Ground-based GPS networks for remote sensing of the atmospheric water vapour content: a review

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1. Introduction

The variability in the atmospheric water vapour content is an important parameter both for operational weather forecasting and climate research. In this presentation I will first describe the interplay between the atmosphere and the accuracy of the estimated positions and vectors that can be obtained in space geodesy. Thereafter, I will focus on how the efforts to model the atmospheric influence on space geodetic measurements led to the application of measuring the water vapour content of the atmosphere. Two major applications have been seen so far: close to real time analyses for use of data in weather forecasting, and (2) the long term application of climate monitoring.

2. The Atmosphere Problem in Space Geodesy

Space geodesy was born when manmade satellites were launched in the 1960ies. At that time also geodetic techniques based on radio astronomical measurements were developed. After about ten years it was realized that—for the application of Very-Long-Baseline Interferometry (VLBI)—variations in the time of arrival, due to water vapour, for the signals propagating through the Earth's atmosphere would soon become one of the limiting error sources.

Microwave radiometers were designed and used as an independent source of information on the water vapour content at VLBI sites, and were used to correct the VLBI observations (Elgered et al. 1991). At the same time the quality of the VLBI data was improved by introducing wider observing bandwidths and faster slewing antennas, resulting in better observing geometries. These facts made it possible to estimate the water vapour content above each site from the VLBI data themselves.

In the 1980ies also the high accuracy positioning applications of the Global Positioning System had reached the quality when it was possible to estimate the atmospheric influence, read the variations in the water vapour content, from the GPS data themselves (Tralli and Lichten 1990), and the term GPS meteorology was born (Bevis et al. 1992).

3. The Application to Weather Forecasting

Several European supported research projects were carried out during a ten-year period, starting around 1996 (e.g. WAVEFRONT, NEWBALTIC, MAGIC, TOUGH, and the COST Action 716) in order to assess the quality of time series of water vapour estimated from GPS data. At the same time national and international surveying and research organizations started to invest in continuously operating ground-based GPS networks and thereby taking the responsibility for a significant, and in some countries the entire, part of the investment costs.

Today we have an impressive GPS network in Europe (see Figure 1), used by the EUMETNET project E-GVAP. Several regional data processing centres routinely provide data in close to real time to a central data archive at the UK MetOffice from which data can be downloaded for operational weather forecasting.

The application of weather forecasting requires results in close to real time. This means that the most accurate results on an absolute scale will not be available but more important are the relative changes together with a good knowledge of the timing and the location of large changes in the water vapour content. These are important for regional and local precipitation events.

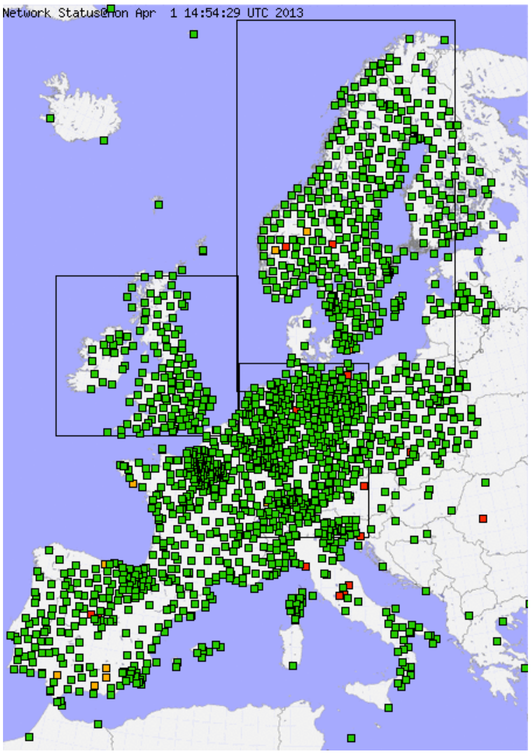

Figure 1. The present network of GNSS receivers in the E-GVAP project (from http://egvap.dmi.dk/).

4. The Climate Research Application

In difference to the application of weather forecasting the use of GPS data in climate research does not require data processing and results in close to real time. Instead the high accuracy on an absolute scale is of outmost importance. This is especially true for the task of climate monitoring, where trends in the water vapour content of the order of a few percent, or less, can be expected over a ten-year period. In order to achieve the best accuracy the most accurate orbit parameters must be used. On a global scale the International GNSS Service (IGS) coordinates many applications for accurate positioning and remote sensing. The global network of IGS stations shown in Figure 2 is routinely used to estimate orbit parameters of the GPS satellites.

