IGS

WORKING GROUPS/ PILOT PROJECTS/COMMITTEES

IGS / BIPM Time Transfer Pilot Project

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Introduction

The IGS/BIPM Pilot Project to Study Accurate Time and Frequency Comparisons using GPS Phase and Code Measurements is sponsored jointly with the Bureau International des Poids et Mesures (BIPM). The project has been underway since early 1998, with the main goal being to investigate and develop operational strategies to exploit geodetic GPS methods for improved global availability of accurate time and frequency comparisons.

The respective roles of the IGS and BIPM are complementary and mutually beneficial. The IGS brings a global GPS tracking network, standards for continuously operating geodetic, dual-frequency receivers, an efficient data delivery system, and state-of-the-art data analysis groups, methods, and products. The BIPM and the timing laboratories contribute expertise in high-accuracy metrological standards and measurements, timing calibration methods, algorithms for maintaining stable time scales, and formation and dissemination of UTC.

Recent activities generally fall into the following areas:

- Workshop — Two days during the "IGS 2000 Analysis Center Workshop," held 25–26 September 2000 at the U.S. Naval Observatory, were devoted to the pilot project.
- Deployment of GPS receivers — The IGS network currently consists of about 250 permanent, continuously operating stations globally distributed. Of these, external frequency standards are used at ~38 with H-masers, ~23 with cesium clocks, and ~17 with rubidium clocks; the remainder use internal crystal oscillators. Table 1 lists the IGS stations currently located at timing laboratories. The former timing lab at the Technical University of Graz, TUG (GRAZ receiver) ended operations in 2000, while the NPLD and SPT0 stations are new. Figure 1 shows the locations of the stations.
- GPS data analysis — A new method to combine satellite and receiver clock estimates, both sampled at 5-minute intervals, was implemented officially by the IGS on 5 November 2000.
- Instrumental delays — The BIPM has demonstrated techniques to calibrate the instrumental biases of the Ashtech Z-XII3T receiver. Efforts are underway to measure the biases of similar receivers deployed at timing laboratories.
- Comparison experiments — Studies are underway comparing geodetic timing results with simultaneous, independent measurements using the common-view and two-way satellite techniques.

For further information, please refer to *http://maia.usno.navy.mil/gpst.html*.

Table 1. IGS Stations Located at BIPM Timing Laboratories (in 2000)

AMC2	AMC*	AOA SNR-12 ACT	H-maser	Colorado Springs, Colorado, USA
BOR1	AOS	AOA TurboRogue	Cesium	Borowiec, Poland
BRUS	ORB	Ashtech Z-XII3T	H-maser	Brussels, Belgium
MDVO	IMVP	Trimble 4000SSE	H-maser	Mendeleevo, Russia
NPLD	NPL*	Ashtech Z-XII3T	H-maser	Teddington, UK
NRC1	NRC*	AOA SNR-12 ACT	H-maser	Ottawa, Canada
NRC2	NRC*	AOA SNR-8100 ACT	H-maser	Ottawa, Canada
OBER	DLR	AOA SNR-8000 ACT	Rubidium	Oberpfaffenhofen, Germany
PENC	SGO	Trimble 4000SSE	Rubidium	Penc, Hungary
SFER	ROA	Trimble 4000SSI	Cesium	San Fernando, Spain
SPT0	SP	JPS Legacy	Cesium	Boras, Sweden
TLSE	CNES	AOA TurboRogue	Cesium	Toulouse, France
USNO	USNO*	AOA SNR-12 ACT	H-maser	Washington, DC, USA
WTZR	IFAG	AOA SNR-8000 ACT	H-maser	Wettzell, Germany

