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Near real time ionospheric monitoring system over Malaysia using GPS Data: My-Iono Service

Nyanasegari Bhoo Pathy[1-2], Tajul Ariffin Musa[1], Mhd Fairos Asillam[3], Wan Anom Wan Aris[1], Siti Syukriah Khamdan[1]

[1]UTM-GNSS & Geodynamics Research Group, Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.

[2]Space Science Division, National Space Agency (ANGKASA), Ministry of Science, Technology and Innovation, Jalan Turi, 42700 Banting, Selangor.

[3]National Planetarium, Ministry of Science, Technology and Innovation, 53, Jalan Perdana, 50480 Kuala Lumpur

ssegary@gmail.com

Abstract. Recently, real time information on the local ionospheric condition is becoming an important need for space and ground based technological systems which are prone to be affected by the local ionospheric state. Knowledge on the impact from the sun activity to the equatorial and low latitude ionosphere is crucial for research and development purpose in all developing nations which are relying on space-based technology systems such as the Global Navigation Satellite System (GNSS). As the first action step to achieve deeper understanding and hands on experience on real time ionospheric monitoring, the National Space Agency of Malaysia (ANGKASA) in collaboration with Universiti Teknologi Malaysia (UTM) has developed the first near real time ionospheric and space weather monitoring system for Malaysia (My-Iono) in year 2015. This web-based platform operates based on the National R&D GPS Continuously operating reference station network (NRC-net). The system runs based on a locally derived algorithm called Equatorial Ionosphere Index (EIX). The EIX was formulated based on 10 years (2004 to 2013) GPS derived empirical Total Electron Content (TEC) data obtained frpm 78 My-RTKnet stations around Malaysia. The fundamental of My-Iono Service consists of vertical TEC maps with a latency of ~ 2 mins over Malaysia and information on the current ionospheric status; Normal, Medium and Severe, time series of Mean VTEC for station specific, time series of RAte of Change of tEc (RACE) for station specific and time series of Ionospheric Zenith (Iz) Delay for station specific estimated in near real time using GPS observations. This paper presents on the development of My-Iono Service in terms of system design and architecture.

1. Introduction

Space weather refers to the conditions of the sun and in the space environment. Knowledge of the state of the ionosphere plays a crucial role in this chaotic weather system as space weather induces severe ionospheric disturbances that can cause damages to space-borne and ground-based technological systems, as well as endanger human life or health. The main industries whose operations can be severely affected by extreme space weather are electric power, space crafts, aviation and GPS/GNSS-based positioning and navigation industries (Fisher, 2011). Ionospheric disturbances are strongly affected by the number of the sunspots. Leong et al. (2009) stated that the ionospheric free electrons, known as TEC are strongly affected by the number of sunspots. It is affected the ionosphere due to the areas around the spots emit greater amounts of the ultraviolet radiation. The solar flare and coronal mass ejection (CME) are originated in magnetically active regions around the visible sunspot grouping.

Since the geomagnetic field and the ionosphere are linked in complex ways, a disturbance in the geomagnetic field often causes a disturbance in the ionosphere through fluctuations in electron density. This process can cause strong scintillation effects and large rapid changes in the ionospheric delay for GPS/GNSS signals, within time periods of about one minute (Janssen, 2012). The travelling ionospheric disturbances (TIDs) are moving ionospheric structures that may affect the use of accurate differential ionospheric refraction values for GPS applications. TIDs are also understood as plasma density fluctuations that propagate through the ionosphere over a wide range of velocities and frequencies, which can be seen in GPS TEC observations. Various studies have demonstrated that TIDs are a manifestation of the interaction between ionospheric and atmospheric gravity waves (Hines, 1960; Memarzadeh, 2009). Therefore, it would be of great advantage that the perturbations in the ionosphere are effectively quantified, translated into indices and disseminated to users as alert/warning

The common practice for quantifying ionospheric perturbations is to utilize geomagnetic indices such as Kp and disturbance storm time index, Dst (Menvielle and Berthelier, 1991). The Kp index quantifies the disturbances in horizontal component of geomagnetic field based on three hours observation of magnetometer. This index used by Space Weather Prediction Center (SWPC) for geomagnetic alerts and warnings that need to be issued to users. The Dst index is derived from a network of near-equatorial geomagnetic observatories that measures the intensity of globally symmetrical equatorial electrojet.

