



第十二次空中航行会议

2012年11月19日至30日，蒙特利尔

议程项目 6： 未来的方向 6.1： 实施计划和方法

全球统一的全球导航卫星系统实施办法 — 电离层的威胁和空间天气角度

（由日本提交）

摘要

《全球空中航行能力和效率计划》(GANP, Doc 9750号文件)已将全球导航卫星系统(GNSS)定义为核心技术之一，该系统通过全球导航卫星系统技术的演变，能够促进基于性能的导航(PBN)业务、基于飞行轨迹的运行(TBO)和其他先进的空中交通管理(ATM)的改善。

认识到对电离层问题和其他空间天气问题进行适当评估并采取应对措施的重要意义，国家之间或国家与产业界之间需要密切合作，以节省成本方式在全球统一实施全球导航卫星系统。

本文件探讨了在预设的全球空中航行计划航空系统组块升级(ASBUs)的时间框架内，影响全球导航卫星系统实施和运行的电离层和空间天气问题，并建议采取行动以补充WP/21号文件“全球导航卫星系统实施问题”提出的与全球导航卫星系统脆弱性相关的行动。

行动：请会议同意第3段中的建议。

1. 引言

1.1 全球导航卫星系统(GNSS)已被视为一项核心的导航基础设施，用以促进基于性能导航(PBN)、基于飞行轨迹的运行(TBO)和其他先进的空中交通管理(ATM)的改善，有助于提高空运的能力和效率。

1.2 WP/21号文件解释了由空间天气现象，特别是电离层异常导致的全球导航卫星系统脆弱性的技术细节，随后，对国际民航组织和各国为有效实施全球导航卫星系统可采取的行动提出了建议。为了将来在次地区或地区这种规模上创造一种可加强基于性能的导航基于性能导航和其他基于全球导航卫星系统的空中交通管理的全球导航卫星系统环境，必须有效解决电离层异常积致的脆弱性问题，只要这种问题仍在妨碍全球导航卫星系统的实施和运行。

1.3 全球导航卫星系统开发商感兴趣的另外一个问题是，如WP/21号文件所述，空间天气可能导致通信导航监视系统(CNS)退化并对人类和航空电子设备造成辐射危害。若干国家一直在进行研究，

以进一步探讨航空中不同现象的机理和对业务的影响。在国际民航组织框架内，一些技术专家机构或地区一级一直在讨论空间天气问题。

1.4 鉴于各方都在期待在 2013 年-2028 年航空系统组块升级的时间框架内稳步实施全球导航卫星系统，各国、空中航行服务提供者（ANSPs）和产业界，需要将电离层的威胁和其他空间天气问题作为一个长期问题加以进一步研究，这些问题对基于全球导航卫星系统的统一导航服务的影响超出国家或地区界线。

2. 讨论

2.1 电离层对全球导航卫星系统的影响

2.1.1 要在特定空域内正确实施和运行全球导航卫星系统，以满足全球导航卫星系统个别运行需求，空中航行服务提供者和监管机构不仅需要具备充分的专门知识，还需要采取适当措施来应对电离层对全球导航卫星系统的影响。由于影响全球导航卫星系统性能的电离层行为和特征因地区而异，更具体地说，因磁纬度而异，因此，应对电离层的特征进行评估并考虑到地区差异（参考：附件一和WP/21号文件）。

2.1.2 为帮助那些需要全球导航卫星系统平台的机构，国际民航组织对全球导航卫星系统的电离层效应进行了研究，并在其文件中载入《全球导航卫星系统（GNSS）手册》（Doc 9849号文件）和《导航系统专家小组关于电离层对全球导航卫星系统航空应用的影响的报告》等（以下称为“导航系统专家电离层文件”）。探索这些课题的进一步研究正在进行之中。

2.2 关于电离层对航空系统组块升级中的全球导航卫星系统的影响的思考

2.2.1 根据WP/21号文件中的全球空中航行计划技术路线图和主要的全球导航卫星系统项目展望，多频率多星座（MF-MC）的全球导航卫星系统预定在组块1后半期（2018-22）到组块2上半期（2023-27）期间首次推出。从理论上讲，多频率多星座的全球导航卫星系统能够帮助减轻和电离层异常有关的脆弱性（参考：WP/21号文件第2段和附件二）。