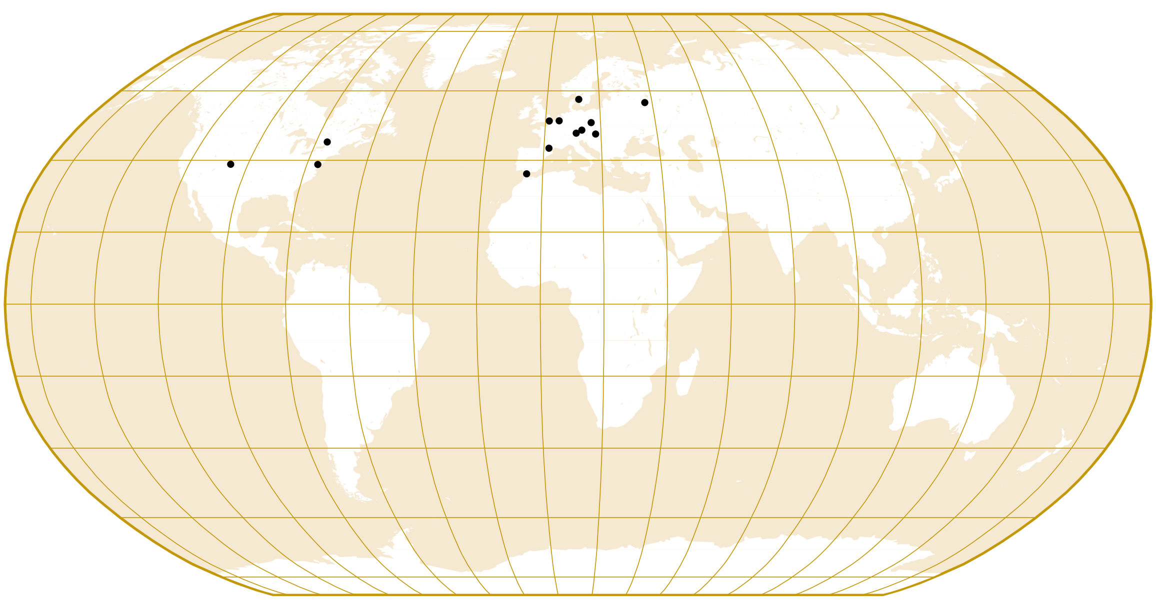

Figure 1. Locations of IGS stations at BIPM timing laboratories

Report of the Tropospheric Working Group

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Product Generation

Since 1997 the IGS regularly generates a combined tropospheric product. It is based on the submission of the individual IGS Analysis Centers (AC), which compute their tropospheric estimates during or after the generation of the IGS final products. Since SIO has joined these activities in February 1998 all IGS ACs contribute to the combination. The product is the weighted mean of the total zenith path delay (ZPD) of the neutral atmosphere (Gendt, 1996). The individual AC biases are calibrated on a weekly basis. The product delay is 2 to 4 weeks. The standards for the analysis are converging, so six ACs have implemented the Niell mapping function, and elevation cut-off angles of 10, 15 and 20 degrees are used by 2 , 4 and 1 centers, respectively.

For more than 210 sites the product is available now (Fig. 1). Nearly 150 sites are used by three or more ACs, which allows to derive reasonable quality measures. The number and quality of the meteorological sensors is slowly improving (Figs. 2, 3). Up to now only 30 sites have reported meteorological data, typically about 25. Information on the quality of all sites to support the selection for new installations were compiled. Presently there are tendencies by some meteorological institutions to assimilate the ZPD directly into the numerical weather prediction (NWP) models. If this proves to be the final strategy then it will have an impact on the installation of meteorological sensors for the regional applications devoted to NWP. However, for sites used in climate studies, which is the case for the global IGS network, meteorological sensors are important, and the usual daily RINEX-met files are sufficient. Therefore IGS should strive to complete the installation of sensors in its global network.

