IGS Products for the Ionosphere

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Abstract

In June 1992 the International GPS Service for Geodynamics (IGS) started with the routine provision of precise GPS orbits and earth orientation parameters. In the meantime other products were included into the product palette: rapid orbits, predicted orbits, GPS satellite clock information, station coordinates and velocities (SINEX), and station-specific tropospheric zenith delays.

For long time the IGS community is well aware of the fact that the world-wide IGS network offers a unique opportunity to extract ionospheric information on a global scale. At the IGS workshop held in Silver Spring in March 1996, a first sub-session was dedicated to the ionosphere. Main subject of this ionosphere sub-session was an intercomparison of ionosphere products provided by several Analysis Centers in order to get an idea of the accuracies that can be achieved. In addition it was identified for the first time, which Analysis Centers indicated their willingness to contribute to an IGS ionosphere product.

Since 1996 considerable progress in ionosphere modeling has been achieved at the different Analysis Centers, and today most of them are able, or in a position very close to be able, to provide ionosphere information on a routine basis. An official format for the exchange of ionosphere maps, called IONEX, has been worked out and approved. It will be the main task of the 1998 IGS Workshop to prepare the start of a coordinated routine processing and combination of future IGS ionosphere products.

1 INTRODUCTION AND MOTIVATION

Since mid 1996 we are approaching the next solar maximum. Therefore good and fast knowledge about the ionosphere's actual state becomes of increased importance: Users of satellite navigation systems need accurate corrections to remove signal degradations caused by the ionosphere, information on the ionosphere's behavior is of great importance for a lot of radio signal propagation applications, and also scientists will benefit from up-to-date and long-term ionosphere information. ESOC is for instance interested to use IGS ionosphere maps for the support of other ESA missions like ERS and ENVISAT.

On the other hand, as part of the IGS activities, GPS dual-frequency data is collected from a global net of ground stations for years. Due to the fact that the ionosphere is a dispersive medium for microwave signals, dual-frequency GPS data provides thus a direct measure of the ionosphere's activity and can be used to extract global ionospheric information.

Since 1992 the IGS Analysis Centers demonstrate that they are capable to routinely determine orbits, earth orientation parameters, and other parameters of geophysical interest. In priniciple, it is a small step for them, to derive ionospheric parameters on a regular basis - provided special software for ionosphere modeling is available.

The main motivation for the IGS to get involved in the ionosphere business is a continuous monitoring of the ionosphere for (at least) the next period of high solar activity and to study in particular the impact of the ionosphere on the "traditional" IGS products.

2 REVIEW OF IONOSPHERE IGS ACTIVITIES SINCE MARCH 1996

Several of the Analysis Centers participating in the IGS have experience with the evaluation of ionospheric parameters from dual-frequency GPS data and maintain corresponding software. Institutions, which do currently not contribute to the IGS with products (like orbits, etc.) but indicated their willingness to contribute routinely with ionosphere products, will in the following text be denoted as “Analysis Centers” too. Table 3.1 provides an overview over all Analysis Centers involved and detailed information about their different kinds of ionosphere modeling.

Looking back for the last two years, it can be noticed positively that some of the Analysis Centers have achieved considerable progress and improvement in their ionosphere processing. And, as reaction on an e-mail inquiry initiated in preparation to this 1998 workshop, new Analysis Centers have manifested their interest to enter into future IGS ionosphere activities. But it must be noticed negatively that, concering the ionosphere, by far the most efforts of the Analysis Centers were directed to internal improvements. Apart from the intercomparison of ionosphere maps and differential code biases, that was made as part of the 1996 IGS workshop session, and the definition and approval of the so-called IOnosphere Map EXchange Format (IONEX) (ref. R3), no considerable contributions in the direction of a common IGS activity could be registered.

A lot of the Analysis Centers are in the meantime in a position, that they can principally participate in a routine IGS ionosphere service or are being very close to do so. Therefore nowadays it should only be a small step to start with a routine provision of ionosphere products within the IGS. It will be the main task of this 1998 workshop to remove last obstacles and to define guidelines to realize this step very soon.

3 CANDIDATES WILLING TO PARTICIPATE IN A ROUTINE IGS SERVICE FOR IONOSPHERE PRODUCTS

In order to get an overview over the possible participants and their individual ionosphere products, an inquiry via e-mail was initiated prior to this 1998 workshop. The reactions on this inquiry are condensed in the following table:

Analysis Center	CODE	DLR	ESOC	JPL	NOAA	NRCan	ROB	UNB	UPC	WUT
IGS Analysis Center ?	yes	no	yes	yes	yes	yes	no	no	no	no
Extent of ionosphere maps	global & regional (Europe)	regional (Europe)	global	global	regional (US)	global (planned) + regional (Canada)	regional (Belgium)		global	local
Temporal resolution	24^h / 2^h in preparation	1^h	24^h	15^m	24^h	24^h	15^m		1^h	
Observable type(s) used	doubly differenced phase or phase-smoothed code	carrier phase leveled to code	carrier phase leveled to code	carrier phase leveled to code	GPS phase information	carrier phase leveled to code	carrier phase leveled to code		carrier phases and differences	doubly differenced phase

