International Civil Aviation Organization

THE THIRD MEETING OF IONOSPHERIC STUDIES TASK FORCE (ISTF/2)

15 – 17 October 2013, Seoul, Republic of Korea

Agenda Item 2: Review of outcome of relevant meetings/conferences

ITU-R REPORT RELATED TO TRANS-IONOSPHERIC PROPAGATION

(Presented by Japan)

SUMMARY

This paper presents a brief report of a meeting of Working Group 3L-3 (trans-ionospheric propagation) of ITU-R held in Geneva from 19 to 26 June 2013. The delegate of Japan proposed "GTEX" as a format to promote international exchange and sharing of GNSS-TEC data in an input document. The document was discussed in the larger context of the need to incorporate new digital products and SG3DB databanks. As a result, the GTEX was included in a Chairman's report towards the definition of new digital products for transionospheric propagation. Some other interesting topics related to trans-ionospheric propagation are also introduced.

1. INTRODUCTION

1.1 A meeting of Working Party 3L (WP 3L) (ionospheric propagation and noise) of International Telecommunication Union Radiocommunications Sector (ITU-R) was held in Geneva from 19 to 26 June 2013. The total number of attendee and input document to WP3L is 84 and 34, respectively. The work of Working Party 3L was divided into four Working Groups:

WG 3L-1: MF and LF propagation , chaired by A. Canavistas
WG 3L-2: HF propagation, chaired by D. Damboldt
WG 3L-3: Trans-ionospheric propagation, chaired by R. Prieto Cerdeira
WG 3L-4: Radio noise, chaired by T Hasenpusch

Most of topics related to the ISTF including trans-ionospheric propagation were discussed in the Working Group 3L-3.

1.2 The delegate of Japan proposed "GTEX" as a format to promote international exchange and sharing of GNSS-TEC data in an input document (see ANNEX 1). This GTEX document was discussed in the WG 3L-3.

2. DISCUSSION

2.1 Drafting group 3L-3B, chaired by Roberto Prieto-Cerdeira, was created for the consideration of new digital products for trans-ionospheric propagation from the GTEX document and other related documents. The group held one meeting. The GTEX Document, which proposed a data format to promote international exchange and sharing of GNSS-TEC data, was discussed in the larger context of the need to incorporate new digital products and DBSG3 tables (Study Group 3 databanks of radiowave propagation measurement data).

2.2 The definition and explanation of GTEX format was included in a Chairman's report towards the definition of new digital products for transionospheric propagation (see ANNEX 2). The Chairman's report also included "IONEX" and "SCINTEX" format. The definition of digital products was added to the list of future work programme in Working Party 3L.

2.3 The "SCINTEX" format included in the Chiarman's report was first proposed by Orus-Perez et al. at the ION GNSS meeting 2011. This is a just a draft proposal, but different from the "SCINTEX" format proposed in the ICAO/ISTF2 meeting though they have the same name and similar concept. Discussion might be needed for this matter.

2.4 Some documents report the importance of space weather forecasting for trans-ionospheric propagation. A document provided links to a report on the effects of extreme space weather was considered in relation to Space Weather data used for trans-ionospheric prediction models. It was agreed to inform ITU-R SG 4 and SG 6 and ITU-T SG4 of the report for information.

2.5 A draft new ITU-R Report "*Electron density models and data for transionospheric radio propagation*" was agreed. This presents the detailed characteristics of all electron density and total electron content software models on trans-ionospheric propagation and supplementary digital products, namely, NeQuick2 and IRI2012 electron density models, and VTEC maps monthly mean maps in IONEX format.

3. ACTION REQUIRED BY THE MEETING

3.1 The meeting is invited to do the following:

a) note the information provided in this paper; and

b) discuss the strategy on SCINTEX format

— — — — — — — — — — — —

Radiocommunication Study Groups

Received: 10 June 2013

Document 3L/50-E

11 June 2013

English only

Japan

DATA FORMAT TO PROMOTE INTERNATIONAL EXCHANGE AND SHARING OF GNSS-TEC DATA

1 Introduction

The ionosphere is well known to affect trans-ionospheric transmissions with satellites for communications, positioning and navigation purposes. The ionosphere varies greatly under the influence of the activities of the sun, the magnetosphere, and the lower atmosphere, and sometimes interferes with satellite communications and degrades precise satellite positioning. It is known that errors in Global Navigation Satellite System (GNSS) including GPS, are caused by several factors, such as satellite clock error, ephemeris error, or multi-pass effects, but the most significant factor is the propagation delay of GNSS signals in the ionosphere. Recently, in the multi-GNSS era, considerable efforts have been directed toward researches on the ionospheric variations and their effects on the precise GNSS positioning and navigation. Precise ionospheric total electron content (TEC) map or model is required to study ionospheric variations and to improve the ionospheric delay correction for GNSS positioning.

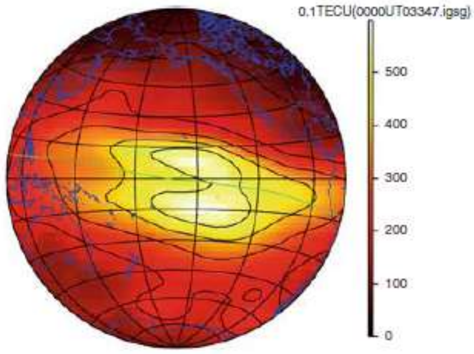
Several 100 km to 1 000 km scale (hereafter referred as “medium-scale”) ionospheric variations caused by equatorial plasma bubble (EPB) and/or travelling ionospheric disturbances (TID) are frequently observed at mid- and low-latitudes. These medium-scale ionospheric variations can degrade single-frequency GNSS positioning and differential GNSS positioning. However, generally used ionospheric TEC maps such as the Klobuchar ionospheric model broadcasted by GPS satellites (e.g., Klobuchar, 1996) and the Global Ionospheric Model (GIM) provided by International GNSS Service (IGS) (e.g., Hernández-Pajares, 2009) do not have enough spatial and temporal resolutions to study these medium-scale ionospheric variations as shown in Figure 1.

