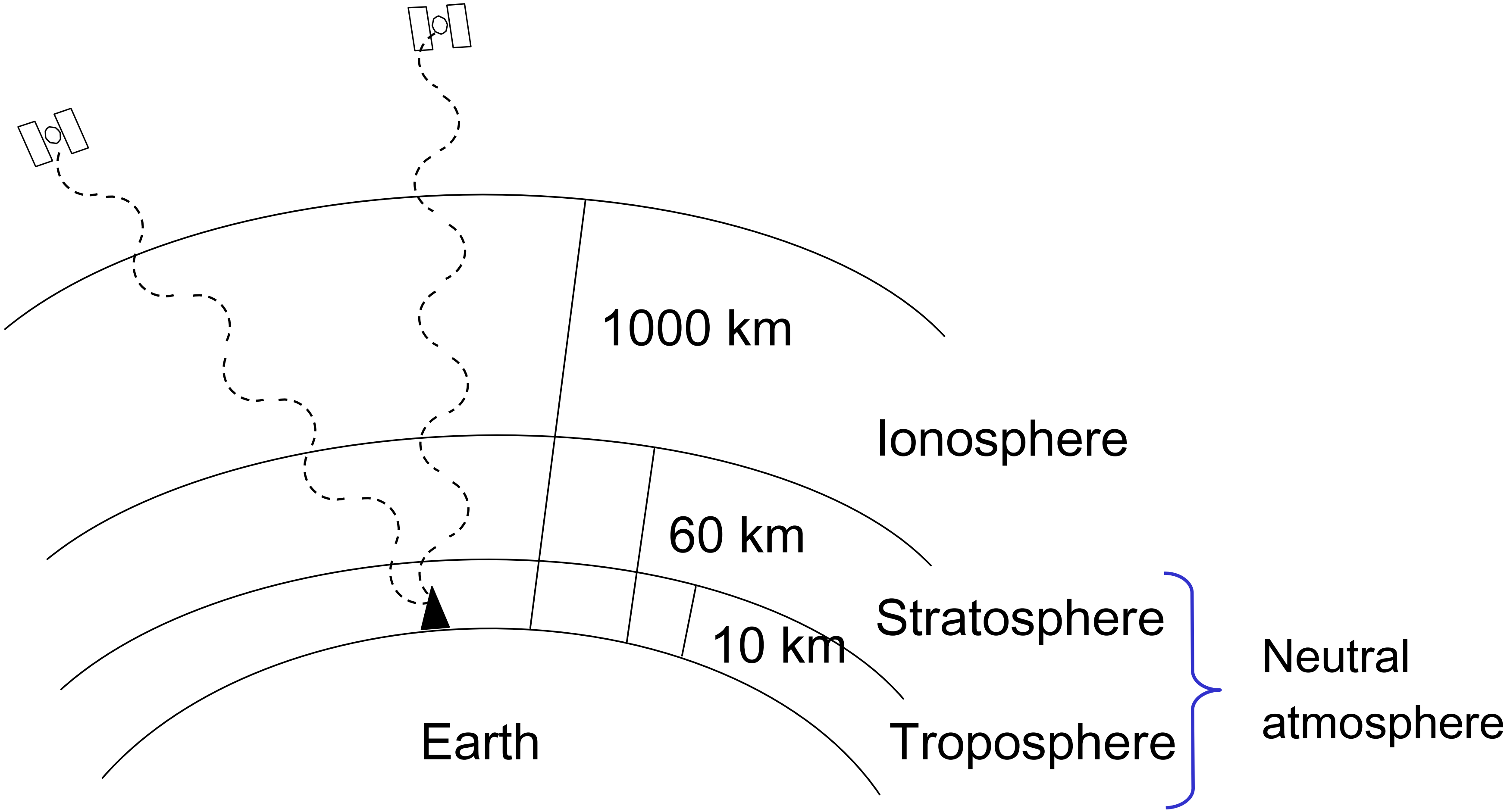
Outline

- The atmosphere and its effect on GPS positioning
- The tropospheric delay
- Numerical Weather Predictions - NWPs
- Verification of NWP derived tropospheric delays
- Static and kinematic positioning tests
- Conclusions and operational considerations

