SESSION 2:

REAL-TIME APPLICATIONS AND PRODUCTS

Position Paper for the Real Time Applications and Products Session

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Guided by the Charter of the IGS Real Time Working Group (RTWG) we seek to assess and address issues that pertain to the IGS developing real-time infrastructure and processes. As in any well-planned project the development of infrastructure, processes, and products must be governed by a set of clear, traceable, and realistic requirements. It is the primary goal of this session to explore the possible requirements for near real time GPS-based products, and analyze their implications. We do that by raising a number of key questions. We provide tentative answers to some questions, while others require more information before they can be answered. The questions and answers are meant to stimulate the discussion during our Session. We would like to hear the user-perspective on these questions, as well as the opinion of the analysis centers, and independent analysts.

First, we should be clear with our terminology. We think that the term "real-time" is too restrictive, and prefer the more flexible "near real time" (nrt) to describe latencies ranging from 0 to 6 hours. The boundary between rt and nrt may be drawn at the latency below which batch processing and data handling is no longer practical. The IGS is currently producing hourly Rinex files from a large sub-set of the network, which feed a number of batch-type processes, including the ultra-rapid orbit determination. We define, therefore, Real Time processes and application as those that require sub-hourly latency.

While we devote our attention to the real time processes, we should also examine their impact on the IGS's nrt processes, some of which may be rendered obsolete, while others, may obviate the need for real time equivalent.

At the most fundamental level we would like to investigate the following question:

Q1) What are the nrt applications for GPS-based products, and what requirements they impose on these products (for example, in terms of latency, accuracy, reliability, availability)

A) The following table reflects our current understanding of the basic requirements by some of the well known applications for nrt GPS-based products. At our session, we would like to examine the entries in this table, change or refine them if necessary and, perhaps, add new entries.

Table 1. Applications for nrt GPS-based precuts and their basic requirements

Application	Latency	Accuracy (in terms of GPS orbits/clocks)	Reliability*	Spatial Scale
Weather Prediction	Hours	Medium (< 25 cm)	Low	Regional
Ionospheric Weather	Hours	Medium (< 25 cm)	Low	Global, Regional

Navigation: Satellites	Seconds	Low (< 50 cm)	Medium	Global
Navigation: Terrestrial	Seconds	Medium (< 25 cm)	High	Regional
Positioning:Earthquake and volcanics monitoring	Minutes	Medium (< 25 cm)	Low	Regional
Positioning: Structures	Seconds	High (<15 cm)	High	Local
Timing	Seconds	Low (<50 cm)	High	Global
Earth orientation	Hours	High (< 15 cm)	Low	Global

* The Reliability entries in Table 1 reflect our understanding of the ability of the user to absorb and/or identify occasional bad data without significant adverse effects

Table 1 omits one important component, namely, the nature of the desired nrt product. For example, weather prediction applications would normally ingest nrt estimates of tropospheric delay, but it may be that the potential user, say, the U.K. Met Office, would prefer to get the nrt GPS orbits and clocks, and derive the by-products of interest using in-house methods and resources. This leads us to the second fundamental question:

Q2) Should the IGS provide all the nrt GPS-based by-products or, perhaps, the IGS should stick to what it knows best – the estimations of GPS orbits and clocks.

A) The IGS should demonstrate the derivation and use of new GPS products, but should refrain from the long term production of products for which the IGS does not provide unique value. For example, the reliable and accurate estimation of tropospheric delays was demonstrated by the IGS, but the analysis can be (and is) carried out by individual organization. Also, this is a regional product by nature, where the IGS global network does not provide significant value. In general, the IGS should provide global-scale products: GPS orbits and clocks.

A related question is:

Q2b) Should the IGS provide solutions to all domains: civil, commercial, scientific, military, or should the IGS focus on just a select few.

A) The IGS should stay out of the military domain.

On a less fundamental, but practical level, we would like to probe the state of the art in nrt GPS processes. Here we will solicit contributions from the various IGS Analysis Center and from elsewhere, addressing the question:

Q3) What is the state of the art in nrt generation of GPS products

In particular, we would like to hear from the various contributors for the ultra rapid products, from the IGS coordinator about the combination of the ultra rapid products. We would like to hear about the JPL nrt orbit production. We would like to hear from analysts producing nrt tropospheric delay estimates, and from the coordinator of the nrt trop combination about the status of his experiment.

We would like the various contributors to our session to address in their talk the following question:

Q4) How should the IGS approach the combination, delivery, and quality control for the potential nrt products.