Analysis Center	CODE	DLR	ESOC	JPL	NOAA	NRCan	ROB	UNB	UPC	WUT
Shell height	*400 km*	*400 km*	*400 km* for 2-d models	*450 km*		*350 km*				*400 km*
Elevation cut-off angle	10^0	10^0	20^0	10^0		15^0				15^0
Elevation-dependent observation weighting	yes		yes	yes		yes				
TEC representation	spherical harmonics, n= 12, m = 8	NTCM model	2-d GE-functtions & 3-d Chapman profile models	composition of local basis functions	Site-specific models		Station-specific profiles		3-d tomography models	spherical harmonics, n,m = 3
Grid width	2.5^0	2.5^0 / 5^0	2.5^0			3^0				2.5^0
Differential code biases	yes	yes	yes	yes	no	yes	yes		no	no
Reference frame internally used	sun-fixed / geographic		sun-fixed / geomagnetic	sun-fixed / geomagnetic		sun-fixed / geographic			sun-fixed	sun-fixed
Mapping function	*1/cosZ*	*1/cosZ*	*1/cosZ* , integrated in Chapman profile models	elevation scaling function based on extended slab model		*1/cosZ*				*1/cosZ*
Single layer shape	spherical		spherical for 2-d models			spherical				spherical
IONEX format implemented ?	yes	in preparation	yes	in preparation		planned	no			yes
Ready for routine processing ?	yes	yes	yes	planned	planned	regional: yes global: planned	yes			yes
RMS maps provided ?	yes		planned							no
Delay of availability	rapid: 12^h, final: 4^d	2^d	coupled with ESOC final orbits, rapid anticipated	3^d (planned)						

Table 3.1: List of willing participants and their ionosphere products.

The Analysis Center identifiers are in alphabetical order:
CODE (AIUB): Center for Orbit Determination in Europe, Berne, Switzerland,
DLR: DLR/DFD Fernerkundungsstation Neustrelitz, Germany,
ESOC: ESA/European Space Operations Centre, Darmstadt, Germany,
JPL: Jet Propulsion Laboratory, Pasadena, CA, U.S.A.,
NOAA: National Oceanic and Atmospheric Administration, Silver Spring, U.S.A.,
NRCan (EMR): Natural Resources Canada, Ottawa, Ontario, Canada,
ROB: Royal Observatory of Belgium, Brussels, Belgium,
UNB: University of New Brunswick, Fredericton, N.B., Canada,
UPC: Politechnical University of Catalonia, Barcelona, Spain,
WUT: Warsaw University of Technology, Warsaw, Poland.

A blank field in Table 3.1 indicates that no information was given on a certain question by an Analysis Center. From UNB no detailed information was provided before the completion of this position paper.

Table 3.1 shows that the number of methods of ionospheric modeling corresponds to the number of Analysis Centers listed. According to the Analysis Centers individual requirements and tasks, representations of the ionosphere are evaluated over different geographic regions, using different mathematical strategies, and analyzing different observation types.

4 POTENTIAL USERS OF IGS IONOSPHERE PRODUCTS

When thinking about future IGS ionosphere products, potential users of such ionosphere products should be specified. Ionospheric electron density models are generally of relevance for GPS/GLONASS users who have only single frequency data available - but can be of benefit for the correction of non-GPS/GLONASS satellite tracking data too. Routine information on ionosphere conditions may also be helpful in other fields of radio signal propagation applications, as well as for scientific interpretation of phenomena in the high atmosphere, the magnetosphere, as well as solar activity.

Depending on the interests of different users, different kinds of ionosphere products are requested. Possible users might be grouped into two basic categories:

1) Users who are interested in fast access to up-to-date ionosphere information, but do not require highest accuracy. Users belonging to that group work for instance in geodetic survey, navigation, road and shipping transport companies. For these people ionosphere models are only of interest in so far that they get reasonable corrections for their tracking data.

2) The second class of users are scientists being interested in highly accurate ionosphere models. To get precise ionosphere information, they will accept time delays in having the data at their disposal. Scientists have already signalized their interest in an IGS ionosphere product.

We may assume, that the majority of potential users will belong to the first category.