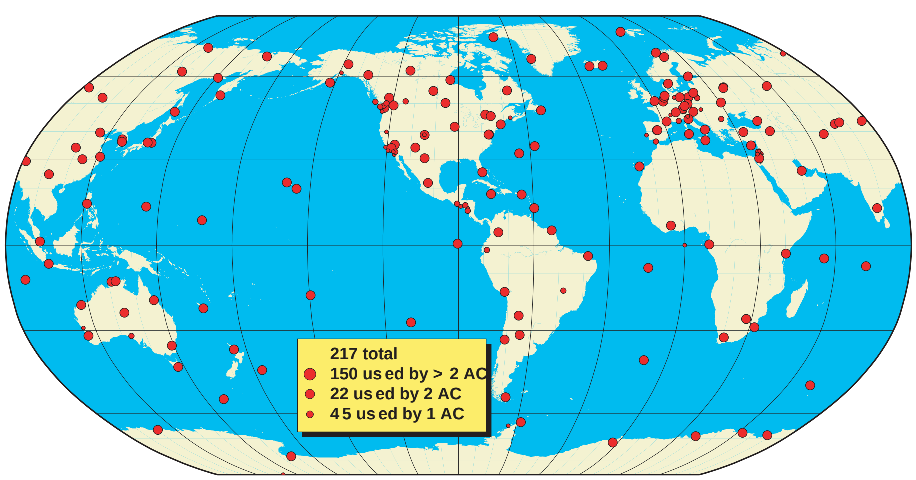

Figure 1. IGS Stations with Tropospheric Estimates

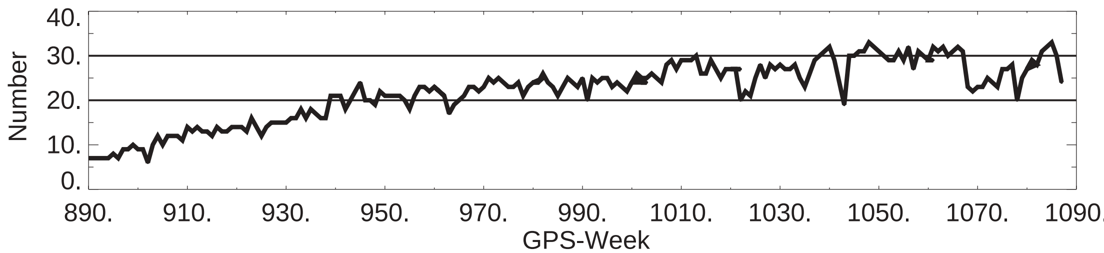

Figure 2. Number of sites with meteorological sensors

Product Quality and Validation

The quality of the product (internal consistency between ACs) is at the level of 3 to 5 mm in the ZPD, which corresponds to ≤ 1 mm in the water vapor (Fig. 4). The biases are even smaller. However, changes in the analysis parameters of the ACs can be seen in most cases in the series.

The histograms in Figure 5 reveal that for most sites the standard deviation is below the 4 mm level. Especially, CODE and SIO have pronounced peaks at 2 – 3 mm, caused by the fact that both centers use many sites in the denser parts of the network where the quality is significantly better than for the sparser parts (Fig. 3). Systematic effects in the biases can clearly be seen for CODE and SIO. The primary reason may be the different cutoff angles applied by both centers (10^o), where the weighted 10^o degrees of CODE seems to correspond to an effective angle of about 20^o.

Regular comparisons with co-located techniques were performed for Potsdam only. Here, a water vapor radiometer (WVR) operated by the German Weather Service is available. All AC GPS solutions monitor the fluctuations in the water vapor with high accuracy. The scattering is of the level of ±1 mm, the best agreement is for the combined series. All ACs have a negative bias of about –1 mm. The fluctuations in the biases are rather large over a longer time interval (~1 mm). The biases may have various reasons, e.g. the WVR itself (calibration) or GPS modeling deficiencies (antenna phase center patterns, mapping functions, satellite antenna offsets). Efforts to make an extensive comparison with globally distributed VLBI sites failed up to now, because older VLBI results had only archived the wet delay without the corresponding pressure values. Such validations should be done in future in a close cooperation with the IVS.

Resume

All IGS components contributing to the combined tropospheric IGS product are performing well. The product has reached a high quality and further investigations on a post-processed tropospheric product in a global scale are not planned. Therefore the activities of working group on this topic will be finished. The established procedures for the regular product generation will be continued, and GFZ agrees to perform the combination (see http://op.gfz-potsdam.de/S11/index_GPSS.html).

Presently near real-time (NRT) monitoring of water vapor is supported by IGS by providing global data, NRT orbits and its Ultra-rapid predictions (Fang et al., 2001). Although NRT activities are more suited to individual countries or regional organizations, where sufficient dense networks are operated, IGS plans to study the feasibility for an Ultra-rapid or even NRT global tropospheric product. Such a product, provided for a relative sparse network only, can be used for NRT quality control in regional network applications.

Up to now only a few users retrieve the IGS tropospheric products (looking into servers at CDDIS, IGN and GFZ). Hopefully, the interest of meteorological community in the product will grow in parallel with the acceptance of GPS products for NWP models. The IGS contribution should also be seen in the context of other activities like the establishment of a similar database (TROP-SINEX format) for Asia and Western Pacific by the Earthquake Research Institute, Tokyo, and the plan to generate a combined tropospheric product within EUREF.

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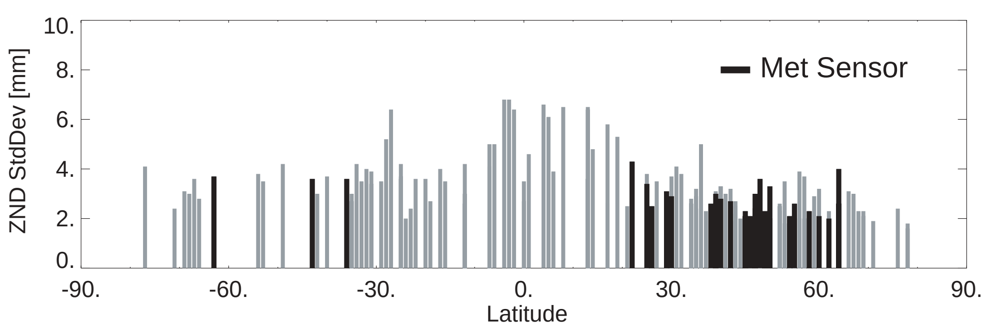

Figure 3. Mean standard deviation for IGS sites used by three or more Analysis Centers, sorted by latitude (mean over GPS weeks 1000 to 1087). Sites equipped with met sensors are marked.