2.2.2 但是，适应多频率多星座的全球导航卫星系统（包括航空电子设备）发展缓慢，且人们对预设期限内技术解决方案的可用性不确定，给多频率多星座的全球导航卫星系统能否按照计划如期部署带来了疑云。预计在全球范围充分奠定多频率多星座的全球导航卫星系统环境基础之前，现在全球流行的全球导航卫星系统在现有单频率单星座（SF-SC）的全球导航卫星系统航空电子设备上的运行，将继续使用并需要得到支助。

2.2.3 只要仍然需要基于单频率单星座的全球导航卫星系统的服务，就必须在设计和开发全球导航卫星系统时，对电离层行为方式和电离层影响全球导航卫星系统的程度进行特征描述。即使在基于多频率多星座的全球导航卫星系统的系统可用时，对电离层进行特征描述也仍然是确保这些系统适当减轻电离层影响的一个重要基础。

2.3 减轻电离层影响的地区和全球做法

2.3.1 WP/21号文件建议，国际民航组织和各国采取措施，以减少电离层影响干扰全球导航卫星系统信号的可能性。对电离层进行特征描述，是制定减轻和电离层有关的全球导航卫星系统脆弱性的技术解决方案的前提条件。

2.3.2 要对电离层进行可信度更高的特征描述，关键在于确保在即将实施全球导航卫星系统服务的地区获得形式适当且数量充足的观测数据。要想高效、有效地对电离层进行特征描述，并使国家、飞行情报区之间的描述一致且可靠，属于同一磁纬度区的国家、飞行情报区应协调数据搜集和共享工作。地区举措，若能适当地整合，将有助于协调全球电离层的特征描述工作，这反过来将支持全球导航卫星系统和基于全球导航卫星系统的导航的统一实施。

2.3.3 日本注重以合作方式应对全球导航卫星系统的此类地区挑战，一直都在就全球导航卫星系统的空中航行应用的电离层异常现象，进行特征描述并且在牵头完成相关的地区活动。ENRI（电子导航研究所）——日本一家专门的通信、导航、监视/空中交通管理研究组织——长期致力于电离层威胁的研究，并对这一课题的国际论坛和国家论坛做出了贡献。

2.3.4 亚洲和太平洋地区已经在亚洲、太平洋地区空中航行规划和实施小组（APANPIRG）通信、导航、监视和气象分组（CNS/MET SG）下，设立了电离层研究特别工作组（ISTF），其最终目标是在2014年之前对电离层进行特征描述，这一目标普遍适用于该地区（参考：附件二）。因此，有关国家可以避免重复工作，并促进在国家、飞行情报区之间实现无缝隙的全球导航卫星系统服务。这应成为国家、空中航行服务提供者、空域用户和全球导航卫星系统制造商的共同惠益。

2.3.5 电离层问题是陆基增强系统（GBAS）国际工作组（IGWG）极其感兴趣的问题，该工作组是由监管机构、空中航行服务提供者、产业界和研究所组成的、研究陆基增强系统各个方面的自愿工作组。陆基增强系统国际工作组的一个分组正在进行陆基增强系统电离层协调研究。日本参与了这一活动并担任陆基增强系统国际工作组与国际民航组织导航系统专家的联络人。

2.3.6 当空中航行服务提供者在特定空域全期运行并提供全球导航卫星系统服务时，在受干扰条件下搜集的电离层数据尤为重要。在太阳活动剧烈期，电离层受到的干扰更为频繁和严重，预计今后几年将达到顶峰，之后，每隔十一年达到一次顶峰。鉴于第2.2段所述的意见，谨建议开发和部署全球导航卫星系统，并抓住十年一遇的机会适当评估太阳对电离层的干扰。

2.3.7 各国参与此类电离层特征描述活动可丰富它们的专门知识和实践经验，有关国家应该获取这些知识和经验，以在本国管辖范围内审定或批准全球导航卫星系统（包括航空电子设备）设计和运作、基于全球导航卫星系统的程序和飞机运营。

2.4 全球导航卫星系统的空间天气信息

2.4.1 空间天气可定义为“太阳、太阳风、磁层、电离层和热层中可能影响空基和陆基技术系统的性能和可靠性并危机人的生命或航空机组人员和乘客的健康条件”（参考：WP/21号文件第3.9段和附件一）。

2.4.2 最近，就其在安全高效的飞机运行中的应用而言，空间天气信息的利用值得一提。国际民航组织气象专家小组正在审查的《支持航空的国际空间天气信息运行概念》（以下称《空间天气运行概念》）建议，可利用空间天气信息来减轻短波通讯中断、全球导航卫星系统失灵和高能粒子的辐射剂量等等。

