INTERNATIONAL CIVIL AVIATION ORGANIZATION
ASIA AND PACIFIC OFFICE

REPORT OF

THE THIRD MEETING OF IONOSPHERIC STUDIES TASK FORCE (ISTF/3)

Seoul, Republic of Korea

(15 – 17 October 2013)

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PART I – HISTORY OF THE MEETING

1. Introduction

1.1 The Third Meeting of Ionospheric Studies Task Force (ISTF/3) was held at the Hotel Westin Chosun Seoul, Republic of Korea from 15 to 17 October 2013. The meeting was hosted by the Ministry of Land, Infrastructure and Transport (MOLIT).

2. Attendance

2.1 The Meeting was attended by 18 participants from 8 States/Administrations. A list of participants is provided at **Attachment 1.**

3. Opening of the Meeting

3.1 Inaugurating the meeting, on behalf of the host, Prof. Jiyun Lee from Department of Aerospace Engineering, Korea Advanced Institute of Science and Technology (KAIST), welcomed participants to Seoul and briefly recalled history of the Task Force. She also emphasized the importance of the work of ionospheric programme for GNSS implementation. On behalf of ICAO Regional Director, Mr. Li Peng, Regional Officer, CNS of the ICAO Asia and Pacific Office extended welcome to the participants and expressed appreciation to the MOLIT for their continuous support to ICAO activities and hosting regional meetings. Dr. Susumu Saito, Chairman of the Task Force appreciated the Republic of Korea for hosting the meeting at the beautiful season and highlighted the objective of the meeting.

4 Officers and Secretariat

4.1 The meeting was co-chaired by Dr. Susumu Saito, Chairman of the Task Force and Prof. Jiyun Lee who was elected as co-chair for this meeting in view of her profound knowledge and experience in the area of Ionopheric studies and development of ionospheric threat model. Mr. Li Peng, Regional Officer, ICAO APAC Office was the Secretary.

5. Working Arrangements, Language and Documentation

5.1 The ISTF met as a single body. The working language for the meeting was English inclusive of all documentation and this Report. Lists of Working/ Information Papers and Presentations are provided at **Attachment 2.**

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Agenda Item 1 – Adoption of agenda

1.1 The agenda adopted by the meeting was as follows:

Agenda Item 1: Adoption of agenda

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

a) ICAO 12th Air Navigation Conference
b) ICAO NSP
c) CNS SG/17 & APANPIRG/24
d) IGWG-14

Agenda item 3: Review of status of States' activities

Agenda item 4: Review TOR of the Task Force including the needs for space weather studies

Agenda item 5: Review of progress of tasks and related action items

a) Task 1 - Data Collection
b) Task 2 - Iono Analysis
c) Task 3 - TEC Generation
d) Task 4 - Scintillation Data
e) Task 5 - Iono Models

Agenda item 6: Any other business

Agenda item 7: Future plan, review of action items

Agenda Item 2: Review of relevant meetings/conferences

ICAO 12th Air Navigation Conference (IP/2)

2.1 The meeting reviewed the outcome of ICAO AN Conf/12 held in November 2012 on the ionospheric and space weather related issues in support of international air navigation. The meeting noted the Recommendations 6/7 and 6/9 regarding Ionosphere and space weather information for future navigation satellite system implementation and considered that the current work programme of the Task Force is in line with the Recommendations.

Relevant Outcome of CNS SG/17 and APANPIRG/24 (WP/3)

2.2 The Secretariat presented a brief report on the outcome of CNS SG/17 and APANPIRG/24 meetings relevant to ionospheric data collection, analysis and sharing of tasks. The meeting noted that the report of ISTF/2 had been reviewed and appreciated by the CNS SG and APANPIRG. APANPIRG/24 meeting noted that global harmonization of space weather information was required to facilitate a uniform interpretation of the effects and development of procedures that would support seamless operations and mitigate cost to the airlines. CNS SG Decision 17/13 regarding the amendment of the ISTF terms of reference aiming at including space weather studies was further discussed under agenda item 4. The meeting realized that the work of the ISTF required to be further progressed in accordance with the direction given by both APANPIRG and CNS SG.

Navigation Systems Panel (NSP) Working Group of the Whole (WGW/13) (IP/3)

2.3 The Secretariat presented the outcome of NSP WGW/13 Meeting held in Montreal in March 2013. The meeting noted the new concept of job cards being introduced for amendments to the technical work proramme of ANC panels including NSP. The purpose and format of “job cards” was introduced. The WGW/13 recommended the development of a number of job cards reflecting required amendments to the NSP work program. The job card process was initiated in May 2012. The six job cards related to NSP address the following work areas:

a) GNSS radio frequency interference;
b) GNSS evolution and multi-constellation;
c) Mitigation of space weather effects;
d) Alternative position navigation and timing (APNT);
e) Navigation aid rationalization; and
f) Maintenance of the Navigation Roadmap

2.3.1 The meeting noted that the job-card NSP007 with title “Mitigation of Space Weather Effects” as follow-up task to AN Conf/12 Recommendations 6/7 and 6/9 submitted by NSP was approved by ANC on 13 June 2013. The next review date for this Task is expected to be in November 2013 for a debriefing of the NSP WGW/14.

2.3.2 The meeting was of the view that the current work programme of the Task Force is a regional complementary input that may contribute to the global efforts by the NSP. Chairman of the ISTF agreed to present the outcome of this meeting to the next NSP WGW meeting in order to promote inter-regional coordination as one of the model cases.