The atmosphere



The atmosphere and GPS

- Satellite signals are affected while being transmitted through the ionosphere and the troposphere
- Normally, global atmospheric models are used to correct for the atmospheric effect, and the models are sufficiently accurate for most GPS positioning
- For high accuracy differential carrier phase-based positioning the global models are not sufficiently accurate

Carrier phase-based positioning

- "Double differencing" is introduced, whereby the influence of any residual atmospheric effect, after modelling, is mitigated
- The ionospheric error can be further mitigated using dual frequency equipment and linear combinations of the L1 and L2 observations
- With a "low" ionospheric activity, the residual tropospheric effect is then the dominant error source

Carrier phase-based positioning

- Applications which will benefit by improved estimates of the tropospheric delay:

  – Real Time Kinematic (RTK) positioning

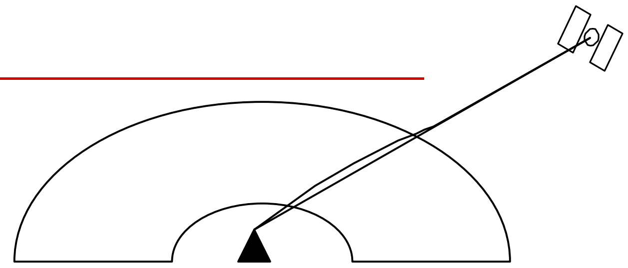
    e.g. construction surveys and cadastral surveying

  – Kinematic post processed positioning

    e.g. photogrammetric flights, airborne laser scanning and road surface maintenance surveys

- For geodetic positioning, long observation time spans are used to account for any residual tropospheric effects

The tropospheric delay



- Refraction in the lowest parts of the atmosphere cause a signal delay and a bending of the ray path

- The consequence is a range error of 2.3 - 2.5 meters in zenith for a GPS receiver at sea level
  - Range error increases with lower elevation angle

- Bending effect is negligible for signals with elevation angle > 15º

Tropospheric modelling

- The tropospheric delay is normally modelled using global tropospheric delay models as e.g. the Hopfield and Saastamoinen models

- The Saastamoinen model is considered to be one of the best global tropospheric models

- The accuracy of the Saastamoinen model is about 3 cm in zenith (Mendes, 1999)
  - For signals received at lower elevation angles the model is more inaccurate

Tropospheric delay

- The tropospheric delay can be determined by integrating the refractivity along the signal path

- The refractivity is a function of:
  - Pressure
  - Temperature
  - Humidity

- The delay can be calculated with information of the meteorological conditions along the signal path

Numerical Weather Predictions

- NWPs are 3D models of the atmospheric conditions for a given area and point in time

- NWPs form the basis for weather predictions and contain the necessary information for estimating the refractivity along the path of a GPS signal

- Idea:
  - Use NWPs, instead of global delay models, for estimating the tropospheric delay

Test data: DMI-HIRLAM-E

- Grid spacing 0.15° x 0.15°
- 31 vertical layers
- Predictions with 1 hour intervals from September 5. 2000