Of relevance to the BALTEX project, existing GPS sites in Sweden and Finland were used to study long-term trends in the water vapour content from 1993 to 2000

(Gradinarsky et al. 2002). These results have thereafter been updated in several studies (Nilsson and Elgered 2008; Elgered et al. 2010). Figure 3 depicts the trends in the water vapour content together with the corresponding trends in the temperature at the ground. An interesting, but not yet understood, pattern is seen. The linear trends are positively correlated for sites in Sweden, whereas the correlation is close to zero for the Finnish sites.

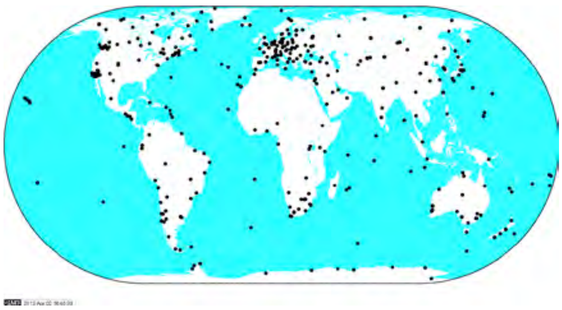

Figure 2. The present IGS network of GNSS receivers. A map of the present network can be downloaded from http://igscb.jpl.nasa.gov/network/netindex.html.

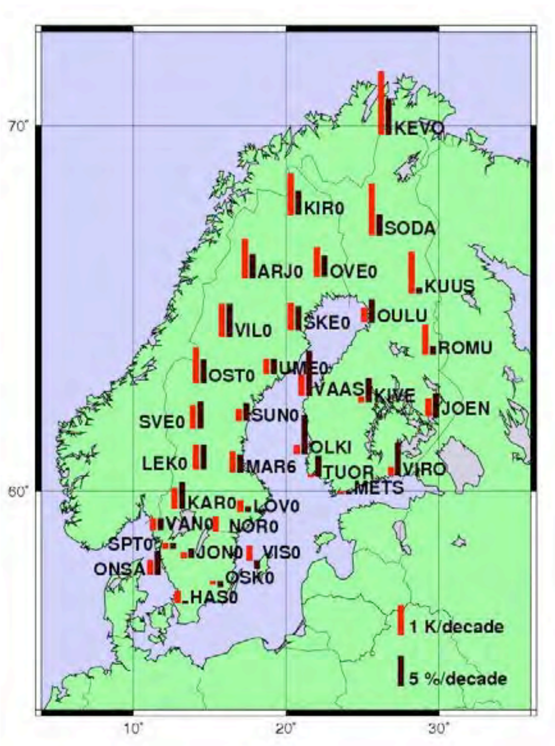

Figure 3. Estimated linear trends in the water vapour content and in the temperature at the ground for GPS sites in Sweden and Finland. The scales of the bars are defined in the lower right corner (from Elgered et al. 2010).

Another example of GPS data in climate research is the evaluation of climate models. Figure 4 depicts results for the diurnal cycle of the water vapour content. In total, 99 European GPS sites are used to evaluate the regional Rossby Centre Atmospheric climate model (RCA). The peak time from the GPS data are compared to the peak times from the RCA for the summer months of June, July, and August. We note an agreement in the geographical variation of the diurnal peak. Averaged over all the sites, a peak at 17 local solar time is obtained from the GPS data while it appears later, at 18 local solar time, in the RCA simulation.

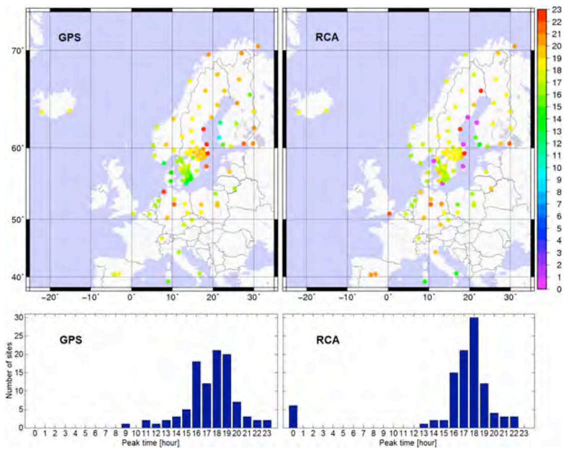

Figure 4. Peak time of the diurnal cycle of the water vapour content, for the summer months, obtained from the GPS data and the RCA simulation for each GPS site (upper) and histograms of the peak time (lower). The hour is in local solar time (from Ning et al. 2013).

5. Conclusions

The continuously operating ground-based GPS (today GNSS) networks have proven to be able to offer new information for the near-real time application of weather forecasting and for different types of studies in climate research. In the latter case the time series of the water vapour content can be used both for climate monitoring and for the evaluation of climate models.

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