The geomagnetic indices have dual purposes which are (i) to give information on the geomagnetic on the geomagnetic activity level and (ii) to study the geomagnetic activity itself and its response to the various parameters such as influence of solar wind parameter and interplanetary magnetic field (IMF) (Svalgaard, 1997; Maezawa, 1978; Berthelier, 1979). These global indices are well suited to represent global phenomena so an offset from local ionospheric behavior must be expected. However, the occurrence and behavior of local ionospheric disturbances do not fully correlate with the characteristics shown in global/planetary indices (Jakowski et al., 2006). These scenarios are worse in the equatorial region as equatorial ionosphere effects is profoundly severe and much less understood than in other regions. The ionospheric TEC exhibits highly dynamic spatial and temporal morphological characteristics (Leong *et al.,* 2011). There is also a lack of ionosphere index to estimate the level of disturbances in Malaysia. To better classify, a local ionosphere index which will more closely describe the ionospheric disturbances over Malaysia must be obtained.

In this frame, the National Space Agency of Malaysia (ANGKASA) in collaboration with Universiti Teknologi Malaysia (UTM) has developed the first near real time ionospheric and space weather monitoring system for Malaysia (My-Iono Service) in year 2015. This web-based platform operates based on the National R&D GPS Continuously operating reference station network (NRC-net). The system runs based on a locally derived algorithm called Equatorial Ionosphere Index (EIX). The EIX was formulated based on 10 years (2004 to 2013) GPS derived empirical Total Electron Content (TEC) data obtained frpm 78 My-RTKnet stations around Malaysia. The details on the system design and architecture of the My-Iono Service will be presented in section 2 below.

2. System Design and Architecture of My-Iono Service Platform

The My-Iono Service design and architecture is illustrated in Figure 1. The system comprised with four (4) major sub-systems. As illustrated in Figure 1; *Subsystem 1* is data collection from NRC-net;

Subsystem 2: My-Iono Processing Centre and near real-time Ionosperic Maping; *Subsystem 3:* Data-based; and finally, *Subsystem 4:* Publicly web-based of My-Iono. Detail of each sub-systems will be described detail in section 2.1 until 2.5.

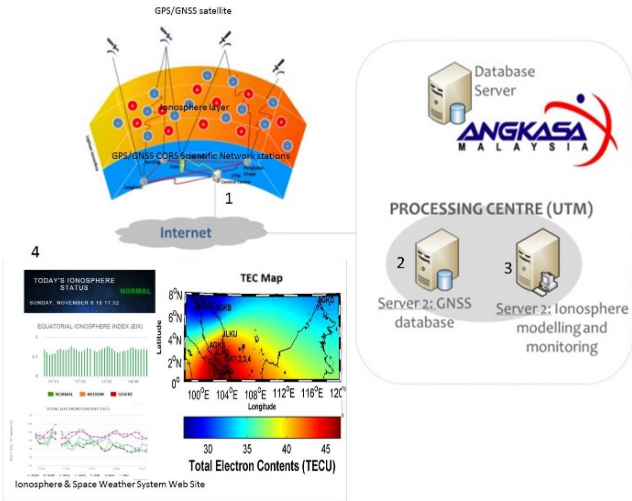

Figure 1: General My-Iono Service with four Subsystems.