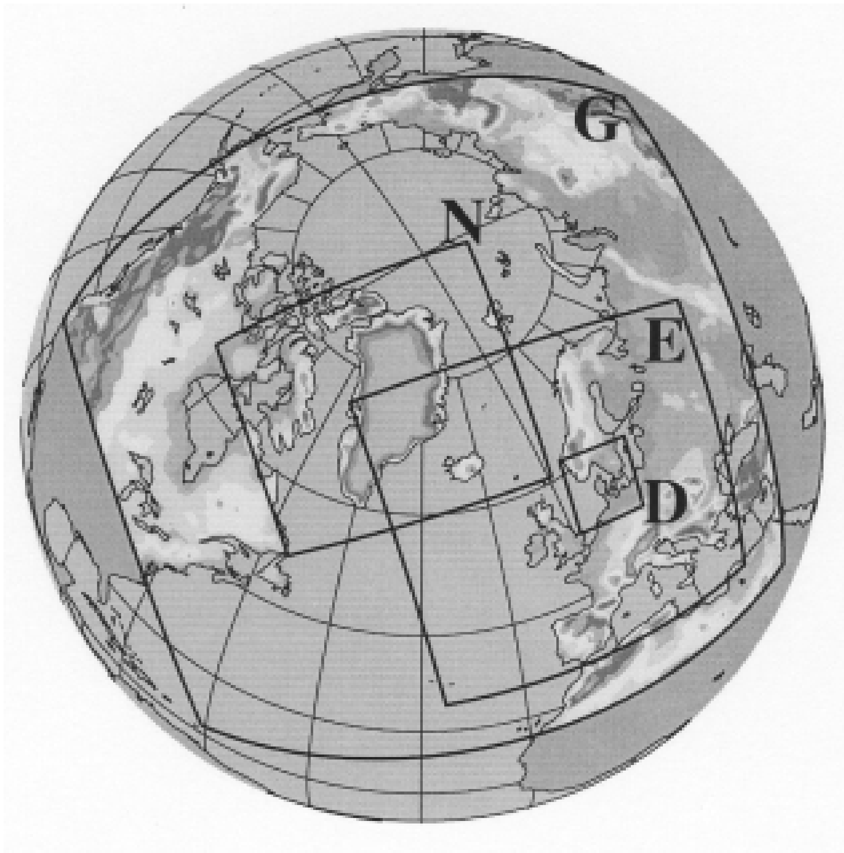


Figure from Sass et al. (2000)

NWP zenith delays

- Zenith delays were determined from NWP data for 14 sites and for 16 epochs in time
- Comparison with GPS derived zenith delays show differences (RMS) of 1.7 cm which is better than the 3.0 cm accuracy of the Saastamoinen model
- This accuracy estimate is similar to results obtained by other groups:
  - Schüler (2001): 1.7 cm (RMS)
  - Pany et al. (2001): 1.0 – 1.5 cm (RMS)
  - Vedel et al. (2001): 0.3 +/- 1.7 cm

Improvement in positioning?

- Is an improvement of 1 cm in the tropospheric zenith delay estimate sufficient to detect an improvement in position accuracy?