A) We think that it is premature at this point in time to analyze the possible combination strategies. That is because the combination strategy depends on such unknowns as the number and relative quality of the contributed products. Specifically, it is not clear at this point how many nrt GPS orbits are going to be available to the IGS, whether they are based on global or regional data sets, how are clocks treated, and what is their accuracy. We recommend a phased approach, beginning with a campaign for generating nrt products, to be followed by inter-comparisons and quality assessment. Only then combination and product delivery strategies can be analyzed fruitfully.

Finally, we would like to pose a set of practical questions:

Q5) Should the IGS continue the ultra rapid process

Q6) What will be the IGS nrt products

Q7)) Does it make sense to have a combination process for real time products, and if so, how

The Italian Near-Real Time GPS Fiducial Network for Meteorological Applications

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Permanent networks of GPS receivers are presently established in many countries. They are primarily devoted to measure the motion of the Earth's tectonic plate, to study deformations associated with earthquakes and volcanoes, to monitor the post-glacial rebound and the global sea-level changes. Beside these applications they can provide, if properly equipped with surface meteorological sensors, continuous and well distributed measurements of Integrated Precipitable Water Vapor (IPWV) which are of great interest for numerical weather prediction and climate research.

The Italian Space Agency (ASI) manages a GPS network of 24 stations and further densification is in progress.The equipment generally consists of a Trimble 4000SSI or Trimble 4700 receiver with a choke ring antenna. The growing of GPS Real-Time and Near-Real-Time applications requires that the tracking network be switched from a daily to an hourly or sub-hourly data retrieval. Presently 16 Italian stations provide hourly data with a nominal latency ranging from 3 to of 10 minutes, Matera provides high rate data as well. GPS raw data collected at the remote stations are sent to Matera/Centro di Geodesia Spaziale (CGS) through INTERNET or ISDN line, are converted into RINEX format and are transferred to ASI web and ftp site GeoDAF (http://geodaf.mt.asi.it).

As far as the GPS atmospheric application is concerned, since January 1999 GPS Zenith Tropospheric Delay (ZTD) are routinely produced in post-processing mode and monitored for a network of 40 stations covering the Central Mediterranean area.(Pacione et al., 2001). Over Italy the network has an higher denser resolution since all the available Italian GPS permanent stations are included in the routine processing. In the middle of 2001 a Near-Real-Time data stream, relying on IGS Ultra Rapid products, has been set-up and it is running operatively providing GPS ZTD estimates for meteorological applications. It has been developed within the European program COST Action 716 (http://www.oso.chalmers.se/geo/cost716.html) dedicated to the "*Exploitation of Ground-based GPS for Climate and Numerical Weather Prediction Applications*".(Elgered, 2000) The GPS processing for the delivering of ZTD from a network of 30 stations, with a delay of 1h45', is performed using a 24 hours sliding window and a standard network approach. The IGU orbits, retrieved twice a day 03:00 and 15:00 UTC, are kept fixed but checked and possibly PRN excluded based on the analysis of the post fit phase observation residuals (Springer et al., 2000). The ZTD estimates of the last hour are taken out from the 24 hours batches and sent to the UK Met Office.

In order to be useful for assimilation into the Numerical Weather Prediction Model the requirements of timeliness and accuracy must be reached, that is 75% of observations must arrive within 1h45' to the met agencies and predicted GPS orbits must be used with minimum degradation of the ZTD products with respect to the Post-Processed ones. The performances of the system for the period June 2001-Febrary 2002 are discussed. We experience that 80% of the predicted solutions have been delivered; the statistic of the GPS hourly data availability per stations shows that 20% of them are available to the users too late to be processed in NRT mode or are lost. We notice that missing data and gaps cause problems in the analysis and instability in the ZTD estimates. To asses the accuracy of the NRT ZTD we compare 9 months of Post-Processed versus NRT estimates having a monthly station bias from -6mm to 10mm and a related standard deviation from 20mm to 5mm, this last decreasing in time due to processing tuning. Finally comparisons with other different NRT ZTD estimates on 1 month (February 2002) of solutions performed within the COST-716 Near-Real Time Demonstration Campaign (http://www.knmi.nl/samenw/cost716/index.html) show few mm bias and 5-7mm standard deviations.

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What About Using GPS for Weather Forecasting?

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The use of ground-based GPS for estimating Integrated Water Vapor (IWV) has been investigated by many (inter)national studies and projects. Today, the operational potential of this technique is demonstrated by several projects. In this presentation we focus, as an example, on the European COST-716 project “Exploitation of Ground-Based GPS for Climate and Numerical Weather Prediction Applications for Europe”. In March 2001, COST-716 started a near real-time demonstration, which one-year later involved more than one hundred GPS stations for which Zenith Total Delay is computed within 1 hour 45 minutes.