2.1. Development of My-Iono Service

The development of My-Iono Service consists of three main steps.

i. Near real-time TEC derivation

The near real-time TEC value is derived from dual-frequency GPS measurement from each CORS station. The TEC real-time readings from CORS are recorded.

ii. Ionospheric perturbation Threshold

In this study, two types of threshold is used which are yearly limit that acquired empirical data from year 2004 to 2013 and monthly running threshold limit. The TEC_{lim} denotes an empirically defined threshold limit of ionospheric perturbation suited for Malaysia.

iii. Formulation of Equatorial Ionosphere Index (EIX)

The EIX is calculated based on gradient (North-South) by using linear regression of regional VTEC spatial variation which can be expressed mathematically as:

$$VTEC^{t0}_{j(\overline{Northing})} = \alpha + \left(\beta \times \left(\overline{Northing}\right)\right) \quad (1)$$

where

$$\alpha = \overline{V}TEC - \left(\beta \times \left(\overline{Northing}\right)\right) \quad (2)$$

$$\beta_n = \frac{\sum_{j=1}^{n}(Northing_j - \overline{Northing})(VTEC_j - \overline{VTEC})}{\sum_{j=1}^{n}(Northing_j - \overline{Northing})^2} \quad (3)$$

where n is the number of line grid in latitudinal direction, j is point grid in line n, $Northing_j$ is the coordinate of j in northing component, $\overline{Northing}$ is the average value of $Northing_j$, $VTEC_j$ is the VTEC for each point grid in line n, $\overline{VTEC}$ is the average $VTEC_j$ in line n, $VTEC^{t0}_{j(\overline{Northing})}$ is the mean VTEC over the region, and β_n is the slope $\overline{VTEC}$ for each line. From equation (3), the EIX is computed which can be expressed mathematically as:

$$EIX = \left[\left(VTEC^{t0}_{j\left(\overline{Northing}\right)}\right) \times \left(\frac{1}{VTEC_{lim}}\right) \times 10\right] \quad (4)$$

where $VTEC_{lim}$ is twice the averaged VTEC over 10 years empirical TEC data. In this research project, the average VTEC from the 10 years Bernese post-processing is 74.4 TECU. The EIX is scaled from 1 to 10 to act as indicator to describe the conditions of the ionosphere in the area. Figure 2 shows the level of indicator that is used in My-Iono Service.

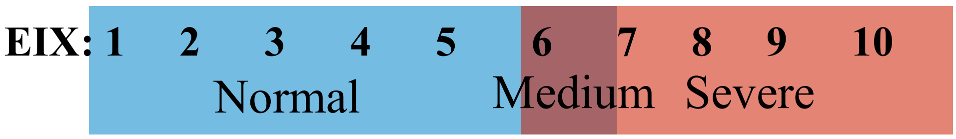

Figure 2: The level of EIX in My-Iono Service.

2.2. *Analysis and performance assessment*

This phase consists of three main steps.

i. EIX assessment

The EIX is assessed by calculating the correlation coefficient between EIX and globally/planetary ionospheric disturbances indices.

ii. EIX correlation analysis

The correlation between EIX and global/planetary ionospheric disturbance indicator is analyzed for the degree of agreement and suitability.

iii. Equatorial Ionosphere Analysis

In this section, the equatorial ionospheric phenomena is recorded and probed. The regional to small scale ionospheric disturbances in monitored.

2.3. *Correction in Differential Code Bias*

The differential code bias (DCB), as inner delay difference between the two frequencies, must be considered when estimating the TEC. Several meters of error, which equal up to ±20 to 40 TECU can occurred if the effect of the DCB is ignored. As a result, the TEC estimation can even turn to negative (Jin *et al.,* 2012; Sardon *et al.,* 1994). Based on the assessment that is carried out during analysis, the results turn out to give a wrong estimation due to the neglected estimation of DCB. Therefore, the DCB should be estimated and removed during TEC estimation in My-Iono System.

The DCB consists of receiver and satellite hardware delays that affect the accuracy of estimation of TEC (Jin *et al.,* 2012; Arikan *et al.,* 2008). The crucial part in DCB estimation is to estimate the receiver DCB which are not available for all analysis center (Jin *et al.,* 2012). However, various studies have been carried out to estimate and developed the suitable algorithm and approaches to estimate the DCB values. In My-Iono Service, the DCB is estimated by adopted method from Jin *et al.* (2012) in Figure 3.

