GNSS Ionosphere Analysis at CODE

S. Schaer

CODE generates final, rapid, as well as predicted ionosphere products (global VTEC maps and two types of differential pseudorange bias values) in various forms. Since 27 April 2003, these products are computed on the basis of GPS and GPS/GLONASS-combined observation data of about 200 IGS/IGLOS ground stations. We are able to present a ionospheric time series of nearly 10 years. Aspects relevant to the IGS are addressed.

Usage of IGS TEC Maps to Explain RF Link Degradations by Spread-F, Observed on Cluster and Other ESA Spacecraft

J. Feltens, J. Dow, G. Billig, D. Fornarelli, S. Pallaschke, B. Smeds, H.-J. Volpp, P. Escoubet, H. Laakso

During autumn and spring 2001, 2002 and 2003 link degradations up to complete signal loss were observed on the Cluster spacecraft: Sudden variations of the received RF signal power were observed on the spacecraft as well as on the ground. The duration of these disturbances ranged from 10 minutes to 4.5 hours, i.e. up to a loss of entire spacecraft passes. The anomaly coincides with the local evening hours and depends on geographical location of the ground station.

A multi-disciplinary working group at ESOC with support from scientists at ESTEC started investigations and could identify a phenomenon in the ionosphere, Spread-F, as a source of the anomalies. Spread-F can occur around the geomagnetic equator during the local evening hours. IGS TEC maps were used to identify the regions in the ionosphere where the Cluster-ground station links did cross the ionospheric shell and could in this way significantly contribute to the identification of the phenomenon. Spread-F is also often called plasma bubbles because they appear as density cavities in satellite observations. The diameter of the plasma bubbles is between 20 and 200 km.

RF link anomalies observed on other ESA spacecraft, namely MSG-1 and XMM, could also be linked to Spread-F. Based on the knowledge earned, the working group came up with recommendations for future missions and operations design.

Global Ionospheric Data Assimilation & IGS Collaboration with Space Weather Programs

B. Wilson, C. Wang, G. Hajj, X. Pi, L. Mandrake, A. Komjathy, A. Mannucci

We are in the midst of a revolution in ionospheric remote sensing driven by the illuminating powers of ground and space-based GPS receivers and the advent of data assimilation techniques for space weather. JPL and the University of Southern Califronia have jointly developed a Global Assimilative Ionospheric Model (GAIM) to monitor space weather, study storm effects, and replace GIM in providing ionospheric calibration for NASA flight projects. GAIM is a physics-based 3D data assimilation model that uses both 4DVAR and Kalman filter techniques to solve for the ion & electron density state and key drivers such as equatorial electrodynamics, neutral winds, and production terms. GAIM can ingest ground GPS TEC data from 900+ sites, occultation links from CHAMP, SAC-C, and the coming COSMIC constellation, UV limb and nadir scans from the TIMED and DMSP satellites, and in situ data from a variety of satellites. GAIM density retrievals have been validated by comparisons to vertical TEC measurements from TOPEX & JASON, slant TEC measurements from independent GPS sites, density profiles from ionosonde & incoherent scatter radars, and alternative tomographic retrievals. Daily GAIM runs have been operational since March 2003 using 100+ ground GPS sites as input and TOPEX/JASON for daily validation. Our presentation will show some GAIM case studies and JASON comparisons for both GAIM and multi-shell GIM runs.

The Space Weather community has recently identified in a decadal plan the importance of global networks of ground sensors as a complement to space- based sensors. For instance, data from the ground GPS network and the IMAGE satellite have recently been combined to develop a new global view of how magnetospheric storm effects penetrate into the ionosphere, resulting in new theories and several landmark publications. The decadal survey envisages a second generation, multi-purpose global ground observatory in which multiple instruments are deployed at each of 1000+ network nodes. The core instrument will be a cheap, modern GPS receiver that can use dual-frequency GPS and Galileo signals to measure ionospheric TEC and scintillation, along with the usual observables such as tropospheric water vapor. Other instruments could include a MET package, an all-sky ionospheric imager, a passive radar receiver, etc. The IGS should be aware of this development and position itself to contribute to and/or benefit from such a next generation network.

gAGE/UPC GNSS Ionosphere Activities: Real-time, Galileo, EGNOS and Tomography

M. Hernández-Pajares, J. M. Juan, J. Sanz, A. Aragon, M. Garcia, R. Orus, P. Roldan

Since 1998 gAGE/UPC has been computing global TEC maps (GTEC) as an Ionosphere Associate Computation Center (IACC). Our research group has been computing weights for the different IAACs as well since 2001 (acting as a Validation Center, IAVC). They have been used in the generation of an optimal IGS final GTEC, by a weighted combination of the GTECs of the different IAACs.