2.4.3 影响全球导航卫星系统信号的电离层不规则是空间天气现象之一。监测和预测属于空间天气信息类别的电离层条件，通过适当应用此类信息，能增强基于单频率单星座的全球导航卫星系统的服务效力和效率。空间天气信息能提供有用数据，用以对未来基于MC-MF全球导航卫星系统的导航系统失灵进行预警、可用性预测或态势感知，因此，它能提高全球导航卫星系统运行的效力和效率。

2.4.4 《空间天气运行概念》最新版本，主要介绍了中高磁纬度区的空间天气对全球导航卫星系统的影响。在低磁纬度区，电离层的热层——种背景中性大气——对全球导航卫星系统的影响甚于其他地

区（参考：《导航系统专家电离层文件》第2.1段）。要想提高其在世界范围的实用性和适用性，应审查在低磁纬度区更具影响力的电离层热层的影响，同时考虑到地区差异并将其适当纳入《运行概念》。

3. 结论

3.1 本文件第2段强调了以合作方式应对电离层威胁的效力和效率，以及通过有效减轻电离层的影响来增强全球导航卫星系统完整性和可用性的空间天气信息最佳用法。在这方面，注意到 WP/21 号文件中的相关建议，请会议同意以下建议：

建议 6/x - 用于全球导航卫星系统未来实施的电离层和空间天气信息

会议请国际民航组织：

- a) 协调电离层特征描述方面的地区和全球活动，以在全球统一实施全球导航卫星系统；
- b) 继续努力应对全球导航卫星系统（GNSS）对空间天气的脆弱性，以协助各国实施全球导航卫星系统，并考虑到全球导航卫星系统的长期演变以及所预测的空间天气现象；以及
- c) 探讨可适用于全球从低到高所有磁纬度区的空间天气信息最佳用法，以在全球范围增强全球导航卫星系统的性能。

会议请各国：

- a) 在需要或计划进行基于全球导航卫星系统（GNSS）的空中交通管理运行的地方，考虑各国或各地区可采取的用以解决电离层问题的合作方式，包括对电离层进行特征描述以进行节省成本的、统一的并且适合各地区的全球导航卫星系统之实施工作。

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APPENDIX A

A NEED FOR IONOSPHERIC THREAT MODEL IN GNSS IMPLEMENTATION

1. Importance of properly addressing ionospheric threat in GNSS implementation

The ionosphere is one of the vulnerabilities, which need to be properly treated when implementing GNSS. (Ref. ANConf/12-WP/21). To achieve safe and available services, the range of variability in the ionospheric effects (or threats) in the airspace where the GNSS-based air navigation service is provided must be clearly defined.

The ionospheric effects depend primarily on the region with respect to the earth's magnetic field and on solar activity. Thus, the ionospheric effects need to be evaluated in a manner suitable for the region where GNSS-based navigation service is given with data covering high solar activity periods.

2. Distribution of ionosphere

Distribution of the ionosphere is subject to the magnetic latitudes determined by the earth's magnetic field rather than the geographic latitude. The magnetic equator where the magnetic latitude is zero and the magnetic field is horizontal deviate from the geographic equator by about $\pm 10^\circ$ (Figure A.1).

The ionosphere can be divided into three regions by the magnetic latitude, namely, Low-latitude ($\pm 20^\circ$), Mid-latitude (20 to about 65°), and High-latitude (above 65°) regions (Figure A.1). Ionospheric dynamics are strongly affected by the magnetic field, and this dynamism makes the ionospheric phenomena vary by region. For example, the aurora-related phenomena is critical in the auroral region, the mid-latitude region is rather moderate except for the period of severe magnetic storms, and the equatorial region is more disturbed due to so called "equatorial anomaly", which translates into the enhancement of ionospheric density around $\pm 15^\circ$ magnetic latitude due to a local sharp depletion of the ionosphere dubbed "depletions" or "bubbles".

It should be noted that when GNSS signals pass the ionosphere region, the GNSS signals received at a particular site is affected. The locations where signals from a particular satellite passes the ionosphere (Ionospheric Pierce Point: IPP) distribute around the receiving sites with a radius of more than 1600 km (assuming the ionospheric altitude at 350 km), when satellites with elevation angles greater than 5° are used. Providers and regulators of GNSS-based air navigation services should consider the ionospheric effects which influence GNSS performance within the said circular area.