FIGURE 1. (A)

Distribution of global GNSS receiver network consisting of about 400 stations provided by IGS.

FIGURE 1. (B)

An example of IGS TEC map with spatial resolution of 5° in longitude, 2.5° in latitude and temporal resolution of 2 hours (Hernández-Pajares, 2009).



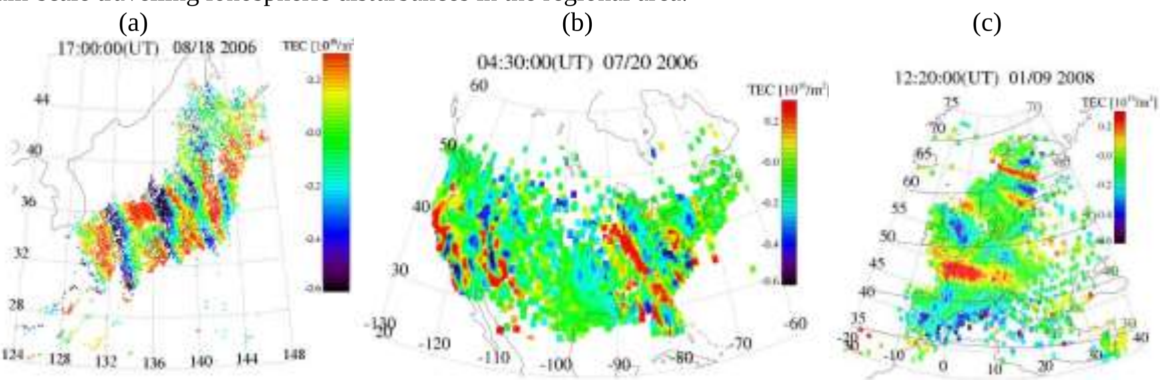
To clarify generation and propagation mechanisms of these ionospheric phenomena and to investigate their effects on GNSS positioning, dense and wide-coverage ionospheric observations and the corresponding TEC mapping techniques are needed.

2 Dense regional GNSS total electron content observations

One of the most effective methods for such dense and wide-coverage ionospheric observations is two-dimensional TEC observations using a dense GNSS receiver network. Figure 2 shows one of such two-dimensional TEC maps over Japan (Tsugawa et al., 2007a), North America (Tsugawa et al., 7b), and Europe (Otsuka et al., 2013) derived from about 1 200, 1 600, and 800 ground-based GNSS receivers.

FIGURE 2

Fig. 2. Dense regional TEC maps (detrended values with 60-min window) over (a) Japan (Tsugawa et al., 2007a), (b) North America (Tsugawa et al., 2007b), and (b) Europe (Otsuka et al., 2013) derived from about 1200, 1600, and 800 GNSS stations, respectively. These TEC maps can reveal spatial and temporal variations of medium-scale travelling ionospheric disturbances in the regional area.

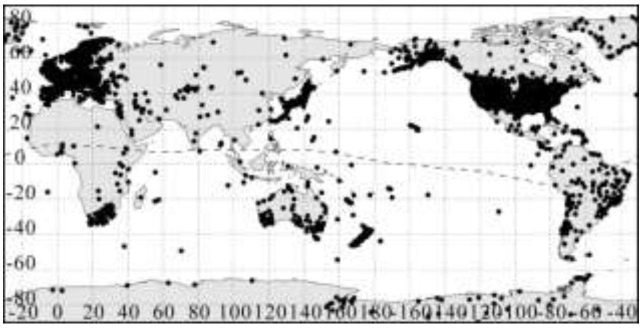


These TEC maps show the detrended values of TEC with 60-min running average and have spatial resolution of 0.15° in longitude, 0.15°in latitude and temporal resolution of 30 seconds. These TEC maps clearly reveal wave-like structures, medium-scale TID (MSTID), whose wavelength is several 100 km (e.g., Tsugawa et al., 2007a). In these regions where the data of dense GNSS receiver networks are available, we can derive high-resolution two-dimensional TEC maps to to monitor the medium-scale ionospheric variations such as EPB and TID. Recently, these TEC maps also revealed clear concentric wave propagations from the epicenter after the great earthquakes such as 2011 Tohoku Earthquake (e.g., Tsugawa et al., 2011).

On the other hand, such dense GNSS receiver networks are available only limited areas such as Japan, North America, and Europe as shown in Figure 3.

FIGURE 3

Distribution of worldwide GNSS stations (more than 6,000 stations as of January 2012) currently available online. The dashed line represents the magnetic equator.



