[EN-I-036] Discussion of Space Weather in ICAO and Related Research Activity in Japan

(EIWAC 2017)

+M. Ishii*, M. Den*, T. Tsugawa*, S. Saito**

*Space Environment Laboratory
National Institute of Information and Communications Technology (NICT)
Tokyo, Japan
[mishii | den | tsugawa]@nict.go.jp

**Surveillance and Communications Department
Electric Navigation Research Institute (ENRI)
Tokyo, Japan
susaito@enri.go.jp

Abstract: Space weather is the electromagnetic conditions from the Sun to the vicinity of the Earth. The solar radiation and high energy particles effect on the ionospheric disturbances which make errors and disabilities of HF communications and satellite positioning. Human exposure needs to be considered in the polar region during severe events. This paper reports on the present status of discussion of space weather in International Civil Aviation Organization (ICAO) and related research activity in Japan. ICAO has been discussing the use of space weather information in civil aviation for several years. The METP of ICAO approved the revision of SARPS and related documents on 2016. In 2017 the process of the selection of ICAO space weather centers cooperated with WMO. Keywords: space weather, ICAO, WMO

1. INTRODUCTION

Space weather is the electromagnetic conditions from the Sun to the vicinity of the Earth. Figure 1 shows the schematic picture of space weather. The source of space weather is the Sun in many cases. The sun is a natural fusion plant and emits not only visible light and heat which is essential for the life living but also harmful radio emission and hot plasma named solar wind. The Earth is protected by the magnetic field (magnetosphere) and the atmosphere but the protection of the magnetic field is not perfect. When the magnetic field in the solar wind is Southward, the plasma of solar wind can enter the inside of the magnetosphere and affect on the spacecraft. In addition it makes ionospheric disturbances and induced current on the polar region which affects on the power grid system.

The series of phenomena are critical on the operational aviation and ICAO discusses to use the space weather information for the civil aviation since 2009. This paper introduces the discussions in ICAO and related research activities in Japan.

2. SPACE WEATHER IMPACT ON AVIATION

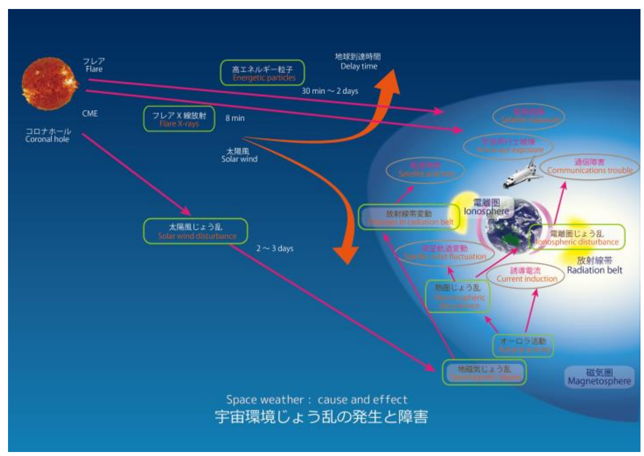

Figure 1 Schematic picture of space weather

There are three categories of space weather impact on aviation; HF telecommunication, GNSS utility and human exposure.

The time line of the social impact of space weather is shown in table 1. In the first stage about eight mitutes after the solar eruption named “flare”, the radio emission e.g, X-ray and Ultra-Violet arrive on the Earth and enhance the D-region (around 80km of altitude) of ionosphere which makes the disabilities of HF telecommunication with absorption. In the second stage, high energy particles

Table 1 Three stages of space weather phenomena from the solar flare

	Time from solar flare	Source of the effect	Space weather phenomena	Social impact
1	～ 8 min later	Radiowave e.g., X-ray and Ultraviolet	Dellinger effect (increase of electron density in D-region), solar radio burst	Disability of HF telecommunications /broadcast, Increase errors/disability of GNSS, disability of airport surveillance radar, disability of mobile phone
2	～30min to 2 days	High energy particles	Exposure of satellite and human in high altitude, PCA (polar cap absorption)	Bit exchange on board in satellites, Human exposure on high altitude /latidude air crew, disabiliby of HF telecommunications/ broadcast
3	～2 to 3 days	CME (Coronal Mass Ejection)	Geomagnetic storm, ionospheric storm, expansion of atmosphere	Disability of HF telecommunications /broadcast, increase errors/disability of GNSS, impact on power grid, satellite anomaly, impact on trajectory of low-altitude satellite and space debris, extension of auroral area.

