Ground-Based GPS for Climate and Numerical Weather Prediction Applications

A summary of on-going activities of COST Action 716 from Gunnar Elgered and co-authors

The aim of this paper is to summarize ongoing activities within COST Action 716 - a voluntary collaboration between 15 European countries. The basic idea is to prepare the grounds for an operational observation system providing information on water vapour variations in the atmosphere above continuously operating GPS networks in Europe. The activity requires a close cooperation between scientists in the areas of geodesy and meteorology.

1. Introduction

The aim of this paper is to summarize ongoing activities within COST Action 716 - a voluntary collaboration between 15 European countries. The basic idea is to prepare the grounds for an operational observation system providing information on water vapour variations in the atmosphere above continuously operation GPS networks in Europe.

The activity requires a close cooperation between scientists in the areas of geodesy and meteorology. The fundamental observables in positioning applications using GPS is the time of arrival of the navigation signals at the receiver sites. Knowledge of the transmission time and the corresponding satellite positions allow for an estimate of the receiver position. An additional propagation delay is caused by dry air and water vapour in the earth's atmosphere. The total influence is often estimated as an equivalent Zenith Total Delay (ZTD) and is expressed in an excess path in units of length.

The different applications of GPS data in meteorology are illustrated in Figure 1. The operational implementations are very different for Numerical Weather Prediction (NWP) forecasts and climate applications. For the NWP application the main difficulty is to produce estimates of the ZTD, with a reasonable quality, within a short time interval from the data acquisition. It is important that the information is not too old because water vapour varies rapidly and knowledge of recent changes is most important for short term forecasts. As a rule of thumb we require an RMS ZTD uncertainty better (smaller) than 1 cm. Assuming that most of the information (variability) is in the Integrated Precipitable Water Vapour (IWV) this corresponds to an uncertainty of 1 kg/m^2 in the IWV. Not surprisingly this is comparable to the uncertainty we obtain today when integrating the observed profiles of temperature and relative humidity from traditional radiosonde launches.

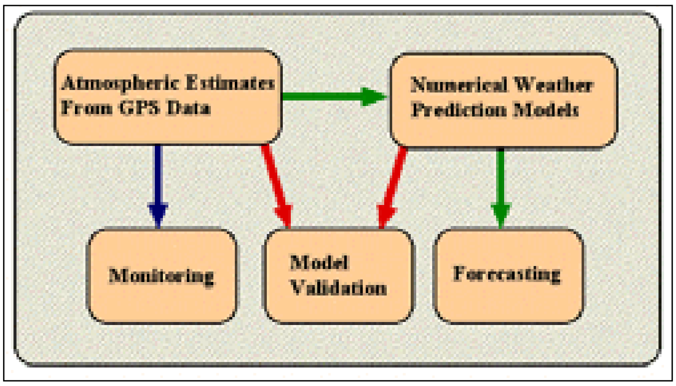

Figure 1. The applications of GPS data in meteorology can have very differentent time scales which imply different requirements on the data processing. In the COST action the focus has been on near real time NWP applications.

The climate monitoring application require long term stability of the entire observing system, hardware as well as software, for the monitoring of IWV. Because the continuously operating GPS networks have only existed during some ten years it is still early to assess the whole potential of the technique for monitoring of the IWV. However, several case studies have been made using ZTD (or IWV) estimates from the independent GPS observations for validation of climate models of different spatial scales and temporal resolutions.

2. What is COST Action 716?

A COST action is run under supervision of the European Community (EC). COST means European Co-operation in the Field of Scientific and Technical Research. [see http://cost.cordis.lu/src/home.cfm]. In a COST Action, a Management Committee (MC) is used to supervise the work in

Working Groups (WGs). MC meetings are typically held once or twice per year. Participation in a COST action is voluntary. In our COST action the following fifteen countries have joined forces: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, and United Kingdom. The financial support through the EC is mainly covering travel expenses for the participants in the MC and WGs to coordinate efforts within independent national and international research projects (also with independent funding) relevant to the objectives of the COST action. There is a significant overlap between membership in the MC and in the WGs. This certainly helps the coordination given the relatively infrequent meeting schedule with 1-2 meetings/yr.

COST Action 716 has been running since early 1999 in the area of meteorology [see http://www.oso.chalmers.se/geo/cost716.html]. The primary objective is specified in the Memorandum of Understanding (MoU):

* Assessment of the operational potential on an international scale of the exploitation of a ground-based GPS system to provide near real time observations for Numerical Weather Prediction (NWP) and climate applications.

There are also four secondary objectives

* Development and demonstration of a prototype ground-based GPS system on an international scale;

* Validation and performance verification of the prototype system;

* Development and demonstration of a data exploitation scheme for NWP and analysis of data exploitation techniques needed for climatic applications;

* Requirements for operational implementation ground-based GPS system on an international scale.