More GNSS receiver data are needed especially in the sparse regions (ex. Asia, Oceania, Africa, and South America) to study the overall spatial structure and temporal evolution of medium-scale ionospheric variations. One of main obstacles of data exchange and sharing of GNSS receiver networks in these regions would attribute to the difficulty for a government and/or a data provider to provide the original GNSS receiver data abroad due to political and/or economic reasons because the raw data of GNSS receiver including multi-frequency carrier phase and psuedorange information are important and valuable to determine precise positioning/navigation and to observe meteorological phenomena. This issue were discussed among the ionosphere and space weather researchers in Asia and Oceania countries (76 researchers from 30 organizations for 10 countries) at the 1st Asia-Oceania Space Weather Alliance (AOSWA) workshop held at Chiang Mai, Thailand during 22-24 February, 2012 (AOSWA, 2013). As a result of the discussion, we can exchange and share the data excluding phase and psuedorange information from raw GNSS observation data and only including necessary data to make dense and wide-coverage TEC maps. It is needed to standardize such GNSS-TEC data to promote the international exchange and sharing of the TEC data and to expand the high-resolution TEC observation area.

3 Proposed format for exchange and sharing of GNSS-TEC data

The Ionosphere Map Exchange (IONEX) is one of well-known standardized format for GNSS-TEC data (e.g., Hernández-Pajares, 2009). Although the IONEX format data cover the global ionosphere, they describe only vertical TEC map data with spatial resolution of 5° in longitude, 2.5°in latitude and temporal resolution of 2 hours. Using the IONEX data, it is difficult to derive higher resolution TEC maps even if there are the dense GNSS receiver networks.

We propose a data format for international exchange and sharing GNSS-TEC data, GNSS-TEC Exchange Format (GTEX), which is available for various ionospheric studies including dense and wide-coverage TEC mapping. The data format can be either in binary or human readable text format. Binary data formats can generally save the file size. However, it is difficult for human to read binary data directly without special software to visualize them. Text data formats are directly human readable, though they generally need more file size than binary formats. Considering that the disk space is getting cheaper and the network bandwidth is getting wider, text data formats would be preferable to international exchange and sharing data. The main concept of the GTEX is to include slant TEC data from each GNSS receiver. By sharing slant TEC data which are not converted to vertical TEC, various ionospheric studies may be possible without affected by specific analysis procedures such as satellite/receiver bias estimation, or different mapping heights. Thus, slant TEC values described in the GTEX can include biases arising from inter-frequency bias of satellites and receivers. The structure of GTEX is designed in such a way that the structure is as close to the format of GNSS observation data, RINEX (version 2) (Gurtner 2013), as possible, because RINEX (Receiver Independent Exchange Format) is a *de facto* standard in exchanging GNSS observation data and potential users of GTEX would be familiar with RINEX. GTEX also include additional information useful to TEC analysis, such as GNSS satellite zenith/azimuth angles, and information of RINEX observable combination (ex. L1L2C1P2) to derive slant TEC values. GTEX may include more data relevant to TEC analysis in the later revisions. The format is designed to allow future extension.

The GTEX data file consists two parts, the header and the TEC data blocks. The header block structure is similar to that of RINEX. All the header items defined in RINEX can be used in GTEX as well. The main data type descriptor, “R1” for slant TEC including bias (“raw TEC”) or “A1” for absolute slant TEC is necessary for GTEX. The other data type descriptors “1F” for TEC status flag, “1O” for RINEX observable combination, “ZN” for satellite zenith angle, and “AZ” for satellite azimuth angle are included in GTEX. There are additional header items to describe the unit of TEC, approximated GNSS receiver position (latitude, longitude, and altitude), bias estimation program name, etc. The TEC data block starts from a line(s) with a time stamp and list of satellites with the same format as “EPOCH/SAT” field of RINEX. Following the EPOCH/SAT field, TEC and additional information data as defined in “# / TYPES OF DATA” in the header part are recorded. After the record of TEC data for all the satellites, data set of the next epoch follows.

An example of TEC data in GETX is shown in Table 1. The data was based on the actual TEC data obtained from 00:00:00 GPS Time on 11 May 2012 at “0132” station, one of the GEONET, a Japanese nationwide GNSS reference network operated by the Geospatial Authority of Japan. The sampling rate is 30 sec. The file name format is similar to the RINEX and defined as follows: ssssdddh.yy_TEC; where “ssss” is the four-character station name defined in “MARKER NAME”, “ddd” is the day of year, and “yy” is two-digit year. “h” is file sequence number and “0” means daily data. In this case, we used the daily data and the file name is 01321320.12_TEC. First 29 lines (to the line of “END OF HEADER”) describe the header part. Five data, raw slant TEC, TEC status flags, RINEX observable combination, satellite zenith angle, and satellite azimuth angle are recorded in the data blocks. The TEC data block starts from the 30th line. The first epoch is 00:00:00 GPS Time on 11 May 2012. 9 GPS satellites (PRN 21, 9, 18, 15, 28, 5, 27, 8, and 26) were tracked. Following this epoch line, 9 lines describe the five data. Some negative values of slant TEC data are caused by satellite and receiver biases. All the TEC flags are 0, meaning that all the slant TEC data are normal. Meaning of TEC status flag is described in the header part. Because the GTEX format has a similar look as the RINEX, which is commonly used in GNSS related works to record GNSS data, it would be friendly to those who have been involved in GNSS related studies as well as those because the data are human readable and meanings of data fields are clearly defined.