14th Meeting of International GBAS Working Group (IP/5)

2.4 Japan presented the outcome of the 14th meeting of International GBAS Working Group (IGWG) held in Everett, USA in June 2013. A brief report on recent activities of IGWG Iono-subgroup was also highlighted. The complete report and materials discussed in the IGWG-14 meeting can be found in the EUROCONTROL’s OneSky Team website (https://ost.eurocontrol.int) where the EUROCONTROL UserID is required. The International GBAS Working Group (IGWG) is an international meeting organized by FAA and EUROCONTROL to exchange information on national and international GBAS implementation plan, to seek opportunities of collaboration, and to discuss on technical and operational aspects of GBAS. The meeting noted that one of the ten presentations to the working session 3 of the meeting regarding the ionospheric aspects and monitoring for GBAS from Honeywell on Iono Analysis at Rio was very useful for the study programme of the ISTF. In this connection, the meeting considered that information on current monitoring activities and status in the APAC States would be of interest to the ISTF. The member States of the Task Force were encouraged to participate in IGWG activities.

2.4.1 The meeting was also informed about the latest version of the LTIAM (Long Term Ionosphere Anomaly Monitor), version 2.1 which was ready for distribution to IGWG members by the FAA. FAA WJHTC (William J. Hughes Technical Center) continued their effort to identify and catalog anomalous gradients.

ITU-R Report related to trans-ionospheric propagation (IP/6)

2.5 Japan provided a brief report on a meeting of Working Group 3L-3 (transionospheric propagation) of ITU-R held in Geneva from 19 to 26 June 2013. An input document related with GTEX (GNSS-TEC Exchange) format was provided by Japan and discussed in the WG3L-3. The GTEX was included in a Chairman's report towards the definition of new digital products for transionospheric propagation. The Chairman's report included another "SCINTEX" format which was based on the similar concept and first proposed at the ION GNSS meeting in 2011. The strategy on ISTF's SCINTEX format was discussed. As a result, Japan was requested to coordinate with the ITU-R on SCINTEX format and following Action Item was developed:

> **Action Item ISTF 3/1:** Japan co-ordinate with Chair of ITU-R Working Group 3L-3 (trans-ionospheric propagation) regarding SCINTEX format. Clarification should be sought from ITU with respect to using the same name of SCINTEX for different contents.

Agenda Item 3: Status of State's relevant activities

3.1 States/Administrations participating in the meeting presented their status of ionospheric data collection and analysis.

<u>India</u>

Longitudinal Variations in the TEC at Low Latitudes (WP/5)

3.1.1 India reported its results on newly discovered phenomena on the longitudinal variations of TEC over low latitude region. The TEC over Eastern side of India is more enhanced compared to Western longitudes at the same local time. The estimated longitudinal gradient of TEC from the long term data set of 2004 to 2012 indicates the presence of longitudinal variability which is dependent on local time, season and solar cycle. In reply to one of the queries on day-to-day behavior of longitudinal variability, India informed that Equatorial Ionization Anomaly (EIA) was observed to be totally absent in western side while it occurs in eastern longitudes of India. The meeting was of the opinion that these results may be useful in developing the region specific iono model.

GNSS Status in India (IP/10)

3.1.2 India provided updates on the status of the GNSS in India. The objectives and performance of its SBAS GAGAN were discussed. India informed that GAGAN certification for RNP0.1 is about to complete. The initiative taken by India on GBAS has been discussed and its present status has been updated. India also stated about the GAGAN SIS usage and expansion within the APAC region for wider harmonization. More information on the flight inspection and certification may be provided in the near future.

<u>Japan</u>

Updates on status of ionospheric studies for GNSS for aviation (IP/4)

3.2 Among the GNSS related studies, mitigation of impacts by the low latitude ionospheric anomalies has been focused on partly because of the differences of ionospheric conditions from those in the mid-latitude region. The studies include active participation in defining and validating the development baseline SARPs of GBAS Service Type-D (GAST-D) which enables Category-III approach by using GPS L1 signals as well as continuous data collection and analysis for characterizing low latitude ionospheric anomalies for GNSS implementation.

3.3 Validation of the GAST-D ionospheric threat model for low latitude. The prototype GAST-D ground subsystem has been delivered in September 2013. It will be installed in the first quarter of 2014 in New Ishigaki Airport, which is close to the equatorial ionization anomaly region. The first flight trials with the prototype of GAST-D ground subsystem and the airborne experimental system for GAST-D are planned in April 2014 including the sunset periods when the ionospheric anomalies associated with plasma bubbles often occur.

3.4 Real time GNSS data collection from 200 GEONET stations is continuously in progress. The scintillation receivers in Ishigaki will be replaced with new receivers capable of tracking L1/L2/L5 signals of GPS, GLONASS, Galileo, QZSS, and SBAS satellites in 2013. An all-sky airglow imager that can detect two-dimensional shapes of plasma bubbles will be installed in Ishigaki by February 2014.

China (IP/12)

3.5 China informed the meeting that the diurnal and day-to-day variations of TEC at four Chinese observational stations in two years are analyzed. The semi-annual and seasonal anomalies appearing in the period of maximum solar activity have been presented. Under the conditions of the same solar activity, daily and seasonal variation of TEC shows different characteristics in different latitudes. Also the timely and spatial evolution of the ionospheric storm in November has been analyzed and presented based on globally distributed receivers under IGS. The research shows that the storm is positive during the main phase of the geomagnetic storm, and then positive and negative storms appear alternately or synchronically, which indicates the complex physical morphology and development of the storm. Knowledge of nominal and anomalous ionosphere is very important to develop methods and models for mitigation of ionospheric effects. Some clarifications were also provided to the queries.