(proton and electron) arrives from 30 min to 2 days after the solar flare and makes exposure for satellites, astronauts and air crews in high altitude. And also the polar cap absorption (PCA) occurs with the high energy particles which makes the disabilities of HF telecommunications. In the third stage, high-density and velocity ionized gas named coronal mass ejection (CME) arrives to the Earth on two or three days after the solar flare. CME interacts with the Earth's magnetosphere when the magnetic field in CME is Southward and the energy inputs in the magnetosphere. It causes the disturbance of ionosphere in global which makes the disability of HF telecommunications and increase error of GNSS. In serious cases the geomagnetically induced current (GIC) in high latitude occurs which can damage the power grid. In addition, this energy input makes the atmosphere expansion which affects on the satellite trajectory.

On the view of the aviation, the HF telecommunication and GNSS are affected in all stage, and human exposure in the high latitude is critical in the second stage.

3. ACTION AND SCHEDULE

3.1 Preparation of ICAO Documents

The preparation of documents related to the space weather in ICAO has been discussed since 2009 temporally in the working group "IAVWOPSG" (International Airways Volcano Watch Operations Group. The structure of the working group changed on 2014 and the discussion has been continued in a permanent subgroup in "WG-MISD" (Working Group- Meteorological Information and Service Development).

There are three documents to be prepared in ICAO related to space weather; (1) Standard and Recommended Practices (SARPs), (2) Concept of Operation (ConOps) and (3) space weather information manual. SARPs and ConOps have been approved in Meteorology Panel of ICAO on July 2016. The discussion of manual continues and plans to approved on 2018.

3.2 Selection of ICAO Space Weather Center

As a parallel process of the preparation of documents, the selection of ICAO Space Weather Center has been discussed since about 2009. The center criteria was discussed and approved on the ICAO meteorology panel on 2016.

The criteria are divided into the following four areas: 1) Institutional; 2) Operational; 3) Technical; and, 4) Communications/Dissemination. The most important criteria is the ability of a potential space weather information provider to deliver the space weather information services, as defined in the draft SARPs.

The institutional criteria pertain to the overarching characteristics that a space weather information provider must possess. These characteristics are at a corporate level and not necessarily unique to the provision of space weather information for aviation.

The operational criteria are those characteristics that are necessary to support aviation decision-makers that operate in a 24/7 environment employing systems with a high degree of both technical sophistication and reliability.

The technical criteria pertain to the ability of a space weather information provider to provide the information required for the space weather information service. This includes the ability to meet all of the information provision requirements defined in the draft SARPs and harmonize information with the space weather information providers for adjacent geographic areas, as necessary.

The communications/dissemination criteria are intended to ensure that any potential global space weather information provider is able to distribute the global advisory message product to aviation decision-makers through both traditional aviation meteorology dissemination channels, such as OPMET data centres, and newer means of dissemination, primarily Internet-based platforms.

Based on the criteria, ICAO sent a state letter to the member states to ask the interest of operating ICAO space weather center. The replies closed on September 8, 2017. The selection process including visiting audits by WMO will be completed by July 2018 and the operational provision of space weather information will start by November 2018.

4. RELATED RSEARCH ACTIVITIES IN JAPAN

NICT has been undertaking ionospheric observations in Japan and Antarctica since the IGY at five stations located in Wakkanai (45.16N, 141,75E), Kokubunji (35.71N, 139.49E), Yamagawa (31.20N, 130.62E), Okinawa (26.68N, 128.15E), and Syowa (69.00S, 39.58E) as of 2013. Additionally, NICT has been one of the ground stations (35.71N, 139.49E) of the Real-Time Solar Wind network (RTSWnet) since 1997 and has been tracking two satellites, Advanced Composition Explorer (ACE) and Solar Terrestrial Relations Observatory (STEREO,), which retrieve real-time information on solar winds and images on the basis of international cooperation. NICT will contribute to provide data reception from Deep Space Climate Observatory (DSCOVR) satellite, which was launched in 2015. Concerning solar observation, NICT has a long history of measuring solar radio waves at the Hiraiso observatory since 1952. In 2014, NICT built a new solar radio telescope in Yamagawa observatory and started solar observation.