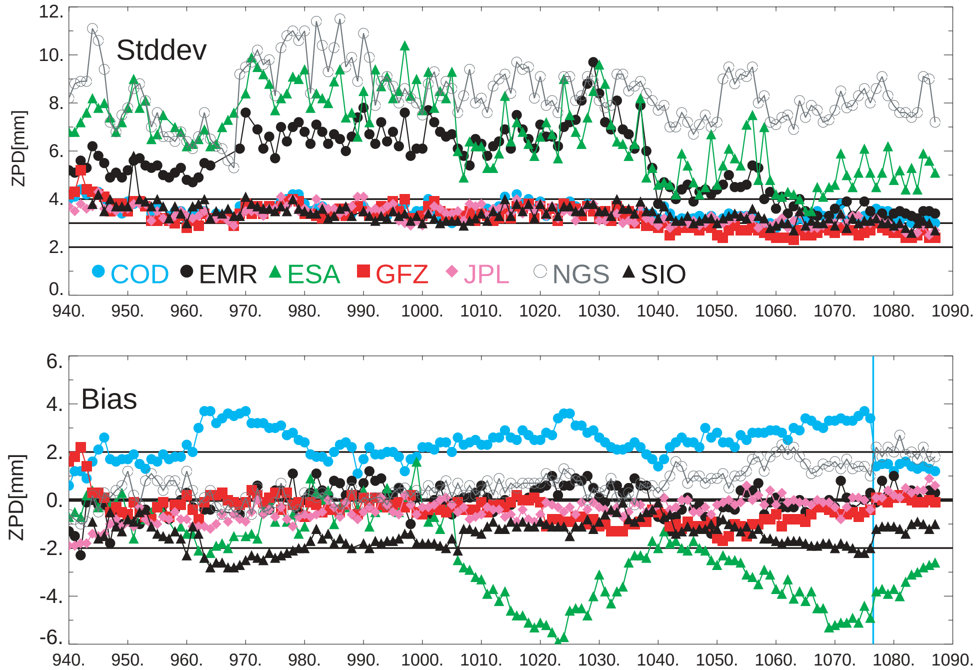

Figure 4. Difference in the zenith neutral delay between the individual GPS estimates and the IGS Combined Product. Mean values (over all sites) per week and per Analysis Center.

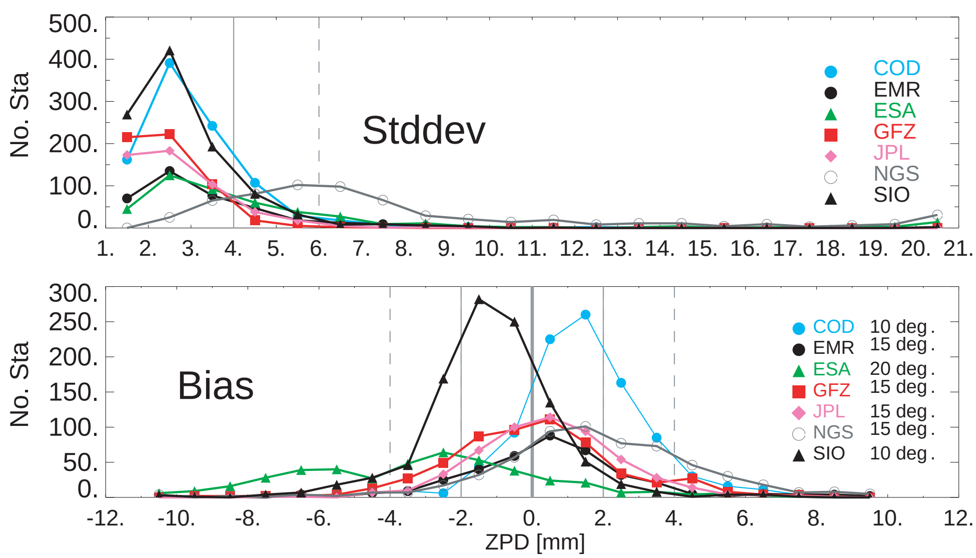

Figure 5. Differences in the zenith path delay between the individual GPS estimates and the IGS Combined Product. Histograms of standard deviation and bias for the GPS weeks 1080 to 1087.

2000 IGS Activities in the Area of the Ionosphere

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Introduction

The IGS Ionosphere Working Group (Iono_WG) is active since June 1998. The working group's most important short-term goal is the routine provision of global ionosphere TEC maps plus GPS spacecraft differential code biases (DCBs) with a delay of some days. The routine delivery of stations DCBs is in preparation and will be included soon. In the medium- and long-term, the development of more sophisticated ionosphere models and the establishment of a near-real-time service are the major tasks. The final target is the establishment of an independent IGS ionosphere model.