Hong Kong China (IP/9)

3.6 Hong Kong, China conducted a presentation for the latest updates about their works in relation to ionospheric studies and also shared their plan for installing one scintillation monitoring station at Hong Kong International Airport (HKIA). After deliberation in the meeting, it was concluded that additional scintillation monitoring stations at/nearby HKIA were considered beneficial for ionospheric studies under the Task Force. Moreover, Hong Kong, China had also delivered the first batch of iono data to ISTF for facilitating ionospheric studies in the APAC Region under the Task Force.

Thailand (IP/13)

3.7 AEROTHAI updated the meeting regarding their Ionospheric Monitoring Stations operational. 5 Stations for measuring ionopheric delay had been installed at Chiang Mai, Phitsanulok, Hat Yai, Surat Thani Airport and Suvarnabhumi International Airports. Each station is equipped with a dual frequency Novetal receiver with data logged at 1 Hz interval with an averaged data of 150 Mega Byte logged per day in RINEX format and/or 100 MB in binary format

Philippines

3.8 Philippines updated the meeting on the data collection status based on information provided at ISTF/1 meeting. As of today, there are 17 active stations as Davao being the last site to be implemented. By the end of 2013, additional 6 stations are targeted to be completed, based on the information from National Mapping and Resource Information Authority (NAMRIA). Accordingly, NAMRIA has identified 5 possible sites capable for collecting scintillation data. The agreement between CAAP and NAMRIA to share their data has already been finalized for approval. However, the terms and conditions requiring sharing these data for inonospheric studies were currently being discussed with NAMRIA.

Agenda Item 4: Review TOR of the Task Force including the needs for space weather studies

Review TOR of ISTF (WP/4)

4.1. The Task Force reviewed Terms of Reference adopted by the CNS Sub-group in its 16th Meeting and Decision 17/13 adopted by the CNS SG/17 meeting regarding amendments to TOR to include space weather item. The meeting further discussed this matter and agreed to the proposed revision to the Terms of Reference as provided in the Appendix A to this report and formulated following Draft Decision for consideration by the CNS Sub-group:

Draft Decision 3/1 - Revised Terms of Reference of ISTF

That, the revised Terms of Reference for Ionospheric Studies Task Force (ISTF) provided in **Appendix A** to the Report be adopted.

4.2 In this connection, the meeting considered necessary to add the following new task i.e. Task No.6 with Dr. Takuya Tsugawa from Japan as lead for the Task:

New Task No. 6 (ISTF3) Space Weather - Analyze, based on data shared within ISTF and public information, the effects of space weather and the concept of operations for the provision of space weather information in support of international air navigation.

Agenda Item 5: Conditions for use of Data

Review Action Items from ISTF/2 Meeting (WP/2)

5.1 The meeting reviewed and updated the status of following 6 action items agreed by the ISTF/2 Meeting held in October 2012:

<u>*Action Item ISTF 2/1:*</u> *ISTF should develop a guidance material on collection of scintillation data at strategic locations. Preliminary draft of the guidance material should be available by November 2012 and the finalized guidance material, incorporating all recommended changes, should be available by December 2012. (WP Prepared, this Action Item closed)*

5.2 In this connection, the meeting reviewed the draft Guidance Material as presented by the Task Lead through WP/09. The meeting further amended the draft guidance material and formulated following Draft Conclusion:

Draft Conclusion 3/2 – Guidance material on collection of scintillation data

That, the guidance material on collection of scintillation data at strategic locations provided in the **Appendix B** to the Report be adopted.

<u>*Action Item ISTF 2/2:*</u> *Secretary to communicate with APEC GIT Co-chairs regarding the data sharing template. Target date for receiving information from APEC GIT is end of December 2012. (Action taken, this action item closed)*

5.3 Coordination with the Co-chairs of GIT was carried out. As a result, Co-chairs of GIT agreed to share data derived from the test-bed in any optional forms. The archived data collected during test-bed, was provided to integration in the data server for analysis by experts.

Action Item ISTF 3/2: (Supersede Action Item ISTF 2/3) Task Lead, Task – 2 to coordinate with FAA WJHTC for obtaining permission to use the LTIAM Tool by ISTF. (by the end of December 2013).

5.4 In this connection, Prof. Jiyun Lee, presented WP/11 outlining the activities of IGWG and brief introduction of LTIAM Tool. Next meeting of IGWG (teleconference) is scheduled for some time in November 2013. The LTIAM tool is required to be obtained from source controller, FAA WJHTC by ISTF members. As one of action items of Task - 2 (part of Action Item 4), Task Lead Prof. Jiyun Lee was requested to coordinate with source controller for clearance for acquiring the tool. The revised target date for this action item is end of 2013.

<u>Action Item ISTF 2/4:</u> Task Lead, Task – 1 to categorize the ionospheric delay measurements and scintillation measurements into geographical regions to confirm an even spread of all the observation sites in the region. Target date for the Action Item was agreed as January 2013. (WP/10 by Japan provided updates, this Action Item closed.)

5.4.1 Ionospheric delay and data sources that have been nominated by States are categorized by their magnetic latitudes. It is reported that there are 119, 422, and 49 ionospheric delay data in the low, mid-, and high magnetic latitude regions, respectively. For ionospheric scintillation data, there are 21, 14, and 2 stations in the low, mid-, and high magnetic latitude regions, respectively. Distributions of the stations are summarized in Figures. It was discussed that there are gaps in the distribution of stations for ionospheric delay and scintillations between India and East Asia. NICT, Japan informed that they have installed scintillation receivers in Phuket, Thailand and Cebu, Philippines and the data will be available. Philippines informed that the number of available stations will increase from 13 to 17, and 5 of them could potentially provide scintillation data. NICT, Japan also informed that they are coordinating with Malaysia for sharing data of a Malaysian GNSS network. China suggested using 7 IGS stations in China.