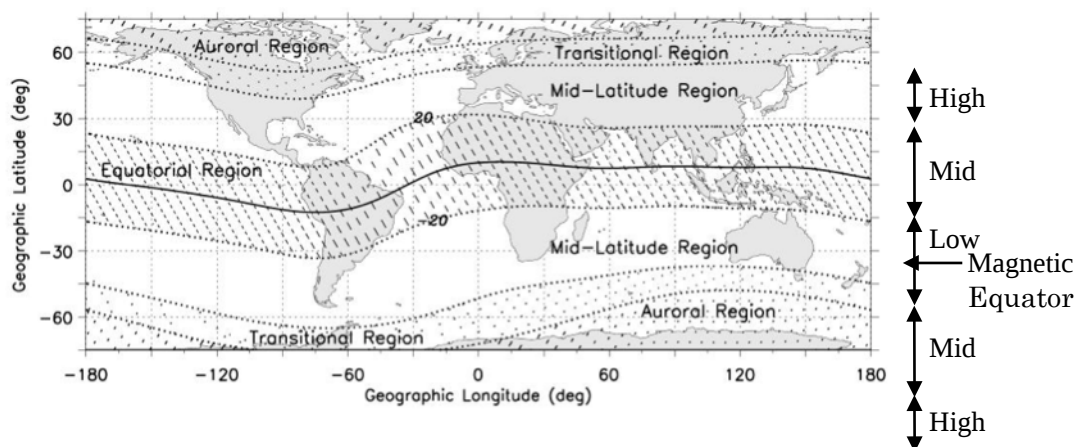


Figure 1. Ionospheric regions (adapted from Figure 3, NSP Iono paper)

3. Solar cycle consideration

The ionospheric activity (density and disturbance) strongly depends on the solar activity in various ways (increase in ionization, increase in the frequency and severity in solar disturbances, increase in thermospheric density and dynamics, etc.). The solar activity has periodicity and repeats the cycle with high and low solar activity periods almost every eleven years. The previous solar cycle reached its bottom in 2009. The current solar cycle is in its increasing phase and is expected to reach its summit around 2013-2014 (Figure A.2). To support GNSS-based services in the long-term, it is obtain to collect ionospheric data during the high solar activity period. Otherwise, it would take another eleven years to obtain data in challenging conditions, which are necessary for GNSS design and engineering to ensure the safety of GNSS-based services as well as the required performance of GNSS.

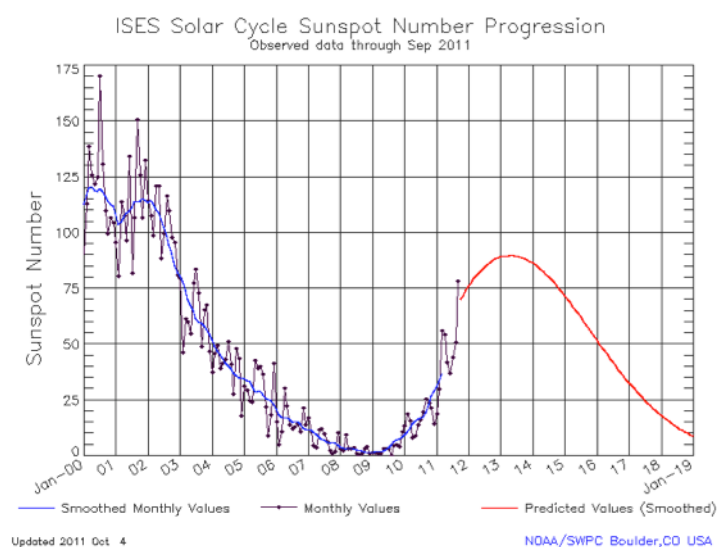


Figure 2. Sun spot number progression as recorded by the U.S. National Oceanic and Atmospheric Administration (NOAA) (Figure 2, NSP Iono paper)

4. Role of providers and regulators of GNSS-based air navigation services

Defining the range and degree of ionospheric variation which affect GNSS performance in their FIRs (ionospheric threat model) is the role of regulators of GNSS-based air navigation services, whether the model is developed by their own or modeled after other data sources. GNSS-based services must be proved to be compliant with international standards by employing the ionospheric characteristics the regulators define. Thus, it is important for regulators and service providers to correctly understand the ionospheric conditions and to build threat models applicable in their FIRs.