Four working groups were established in the COST Action 716:

* WG 1 reviewed the state of the art of ground based GPS meteorology.

* WG 2 has established the Near Real-Time (NRT) demonstrationexperiment and is now performing a continuous data analysis.

* WG 3 focus on the applications of using the ground-based GPS data in Numerical Weather prediction and climate applications.

* WG 4 deals with the planning for implementation and operations. This work includes specification of product requirement, cost analysis and will produce a recommendation for an implementation plan.

3. Atmospheric parameters in ground-based GPS meteorology

The fundamental atmospheric observable from ground-based GPS data is the ZTD. A specification of data exchange formats for GPS estimates of the ZTD was forwarded to the WMO with a request for formal approval. Figure 2 present the concept of direct assimilation of this observable into NWP models. Figure 2 also indicates that in order to derive the water vapour contribution, the Zenith Wet Delay (ZWD), knowledge about the ground pressure is needed. Depending on the topography and the quality of nearby pressure observations it can be sufficient to interpolate the pressure field to the GPS site. An uncertainty of 1 hPa corresponds to 2.3 mm error in the ZWD, or 0.4 kg/m^2 in IWV. If the requirements are higher than what can be accomplished through interpolation it is necessary to equip the GPS site with a barometer of a sufficient accuracy.

4. Near real time operation

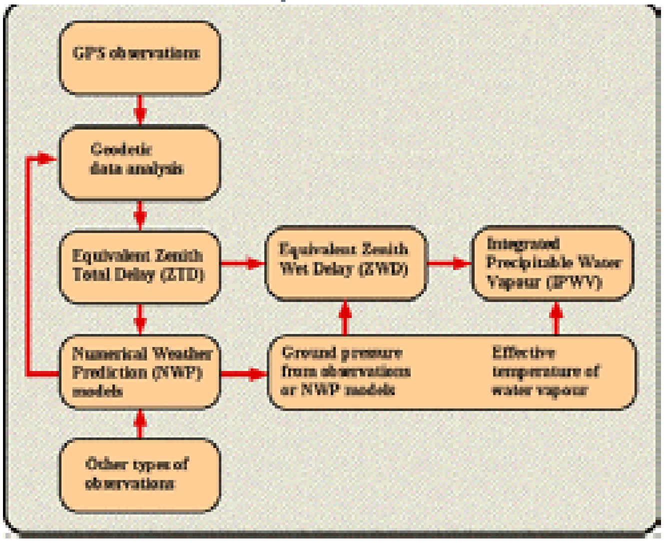

Figure 2. Data flow in GPS meteorology. We have adopted the method of assimilation of the ZTD into the NWP models. For applications when GPS data shall be used for comparisons/validation purposes with instruments and/or methods providing water vapour parameters such as the ZWD and the IWV it is possible to use information from other observations assimilated into the NWP model. It is also possible to use information from the NWP model in the geodetic data processing in order to improve the geodetic results. In the future one can imagine an integrated software package which assimilates all the raw observations.

The 2nd working group has established the Near Real-Time (NRT) demonstration experiment and are now performing a continuous data analysis. The participants in this working group have a background of research in space geodesy. The NRT demonstration experiment started in February 2001. In March 2002 the NRT network consisted of about 120 stations. Since then the network has continued to grow, in terms of the number of GPS sites and hence the spatial resolution continues to improve. Therefore, the analysis centres have at several occasions decided to continue the work in spite of that its formal task within the COST Action 716 can be regarded as completed.

Now there are 217 stations in Europe taking part in the NRT demonstration campaign. These are processed by 7 analysis centres:

ASI Agenzia Spaziale Italiana, Matera, Italy analyzes 38 stations, GOP Geodetic Observatory, Pecny, Czech Republic 45 stations, GFZ GeoForschungsZentrum, Potsdam, Germany 71 stations, IEEC Institut d'Estudis Espacials de Catalunya, Barcelona, Spain 13 stations, LPT Federal Office of Topography, Wabern, Switzerland 62 stations, NKGN Nordic Geodetic Commission, Statens Kartverk, Norway 25 stations, NKGS Nordic Geodetic Commission, Onsala Space Observatory, Sweden 44 stations.