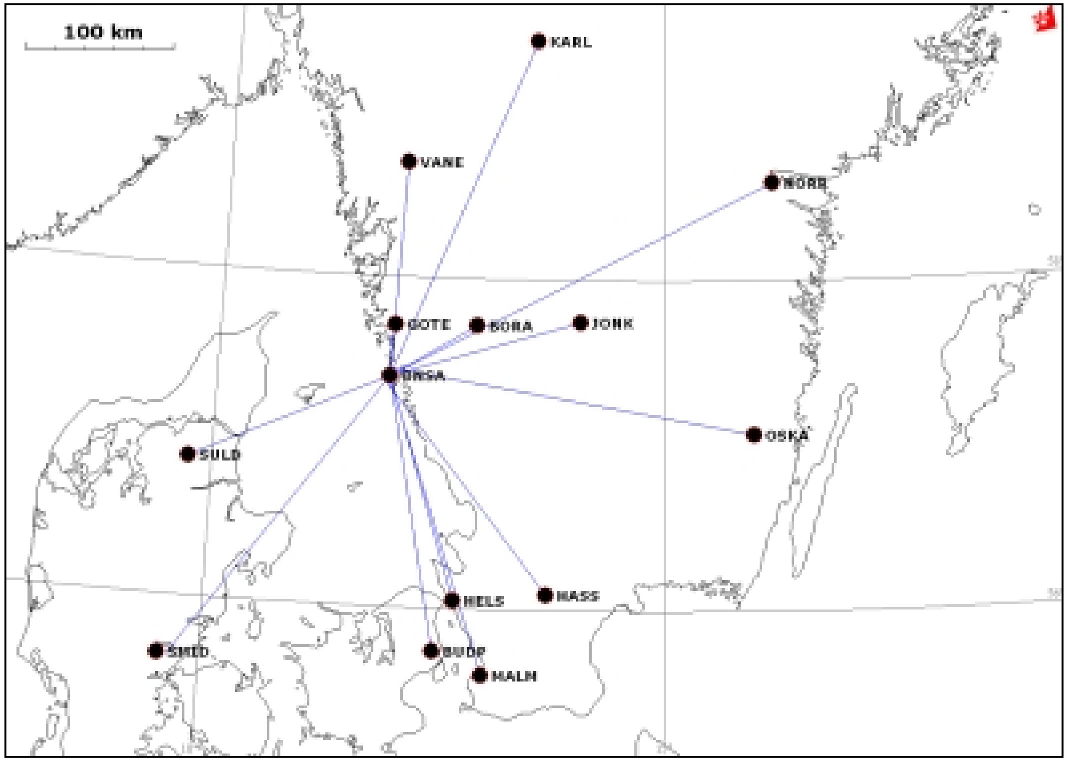
Maybe

- Tsujii et al. (2001): Use of NWPs improved the ambiguity resolution for airborne kinematic tests

- Behrend et al. (2001): Use of NWPs improved the height accuracy for static post processed single point positioning

Test data - GPS

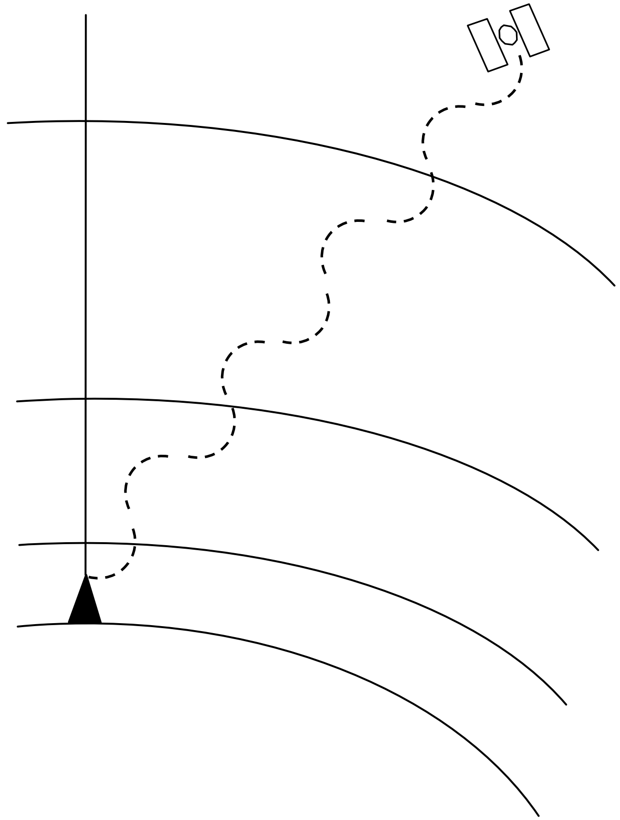
- 14 permanent GPS stations in Denmark and Sweden
- 15 second data rate
- 2 x 6 hours of data