4 Concluding remarks

Several 100 km to 1 000 km scale (medium-scale) ionospheric variations caused by equatorial plasma bubble (EPB) and/or travelling ionospheric disturbances (TID) can degrade single-frequency GNSS positioning and differential GNSS positioning. However, these medium-scale ionospheric variations have not been studied enough due to the lack of dense wide-coverage ionospheric observations. It is

needed to expand their observation area using all the available GNSS receiver networks with international collaboration of ionosphere and space weather researchers in the world. We propose a data format, GTEX, to promote international exchange and sharing
GNSS-TEC data. Because the GTEX has a similar look as the RINEX, which is commonly used in GNSS related works to record GNSS data, it would be friendly to those who have been involved in GNSS ionospheric studies because the data are human readable and meanings of data fields are clearly defined. The original TEC data format for GTEX has been developed by National Institute of Information and Communications Technology (NICT), Electronic Navigation Research Institute (ENRI), Kyoto University, and Nagoya University in Japan for high-resolution GNSS-TEC observations. Since the 1st AOSWA workshop, NICT has collaborated with several organizations researching ionosphere and space weather in Korea, Thailand, Indonesia, Malaysia, and China to share the GTEX data of each country and to develop dense wide-coverage TEC maps in the Asia-Oceania region. The GTEX have been adopted as the basis of ionospheric data sharing by Ionospheric Studies Task Force (ISTF) established in the Asia-Pacific Region of International Civil Aviation Organization (ICAO), which is working on ionospheric characterization for facilitation of GNSS implementation for aviation (ICAO/ISTF, 2012). NICT has developed the applications to convert RINEX data to GTEX data and to make high-resolution TEC maps in the arbitrary region using the GTEX data. Such applications would be necessary to promote exchange and sharing of GTEX data in the countries where sharing of raw GNSS measurement data are not permitted.

References

Asia-Oceania Space Weather Alliance (AOSWA) (2013), http://aoswa.nict.go.jp/

Gurtner, W. (2007), RINEX: The Receiver Independent Exchange Format Version 2.10 and 2.11 available from IGS (International GNSS service), http://igscb.jpl.nasa.gov/

Hernández-Pajares, M., J. M. Juan, J. Sanz, R. Orus, A. Garcia-Rigo,J. Feltens, A. Komjathy, S. C. Schaer, A. Krankowski (2009), The IGS VTEC maps: a reliable source of ionospheric information since 1998, J. Geod., 83:263–275, DOI 10.1007/s00190-008-0266-1.

ICAO/ISTF (2012), Report of the second meeting of ionospheric studies task force (ISTF/2), International Civil Aviation Organization Asia and Pacific Office, Bangkok, Thailand, October 2012, http://www.bangkok.icao.int/cns/meeting.do?method=MeetingDetail&meeting_id=206

Klobuchar, J.A. (1996). Ionospheric effects on GPS. In Parkinson& Spilker, Jr. (Eds.), Global positioning systems: Theory and applications. Progress in Astronautics and Aeronautics, Volume 163, American Institute of Aeronautics and Astronautics, Inc.

Otsuka, Y., K. Suzuki, S. Nakagawa, M. Nishioka, K. Shiokawa, and T. Tsugawa (2013), GPS Observations of Medium-Scale Traveling Ionospheric Disturbances over Europe, Annales Geophysicae, 31, 163-172, doi:10.5194/angeo-31-163-2013.

Tsugawa, T., N. Kotake, Y. Otsuka, and A. Saito (2007a), Medium-scale traveling ionospheric disturbances observed by GPS receiver network in Japan: a short review, GPS Solut, 11, 39-144, DOI 10.1007/s10291-006-0045-5.

Tsugawa, T., Y. Otsuka, A. J. Coster, and A. Saito (2007b), Medium-scale traveling ionospheric disturbances detected with dense and wide TEC maps over North America, Geophys. Res. Lett., 34, L22101, doi:10.1029/2007GL031663.

Tsugawa, T., A. Saito, Y. Otsuka, M. Nishioka, T. Maruyama, H. Kato, T. Nagatsuma, and K. T. Murata (2011), Ionospheric disturbances detected by GPS total electron content observation after the 2011 off the Pacific coast of Tohoku Earthquake, Earth, Planets, and Space, 63, 875-879.

TABLE 1

Example of GTEX (version 1.0) derived from daily data of “0132” GNSS station of GEONET.

```
----|---1|0---|---2|0---|---3|0---|---4|0---|---5|0---|---6|0---|---7|0---|---8|
     1.0             GTEX DATA            GNSS                GTEX VERSION / TYPE
RNX2GTEX V1.0       NICT, JAPAN                               PGM / RUN BY
     0                                                        EXPONENT OF TECU
     TEC values in 10^16 el/m^2 (1 TEC Unit)                  COMMENT
     TEC Status Flag = 0 : Normal data                        COMMENT
                     = 1 : Lack of observables (TEC=999.)     COMMENT
                     = 2 : Too large TEC (TEC=999.)           COMMENT
                     = 4 : Cycle slip (TEC discontinuity)     COMMENT
                     = 5 : Cycle slip (LLI)                   COMMENT
                     = 6 : Beginning of arc                   COMMENT
     TYPES OF DATA   = R1 : Raw slant TEC including bias      COMMENT
                       A1 : Absolute slant TEC                COMMENT
                            R1 or A1 is necessary             COMMENT
                       1F : TEC status flag                   COMMENT
                       1O : Observation data used for TEC     COMMENT
                       ZN : Satellite zenith angle            COMMENT
                       AZ : Satellite azimuth angle           COMMENT
                                                              BIAS ESTIMATION PGM
01321310.12o  01321320.12o  01321330.12o                      RINEX FILE NAME
0132                                                          MARKER NAME
00000               TPS NETG3           3.4 EG3 Jul,02,2010 REC # / TYPE / VERS
                    TRM29659.00     GSI                       ANT # / TYPE
 -3690821.3891  2897721.3097  4305504.4426                    APPROX POSITION XYZ
      42.7294      141.8640        0.0486                     POSITION LAT LON ALT
     6    L1    C1    L2    P2    S1    S2                    # / TYPES OF OBSERV
     5    R1    1F    1O    ZN    AZ                          # / TYPES OF DATA
    30.000                                                    INTERVAL
  2012    5     11     0     0    0.0000000     GPS           TIME OF FIRST OBS
                                                              END OF HEADER
 12  5 11  0  0  0.0000000  0  9G21G 9G18G15G28G 5G27G 8G26
 -61.7242  0  L1L2C1P2  32.45  194.42
 -33.4733  0  L1L2C1P2   9.32   14.04
 -49.7988  0  L1L2C1P2  20.39    9.03
 -55.8391  0  L1L2C1P2  83.27   39.34
 -43.6837  0  L1L2C1P2  32.21   44.21
 -38.7060  0  L1L2C1P2   8.31    3.34
 -44.8228  0  L1L2C1P2  74.42  265.99
 -31.3004  0  L1L2C1P2  23.01  343.20
 -48.7904  0  L1L2C1P2  50.12  115.79
 12  5 11  0  0 30.0000000  0  9G21G 9G18G15G28G 5G27G 8G26
```