<u>Action Item ISTF 2/5:</u> Task Lead, Task – 1 to prepare a mechanism to identify the terms of use of data as proposed by the data sources and incorporates that in the data processing. Target date for this Action Item is January 2013. (Paper prepared and mechanism developed. This Action Item closed).

5.5 The meeting reviewed the proposed access, authorization procedure for sharing the data collected and means of data collection as presented by the Task Lead through WP/6. Notification scheme of data policy of the data shared in the ISTF activities was proposed. The paper proposed that the GTEX and SCINTEX data should have a header field to indicate the restriction, and other data should be stored different directories in the data server according to their restrictions. After discussions, the meeting decided to insert a comment block in the GTEX and SCINTEX data instead of defining a new field. The meeting also agreed to store other data in different directories and permission of access to the restricted data should be provided to users based on application. A link pointing conditions of use for the restricted data will be provided in the server. The meeting also requested Japan to develop a user interface to keep logs of accessing the restricted data. A manual to the data server access will be provided by Japan.

Action Item ISTF 3/3: (Supersede ISTF 2/6) – Data server user interface and use Manual. Data server user interface be updated according to outcome of ISTF/3 and prepare User Manual for the use of the data server including keeping logs of accessing the restricted data.

<u>Action Item ISTF 2/6:</u> Data server sponsored by ENRI needs to be ready to receive/compile data. Discussions on period of analysis could start from analyzing which key parameters could be used to identify such periods. States like India and Japan, which have already carried out some level of analysis, were requested to suggest these periods/parameters based on their experience. Data formats need to be reviewed and updated for their applicability for the purpose of analysis:

a) Setting up of Server – Japan (January 2013) Implemented & closed;

b) Finalizing data format – Japan (January 2013) closed as superseded with new Action Item; and

c) Key parameters to categorize data – Republic of Korea (January – 2013)

Data Server and data transfer progress (WP/7)

5.6 Regarding Action Items 6a and 6b identified by the second meeting of the Ionospheric Studies Task Force (ISTF/2), Japan informed the meeting about the data server for data sharing which had been installed at ENRI, Japan. The server has 27 TB storage space configured as RAID6 with 9 hard disk drives (HDDs) with 3 TB each for data, 2 HDDs for parity, and 1 HDD for hot spare. The CPU is Intel Xeon E5620 at 2.40GHz which has 8 logical cores (4 physical cores). The disk space is divided into two directories, one for the observation data, and one for the analyzed data. The detailed directory structures will be finalized very soon and announced at ISTF Forum. The server is ready to be connected to the internet with a 1 Gbps optical fiber network. The IP address to access the server has not been fixed yet, and will be announced to ISTF members later. The server will be accessed by ISTF members for uploading and downloading data. It will be accessed from registered IP addresses based on applications. The draft application form for access the server is provided in **Appendix C** to this report. The access protocols will include FTP, and SSH (supporting SFTP).

5.7 Although the server is connected to a high speed internet, the capacity may not be high enough for transferring huge amount of data that have been accumulated over years and/or being accumulated. Therefore, the following strategy with three phases is proposed:

<u>Phase 0:</u> Accumulated data is transferred to the server via physical media. (Hong Kong China, Thailand and APEC GIT Testbed data have been transferred during ISTF/3.

<u>Phase 1</u>: Identify the key periods of data for analysis in the past and transfer the data only in the period to the server via internet or in physical media including DVD, HDD, or Silicon Memory. The meeting considered that the archived data collected during period from 2001 to September 2013 would be required.

<u>Phase 2:</u> Identify the expected key periods in the future and transfer the data when they become available. In events of solar storms, magnetic storms, or any events where ionospheric disturbances are expected, ISTF may ask special data collection campaign.

(Generally expected seasonal period would be March/April and September/October each year)

Action Item ISTF 3/4: Task 2 Lead to identify the past periods of interest for data analysis.

Current status of data conversion tool and database of GTEX (WP/8)

5.8 Japan reported the current status of data conversion tool and database of GTEX. It was informed that software to convert RINEX data to GTEX data (RNX2GTEX ver. 0.1) for Linux/Unix and for Windows XP/Vista/7 is available from NICT website. RNX2GTEX ver 1.0 which can produce GTEX 1.0 is still under development and was estimated to be available by the end of 2013. Database of GTEX (ver. 0.1) data had been developed and available via NICT Science Cloud.

Categorizing of GPS TEC Data for Task 2 - Ionospheric Analysis (IP/7)

5.9 The meeting reviewed draft categorizing of GPS TEC data for Task 2 presented by ROK through IP/7. The meeting discussed about proposed method. The tentative agreed categorizing of GPS TEC data for the region is provided in **Appendix D** to this report.

CAT-I GBAS Ionospheric Threat Model for Republic of Korea (IP/8)

5.10 The Republic of Korea informed the meeting about their CAT-I GBAS Ionospheric Threat Model developed to support GBAS certification purpose. The limited data used for the model collected from 63 data stations during the period from 2001 to 2004 (covering last peak solar storm) throughout the country from three agencies. The distance between most of these stations are 30-40 kilometers apart. Separation distance between few stations is about 5-10 KM. The total of 288 threat points were validated. By adding a margin of about 15% to largest gradient the upper bound on Korea ionospheric threat model is 160 mm/km (no elevation dependency) which is well under the bound of the current LAAS CONUS threat model. It was also informed that the bound on Germany threat model is 140 mm/km. The meeting appreciated work carried by Republic of Korea.

