Chalmers Contributions to TOUGH

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Introduction

TOUGH (Targeting Optimal Use of GPS Humidity Measurements in Meteorology) is a research project supported by the EU 5th Framework Programme. The main purpose of this project is to develop and refine methods enabling the use of GPS data from existing European GPS stations in numerical weather prediction models, and to assess the impact of such data upon the skill of weather forecasts. The contributions from the Chalmers are:

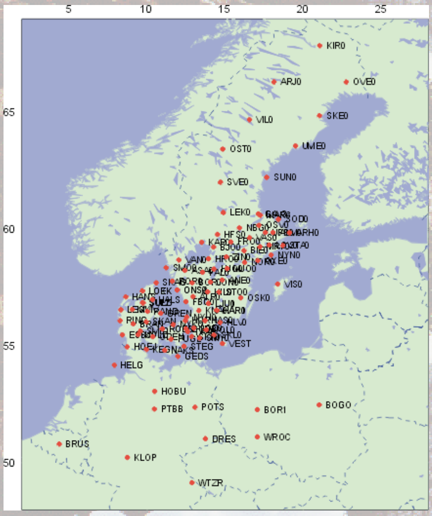
- GPS data analysis in near real time
- Assessment and characterization of correlated estimation errors (spatial as well as temporal)
- GPS system research, assessing the stability and accuracy of time series of the estimated atmospheric propagation delays.

GPS Data Analysis

We have operated the NKGS GPS data analysis centre, first during COST Action 716, and later during the TOUGH project.

The Swedish GPS network SWEPOS consists of 21 geodetic stations (on temperature controlled concrete pillars on bedrock) and 45 other permanent reference stations (mostly on top of buildings).

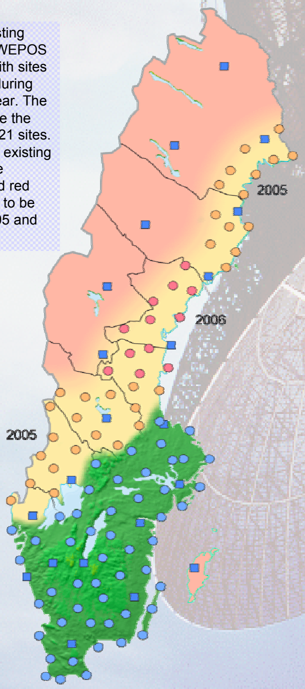
A total of 26 stations deliver data from Denmark (on a best effort basis). Data from additional stations, mainly in northern Europe, are also processed, resulting in a total of about 115 stations that deliver data every hour. On the average the bulk of the estimated Zenith Total Delays (ZTD) are delivered around the stipulated maximum delay of 1 hour and 45 minutes.



The network of GPS sites presently analyzed by NKGS.

The collocated techniques of Very Long Baseline Interferometry (VLBI), the Global Positioning System (GPS) and Water Vapour Radiometry (WVR) at the Onsala Space Observatory on the west coast of Sweden.

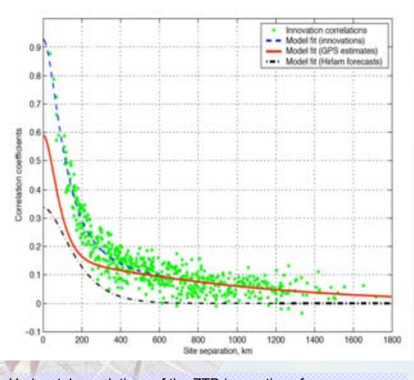
The network of existing GPS sites in the SWEPOS network together with sites being established during this and the next year. The blue squares denote the original network of 21 sites. Blue circles are the existing additional reference stations. Yellow and red circles denote sites to be installed during 2005 and 2006, respectively.



Spatial and Temporal Correlation of the Estmation Errors for the Zenith Total Delay (ZTD)

We have studied the spatial correlation structure of the estimation errors when the GPS technique is used to derive the atmospheric propagation delay in the zenith direction. These error correlations are parameterized using an analytical function. For spatial scales smaller than 200 km the GPS error correlations become significant; for larger spatial scales, the error correlations are small and slowly decreasing with distance. These results are based on a study of the differences between the propagation delays obtained from the HIRLAM numerical weather model, and the corresponding GPS estimates.