As a research project mainly studying the dynamics and characteristics of plasma bubbles and geospace disturbances related to radiation belt dynamics, NICT has network observations of the ionosphere in Southeast Asia, a ground-based magnetometer network in the Siberian region, and an HF radar in Alaska in cooperation with universities and academic institutes. At present, there are ionospheric observations with ionosondes in Chiang Mai, Chumphon (Thailand), Bac Lieu (Vietnam), Cebu (Philippines), and Kototabang (Indonesia). Other than GPS receivers, scintillation monitors and magnetometers are operated. The location of Southeast Asia Low-latitude Ionospheric Network (SEALION) makes it possible to perform magnetic conjugate observation, which is ideal for studying plasma bubbles, and some fruitful results have already been published as scientific papers (e.g., Uemoto et al., 2007, Maruyama et al., 2014). Geomagnetic observatories are located in Russia at Paratunka, Stecolny, Pebek, Tixie Bay, Dixon, Amderma (Russia), and at King Salmon (USA). An HF radar is also operated at King Salmon as a set of the Super Dual Auroral Radar Network (SuperDARN). The magnetometer network and HF radar observations enable us to study geomagnetic pulsations related to the supply and loss of radiation belt particles. NICT has also monitored ionospheric variations using two-dimensional maps of total electron content (TEC) derived from the Japanese dense GNSS network, GEONET. GEONET consists of more than 1,200 GPS receivers and is operated by the Geospatial Information Authority of Japan (GSI). Currently, NICT routinely provides quasi-real-time two-dimensional maps of absolute TEC, detrended TEC with 60-, 30-, and 15-minute windows, rate of TEC change index (ROTI), and loss-of-lock on GNSS signal over Japan (http://seg-web.nict.go.jp/GPS/QR_GEONET/index_e.html). These maps with a spatial resolution of 0.15 deg longitude and 0.15 deg latitude are useful for revealing spatial structures and temporal evolutions of wavelike ionospheric phenomena such as plasma bubbles and travelling ionospheric disturbances (TIDs), which can degrade single-frequency GNSS positioning and differential GNSS positioning. To expand the ionospheric observation area, NICT has collected all the available GNSS receiver data in the world (more than 6,000 GNSS stations as of 2014) and made regional and global high-resolution TEC maps. NICT has developed a new standardized TEC data format, the GNSS-TEC exchange (GTEX) format, to promote international sharing and the exchange of TEC data especially in the Asia–Oceania region. Data sharing based on the GTEX format has been discussed in Asia-Oceania Space Weather Alliance (AOSWA), the Ionospheric Studies Task Force (ISTF) of International Civil Aviation Organization/Asia and Pacific (ICAO APAC), and International Telecommunication Union-Radiocommunication sector / Study Group 3 (ITU-R SG3) since 2012. In 2015, the GTEX format was approved as one of the standard TEC formats in ITU-R (ITU-R Rec. P.311).

NICT has been developing the empirical, statistical and physical models and simulation codes of ionosphere and magnetosphere to improve the precision of space weather forecast. As some processes in space weather are still unknown, it is very difficult to build a numerical simulation code. On the other hand, NICT is required to provide space weather forecast for some applications, e.g., aviation, and. Currently NICT is providing some information with empirical models and developing numerical models. NICT created several empirical models to satisfy current user needs. Such models can provide practical information in near real time. Watanabe et al. [2003] developed an operational forecasting model for the Dst index using a neural network approach. Additionally, NICT has developed a Kalman filter based on a multivariate autoregressive model to predict relativistic electron flux at geostationary orbit [Sakaguchi et al., 2013]. In this model solar wind velocity, the magnitude of the north–south component of interplanetary magnetic field (IMF Bz), and current values of the relativistic electron flux are used for the prediction. The current status and prediction of relativistic electron flux at Geostationary orbit can be accessed online at http://seg-web.nict.go.jp/radi/.