Five Ionosphere Associate Analysis Centers (IAACs) contribute with their products to the Iono_WG activities:

1. CODE, Center for Orbit Determination in Europe, Astronomical Institute, University of Berne, Switzerland.
2. ESOC, European Space Operations Centre of ESA, Darmstadt, Germany.
3. JPL, Jet Propulsion Laboratory, Pasadena, California, U.S.A.
4. NRCan, National Resources Canada, Ottawa, Ontario, Canada.
5. UPC, Polytechnical University of Catalonia, Barcelona, Spain.

It is the intent of this Technical Report to give an overview over the Iono_WG activities in 2000.

Routine Activities

Daily Ionospheric Total Electron Content (TEC) Information

Each IAAC delivers per 24 hours an IONEX file (Schaer et al., 1997) with 12 TEC maps containing global TEC information with a 2-hours time resolution and a daily set of GPS satellite DCBs in its header. The inclusion of ground station receivers DCBs is in preparation.

Weekly Comparisons

On Tuesday of each week the TEC maps from the different IAACs are compared for all days of the week before. These comparisons are done at ESA/ESOC. A weekly comparison summary is e-mailed to the "Iono_WG members" via IONO-WG mail.

Furthermore, the daily summaries, the daily IONEX files with the "mean" TEC maps & GPS satellite DCBs and daily TEC & DCB difference files with respect to the "mean" for each IAAC, and also plots of these maps, are made available to the "Iono_WG members" on ESOC's FTP account. The algorithm used in the comparison program is described in (Feltens, 1999 - Appendix A). This algorithm is currently being upgraded with a new weighting scheme, for more details (see next chapter "Improvement of the Comparison Scheme/Validations").

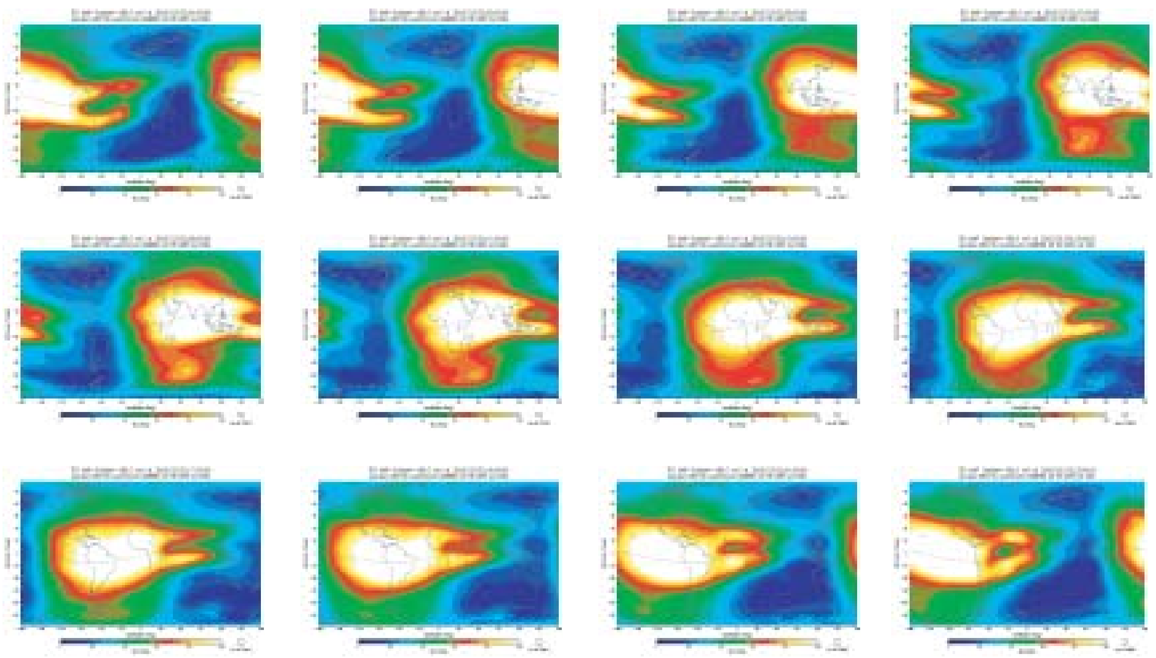

Figure 1: The IGS "weighted mean" TEC maps of 28 March 2000 in [TECU]
(1st row: 1^h, 3^h, 5^h, 7^h ; 2nd row: 9^h, 11^h, 13^h, 15^h ; 3rd row: 17^h, 19^h, 21^h, 23^h).