The temporal correlations of the propagation delay estimation errors are also examined and the decorrelation times are of the order of 1–2 days. The temporal correlation results are derived for Swedish GPS sites, using the relation between the estimation errors for the vertical coordinate and the zenith propagation delay. The longer correlation times are found for the inland stations in the northern parts of Sweden. One explanation for this effect is the possible accumulation of ice and snow on the radome covering the GPS antenna during certain winter conditions.



Horizontal correlations of the ZTD innovations for a one year period (*). The dash-dotted black line represents the contribution of the forecast errors correlations for ZTD, estimated using the NMC method for HIRLAM at a resolution of 22 km. The dashed blue line shows the best-fit composite model for the innovation correlations. The solid red line represents the remaining term, corresponding to the GPS error correlations.

System Research of Global Navigational Satellite Systems (GNSS) for Long Term Stability in Estimated ZTDs

Site Calibration

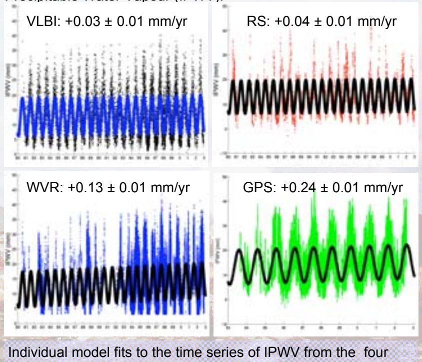
The focus of our studies has been to search for systematic site dependent effects in estimated atmospheric delays. The goal is to understand and eliminate these effects to a non-significant level.

We are producing calibration matrices from in situ measurements based on GIPSY processed residuals. This new analysis is tested on measurements acquired at Onsala in October 2003. The assement of the impact of the calibration matrices on the estimated ZTD remains to be carried out.

Long Term Stability

We have also performed a statistical assessment of reprocessed SWEPOS data, using different elevation cut-off angles, we find significant differences in the estimated trends of the ZTD time series.

We have compared the different techniques of GPS, VLBI, WVR, and radiosondes (RS) in terms of estimating the Integrated Precipitable Water Vapour (IPWV):

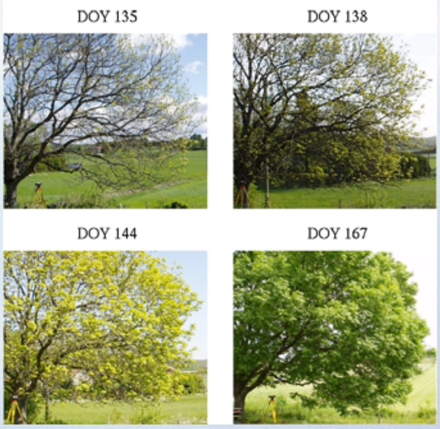


Individual model fits to the time series of IPWV from the four techniques. The sinusoidal continuous lines show the model fits. The values of the estimated trend parameters are given explicitely. Note the different time scales!

IPWV trends derived from pairwise time series with synchronized sampling and the corresponding RMS differences. Trends are in (mm/yr), RMS differences in (mm).

Comparison pair	IPWV trend from (a)	IPWV trend from (b)	RMS diff.
VLBI (a) <=> WVR (b)	+0.19 ± 0.01	+0.13 ± 0.01	1.6
VLBI (a) <=> GPS (b)	–0.07 ± 0.01	–0.05 ± 0.01	1.3
VLBI (a) <=> RS (b)	+0.05 ± 0.01	+0.03 ± 0.01	2.1
WVR (a) <=> GPS (b)	+0.31 ± 0.01	+0.31 ± 0.01	1.6
WVR (a) <=> RS (b)	+0.11 ± 0.01	+0.12 ± 0.01	1.7
GPS (a) <=> RS(b)	+0.25 ± 0.01	+0.20 ± 0.01	2.0

The Influence of Vegetation



Many continuously operating GPS sites are located nearby areas of vegetation. As the size and characteristics of the vegetation change with time, it is important to assess the impact of vegetation on the GPS signal and the ZTD time series estimated from the acquired data. During the growth season of 2004 a measurement campaign was performed. The main effect from the leaves is the water content that increases as the leaves grow. A large ash tree was chosen to be the growing object between the receiving antenna and the orbiting satellites. We found that as much as 30% of the expected data were lost due to attenuation of the GNSS signals when propagating through the tree. The effect is most clear in the stage of full summer around day of year (DOY) 170–250.