The map shown in Figure 3 illustrate the present distribution of sites. A large fraction of the estimated ZTD's for the various computing centers is arriving at a dedicated computer at the UK Met Office within the time limit of 1 hour and 45 minutes (specified by members in our COST action). In total, approximately 500,000 observations of the zenith total

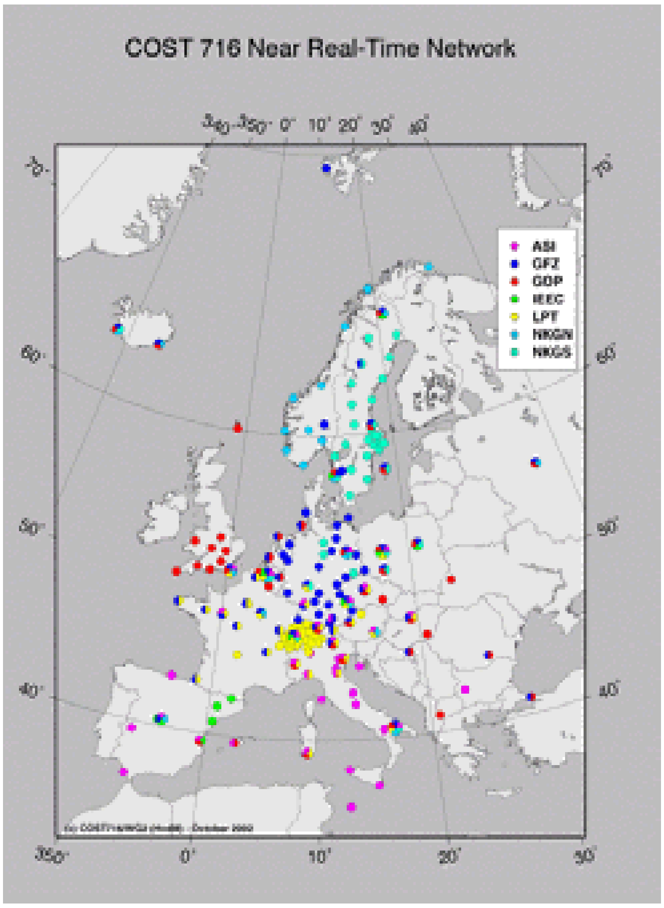

Figure 3. The entire GPS network of the near real time demonstration experiment in October 2002. The site markers are colour coded showing which analysis centre(s) are processing data from that site.

delay (ZTD) are made per month (September 2002). Many of the stations are processed by more than one analysis centre.

At least four analysis centres are now capable of delivering more than 75% of the data within the time limit of 1 hour and 45 minutes. It is worth noting that the latency is still improving and especially for the processing centres that are in a “start-up” phase and do not yet meet the requirements. It shall also be noted that in some cases there may be a higher priority to include as many sites as possible rather then reducing the number of sites in order to meet the requirement on the time of delivery. In any case the demonstration experiment has clearly shown that it is possible to design an operational system which can meet the latency requirements.

5. Evaluation and impact studies

The members of the 3rd WG have a meteorological background and focus on the applications of NWP and climate. A web site has been made where the most recent time series of ZTD (and IWV) from the NRT demonstration experiment can be examined. [http://www.knmi.nl/samenw/cost716/] The GPS time series are here presented together with radiosonde data and the HIRLAM NWP model where they can be viewed on-line.

Impact studies of using the GPS data in the NWP model forecasts have been performed at the the German, the Swiss, the Danish, and the Swedish Met Services with both positive and negative impacts. It is anticipated that the quality of this type of impact studies will improve when using a GPS network with more sites. For instance, forecasters use this web site as an aid in interpreting NWP model output. The UK Met Office presented signatures for the onset of dangerous weather using moisture fields derived from its higher density national network.

WG 4 deals with the planning for implementation and operations. This work started in November 2001. The final report from WG 4 will describe the available semi-operational solutions in Europe, specifies product requirement, and describes the current state of the art and its limitations. This group will also carry out the difficult cost analysis and produce a recommendation for an implementation plan.

The Final Workshop of COST Action 716 is preliminary planned for the second half of 2003 at the KNMI in the Netherlands. Here the results from all the working groups will be summarized and plans for the future of ground-based GPS meteorology will be discussed.

6. The future of ground-based GPS meteorology

The COST Action 716 has helped scientists in geodesy and meteorology to work together and to deliver state of the art results so far. The work has demonstrated that it is possible to provide ZTD estimates from a ground-based GPS network in near real time and on an international scale within Europe. A major and very interesting task remains, namely the intensified impact studies within WG 3. Without a good estimate of the impact on the quality of weather forecasts it will be difficult to motivate investments in more permanent operational activities. It is expected that these results will vary depending on season, weather conditions as well as the local climate. Therefore, in order to have a solid statistical knowledge large amounts of data must be analyzed - ideally covering many years.

7. Links to additional and related information

Web page of COST Action 716: http://www.oso.chalmers.se/geo/cost716.html

Web page of the near real-time demonstration experiment: http://www.knmi.nl/samenw/cost716/

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