Positioning test procedure

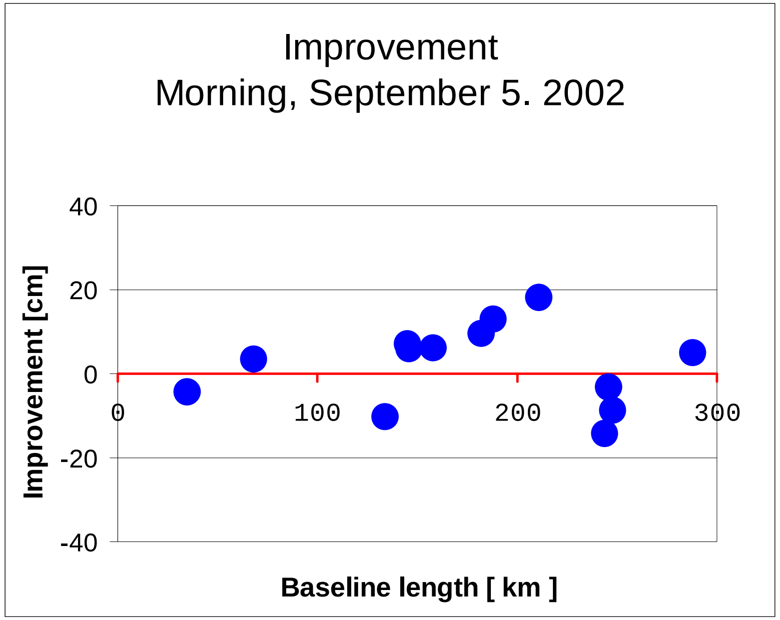
- New tropospheric correction approach developed:

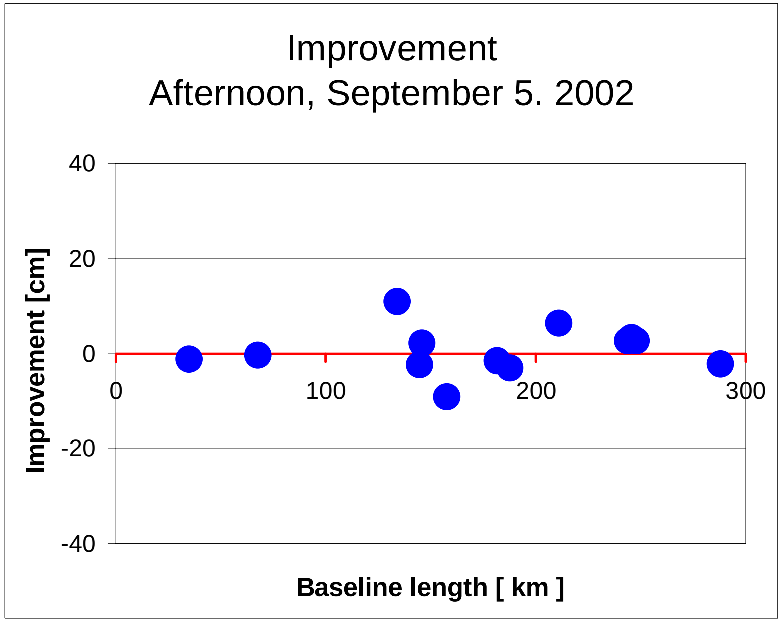
1. Estimate zenith delays from the NWP
2. Temporal interpolation between hourly zenith delays
3. Apply mapping function to determine slant delay
4. Subtract delays from code and phase observations