Radiocommunication Study Groups

Source: Document 3L/TEMP/34

Annex 2 to
Document 3L/63-E

1 July 2013

English only

Annex 2 to Working Party 3L Chairman's Report

WORKING DOCUMENT TOWARDS THE DEFINITION OF NEW DIGITAL PRODUCTS FOR TRANSIONOSPHERIC PROPAGATION

During the last WP 3L meetings, a number of contributions related to digital products for transionospheric propagation have been submitted by a number of administrations evidencing the lack of a number of digital products, in particular reference datasets and Study Group 3 data formats for model verification and prediction of propagation characteristics. Other digital products exist for the prediction methods in tropospheric propagation, multipath and radio noise (Rec. ITU-R P.311 and Study group 3 databanks and DGSG3). It is considered that statistical experimental data and related tables would be beneficial for Study Group 3 in the area of (trans)-ionospheric propagation.

It is important to remark that the aim of Study Group 3 is not to archive raw data from individual experiments, but instead relevant statistical parameters and reference datasets for prediction and evaluation of propagation models.

In this document, the work plan for the establishment of relevant digital products on transionospheric propagation is described. The following workplan is defined:

1) The definition of new Study Group 3 table formats incorporating statistics relevant analysis, at least for the following types of experimental data and products:
   a) Global and regional Vertical Total Electron Content (VTEC) grid maps.
   b) Ground-based location specific Vertical or Slant Total Electron Content (STEC) from GNSS experiments or inverted from ionosondes.
   c) Space-based TEC for specific tracks/passes (from altimeters or radio-occultation experiments).
   d) TEC variability for the type of experiments (as Rate-of-TEC along arc, temporal gradient, etc…).
   e) Ionospheric scintillation fading and phase variation statistics.
2) The draft revision of Recommendation ITU-R P.311 in order to reflect the new table formats.

3) The publication of WP 3L Fascicle including the requirements for experimental data relevant for analysis and generation of new tables, description of statistical analysis procedures to fill the tables, testing variables for testing quality of data and models.

4) The inclusion of Tables in DBSG3 database and the population of such tables with reference relevant data.

A first draft of the Fascicle is described in Appendix 1.

APPENDIX 1

Draft new fascicle on "Definition, experimental requirements, analysis and testing variables for SG 3 tables on transionospheric propagation"

Scope

This fascicle provides the definition of parameters of in SG 3 tables for transionospheric propagation, the experimental requirements and recommended exchange formats, the description of procedures of statistical analysis for populating SG3 tables and the testing variables to be used.

[Remark: This document is prepared as a draft document.]

1 Definition of parameters and association with tables

Global and regional Vertical Total Electron Content (VTEC) and VTEC rate grid maps

– Monthly median for different solar activity periods including its variability.

– Seasonal, annual and solar cycle statistics. Inter-solar cycle variability.

Location-specific Vertical, Slant or Horizontal TEC and TEC rates

– Total statistics and as a function of time of day, elevation and azimuth/solar zenith angle for ground-based and space-based experiments.

Electron-density profile

– Statistical description of profile characteristics for the testing of electron density and mapping function models.

Ionospheric scintillation fading and phase variation statistics

– Statistics as a function of frequency, location, solar activity, season and time-of-day.

2 Experimental requirements for extraction of parameters for tables and recommended exchange formats

Global and regional Vertical Total Electron Content (VTEC) and VTEC rate grid maps

For this type of data, the following complementary information needs to be provided:

1) Measure of the quality per grid point needs to be provided.

2) Description of reference data and method used for generation of map.

3) Range of heights for the map (bottomside, topside, all).

4) Temporal and spatial resolution.

5) For VTEC rate calculation, a sampling rate below 60 seconds is expected.

6) Related solar and geomagnetic activity for the period of experiments.

7) For exchange of VTEC data, the IONEX format is proposed (see Annex 1).

Location-specific Vertical, Slant or Horizontal TEC and TEC rates

For this type of data, the following complementary information needs to be provided:

1) Absolute or relative calibration, expected calibration errors and calibration method.

2) Range of heights covered by the data (bottomside, topside, all).

3) Temporal and spatial resolution.