APPENDIX B

IONOSPHERIC STUDY TASK FORCE ACTIVITY IN ASIA/PACIFIC REGION

1. Background

1.1 In the Asia/Pacific Region, it has been widely recognized that ionosphere data collection is indispensable to characterize the low latitude ionosphere more appropriately for implementing GNSS infrastructure in the region. Such awareness was shared not only by air navigation domain, but also by regional multi-national fora such as Asia Pacific Economic Cooperation (APEC).

1.2 In the ICAO framework, the question on how to properly address ionospheric effects on GNSS was table on the 20th Asia/Pacific Air Navigation Planning and Implementing Regional Group meeting (APANPIRG/20) in September 2009. The meeting resolved that the member States cooperate with each other to collect ionosphere data and urged the member States to provide a focal point of contact in their Administration to ICAO for coordinated collection and exchange of the ionosphere data (Ref. APANPIRG/20 Report).

1.3 As a follow-up to the APANPIRG Resolution, its CNS/MET Subgroup meeting in 2010 agreed on conducting a coordinated ionospheric review and measurement campaign in the Asia Pacific region. Recognizing its dedication to R & D on ionospheric threat modeling as well as GNSS, Japan was invited to assume the technical leadership in that regional missions. (Ref. APANPIRG CNS/MET-SG/14 Report and APANPIRG 21 Report).

1.4 Inception of the mission of convening a workshop on the ionosphere data collection, analysis, and sharing in May 2011, which was followed by establishment of a dedicated Task Force, named “Ionospheric Studies Task Force (ISTF)”, of which outlines are explained in the following sections. The 1st meeting of the ISTF (ISTF/1) was held in Tokyo, Japan, in February 2012 resulting in a good kick-off for driving the regional initiative.

2. Purpose and Terms of Reference

2.1 The objectives of ISTF are to facilitate ionospheric data collection and sharing, to study the need for development of Regional Ionospheric Threat Models for GBAS and SBAS, and to develop them if the need is identified.

2.2 The current TOR of ISTF is as follows: Take the responsibility for identification of the available GNSS data source:

- a) make recommendation on sharing scenario for Ionospheric data collected;
- b) make recommendations on selecting ionospheric data sources and sharing scenario for the collected data;
- c) steer process for evaluation of the data analysis;
- d) study the need for development of regional Ionospheric threat models for GBAS and SBAS;
- e) provide guidance on the development of regional Ionospheric threat models for GBAS and SBAS if the need is identified; and
- f) establish rules for use of shared data and the result of study for non-commercial purpose.

3. Membership

3.1 The membership of ISTF is open to all the member States of APANPIRG.

3.2 The ISTF/1 meeting was attended by 9 States/Administrations including Australia, Hong Kong China, India, Japan, The Philippines, Republic of Korea, Singapore, Thailand, and United States of America.

3.3 The States which are not participating in the Ionospheric Studies Task Force are expected to share ionospheric data from their national sources with the Task Force to support development of regional ionospheric models for GBAS and SBAS.

4. Work plan

4.1 Five specific tasks were identified by ISTF/1 with sequence and corresponding task leads as follows:

- a) identification of data source, GNSS data collection, sharing, distribution and archiving. Identification of data sharing format. (Sequence 1);
- b) identification of analysis methodology and GNSS ionospheric data analysis (Sequence 1);
- c) GNSS total electron content (TEC) gradient data generation (Sequence 2);
- d) GNSS ionospheric scintillation data generation (Sequence 2); and
- e) assessment of need to Regional GBAS and SBAS ionospheric models and development of these models if it is needed (Sequence 3).

4.2 The ISTF plans to have meetings twice in the first year and once from the second year, with a target of delivery of its final product by 2014.

5. Financial implication

5.1 The ISTF activities are supported by the voluntary contributions by the participating States, who have already been engaged with great interest in their domestic activities in this subject.

5.2 The cost incurred from data collection and ionospheric threat modeling can be minimized by making the best use of the GNSS networks which have already been operated by national organizations for such purposes of geodetic reference, reference for intelligent transportation system, GNSS augmentation or scientific research. In light of the regional or global nature of GNSS and the entire implementation cost of relatively large-scale projects, team work by those of the common interest can reduce the total cost and time by avoiding duplication of similar work as well as system harmonization in an efficient way. ICAO, being as facilitator or usher, assists them in building inter-regional or global ionospheric threat models, which allow States and ANSPs to enhance PBN as well as GNSS in a globally harmonized fashion.

5.3 The ISTF adopted a sample MOU for assisting States in entering into a data sharing agreement with their national organizations concerned.