The techniques used in such tasks have been -and will be- closely related with some of the new achievements and techniques developed by the authors in GNSS ionospheric sounding. In such context this presentation will focus on summarizing an update of such developments, namely:

- Accurate real-time ionospheric corrections in Wide Area GPS networks, including integrity algorithms, which makes feasible the sub-decimeter navigation at distances of hundreds of kilometers from the nearest reference station (Wide Area Real Time Kinematics, WARTK, technique). A first ionospheric prototype is being implemented Catalonia, at the NE Spain.
- The extension of WARTK to Galileo and Modernized GPS systems (WARTK-3 technique, under international patent funded by ESA). The results obtained so far, strongly suggest the feasibility of the subdecimeter navigation capability in Wide Area Networks in single-epoch, the most part of the time.
- Monitoring and Analysis of the EGNOS Test Bed SBAS system. In particular the performance of the broadcast ionospheric corrections are being analyzed.
- The improvement of tomographic techniques, such as the inverse Abel transform in GPS occultation scenarios. They have been extensively tested in different ionospheric conditions, and with 3 different LEOs.

Activities of Swisstopo in GPS Meteorology

E. Brockmann, D. Ineichen, G. Guerova, J.-M. Bettems, A. Somieski, M. Troller, M. Becker, P. Haefele

Since 1999, the Swiss Federal Office of Topography (swisstopo) actively combines the domains of national surveying using GPS and meteorology. Swisstopo operates an automated GPS network for Switzerland (AGNES) consisting of 29 sites. AGNES is a multipurpose network serving surveying applications (reference frame maintenance, densification of the reference frame) as well as scientific applications (geodynamics and atmospheric research). In addition, a positioning service is offered on a commercial basis under the product name swipos-GIS/GEO? (Swiss Positioning Service for GIS and Geodetic Applications). The full network together with approximately 30 additional IGS/EUREF sites is analyzed for reference frame purposes with a time delay of about 2 weeks using the final IGS orbits. Hourly tropospheric zenith total delay estimates are a by-product of this processing.

Since the end of 2001, swisstopo contributes hourly zenith path delay estimates with a time delay of 1:15 hours to the European COST-716 project, to the European TOUGH project, and to the Swiss Meteorological Institute MeteoSwiss as additional information for numerical weather prediction. Since January 2003, the real-time software, which is used for the positioning service, also delivers zenith total delay estimates. Due to the fact that this software works with 1-second data and a negligible time delay, the troposphere information is already available within time delays of 1 minute (accumulation interval of 10 minutes).

In addition, swisstopo cooperates with different research organizations (ETH Zurich, University of Bern, UniBW Munich) in order to compare the estimated zenith total delay estimates with other measurements, e.g., radiosondes, water vapor radiometers, and a solar spectrometer.

The presentation shows some of the mentioned activities, demonstrates the achievable accuracies, validates the different estimates by comparing them to additional information such as forecast models of MeteoSwiss, and addresses possible future developments (GPS tomography).

Determination of Ionospheric Delays of GPS Signals on the Basis of Measuring Results Obtained by a Single-Frequency Receiver

M. Kaufman, S. Pasynok, D. Filonov

When using GPS single frequency receiver the ionospheric delay calculation is performed through mathematical models, current parameters of which are preliminarily calculated either on geophysical measurement data or on the GPS signal measurement results obtained by a net of double-frequency receivers. One way or another, the ionospheric models are built on the basis of data generalization in a global or regional scale, and these are predicted for using in real-time mode, so the correction proved to be not quite adequate to the real ionosphere state above the definite observing site.

There is a principal possibility of calculating the ionospheric delay from the measurement data themselves made by the single frequency receiver. The possibility is based on the fact, that the correction for ionosphere in the code and phase measurements has opposite signs. Although such a simple and effective way of ionospheric delay elimination was discussed in the literature, but it did not find a practical realization by virtue of at least two reasons:

1) code measurement errors (noise component) are higher by two orders of magnitude than these of the phase measurements and that limits the possibility of the effective using the advantages of the phase method;

2) the results of phase range measurements contain uncertainties in the whole wave number which is not eliminated at combination of phase and code data. We tried to construct an algorithm for the ionosphere delay calculation permitting to get over the above difficulties by means of smoothing the measurements and joint processing of the simultaneous measurements of several satellites.

GIM Models for Single Frequency Radar Altimetry

T. Schöne, S. Esselborn

Sea level is a very sensitive parameter to natural and human-driven climate related changes and an important factor for the vulnerability of the Society. For almost two decades, satellite altimetry is now used to monitor changes in sea level and ocean variability. While the later missions, TOPEX/Poseidon, JASON-1 and ENVISAT carry two-frequency altimeters, ERS-1 and ERS-2 had only one-frequency altimeters. Therefore, ionospheric correction models have to be used to account for two-way travel time delays. For most of the applications the IRI95 or BENT model is used, but both are know to have deficiencies in the Tropics. Since a few years GPS derived Global Ionospheric Maps are available from CODE and JPL IGS analysis centers. These maps are used to evaluate their usefulness for correcting the ionospheric path delays of different altimeter missions. The results, especially for TOPEX/Poseidon and ERS-2 will be discussed.