4) For VTEC rate calculation, a sampling rate below 60 seconds is expected.

5) Related solar and geomagnetic activity for the period of experiments.

6) For exchange of STEC data, the GTEX format is proposed (see Annex 1).

Electron-density profile

For this type of data, the following complementary information needs to be provided:

1) Absolute or relative calibration or measure of quality. Details of estimation or inversion method.

2) Range of heights for the map (bottomside, topside, all).

3) Temporal and height resolution.

4) Related solar and geomagnetic activity for the period of experiments.

Ionospheric scintillation fading and phase variation statistics

– Accuracy of estimation (phase and amplitude).

– Method for index estimation (including detrending).

– Geometrical description. Sampling rate.

– Temporal resolution.

– Related solar and geomagnetic activity for the period of experiments.

– For exchange of ionospheric scintillation indices, the SCINTEX format is proposed (see Annex 1).

3 Procedures for statistical analysis

(*This section will be completed once the table formats are defined.)*

4 Testing variables

(*This section will be completed once the table formats are defined.)*

ANNEX 1

Formats for exchange of experimental data and products.

1 IONEX

A *de facto* standard widely used by various scientific communities is proposed for the format of the provided VTEC maps. Such format is the IONEX (IONosphere map EXchange) format, see details in: http://igscb.jpl.nasa.gov/igscb/data/format/ionex1.pdf.

IONEX map file example:

```
     1.0            IONOSPHERE MAPS     MIX                 IONEX VERSION / TYPE
ionex_mean v0        ESA/ESTEC          12-Jun-12 15:46     PGM / RUN BY / DATE
ionex file containing IGS 30-DAY average maps               COMMENT
global ionosphere maps for day 079,     0                   DESCRIPTION
IONEX file containing the 30-DAY average IGS MAP and st.dev DESCRIPTION
  2002     3    20     1     0     0                        EPOCH OF FIRST MAP
  2002     3    20    23     0     0                        EPOCH OF LAST MAP
  7200                                                      INTERVAL
     0                                                      # OF MAPS IN FILE
  COSZ                                                      MAPPING FUNCTION
     0.0                                                    ELEVATION CUTOFF
   000                                                      # OF STATIONS
    00                                                      # OF SATELLITES
  6371.0                                                    BASE RADIUS
     2                                                      MAP DIMENSION
   450.0 450.0   0.0                                        HGT1 / HGT2 / DHGT
    87.5 -87.5  -2.5                                        LAT1 / LAT2 / DLAT
  -180.0 180.0   5.0                                        LON1 / LON2 / DLON
    -1                                                      EXPONENT
                                                            END OF HEADER
     1                                                      START OF TEC MAP
  2002     3    20     1     0     0                        EPOCH OF CURRENT MAP
   -87.5-180.0 180.0   5.0 450.0                            LAT/LON1/LON2/DLON/H
  322  320  318  315  314  313  313  313  318  317  316  317  318  319  319  318
  317  317  317  314  311  309  307  306  307  307  307  306  305  302  297  290
  289  293  297  296  296  297  299  300  301  302  304  307  308  309  311  313
  316  317  319  320  322  324  327  329  330  331  332  333  333  334  335  336
  336  336  336  334  332  328  326  326  322
   -85.0-180.0 180.0   5.0 450.0                            LAT/LON1/LON2/DLON/H
  335  330  328  325  322  318  317  316  322  319  318  318  319  319  320  318
  315  311  307  302  297  291  289  286  285  283  280  277  275  274  273  274
  272  273  274  275  276  277  279  283  287  291  296  300  302  305  308  312
  315  318  321  324  327  331  335  338  341  344  346  348  350  351  352  352
  352  352  351  349  347  343  340  336  335
   -82.5-180.0 180.0   5.0 450.0                            LAT/LON1/LON2/DLON/H
  347  345  343  337  334  331  328  325  324  324  322  321  321  321  322  316
  303  295  291  285  281  279  276  271  266  262  257  255  253  253  252  253
  253  253  252  253  256  259  262  265  269  275  281  288  294  298  303  308
  313  317  322  327  332  337  342  347  351  355  358  361  363  366  367  368
  368  368  367  365  362  359  356  351  347
   -80.0-180.0 180.0   5.0 450.0                            LAT/LON1/LON2/DLON/H
  363  358  354  353  346  344  341  337  335  332  332  332  329  323  320  308
  293  278  271  271  269  262  254  249  244  238  237  234  232  233  233  231
  231  232  233  234  237  241  245  248  253  259  267  272  281  288  295  301
  307  313  320  326  333  340  347  353  359  364  368  372  376  379  381  383
  383  383  382  380  379  376  371  367  363
```

2 GTEX

GNSS-TEC data, GNSS-TEC Exchange Format (GTEX) is a data format proposed for international exchange and sharing, which is available for various ionospheric studies including dense and wide-coverage TEC mapping. The main concept of the GTEX is to include slant TEC data from each receiver. By sharing slant TEC data which are not converted to vertical TEC, various ionospheric studies may be possible without affected by specific analysis procedures such as satellite/receiver bias estimation, or different mapping heights. Thus, slant TEC values described in the GTEX can include biases arising from inter-frequency bias of satellites and receivers. The structure of GTEX is designed in such a way that the structure is as close to the format of GNSS observation data, RINEX (version 2) (Gurtner 2013), as possible, because RINEX (Receiver Independent Exchange Format) is a *de facto* standard in exchanging GNSS observation data and potential users of GTEX would be familiar with RINEX. GTEX also include additional information useful to TEC analysis, such as GNSS satellite zenith/azimuth angles, and information of RINEX observable combination (ex. L1L2C1P2) to derive slant TEC values. GTEX may include more data relevant to TEC analysis in the later revisions. The format is designed to allow future extension.