To achieve objective and advanced space weather forecast for operational use in the near future, a numerical simulation code for space weather should also be developed. We have been developing two types of magnetospheric models: 1) A global magnetospheric magneto-hydro dynamics (MHD) simulation for understanding the physical processed of space weather [Tanaka, 1995]; and 2) A fast real-time 3-D MHD magnetospheric simulator used from 2004 to 2012 [Den et al., 2006]. The next-generation of the real-time simulation system is now under development. NICT has also developed a 3-D MHD simulation model extending from the solar surface into the heliosphere. Model-data comparisons confirmed that the MHD model successfully reproduces many features of the fine solar coronal structure and the global solar wind structure. [Nakamizo et al. 2009].

As some processes in space weather are still poorly understood, it is very difficult to build a numerical simulation code. Plasma bubbles are known to affect satellite positioning, and it is still difficult to forecast their occurrence numerically. NICT is now developing an empirical model of the occurrence of plasma bubbles using a neural net. At present, NICT can provide the TEC distribution in the vicinity of Japan every hour and also provide a forecast 24 hours in advance.

The behaviour of the lower atmosphere also influences ionospheric and thermospheric variations. NICT's Ground-to-Topside Model of Atmosphere and Ionosphere for Aeronomy (GAIA) [Jin et al., 2011] is being developed to solve ionosphere-thermosphere, including electrodynamics, in a self-consistent manner. Figure 2 is an example of GAIA. Thus far, the GAIA simulations reproduce and confirm vertical coupling processes involved in the formation of the averaged longitudinal structure of equatorial ionospheric anomalies. Although these numerical simulations are still far from practical use, these approaches are very important for future advanced numerical space weather forecast.

Data Center Support and International Cooperation: NICT functions as a World Data Center for the ionosphere and space weather in the framework of the International Council for Science (ICSU). This involves the compilation and maintenance of data archives of ionospheric observations, including NICT's own ionospheric observational data collected since the IGY, as well as internationally exchanged observational data. NICT is also actively working on data rescue activities to ensure that