Ionospheric Studies under GAGAN Project (IP/11)

5.11 India reported the results of ionospheric analysis carried out under GAGAN project. The improvement in position accuracy with GAGAN correction was validated through experimental analysis. India reported the various effects of scintillation on GNSS and considered it as a potential threat on GNSS implementation over APAC Region. India also mentioned about the development of scintillation monitor tool. The meeting appreciated the usefulness of the scintillation monitor tool. India also requested for a formal communication from ICAO, APAC Regional Office on the data sharing for ISTF activities.

Action Item ISTF 3/5: Secretary to issue a letter to India (Airport Authority of India) requesting the use of GAGAN-TEC data.

Agenda Item 6: Any other business

6.1 Technical visit to GBAS site at GIMPO airport was organized on 16 October 2013. The participants of the meeting were briefed about R&D activities in Korean Airports Corporation (KAC) that had been taken up by KAC. A brief presentation, information on the GBAS trials conducted in Gimpo Airport was provided.

6.2 The meeting participants appreciated the excellent arrangement made by the host for the meeting and thanked Ministry of Land, Infrastructure and Transport and the Korean Advanced Institute of Science and Technology for hosting the meeting. The participants also expressed their appreciation for the hospitality extended to them.

6.3 Hong Kong China and Aerothai have provided their collected data in a form of disk for integration into the regional server established at ENRI, Japan. The test bed data from APEC GIT was also transferred for integration and further analysis.

Agenda item 7: Future Plan, Review of Action Items

7.1 The updated action items by the meeting are provided in the **Appendix E** to this report.

7.2 The meeting discussed about next meeting of the Task Force and appreciated India for their offer to host ISTF/4 in New Delhi from 5-7 February 2014. Further coordination for the meeting including the venue of meeting will be carried out among member of the Task Force by the end of November 2013. Letter of invitation is required to be issued as soon as possible if it is agreed by members of the Task Force.

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REVISED TERMS OF REFERENCE OF ISTF

1) Take the responsibility for identification of the available GNSS data source;

2) Make recommendation on sharing scenario for Ionospheric data collected;

3) Make recommendations on selecting ionospheric data sources and sharing scenario for the collected data;

4) Steer process for evaluation of the data analysis;

5) Study the need for development of Regional Ionospheric Threat Models for GBAS and SBAS;

6) Development of Regional Ionospheric Threat Models for GBAS and SBAS if the need is identified;

7) Establish rules for use of shared data and the result of study for non-commercial purpose; and

8) Investigate the effects of space weather on CNS systems in the APAC Region.

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Guidance Material on collection of Ionospheric Scintillation data at strategic locations in the Low-latitude Region

(Ver. 1)

1. Background

The second meeting of Ionospheric Studies Task Force (ISTF/2) noted the limited scintillation monitoring facilities established in the region, and decided to develop a guidance material on collection of scintillation data at strategic locations (Action Item 1). This document has been developed to address the AI-1 of ISTF/2.

There are two types of ionospheric scintillations in GPS measurements, amplitude and phase scintillations. Amplitude scintillation refers to rapid fluctuation in signal intensity (or carrier-to-noise ratio, C/N0) measured by a receiver, while phase scintillation refers to rapid fluctuation in the carrier-phase measurements. Levels of amplitude and phase scintillations are commonly represented by the standard deviations of amplitude and phase, respectively S4 and σ_φ, in a certain time period (typically 1 min). The ways of estimating the S4 and σ_φ indices are given in Appendices A.1 and A.2.

For the amplitude scintillation, rapid sampling of C/N0 is necessary, while rapid carrier-phase measurements are required for the phase scintillation. Furthermore, GPS receivers for phase scintillation measurements need to be equipped with a highly stable clock (oscillator) such as OCXO (oven-controlled crystal oscillator) to distinguish the phase fluctuations due to ionospheric scintillation and clock (oscillator) noise.

Both types of ionospheric scintillations are caused by plasma irregularities in the ionosphere. In the low-latitude regions where the background electron density is high and plasma drift velocity is relatively slow, the amplitude scintillation is dominant. In this guidance, therefore, the amplitude scintillation is focused on.

2. Receiver performance

2.1 Receiving frequency

Since only the GPS L1 (1.57542 GHz) is currently used, GPS L1 single-frequency receivers satisfying other performance requirements in this section are acceptable. In addition to GPS, however, receivers should be capable of GLONASS and SBAS GEO satellites for wide coverage of the sky.

For the use of the L5 frequency in the future, receivers capable of tracking L1 and L5 signals would be a good choice.

If a receiver could track L2 frequency, it could be used to measure ionospheric delays (or ionospheric total electron contents (TECs)).

2.2 Receiver clock

Since the amplitude scintillation is of interest, a highly stable clock is not necessary, but a standard clock such as TCXO (temperature compensated crystal oscillator) is enough.

2.3 Sampling rate

The amplitude scintillation is caused by the Fresnel diffraction due to the ionospheric irregularities. The typical scale size causing the Fresnel diffraction (D_F) is described as

$$D_F = \sqrt{2\lambda h} \qquad (1)$$

where λ is the wavelength of the radio wave (0.19 m for the GPS L1 frequency) and h the height of the irregularities (typically 300-400 km). Thus, the typical scale size is 300-400 m. The amplitude will fluctuate at the Fresnel frequency

$$f_F = V / D_F \qquad (2)$$

where V is the drift velocity of the irregularities. Since the drift velocity of plasma irregularities (V) is typically 100-200 m/s, the amplitude will fluctuate at 0.25-0.67 Hz.