The GTEX data file consists two parts, the header and the TEC data blocks. The header block structure is similar to that of RINEX. All the header items defined in RINEX can be used in GTEX as well. The main data type descriptor, "R1" for slant TEC including bias ("raw TEC") or "A1" for absolute slant TEC is necessary for GTEX. The other data type descriptors "1F" for TEC status flag, "1O" for RINEX observable combination, "ZN" for satellite zenith angle, and "AZ" for satellite azimuth angle are included in GTEX. There are additional header items to describe the unit of TEC, approximated GNSS receiver position (latitude, longitude, and altitude), bias estimation program name, etc. The TEC data block starts from a line(s) with a time stamp and list of satellites with the same format as "EPOCH/SAT" field of RINEX. Following the EPOCH/SAT field, TEC and additional information data as defined in "# / TYPES OF DATA" in the header part are recorded. After the record of TEC data for all the satellites, data set of the next epoch follows.

An example of TEC data in GETX is shown below. The sampling rate is 30 sec. The file name format is similar to the RINEX and defined as follows: ssssdddh.yy_TEC; where "ssss" is the four-character station name defined in "MARKER NAME", "ddd" is the day of year, and "yy" is two-digit year. "h" is file sequence number and "0" means daily data. In this case, we used the daily data and the file name is 01321320.12_TEC. First 29 lines (to the line of "END OF HEADER") describe the header part. Five data, raw slant TEC, TEC status flags, RINEX observable combination, satellite zenith angle, and satellite azimuth angle are recorded in the data blocks. The TEC data block starts from the 30th line. The first epoch is 00:00:00 GPS Time on 11 May 2012. 9 GPS satellites (PRN 21, 9, 18, 15, 28, 5, 27, 8, and 26) were tracked. Following this epoch line, 9 lines describe the five data. Some negative values of slant TEC data are caused by satellite and receiver biases. All the TEC flags are 0, meaning that all the slant TEC data are normal. Meaning of TEC status flag is described in the header part. Because the GTEX format has a similar look as the RINEX, which is commonly used in GNSS related works to record GNSS data, it would be friendly to those who have been involved in GNSS related studies as well as those because the data are human readable and meanings of data fields are clearly defined.

GTEX file example:

```
----|---1|0---|---2|0---|---3|0---|---4|0---|---5|0---|---6|0---|---7|0---|---8|
     1.0            GTEX DATA            GNSS                GTEX VERSION / TYPE
RNX2GTEX V1.0       NICT, JAPAN                              PGM / RUN BY
     0                                                       EXPONENT OF TECU
     TEC values in 10^16 el/m^2 (1 TEC Unit)                 COMMENT
     TEC Status Flag = 0 : Normal data                       COMMENT
                     = 1 : Lack of observables (TEC=999.)    COMMENT
                     = 2 : Too large TEC (TEC=999.)          COMMENT
                     = 4 : Cycle slip (TEC discontinuity)    COMMENT
                     = 5 : Cycle slip (LLI)                  COMMENT
                     = 6 : Beginning of arc                  COMMENT
     TYPES OF DATA   = R1 : Raw slant TEC including bias     COMMENT
                       A1 : Absolute slant TEC               COMMENT
                            R1 or A1 is necessary            COMMENT
                       1F : TEC status flag                  COMMENT
                       1O : Observation data used for TEC    COMMENT
                       ZN : Satellite zenith angle           COMMENT
                       AZ : Satellite azimuth angle          COMMENT
                                                             BIAS ESTIMATION PGM
01321310.12o  01321320.12o  01321330.12o                     RINEX FILE NAME
0132                                                         MARKER NAME
00000               TPS NETG3          3.4 EG3 Jul,02,2010 REC # / TYPE / VERS
                    TRM29659.00     GSI                      ANT # / TYPE
 -3690821.3891  2897721.3097  4305504.4426                   APPROX POSITION XYZ
       42.7294      141.8640        0.0486                   POSITION LAT LON ALT
     6    L1    C1    L2    P2    S1    S2                   # / TYPES OF OBSERV
     5    R1    1F    1O    ZN    AZ                         # / TYPES OF DATA
    30.000                                                   INTERVAL
  2012     5     11      0      0    0.0000000     GPS       TIME OF FIRST OBS
                                                             END OF HEADER
 12   5 11   0   0  0.0000000  0   9G21G 9G18G15G28G 5G27G 8G26
 -61.7242  0  L1L2C1P2  32.45  194.42
 -33.4733  0  L1L2C1P2   9.32   14.04
 -49.7988  0  L1L2C1P2  20.39    9.03
 -55.8391  0  L1L2C1P2  83.27   39.34
 -43.6837  0  L1L2C1P2  32.21   44.21
 -38.7060  0  L1L2C1P2   8.31    3.34
 -44.8228  0  L1L2C1P2  74.42  265.99
 -31.3004  0  L1L2C1P2  23.01  343.20
 -48.7904  0  L1L2C1P2  50.12  115.79
 12   5 11   0   0 30.0000000  0   9G21G 9G18G15G28G 5G27G 8G26
```

3 SCINTEX

A receiver independent ionospheric scintillation format named as SCINTEX is proposed. It is based on RINEX v3 (ftp.igs.org/igscb/data/format/rinex300.pdf) . It contains the following observables:

- S_4 and σ_φ for all available frequencies.
- Carrier-to-Noise-Density Ratio C/No.
- (Optional) Real-time TEC and Differential TEC estimation.
- Code Carrier Divergence.