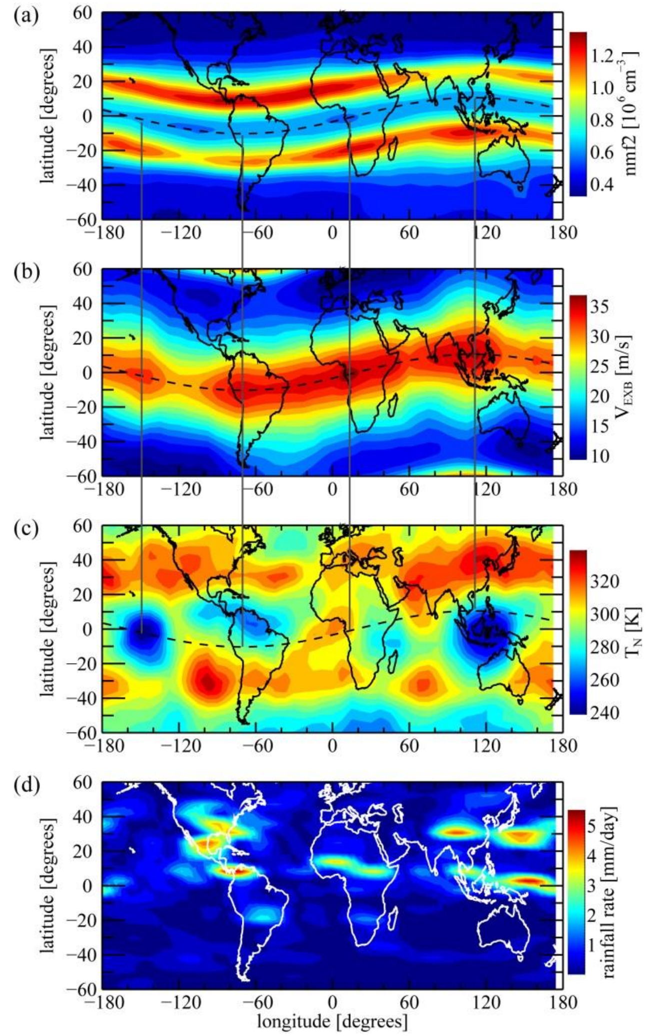

Figure 2 An example of the results of "Ground-to-Topside Model of Atmosphere and Ionosphere for Aeronomy" (GAIA) shown in Fig.2 of Jin et al. 2011. GAIA solves the ionosphere–thermosphere interaction self-consistently including the electrodynamics and lower atmospheric effects. This figure shows longitude-latitude distribution of 30 day averaged variables in September. (a) nmf2, (b) upward ExB velocity at 300km height, and (c) neutral temperature at a 110km height, (d) diurnal amplitude of the rainfall rate on the ground.

old film datasets can be preserved and used digitally. As a part of its data center functions, NICT is planning to start generating and providing metadata catalogues in accordance with internationally agreed standards, including that of the World Meteorology Organization (WMO) Information system (WIS).

NICT has been organizing the AOSWA for the collaboration of the operation and research of space weather in the Asia–Oceania region since 2011. At present, twenty-six institutes in thirteen countries are members of AOSWA. NICT has published (or regularly publishes) newsletters (AOSWA Link), which serve as a communication tool for its members, as AOSWA Secretariat. The 3rd AOSWA Workshop was organized by NICT in Fukuoka, Japan in March 2014. In addition, NICT contributes to activities for international cooperation on space weather in WMO, ITU, ICAO, and Coordination Group for Meteorological Satellites (CGMS).

5. ACKNOWLEDGMENTS

A part of this work was supported by JSPS KAKENHI Grant Number JP15H05813, "The Project for Solar-Terrestrial Environment Prediction (PSTEP)"

6. REFERENCES

[1] Uemoto, J., T. Ono, T. Maruyama, S. Saito, M. Iizima, and A. Kumamoto, Magnetic conjugate observation of the F3 layer using the SEALION ionosonde network, Geophys. Res. Lett., DOI: 10.1029/2006GL028783, 2007.

[2] Maruyama, T., J. Uemoto, M. Ishii, T. Tsugawa, P. Supnithi, and T. Komolmis, Low-latitude ionospheric height variation as observed by meridional ionosonde chain: Formation of ionospheric ceiling over the magnetic equator, J. Geophys. Res., doi: 10.1002/2014JA020215, 2014.

[3] Watanabe, S., E. Sagawa, K. Ohtaka, and H. Shimazu, Operational models for forecasting Dst, Adv. Space Res., 31, 2003, 829–834.

[4] Sakaguchi, K., Y. Miyoshi, S. Saito, T. Nagatsuma, K. Seki, and K. T. Murata, Relativistic electron flux forecast at geostationary orbit using Kalman filter based on multivariate auto-regressive model, Space Weather, 11, doi:10.1029/2012SW000864, 2013.

[5] Tanaka, T., Generation mechanisms for magnetosphere ionosphere current systems deduced from a three-dimensional MHD simulation of the solar wind-magnetosphere-ionosphere coupling processes, J. Geophys. Res., 100, 12,057, doi:10.1029/95JA00419, 1995.

[6] Nakamizo, A., T. Tanaka, Y. Kubo, S. Kamei, H. Shimazu, and H. Shinagawa, Development of the 3-D MHD model of the solar corona-solar wind combining system, J. Geophys. Res., 114, A07109, doi:10.1029/2008JA013844, 2009.

[7] Jin, H., Y. Miyoshi, H. Fujiwara, H. Shinagawa, K. Terada, M. Ishii, Y. Otsuka, and A. Saito, Vertical connection from the tropospheric activities to the ionospheric longitudinal structure simulated by a new Earth's whole atmosphere-ionosphere coupled model, J. Geophys. Res., 116, A01316, doi:10.1029/2010JA015925, 2011.

7. COPYRIGHT