According to the sampling theory, the sampling rate of the amplitude should be at least twice as fast as the Fresnel frequency, 0.5-1.33 Hz. Considering that the spectrum of amplitude fluctuation contains higher frequency components, the sampling rate should be much higher than the Fresnel frequency. It is common to sample the amplitude at 20 Hz or more. It should also be noted that the default sampling rate of the amplitude by the widely used GSV4004B receiver is 50 Hz.

The raw amplitude measurements at high sampling rates can be recorded. However, it would take a lot of file size. Therefore, the raw amplitude measurements could be discarded after calculating and recording scintillation intensity, although the raw amplitude measurements data would still be useful for future re-analysis and irregularity drift measurements with closely spaced scintillation receivers.

If the ionospheric delay is desired to be derived, both the pseudo-range and carrier-phase need to be sampled. However, the sampling rates of them do not have to be the same as the amplitudes, but can be much slower than that of the amplitude. The typical sampling rate for the ionospheric delay measurements is 1 sec. (For GBAS, the minimum sampling rate of a ground subsystem is 2 Hz, though)

TEC measurements can also be used to derive another index of ionospheric irregularities: the rate of TEC Index (ROTI). ROTI is defined as the standard deviation of rate of TEC in a certain time period, typically 5 min [2]. ROTI is another indicator of ionospheric irregularities that can be derived from standard low sampling rate dual-frequency receiver measurements. The way of estimating ROTI is given in Appendix A.3.

2.4 Multi-path effect avoidance

The measured amplitude often fluctuates at low elevation angles due to multi-path effects and result in artificial enhancements in the scintillation level. There are two ways to eliminate the multi-path effects. One is simply to set a higher elevation mask such as 30º. However, it would have a drawback of loosing data at low elevation angles where the path length in the ionosphere is long and more scintillation is expected.

Alternatively, the standard deviation of the code-carrier divergence (sigma-CCD) can be utilized. The code-carrier divergence is the difference between the rates of change in pseudo-range and carrier-phase measurements. When there is no multi-path and ionospheric effects, the rates of change in pseudo-range and carrier-phase changes will be the same, except for ambient and receiver internal noises.

The multi-path signal generally accompanies much larger sigma-CCD than ionospheric scintillation signal, which can be used to distinguish between scintillation enhancements by multi-path and ionospheric irregularities [1]. If a sigma-CCD value calculated for the same period as the S4 index exceeds a certain limit, the signal is likely to be affected by multi-path effects. To do this, the pseudo-range and carrier-phase need to be sampled at a certain rate, such as 1 Hz. Sigma-CCD can be calculated afterwards if the pseudo-range and carrier-phase are recorded, while some receivers such as GSV4004B can calculate sigma-CCD internally and record it. The way of deriving the sigma-CCD is given in Appendix A.4.

2.5 Other useful measurements

The satellite azimuth and elevation angles are not essential, but will make post-analysis easier. The sampling rates of the azimuth and elevation angles can be as low as those of the pseudo-range and carrier-phase.

2.6 Summary

The receiver should be able to track at least GPS L1 frequency signals. Tracking capability of GLONASS and SBAS GEO satellites are very useful.

The receiver do not have to be equipped with a highly stable clock (oscillator) as long as it is used for the amplitude scintillation measurements, which is the case in the low latitude regions.

The most important value to be recorded for the low latitude ionospheric scintillation is the amplitudes (C/N0) of the signal for each satellite. The sampling rate should be much higher than the Fresnel frequency and typically 20 Hz or more. Once the scintillation intensity is calculated and recorded, the raw amplitude measurements data can be discarded, unless future re-analysis or irregularity drift velocity measurements are not planned.

The pseudo-range and carrier-phase can be recorded at relatively low rates than the amplitude, such as 1 Hz. They are not mandatory, but useful to distinguish between ionospheric scintillation and multi-path signals.

The satellite azimuth and elevation angles are not essential, but will make post-analysis easier, if recorded together.

3. Antenna

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3.1 Antenna frequency

Antenna should be able to track signals corresponding to the signals which are desired to be tracked by the receiver.

As described in 2.1, an antenna capable of tracking L1 and L5 signals is a good choice.

3.2 Antenna type

To avoid the multi-path effect as much as possible, a choke-ring antenna or others with equivalent multi-path-resistant performance are preferable. Simple antennas could be used, but with a drawback of lower data availability especially at low elevation angles.

3.3 Antenna environment

Antennas should be located at places with the open sky without obstacles that may shadow satellites down to the elevation angle as low as possible.

The antenna site should be free from obstacles as wide as possible to avoid multi-path effects. Practically, it is very difficult to find ideal antenna locations. Therefore, the sigma-CCD filtering is very useful to enhance data availability under the multi-path conditions.

For example, installation of receiver in localizer building is recommended owing to its strategic location which is usually free from multipath. However, seaside runways are at disadvantage. We have observed more multipath effects in scintillation at sites surrounded by ocean.

3.4 Antenna separation

When more than one scintillation receivers are available, one can consider operating them with spaced antenna groups. There are some advantages of spaced antenna measurements.

With a few 100 m to a few kilometers antenna separation and the high frequency C/N0 data recording, drift velocity of ionospheric irregularities causing scintillation can be derived from the time lag between the two C/N0 variation patterns. It could potentially used to predict propagation of the ionospheric irregularities.