On the northern hemisphere the deviations of the different IAAC TEC maps from the IGS "mean" are under normal conditions 5 TECU or less. At the equator and on the southern hemisphere the situation is more problematic, because of gaps in the station coverage at these latitudes. However, the deployment of new IGS stations in these areas has reduced these gaps since 1999. Figure 1 above shows the sequence of IGS "weighted mean" TEC maps of 28 March 2000, a day during a period in the current solar maximum, when the TEC level was very high.

The day-by-day variations of the different IAAC DCB sets are normally less than 0.3 nanoseconds, sometimes 0.5 nanoseconds. IAAC DCB sets showing deviations of one 1 nanosecond and more with respect to the IGS "mean" are excluded from the comparison. According to a presentation of S. Schaer at the IGS Workshop, 27 - 29 September 2000, Washington, mean IAAC satellite DCB series show an agreement of about 0.1 nanoseconds. For his analysis Schaer took three months (GPS weeks 1065 - 1077) of daily satellite DCB sets from the IAACs IONEX files and computed from these daily values IAAC-specific mean DCB sets. The five mean DCB sets thus obtained were then compared with respect to each other and also with respect to an overall mean set (All). Table 1 below is an extract of Schaer's presentation and shows the obtained rms errors (in nanoseconds). When interpreting these numbers one has to keep in mind that some IAACs estimate their DCB sets together with their TEC maps, while others make separate program runs for this. Some IAACs introduce constraints in their DCBs estimation, while others do not.

Table 1: Agreement of the distinct IAACs satellite DCB sets in [nanoseconds] (according to S. Schaer).

	NRCan	***ESOC***	***JPL***	***UPC***	***All***
CODE	*0.122*	*0.106*	*0.110*	*0.370*	*0.094*
NRCan		*0.109*	*0.144*	*0.371*	*0.104*
ESOC			*0.118*	*0.373*	*0.095*
JPL				*0.393*	*0.117*
UPC					*0.296*

Improvement of the Comparison Scheme / Validations

The current comparison/combination algorithm is based on a pure statistical approach using weighted means. On the other hand, the methods used by the IAACs to model the ionosphere are very different. In order to achieve an objective weighting for a combination scheme the existing comparison/combination is currently upgraded: Based on two self-consistency methods proposed by NRCan and UPC, in which directly from GPS-observables derived TEC values are compared with corresponding TEC values interpolated from the IAACs TEC maps, new geographic-dependent weights will be computed and thus replace the old kind of weighting in the comparison/combination algorithm. A detailed description on how these two methods work can be found in (Feltens, 2000a; Feltens, 2000c; Hernandez-Pajares, 2000; Heroux, 1999).

Figure 2 below shows in form of histograms the results of an analysis made at UPC with TOPEX data for each of the five IAACs for the year 2000; the Number of TOPEX observations are shown on the ordinate and the differences {TEC(TOPEX) - TEC(GPS)} in [TECU] are shown on the abscissa. When interpreting these histograms it should be taken into account that, in these plots, a negative bias means that the estimated TEC with GPS (h < 20200 km) is greater than the TOPEX TEC (h < 1300 km). Then a positive bias means directly a mean underestimation of the TEC with GPS at least equal to the bias (the TOPEX accuracy seems to be 2 TECU).