Saastamoinen vs. NWP approach

- Static results
  - Improvement obtained for 14 of the 26 vectors





- 3D coordinate differences

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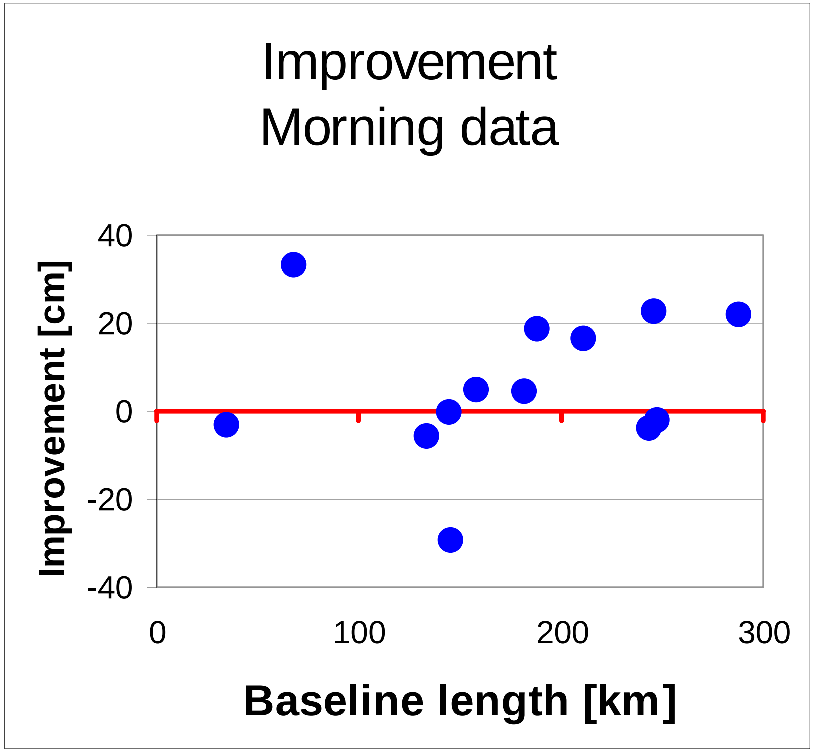
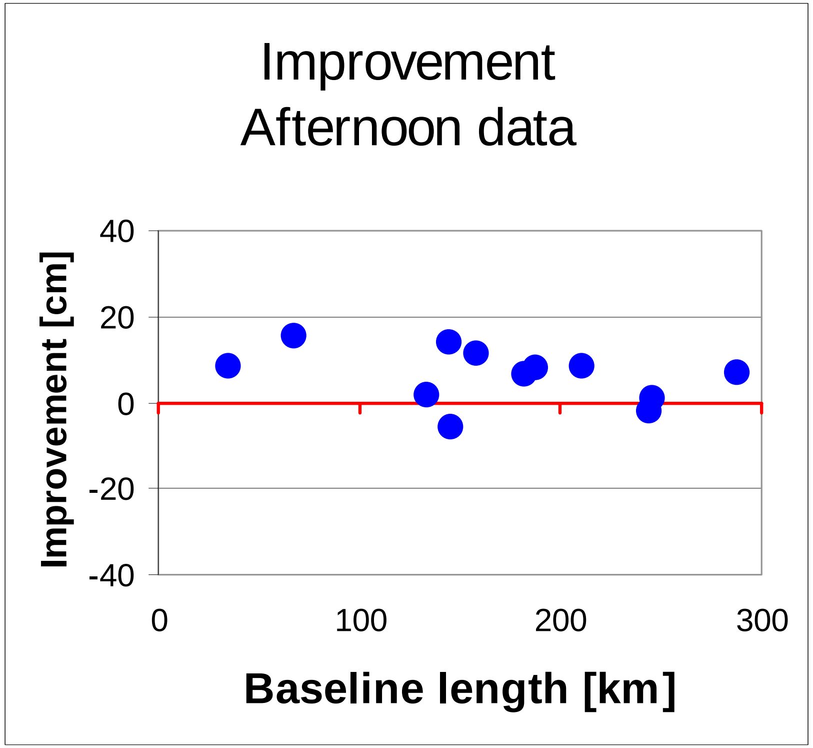
Saastamoinen vs. NWP approach

- Kinematic results
  - Improvement obtained for 18 of 26 scenarios





- 3D RMS of coordinate differences

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Conclusions

- A new approach for estimating the tropospheric delay for high accuracy GPS positioning has been developed

- Tests indicate that the method does have a potential for improving GPS positioning performance, most significantly for kinematic positioning

- Tests with more data are necessary to finally conclude whether the method is feasible

Operational considerations

- NWPs can be provided by a meteorological organisation e.g. every 6 hours
- Can be used for both real time and post processed positioning
- NWPs can be used for network-based RTK positioning in solving ambiguities for baselines between reference stations
- Problem with local weather phenomena that are not modelled in the NWP

Acknowledgments

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- The National Land Survey of Sweden is acknowledged for the SWEPOS GPS data