5 DEFINITION OF A COMBINED IGS PRODUCT FOR THE IONOSPHERE

Each Analysis Center has special reasons and interests why it computes ionosphere information, and therefore different approaches are established. Nine Analysis Centers are now willing to offer their ionosphere products to the IGS. The IGS should thus not try to intervene into the Analysis Centers indiviual ionosphere processing. Instead of this, the IGS should define certain mandatory standards, according to which the ionosphere products shall be deliverd to the IGS. These standards should be defined in such a way, that they allow on one hand each Analysis Center to continue with its individual processing strategy (i.e., internal reference frames, geographical extents, etc.) and on the other hand easily enable to transform its products to these IGS standards. These mandatory standards should include:

- All Ionosphere products must be delivered to the IGS in IONEX format.
- All TEC maps are “snapshots of the ionosphere” and have to be referred to compatible reference epochs.
- Unified reference epochs must be agreed upon.
- Unified grid width(s) must be agreed upon.

When using unique epochs and grids, there will be no necessity for map rotations and interpolations. Both, rotations and interpolations, would require the establishment of additional software and would be additional source of errors, degrading the quality of TEC maps.

- A unified shell height should be recommended.

- Instructions concerning naming and compressing of IONEX files have to be available.

Considering the different mathematical models and their geographical extent as offered by the Analysis Centers (see Table 3.1) on the one hand, and the requirements of potential users on the other hand, a combination of several mathematical models - complementing each other - should be strived for. Ideally a global model should provide overall VTEC with restricted accuracy to which local and regional models are attached to in geographical zones of special interest (e.g. Europe or North America) to account for small-area ionosphere features. An appropriate weighting scheme must be found for the combination.

Methods to interpolate between IGS TEC maps of two successive epochs must be defined. The interpolation schemes presented in ref. R3 are possible candidates.

It must be decided whether satellite (and perhaps also receiver) differential code biases shall be exchanged and combined. The reference where differential code biases are referred to may be chosen arbitrarily. Different references can be taken into account in the combination step. Daily sets of differential code bias values might be of interest also for time-transfer people.

Deadlines must be defined, e.g. for the delivery of rapid and final products, and for the combination of these products.

6 NEXT STEPS TO BE UNDERTAKEN

However, such a complex program cannot be established all at once - it must be realized in successive steps. In a first step processing should be restricted to final processing in order to allow the Analysis Centers to earn experience and to familiarize with routine IGS ionosphere processing without being under too high time pressure. If after some time a certain routine has been achieved, a rapid ionosphere product can be taken into consideration.

The first IGS ionosphere product will base on the those models that are currently offered by the Analysis Centers. After gathering experiences with the current models, one may expect a refinement of the modeling techniques as seen e.g. for the IGS orbit products.

The next immediate steps to be undertaken to realize an IGS ionosphere products might be:

1) Preparational phase: Analysis Centers that have signalized their interest to contribute to an ionosphere service shall prove whether they have (and install if missing):

- the IONEX interface,

- tools to convert their ionosphere products into the above listed mandatory IGS standards,

- prepare on their platforms the environment needed for routine ionosphere processing, data exchange, etc.

An Analysis Center must be found that is interested in doing then IGS ionosphere combinations on a regular basis. It is clear, that the combination results will be very useful for all contributing Analysis Centers!

People must be found who declare their willingess to work out combination methods and to set up corresponding algorithms. Prior to this an inventory concerning already existing combination software should be done.

Preparations at the IGS Global Data Centers must be done in order to be able to control the flow of IGS ionosphere products.

2) Test phase: As soon as an Analysis Center is in a position to provide ionosphere information according to the IGS standards, it shall deliver its TEC maps to the IGS. It will be one task of this test phase to gather first experience with operational ionosphere processing and to allow those Analysis Centers, which need more time to become operational, to keep connected to the "IGS ionosphere train". New combination strategies and software can be tested in this phase.

3) Pilot phase: After some months every Analysis Center will have gained so much routine, that a loose time deadline for products delivery (e.g. 2 weeks) can be introduced. With the progress of time this deadline will then be strengthened, and the production of rapid ionosphere information can be discussed. The pilot phase will thus lead over to a real operational and routine IGS ionosphere product.

Last but not least a person must be nominated who is willing to take over the responsibility to coordinate all these IGS ionosphere activities.

7 CONCLUSION

The following issues should be discussed at the 1998 IGS Analysis Centers workshop:

- What are the potential users of an IGS ionosphere product ?
- How should an IGS ionosphere product look like ?
- How long do the Analysis Centers need to adapt the IGS standards and to be ready for a routine service ?
- Who is interested to work out possible combination strategies and to develop corresponding software ?
- Which Analysis Center(s) would be willing to do the combination work ?
- Who is willing to take over the responsibility of ionosphere products coordination ?

8 REFERENCES

R1. Feltens, J. (1996a): '*Ionosphere Models - A New Product of IGS ?*' IGS Position Paper, IGS Analysis Center Workshop, Silver Spring, MD, U.S.A., March 19-21, 1996.

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R3. Schaer, S., W. Gurtner, and J. Feltens (1997): '*IONEX: The IONosphere Map EXchange Format Version 1*.', September 22, 1997, Proceedings of the IGS Analysis Centers Workshop, ESOC, Darmstadt, Germany, February 9-11, 1998.