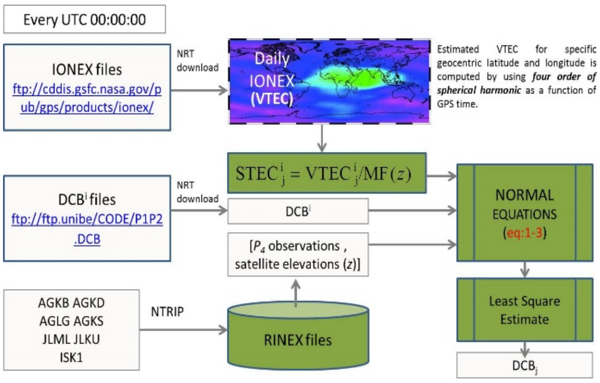

Figure 3: The processing strategy of near real time DCB in My-Iono Service.

2.4 Customization of My-Iono Service and Output

The My-Iono Service provides the near real time information such as:

a. Time measurement in local time;
b. The current ionopheric status; Normal, Medium and Severe.
c. A bar chart of the indicator,
d. Time series of mean VTEC for station specific,
e. Time series of Rate of Change of TEC (RACE) for station specific; and
f. Time series of Ionospheric Zenith (Iz) delay for station specific.

All of the above information's are displayed and saved per-epoch in form JPEG file. The system also provides the status of the program progress and problem trouble shooting such as internet connection status or system blackout where no data is provided from the server. Moreover, the near real-time TEC, RACE and Iz for each station are provided in form of numerical values and automatically written and saved in daily log file.

2.5. *My-Iono Service Webpage*

A webpage, My-Iono Service, is used in giving out alert/warning and information regarding current conditions and status from My-Iono Service to users. The My-Iono Service webpage can be access through www.myiono.angkasa.gov.my in Figure 4.

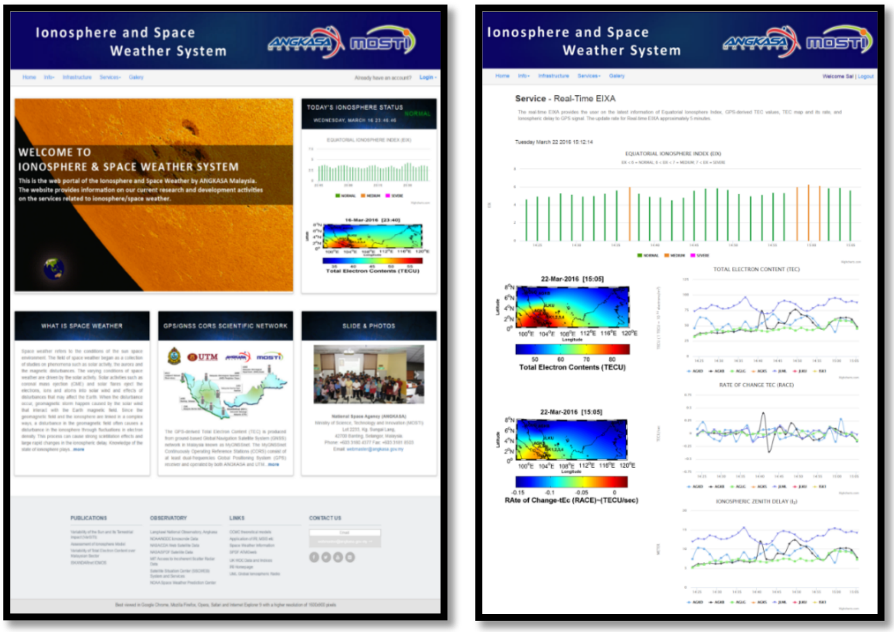

Figure 4: The layout of My-Iono Service webpage

3. Summary and outlook

This paper presents on the development of My-Iono Service in terms of system design and architecture. The My-Iono Service that has been developed has shown a good correlation with the global index and global TEC maps provided by other agencies. Moreover, this system able to trigger warning during the medium and severe conditions of ionosphere in the area during the performance assesment. Work is currently on going to address the performance of the system in regards with solar events in year 2015, 2016 and 2017.

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