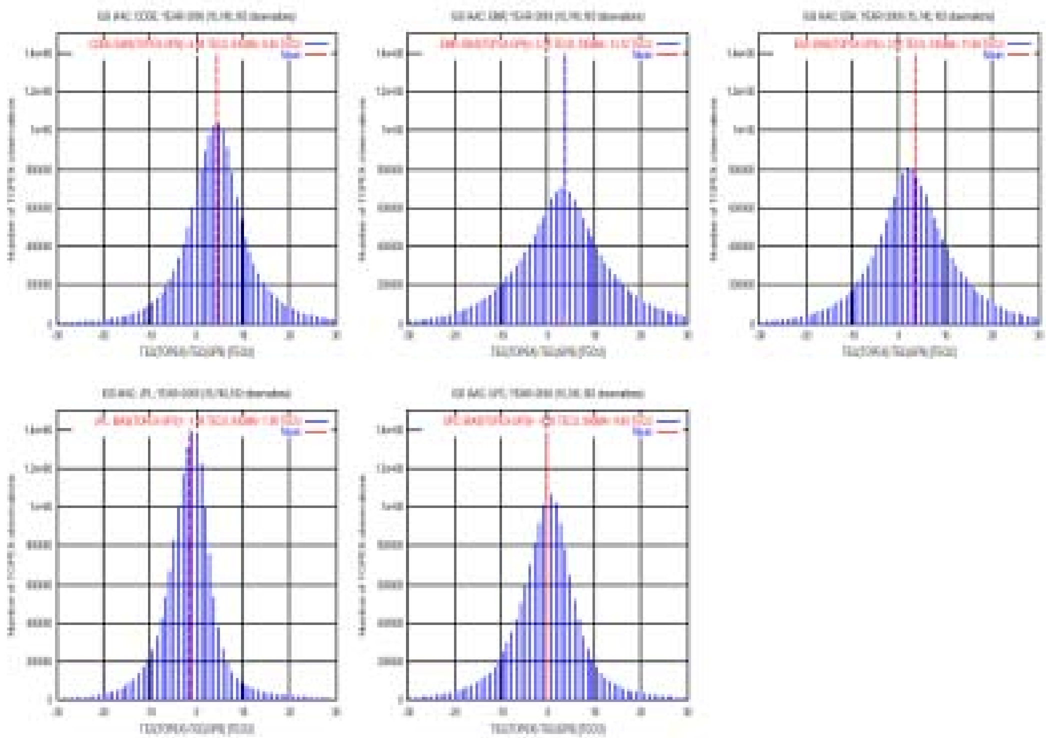

Figure 2: TOPEX- vs GPS-TEC for the year 2000 (figure made at UPC).

Special Activities

During events which are of special interest for the ionosphere community and for ionospheric research, the Iono_WG organizes special high-rate tracking campaigns with the global IGS ground stations network. After the Solar Eclipse Campaign on 11 August 1999, the preparations for a new high-rate campaign with the name "HIRAC/SolarMax" were started with an initiative of J. Feltens and N. Jakowski through IGSmail #3091 (Feltens, 2000b): the objective was to collect in April or May 2001 one week of global high-rate GPS/GLONASS data as a basis for analyses of ionospheric behavior under the current solar maximum conditions. Further details about the HIRAC/SolarMax campaign will then be a topic for the IGS 2001 Technical Report.

Future Tasks

As soon as the new weighting scheme is implemented into the comparison/combination program, it is intended to start with the routine delivery of a combined IGS ionosphere product.

Preparations are made to attach to the weekly comparison program runs validations by comparing IAACs model vertical TEC values with vertical TEC values derived from TOPEX (and Envisat, once launched) altimeter data. Another important aspect will be the reduction of the time deadline for ionosphere products delivery. The ionosphere is a very rapidly changing medium, and it must be the working group's intention to provide actual ionosphere models in short time frames - especially with regard to the current solar maximum.

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IGS LEO Pilot Project

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The Call for Participation in the IGS Low-Earth Orbiter (LEO) Pilot Project was announced in January 2000. It elicited a very strong response evident by the 26 proposals submitted to the Central Bureau. All components were represented (stations, data centers, Associate Analysis Centers, etc.), and the Governing Board accepted all the proposals at the June meeting at the U.S. Naval Observatory. The constitutional meeting to organize the project was planned for January 2001 at GeoForschungsZentrum (GFZ) in Potsdam, Germany. The CHAMP satellite launched successfully on 15 July. In November, after an initial commissioning phase of the satellite, members of the IGS LEO Pilot Project were provided with one day of CHAMP GPS, gravity, and magnetic field sensor data, as well as accelerometer and attitude data plus reference frame and data format descriptions. Data from the U.S.–Argentina mission SAC-C, which successfully launched on 21 November, are also available to the project. The benefits of a common ground-based infrastructure to serve upcoming multimissions cannot be overlooked.

The definition and operation of a robust, high-sampling-rate, low-latency subset of the global tracking network is progressing rapidly, and issues such as data formats, access, products, etc., will be discussed in more detail in 2001 when the project members have had opportunity to examine the space and ground data and produce preliminary results.

One of the key questions is the structure of the project, and in particular, identifying the Associate Analysis Coordinator for the project. Various groups will evaluate the inclusion of LEO data as a core element of the IGS. An assessment of the effects on the traditional IGS analysis products will be performed (GPS ephemerides, clocks, Earth orientation, and troposphere), as well as an assessment of the additional computational and data center burdens. There are clear potential benefits, but these are balanced by additional complexity. In the spirit of the IGS, the pilot project looks to provide a collaborative approach. The data from the satellites are generated by spaceborne, geodetic-quality GPS receivers designed by JPL. In addition to CHAMP and SAC-C, these flight receivers will be flown on board a number of upcoming missions — Jason-1, Gravity Recovery and Climate Experiment (GRACE), and ICESat.

It is clear that the next few years will provide interesting opportunities to explore the enhancement of the IGS through many applications projects. The LEO Pilot Project promises fertile cooperation, noting that by 2003 nearly a half dozen missions will be on orbit and available to the pilot project.