GPS Ionosphere Rapid Service for Europe – Suggestions and First Experiences

M. Figurski, J. B. Rogowski

Modelling of the ionosphere was made using GPS data since last 10 years. The great part of ionosphere services based on the daily GPS data. The alternative of them is permanent GPS data processing using hourly data upload. Utilisation of the near real time GPS data for determination of ionosphere parameters by hourly data processing is insignificant now. Strategy of ionosphere modelling using near real time data is presented in the paper. This strategy base on modification of Bernese v.4.2 software. The main problem of hourly data processing for determination of ionosphere parameters is optimisation geometric distribution of the GPS stations. The system elaborate by the authors was tested in the time were ionosphere was quiet as well as during storm of ionosphere (f.i. 2003.10.28). Results obtained during 3 month test oh the system of rapid service for Europe was compared with CODE, JPL, UPC, ESA and IGS global TEC model. The same comparison was made with CODE model for Europe. All data was compared with TEC value obtained from JASON satellite data. The future analysis of the TEC values obtained in different way to let know precision of the rapid modelling of the ionosphere for Europe.

GPS Tomography and Remote Sensing Techniques for Water Vapor Determination in the ESCOMPTE Campaign

S. Lutz, M. Troller, A. Somieski, A. Walpersdorf, E. Doerflinger, A. Geiger, B. Buerki
O. Bock, H.-G. Kahle

Tropsperic water vapor is the most variable parameter of the major constituents in the atmosphere in space and time. Water vapor in the atmosphere has a strong impact on the refraction of microwave signals, emitted by GPS satellites. It is, therefore, mandatory to determine the water vapor and its distribution with a high accuracy for geodetic applications.

The ESCOMPTE field campaign (Expérience sur Site pour COntraindre les Modèles de Pollution atmosphérique et de Transport d'Emissions, http://medias.obs-mip.fr/escompte) was carried out in June 2001 near Marseille (France). The goal was to acquire data for investigation in complex processes in the atmosphere. Several instruments and techniques were deployed to provide independent data sets for validation purposes, such as microwave radiometer, solar spectrometer and radiosondes. The comparison of the integrated precipitable water vapor (IPWV) retrieved by different methods shows a good agreement within approximately 2 mm.The software package AWATOS (Atmospheric Water Vapor Tomography Software) was used to determine the spatial distribution as well as the temporal variation of water vapor in the project area. Validations with radiosondes show the success of the method.

Mapping Function Parameters Derived from Numerical Weather Model Data in Global GPS Network Analysis - a Comparative Study

S. Vey, A. Rülke, R. Dietrich, M. Rothacher

One major part in the error budget of GPS measurements is the inaccurate modelling of the elevation dependence of the tropospheric path delay. The Mapping Function (MF) which has been applied here uses meteorological data from the Numerical Weather Model of the National Centre of Environmental Prediction (NCEP). In order to derive MF parameters an algorithm proposed by Niell (2001) was applied. We present the differences between this so called Integrated Mapping Function (IMF) and the commonly used Niell Mapping Function (NMF).

Test computations using IGS data were carried out with the Bernese Software. As a result we show the influence of the IMF on estimated GPS coordinate time series in comparison to the NMF solution. This investigation is part of the optimization strategy concerning tropospheric modelling for the ongoing GPS reprocessing project.

MATRAG - Measurement of Alpine Tropospheric Delay by Radiometer and GPS

P. Häfele, M. Becker, E. Brockmann, L. Martin, M. Kirchner

Within the project MATRAG (Modeling of Alpine Tropospheric Delay by Radiometers and GPS), water vapor has been observed at three permanent GPS stations in Central Switzerland. At the AGNES (Swiss permanent GPS network) sites Bern (EXWI), Jungfraujoch (JUJO) and Zimmerwald (ZIMM), two Radiometrics Water Vapor Radiometers (WVR) and ASMUWARA, a radiometer of the Institute of Applied Physics of the University of Bern were installed in September 2003.

Ground based WVR's represent an independent technique to measure the atmospheric integrated water vapor along a specified line of sight as well as the integrated liquid water. For calibration purposes the two Radiometrics WVR's have been measuring simultaneously for three days with the ASMUWARA Radiometer on the roof of the University of Bern in the beginning and end of the experiment. The other ten days of the campaign, the triangle EXWI - ZIMM - JUJO with a height difference of about 3000 m has been observed.