Spaced antenna measurements with separation of several tens to a hundred kilometers, which is comparable to the typical scale size of plasma bubbles contribute to increase the number of points probed by the GNSS signals to achieve spatially denser observations.

Multiple receiver measurements at multiple locations that share common sky () would be useful for redundant measurements against receiver failure. The radius of the area of the ionosphere that can be probed at an altitude of 350 km is about 560 and 1600 km for elevation mask angles of 30 and 5º, respectively.

4. Cables

A cable between an antenna and a receiver should be selected so that the signal level at the front-end of the receiver is in the range suitable for each receiver.

The expected signal level at the front-end of the receiver (P_{in}) is given by

$$P_{in} = P_{nom} + G_{ant} + G_{pa} + L_{cable} + G_{ila} \qquad (3)$$

where P_{nom} is the nominal signal level at the antenna, G_{ant} the antenna gain, G_{pa} the gain of the preamplifier, L_{cable} the cable loss, and G_{ila} the gain of an in-line amplifier. The nominal signal level of GPS on the ground is between -153 and -160 dBm for L1 C/A signal [3]. G_{ant} and G_{pa} depends on the antenna model. L_{cable} is determined by the type, thickness of the cable and proportional to the length.

Cable length should be determined so that P_{in} is in the range of signal level suitable for the receiver. When the cable has to be too long to keep P_{in} in the suitable range, an in-line amplifier can be inserted between the antenna and the receiver. However, the gain should not be too high not to exceed the upper limit of the input signal level.

5. References

[1] Van Dierendonck, A. J., and Q. Hua, Measuring ionospheric scintillation effects from GPS signals, proceedings of ION 57th Annual Meeting, 391-396, 2001;

[2] Pi, X., A. J. Mannucci, U. J. Lindqwister, and C. M. Ho, Monitoring of global ionospheric irregularities using the worldwide GPS network, Geophysical Research Letters, 24, 2283-2286,1997;

[3] ICD-GPS-200 IRN-200C-004, Navstar GPS Space Segment / Navigation User Interfaces. April 2000.

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Appendix A. Parameter estimation

A.1 Amplitude scintillation index (S4 index)

The amplitude scintillation index (S4 index) is defined as a normalized standard deviation of C/N0 as given by:

$$S4 = \sqrt{\frac{\langle s_i^2 \rangle - \langle s_i \rangle^2}{\langle s_i \rangle^2}} \quad (4)$$

where < > denotes average , and s_i is the C/N0 in linear scale (not in dBHz) of the i-th satellite. The linear-scale C/N0 (s_i) is related to the C/N0 in dBHz (c_i) as:

$$s_i = 10^{(0.1 \times C_i)} \quad (5)$$

The period of taking average depends on the time scale of interest. It is common to calculate S4 every 1 min (i.e., the averaging period of 1 min).

A.2 Phase scintillation index (σ_φ)

The phase scintillation index (σ_φ) is basically a standard deviation of carrier-phase measurements. However, the carrier-phase measurements have a trend associated with the change of the geometric range. Therefore, the carrier-phase measurements have to be detrended first.

Defining φ’ as the detrended carrier-phase measurements, σ_φ can be defined as:

$$\sigma_\varphi = \sqrt{\langle \varphi'^2 \rangle - \langle \varphi' \rangle^2} \quad (6)$$

A.3 Rate of TEC index (ROTI)

ROTI is defined for each satellite as the standard deviation of rate of TEC (ROT) as given by:

$$ROTI_i = \langle ROT_i^2 \rangle - \langle ROT_i \rangle^2 \quad (7)$$

where ROT_i is the rate of TEC of the i-th satellite in the unit of TEC/min as given by:

$$ROT_i(t) = \left(TEC_i(t) - TEC_i(t-\tau)\right)/\tau \quad (8)$$

where τ is the sampling interval.

A.4 Sigma-CCD

Sigma-CCD is defined for each satellite as the standard deviation of code-carrier divergence as given by:

$$SigmaCCD_i = \langle d_i^2 \rangle - \langle d_i \rangle^2 \qquad (9)$$

where d_i is the code-carrier divergence of the i-th satellite as given by:

$$d_i = \left(\rho_i(t+\tau) - \rho_i(t)\right) - \left(\varphi_i(t+\tau) - \varphi_i(t)\right) \qquad (10)$$

where $\rho_i(t)$ and $\varphi_i(t)$ are respectively the pseudo-range and carrier-phase measurements of the i-th satellite at a time t, and τ is the sampling interval of the pseudo-range and carrier-phase.

The period of taking average should be the same as S4 index, and typically 1 min. The sampling interval of the pseudo-range and carrier-phase is typically 1 sec.

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Application Form for Access to the ISTF Data Server

1. State/Organization:

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2. Contact Person (Title or Official Position and Name in full):

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3. Contact Address

E-mail Address: ______________________________

Mailing Address: ______________________________

Phone Number: ______________________________

Fax Number: ______________________________

4. IP Address(es) for Access:

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5. Data Category to Access:

☐ Analyzed Only

☐ Non-restricted and Analyzed

☐ All (Restricted, Non-restricted, and Analyzed)

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Tentative Agreed Categorizing of GPS TEC Data for the Region

1.1 The Asia-Pacific sector has middle and low ionospheric status and northern and southern hemispheres. Ionosphere has similar reactions according to solar and geomagnetic activities, and different characteristics according to chemical reaction with thermospheric neutral components and neutral wind in different regions.