International GLONASS Service Pilot Project

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Introduction

Russia launched the first GLONASS satellites in late 1982. However, until the International GLONASS Experiment (IGEX-98) was conducted in 1998-1999, no coordinated international effort had been organized to collect and process GLONASS data. IGEX-98 created a global tracking network of stations with geodetic receivers, obtained increased laser tracking support from the satellite laser ranging community, generated a continuous archive of satellite observations, and produced post-processed precise orbits. As a result of continued interest in GLONASS, the IGS initiated a pilot project, the International GLONASS Service Pilot Project (IGLOS-PP), to exploit the GLONASS system as long as it remained viable.

A Call for Participation was issued in May 2000 with the following goals and objectives:

1. Establish and maintain a global GLONASS tracking network
2. Produce precise (10-cm level) orbits, satellite clock estimates, and station coordinates
3. Monitor and assess GLONASS system performance
4. Investigate the use of GLONASS to improve Earth orientation parameters
5. Improve atmospheric products of the IGS
6. Fully integrate GLONASS into IGS products, operations and programs.

A pilot project committee was formed consisting of Vladimir Glotov (Russian Space Agency), Ramesh Govind (Australian Survey and Land Information Group), Werner Gurtner (University of Berne, International Laser Ranging Service liaison), Arne Jungstand (EC Joint Research Centre and DLR), Angelyn Moore (IGS Central Bureau), Carey Noll (NASA Goddard Space Flight Center, Data Center Coordinator), James Slater (National Imagery and Mapping Agency, Chair), Robert Weber (University of Technology, Vienna, IGLOS Analysis Center Coordinator), and Pascal Willis (Institut Geographique National). In addition, the IGS Central Bureau initiated a new mail service, IGLOSMAIL, on May 25, 2000 for participants in the project.

The pilot service is based on the infrastructure already in place in the IGS for GPS. Tracking stations forward their data to regional and global data centers where the data are retrieved by Analysis Centers that compute precise orbits and other products. These products are then archived at global data centers for access by the user community.

Tracking Network

As of December 2000, there were 32 operational, dual-frequency tracking stations and 13 proposed stations in the IGLOS pilot project global tracking network. Most of the operational receivers are Ashtech Z-18 or JPS Legacy models. The remainder are 3S Navigation receivers. In conjunction with this, the International Laser Ranging Service has been coordinating laser tracking of three GLONASS satellites (in slot numbers 1, 15, and 24) as part of its routine schedule. The laser tracking takes advantage of laser retroreflectors that are on every GLONASS satellite.

Analysis Centers and Global Data Center

Two Analysis Centers, BKG and ESA/ESOC, have been computing precise orbits on a weekly basis using the receiver data from the tracking network. The Mission Control Center of the Russian Space Agency and the NERC Space Geodesy Facility in the United Kingdom have been computing orbits from the laser tracking data on an intermittent basis. After the BKG and ESA/ESOC orbits are produced, the IGLOS Analysis Coordinator computes a combined orbit at the University of Technology in Vienna.

Data and precise orbits are stored in the CDDIS global data center at NASA's Goddard Space Flight Center. Between August and November 2000, 28 organizations primarily from Austria, Germany, Russia and the U.S. retrieved IGLOS data from the global data center.

Precise GLONASS Orbits

Precise GLONASS orbits have been computed continuously by BKG and ESA for each day in 2000 for all the operational satellites. BKG uses the Bernese software, while ESA uses its GPSOBS/BAHN software. Orbit repeatability is generally in the 10-20 cm range (rms). The Analysis Centers also compute the time offset between GPS and GLONASS times, and estimate datum transformations between the GLONASS PZ-90 reference frame and the International Terrestrial Reference Frame using the GLONASS broadcast message. After the individual center orbits are released, a weighted combination of the two orbits is generated and made available through the CDDIS.

NERC has computed GLONASS orbits using SLR data alone and compared it with microwave receiver-based orbits. It has also compared laser ranges directly with ranges derived from the microwave receiver-based orbits. RMS differences between the laser and microwave orbits are approximately 10 cm radially and 50 cm in the along-track and cross-track directions.

Plans

Efforts during 2001 will be focussed on integrating the GLONASS receiver sites with the GPS sites in the IGS. Site log forms, data archives and analysis center software will be revised where possible to process combined GPS and GLONASS data. Stations will all have to meet IGS standards. Improved timeliness of orbit products will also be a goal. There is still some uncertainty regarding the GLONASS constellation and its long term reliability and maintenance. Nine satellites were operational in December, but without a new launch in 2001, this number will probably go down.