The WVR data is used to assess the accuracy of the GPS derived height and to detect potential biases in the GPS signal processing. In our poster we show comparisons of zenith total delay (ZTD) between our GPS-solution, the AGNES-GPS-solution and WVR as well as inter-comparisons of the three WVR's during the calibration. The benefits of the introduction of the WVR ZTD results into the GPS processing in view of the height component repeatability are studied.

Modeling and Forecasting of TEC Obtained with IGS Network over Europe

A. Krankowski, L.W. Baran, I.I. Shagimuratov

The monitoring and modeling ionospheric effects have been carried since 1995 by Lamkowko Satellite Observatory of Warmia and Mazury University in Olsztyn jointly with West Department of the IZMIRAN of the Russian Academy of the Sciences in Kaliningrad.

GPS measurements from 100 European IGS/EPN permanent stations were used to monitor the behaviour of the ionosphere during geomagnetic storms. A series of ionosphere maps were produced to present the spatial distribution of TEC. The dense network of GPS stations in Europe allows to obtain high spatial and temporal resolution of TEC. Our estimation technique provided TEC maps with 15 min interval and with a spatial resolution of 150-350 km. As the examples we analysed geomagnetic disturbances, which occurred during the month of March 2001.

It was found that the storm essentially modified the ionosphere. During the storm the large and medium-scale irregularities were detected in the high-latitude ionosphere as well as at middle latitudes. The deep spatial TEC changes were caused by occurrence of the main ionospheric trough, which during the storm moved in the direction of the Equator.

Different prediction methods like: Autocovariance, Similar Pattern and ARMA have been also used to predict VTEC obtained from GPS permanent observations which forecast TEC values for one, two, three and four-hour ahead at a single location. The TEC time series for ionospheric quiet and disturbed conditions for years 1995 (minimum solar activity) and 2001 (maximum solar activity) at different European stations: Onsala, Metsahovi, Hailsham, Lamkowko, Borowiec and Matera were studied to clarify the forecasting ability of the method for ionospheric purposes. Latitudes of selected stations range from 40N to 60N. The accuracy of the methods varies within reasonable limits depending on the time range of the forecast for different conditions. Sample of the results for the representative periods are presented. The forecast was compared with real data of the TEC obtained from GPS permanent observations.

Swedish Activities During 10 Years as a Data Provider and Customer of the IGS: Atmospheric Monitoring

B. Stoew, G. Elgered, R. Emardson, L. Gradinarsky, R. Haas, P. Jarlemark, J. Johansson

We present results on long-term trends of integrated precipitable water vapour (IPWV) over the Scandinavian region based on data from the Swedish permanent GPS network (SWEPOS), obtained during the period August 1993 to June 2003. We assess the magnitude of the effects on the estimated IPWV caused by the radome changes by comparison with other independent techniques, such as the microwave radiometry and radiosondes. The processing is carried out in a similar way and with the same software tools as for the Geophysical and Geodetic projects.

We also present results from the Near Real Time (NRT) processing of the SWEPOS network and other permanent stations in North Europe. This data analysis is based on GIPSY software package and a moving data window approach. The results obtained are assimilated in Numerical Weather Prediction (NWP) models. We also show example of attempt to assimilate the GNSS-based data.

Furthermore, SWEPOS and other Nordic permanent networks are used for monitoring of the Total Electron Content (TEC) both post-processing, Near Real Time, and in Real Time. We show some examples from the Near Real Time TEC monitoring. Common for all analyses methods is the extensive use of IGS data and the use of either IGS final, rapid or predicted products.

VMF and IMF Mapping Functions Based on Data from the ECMWF

H. Schuh, J. Boehm

Numerical weather models (NWM) have been investigated to improve mapping functions which are used for tropospheric delay modeling in VLBI and GPS data analyses. The Vienna Mapping Functions (VMF) are based on direct raytracing through NWM, and allow to exploit the full information provided in the NWM. Contrarily, the Isobaric Mapping Functions (IMF) use intermediate parameters calculated from the NWM. Pressure level data from ECMWF (European Centre for Medium-Range Weather Forecasts) are applied to determine the coefficients of the VMF and the IMF. In the analyses of IVS-R1 and IVS-R4 VLBI sessions, both mapping functions improve the repeatability of baseline lengths (by ~10% for IVS-R1 and ~5% for IVS-R4) and height components compared to analyses using the Niell Mapping Functions (NMF). The Institute of Geodesy and Geophysics of the Vienna University of Technology provides the parameters for VMF and IMF since 1979 on a regular basis (http://www.hg.tuwien.ac.at/~ecmwf) for all IVS stations for non-commercial applications. Additionally, the IMF parameters are operationally computed on a global grid of 2.5 deg x 2.0 deg.