The near real-time demonstration is organised around several near real-time networks. GPS data collection and processing is handled by six analysis centers: ASI, Matera, Italy; GOP, Czech Republic; GFZ, Potsdam; Germany, IEEC, Barcelona, Spain; Federal Office of Topography, Switzerland; Nordic Geodetic Commission. Each analysis center uses IGS and EPN data centers, completed with several local data centers, resulting in a dense network. The analysis centers are relatively “free” to organise the processing as they like, as long as they compute properly validated Zenith Total Delays (ZTD), with a well defined quality indicator, in an agreed format (COST v1.0 format), and deliver it to the UK Met Office (UKMO) - which acts as a gateway to other meteorological institutes - within 1h45m. An ftp-mirror at TUD/Delft holds the full archive. The ZTD is converted to IWV at KNMI using measured pressure and temperature at the GPS site or from nearby synoptic sites, and is compared routinely to Numerical Weather Prediction (NWP) models (http://www.knmi.nl/samenw/cost716.html).

COST-716 has shown it is possible to compute ZTD for NWP within 1h45m using existing GPS networks. The accuracy is sufficient for NWP and forecasting. The overall consistency between the solutions is about 5-6 mm for the Zenith Delay (1 kg/m^2 in Integrated Water Vapor), with biases of up to 3-4 mm. Comparisons with the post-processed EUREF solution are in the same range. The rms difference with Radiosondes is 11 mm + 0.1mm/km in ZTD, with some non-negligible biases. Assimilation trials show that the GPS data does not make the forecast worse, and in some cases give a slight improvement in the forecast of precipitation. A possible explanation for this modest impact could be that radiosondes and other data tend to dominate the models and the models are tuned for these observations. It is expected that (high resolution) 4D-VAR models would be better at utilizing GPS data, but it takes time to develop these models. On the other hand comparisons against NWP models were extremely useful, and often highlighted major discrepancies with the GPS observations, which would be useful for forecasting if available in time. Several nowcasting and forecasting applications emerged from the project. Ideally, these would require a data interval of 15 minutes (instead of 15-60 minutes), the timeliness of a real time service (latency < 1 hour), a spatial scale of the data that can be regarded as sub-regional and a horizontal spacing of better than 70-100 km. Accuracy and reliability should be more or less the same as NWP.

Operational weather prediction does not fall into a single category: some aspects are scientific, some civil, some military, and some commercial. This is more of a problem for operations than in the development phases, where the work can be treated as purely scientific. For operational work, ZTD computations for weather forecasting should be performed on computers managed by meteorological institutes in liaison with geodetic institutes, and would rely on IGS orbits and clocks. Orbit improvement, or the processing of a global network, should not be necessary for the ZTD processing. For some applications real-time orbits and clocks could be needed. It is not clear whether near real-time ZTD from IGS would be needed; it could be useful for comparison purposes or for constraining of stations common with IGS (this could apply to double difference processing in (sub-)regional networks).

Real-Time Delivery of the Canadian Spatial Reference System - Strategy and Applications

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Since confederation, Canada has always relied on a consistent survey system as an integral part of the national infrastructure. In 1909, the Geodetic Survey of Canada was created by an order-in-council and given the mandate to provide control in support of all surveys and mapping within the country. Today, as part of Natural Resources Canada, the primary role of the Geodetic Survey Division (GSD) is to maintain, continuously improve, and facilitate efficient access to what is now known as the Canadian Spatial Reference System (CSRS). The CSRS serves as a reference for all positioning, mapping, charting, navigation, boundary demarcation, crustal deformation, and other georeferencing needs within Canada.

While continuing to serve ongoing requirements for survey control, the growing demands of Global Positioning System (GPS) users in particular have resulted in a new focus for the Division, a focus on supporting positioning from space. The Canadian Active Control System (CACS) was established during the 1990's to facilitate GPS user access to the CSRS. A real-time capability is expected to further expand access to the national reference frame and has been under development since the mid-1990's. A project for one mode of delivery of real-time GPS corrections using MSAT will be completed this year . This federal-provincial collaboration is known as the Canadian Differential GPS Service (CDGPS).

Through the perspective of efficiently delivering a national spatial reference frame in real-time, the requirements and components of CACS will be described, including the links to the International GPS Service (IGS) data and products. The current real-time data access and product distribution mechanisms and applications served will be described. Future applications will be considered along with anticipated system and user limitations.