1.2 GPS TEC are categorized by their solar fluxes into three classes; solar minimum (F10.7 < 100), solar moderate (100 ≤ F10.7 < 200), solar maximum (F10.7 ≥ 200). GPS TEC are also classified by geomagnetic activities into three classes; geomagnetic quiet (Kp < 3), geomagnetic moderate (3 ≤ Kp < 5), geomagnetic disturbance (Kp ≥ 5).

1.3 Nine criteria for GPS TEC analysis are proposed as below.

Low Solar Activity Geomagnetic Quiet	Low Solar Activity Geomagnetic Moderate	Low Solar Activity Geomagnetic Disturbance
Mid Solar Activity Geomagnetic Quiet	Mid Solar Activity Geomagnetic Moderate	Mid Solar Activity Geomagnetic Disturbance
High Solar Activity Geomagnetic Quiet	High Solar Activity Geomagnetic Moderate	High Solar Activity Geomagnetic Disturbance

Table 1 - Nine criteria defined based on solar and geomagnetic activities for GPS TEC analysis

1.4 When the temporal coverage of GPS TEC data is shorter or equal to 11 years, four criteria can be used instead of nine criteria. In this case, GPS TEC are categorized into two classes by their solar fluxes; solar low (F10.7 < 150), solar high (F10.7 ≥ 150), and also classified into two classes by geomagnetic activities; geomagnetic low (Kp < 3), geomagnetic high (Kp ≥ 3).

1.5 The correlation between GPS TEC and solar activities can be well represented with quadratic equations - $\mathrm{y_{GPS\ TEC}} = \mathrm{ax}^2{}_{F10.7} + bx_{F10.7} + c$.

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List of Action Items Updated by ISTF/3 Meeting

ACTION ITEM 3/1	-	Task Lead, Task-1 and Dr. Tsugawa, Japan to coordinate with the Chairman of ITU-R WP-3L for the formats of scintillation data with the same name "SCINTEX" to have a unified format.
ACTION ITEM 3/2	-	Task Lead, Task-2 and Prof. Lee, ROK to coordinate with FAA for obtaining permission to use the LTIAM tool by ISTF.
ACTION ITEM 3/3	-	Task Lead, Task-1 to set up the data server for data sharing according to the outcome of ISTF/3 and prepare a manual for the use of the data server including keeping logs for accessing the restricted data.
ACTION ITEM 3/4	-	Task Lead, Task-2 and Prof. Lee, ROK to identify the past periods of interest for data analysis.
ACTION ITEM 3/5	-	Secretary to issue a letter to India (Airport Authority of India) requesting the use of GAGAN-TEC data.

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Third Meeting of Ionospheric Studies Task Force (ISTF/3)

Seoul, Republic of Korea
15 – 17 October 2013

Attachment 1 to the Report

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International Civil Aviation Organization

THE THIRD MEETING OF IONOSPHERIC STUDIES TASK FORCE (ISTF/3)

15 – 17 October 2013, Seoul, Republic of Korea

LIST OF WORKING/INFORMATION PAPERS

WP/IP SP No.	Agenda Item	Subject	Presented by
LIST OF WORKING PAPERS			
WP/1	-	Provisional Agenda	Secretariat
WP/2	5	Review Actions Items from Second Meeting of Ionosperic Studies Task Force (ISTF/2)	Secretariat
WP/3	2 (c)	Outcome of CNS SG/17 and APANPIRG/24 on Ionospheric Related Issues	Secretariat
WP/4	4	Review Terms of Reference of ISTF	Secretariat
WP/5	3	Longitudinal Variations in TEC at Low Latitudes	India
WP/6	5 (a)	Notification Scheme of Data Policy for Sharing	Japan
WP/7	5 (a)	Data Server for Data Sharing and Possible Means of Data Transfer for Data Exchange	Japan
WP/8	5 (a)	Current Status of Data Conversion Tool and Database of GTEX	Japan
WP/9	5 (a)	Guidance Material on Scintillation Measurements	Japan
WP/10	5 (a)	Categorization of Data Sources	Japan
WP/11	3	Updates on Long Term Ionospheric Anomaly Monitor	Republic of Korea
LIST OF INFORMATION PAPERS			
IP/1	-	Meeting Bulletin	Secretariat
IP/2	2 (a)	12th Air Navigation Conference on Ionospheric and Space Weather Issues	Secretariat

WP/IP SP No.	Agenda Item	Subject	Presented by
IP/3	2 (b)	Review Outcome of ICAO Navigation Systems Panel Working Group of the Whole (WGW/13) Meeting	Secretariat
IP/4	3	Current Status of Activities on Ionospheric Studies for GNSS in Japan	Japan
IP/5	2 (d)	Report on the 14th Meeting of International GBAS Working Group	Japan
IP/6	2	ITU-R Report Related to Trans Ionospheric Propagation	Japan
IP/6	5 (a)	Data Server for Data Sharing and Possible Means of Data Transfer for Data Exchange	Japan
IP/7	3	Categorizing of GPS TEC Data for Task 2 – Ionospheric Analysis	Republic of Korea
IP/8	3	Korean CAT-I GBAS Ionospheric Threat Model	Republic of Korea
IP/9	3	Updates for ISTF3	Hong Kong, China
IP/10	3	GNSS Status in India	India
IP/11	5	Update on Ionospheric Studies under GAGAN Project	India
IP/12	3	Preliminary Research Results on Characterizing Ionosphere over China	China
IP/13	3	Ionospheric Data Collection in Thailand	Thailand

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