- Elevation and Azimuth of the satellite.
- Lock signal time.

An example of a SCINTEX file is presented below:

scintex_example.11s (~\My Documents\ESA\Congres-meetings\Galileo Colloquium 2011) - GVIM

File Edit Tools Syntax Buffers Window Help

```
     3.0           SCINTILLATION DATA  MIX                 SCINT VERSION / TYPE
scintex_sept_v0    ESA                 28-aug-11 15:39     PGM / RUN BY / DATE
scintex file containing scintillation information          COMMENT
ESTE                                                        MARKER NAME
Unknown                                                     MARKER NUMBER
Unknown            Unknown                                  OBSERVER / AGENCY
9999999            Septentrio PolaRxS  0.0.0                REC # / TYPE / VERS
Unknown            Unknown                                  ANT # / TYPE
  5760940.0104 -1556238.7358  2276652.7023                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
E    18 SS41 S4C1 SPH1 CN01 LKT1 CCD1 SCD1 SS47 S4C7 SPH7   SYS / # / OBS TYPES
CN07 LKT7 CCD7 SCD7 TECI DTEC ELEV AZIM                     SYS / # / OBS TYPES
G    18 SS41 S4C1 SPH1 CN01 LKT1 CCD1 SCD1 SS42 S4C2 SPH2   SYS / # / OBS TYPES
CN02 LKT2 CCD2 SCD2 TECI DTEC ELEV AZIM                     SYS / # / OBS TYPES
S    11 SS41 S4C1 SPH1 CN01 LKT1 CCD1 SCD1 TECI DTEC ELEV   SYS / # / OBS TYPES
AZIM                                                        SYS / # / OBS TYPES
    60.000                                                  INTERVAL
  2011     8    28    21    11    0.0000000     GPS         TIME OF FIRST OBS
  2011     8    28    21    59   59.0000000     GPS         TIME OF LAST OBS
    21                                                      # OF SATELLITES
                                                            END OF HEADER
> 2011 08 28 21 11  0.0000000  0 21
E10 0.04  0.04   0.00 49.10  187.00   -0.10    0.10   0.03 0.03  0.00  51.30  187.00   0.
E19 0.04  0.04   0.00 48.60  311.00  -88.39   87.65   0.03 0.03  0.00  50.80  311.00 -90.:
E12 0.04  0.04   0.00 49.20  185.00 -123.46  143.93   0.03 0.03  0.00  51.40  185.00   0.
E11 0.04  0.03   0.00 49.70  257.00    0.09    0.10   0.03 0.03  0.00  51.90  257.00   0.
E06 0.04  0.04   0.00 48.70  196.00  -11.36   22.57   0.03 0.03  0.00  50.90  196.00   0.
E07 0.86  0.04   0.00 47.60  194.00  -13.79   56.72   0.86 0.03  0.00  49.80  194.00   0.
E25 0.04  0.04   0.00 48.60  228.00    0.21    0.20   0.03 0.03  0.00  50.80  228.00   0.
E26 0.31  0.03   0.00 49.30  226.00  -61.96  115.60   0.31 0.03  0.00  51.50  225.00   0.
E27 0.74  0.04   0.00 48.40  224.00    0.25    0.18   0.74 0.03  0.00  50.60  223.00   0.
E08 0.53  0.04   0.00 48.20  266.00  -62.16  115.70   0.53 0.03  0.00  50.40  266.00   0.
G26 0.28  0.04   0.00 48.00  333.00    0.01    0.06   0.00 0.00  0.00   0.00    0.00   0.
G07 0.04  0.05   0.00 46.50  381.00    0.01    0.06   0.00 0.00  0.00   0.00    0.00   0.
G08 0.51  0.04   0.00 47.20  380.00    0.01    0.08   0.00 0.00  0.00   0.00    0.00   0.
G10 0.72  0.05   0.00 46.50  380.00    0.02    0.08   0.00 0.00  0.00   0.00    0.00   0.
G27 0.11  0.04   0.00 46.90  332.00    0.20    0.06   0.00 0.00  0.00   0.00    0.00   0.
G28 0.05  0.04   0.00 47.60  332.00    0.20    0.05   0.00 0.00  0.00   0.00    0.00   0.
G21 0.04  0.05   0.00 46.80  302.00    0.21    0.06   0.00 0.00  0.00   0.00    0.00   0.
G15 0.84  0.05   0.00 45.80    0.00   -0.17    0.17   0.00 0.00  0.00   0.00    0.00   0.
G24 0.04  0.04   0.00 46.90  299.00    0.19    0.06   0.00 0.00  0.00   0.00    0.00   0.
S20 0.14  0.04   0.00 48.30 3407.00    3.57    0.59   0.00   +0.00+41.00+121.00
S24 0.14  0.05   0.00 46.20 3379.00    0.01    0.75   0.00   +0.00+39.00+124.00
> 2011 08 28 21 12  0.0000000  0 21
E10 0.04  0.03   0.00 49.40  247.00   -0.09    0.09   0.03 0.03  0.00  51.10  247.00   0.
E19 0.04  0.04   0.00 48.90  371.00 -148.47  141.90   0.03 0.03  0.00  50.60  371.00   0.
```