Final Project Report
Detailed Form

I. Title of Proposed Project:

GNSS and Ionospheric Data Products for Disaster Prevention and Aviation in Magnetic Low-Latitude Regions

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IV. Project Report

i) Introduction

Solar terrestrial environment plays a crucial role in the study of magnetosphere and ionosphere which surround the earth. The ionosphere, an ionized layer at the altitude from 60 km to 1000 km, in magnetic low-latitude and equatorial region is known to be highly variable due to unique disturbance events. A well-known ionospheric irregularity, such as plasma bubble phenomenon, typically occurs after sunset due to the bottomside instability. The fresh plasma bubbles are known to develop from the magnetic equator to the higher latitudes along the magnetic field line and travel from the west to east direction. Occasional solar storm can also cause ionospheric storms.

Ionospheric irregularity often leads to degradation in communication and navigation. For communication, radio degradations especially at the high-frequency (HF) communication, which is used in maritime communication, aircrafts and disaster communication, may arise due to strong ionospheric variations such as the spread F events. For navigation, ionospheric scintillation effects [1] in Global Navigation Satellite System (GNSS) signals may result in loss-of-lock events, hence, fewer visible satellite signals are received. Reduced number of satellites inevitably increases the positional errors for users and reduces the continuity, integrity and availability of cm-level accuracy as required in precisioned agriculture, aviation as well as autonomous transportation. Recently, International Civil Aviation Organization (ICAO) and World Meteorology Organization (WMO) recognized the threat of space weather and its impact on aviation [1,3]. Although only several space weather centers were selected, the member states need to be knowledgeable in understanding space weather parameters and levels such as solar flares, solar radio bursts, coronal mass ejections (CME), high-speed solar wind streams, geomagnetic storms, and ionospheric activity. In additions, local ionospheric conditions need to be continuously monitored (similar to Weather forecasting). In fact, in 2019, the space weather data products were planned to be disseminated in aviation industry.

Thailand and neighboring countries are located in the low-latitude areas, where cover magnetic equator. King Mongkut's Institute of Technology Ladkrabang (KMITL) is a member of SouthEast Asia Low-latitude IOnospheric Network (SEALION), which is conducted by NICT and consists of 6 countries and 7 institutions in Southeast Asia and Japan. KMITL currently maintains three stations: KMITL campus (KMIT), Chumphon campus (CPN) and Phuket (PKT). These stations host an Ionosonde station, three GNSS stations as well as other instruments. Beside these three GNSS stations, KMTIL maintains four additional GNSS stations in the North as well as Northeastern part of the Thailand. Additionally, in 2019, NICT planned to install a large-scale VHF radar station at Chumphon campus, where is located near the magnetic equator, to monitor precise structures of plasma bubble. Together with the existing similar VHF radar station in Indonesia and the SEALION, the Chumphon VHF radar will enhance a better understanding in the generation and characteristics of plasma bubbles as well as benefit disturbance detection and warning capability.

As GNSS and Ionospheric data are vital to disaster prevention as well as aviation Industry and ionospheric effect is borderless, it is thus essential that KMITL develops GNSS and ionospheric data products for domestic users, and collaborates with researchers in neighboring countries. To collaborate with local industry and users, KMITL will need to keep developing our GNSS, Ionospheric and Space Weather data portal and carry out capacity-building activity for local users as well as our partnered institutions in neighboring region. Importantly, high-quality research works in this area will need to be continuously carried out.

ii) Project Activities

(1) Development and Implement

In this project, we have developed various data products in the field of GNSS and Space Weather. For space weather data products, we have developed daily GNSS data products for disaster and Aviation, i.e., 2-D TEC map, ROTI data products, the loss-of-lock statistics and scintillation. In addition, daily ionospheric data products such as foF2, Spread F and and prediction model for maximum usable frequency parameters and maps are generated. Figure 1 shows the locations of observation equipment and data network. On each day, the GNSS data from various stations as well as ionosonde data (ionogram) are transferred to the server at KMITL. Then we analyze the data and generate daily maps. The maps and plots are displayed on the website: http://iono-gnss.kmitl.ac.th.

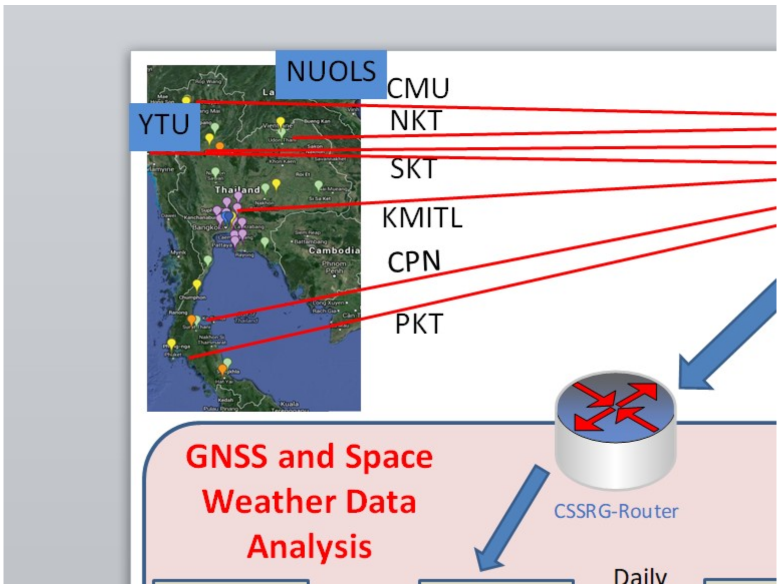


Fig. 1. Observation equipment and data network.

(2) Leveraged Resources and Participants

In this project, we tremendously rely on the participants from all institutes. Below are the responsible members for each task. Particularly, to analyze the ionospheric disturbances, data from many stations are needed. Therefore, we installed two additional GNSS receivers at National University of Laos (NUOL), Laos, as well as Yangon Technological University (YTU), Myanmar.

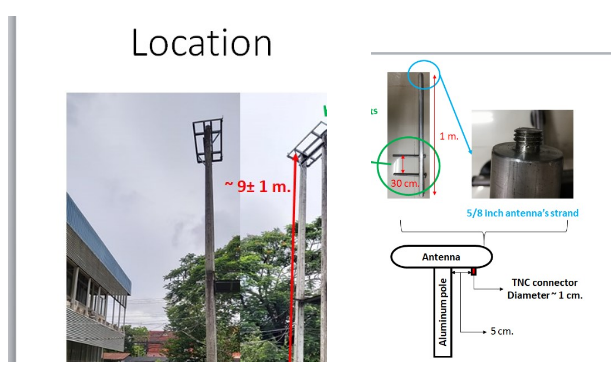
TEC and ROTI values are analyzed at all stations. The raw GNSS data in RINEX formats are transferred to KMITL servers on a daily basis via secure shell (SSH), then in-house TEC computation software is used for analysis. The maps are then generated as well. The MATLAB software is used mostly. For the satellite bias values, they are downloaded from CODE website.

For spread F and foF2 statistics, the data from Chumphon and Chiangmai stations are used. The ionogram images are scaled manaually, and then MATLAB software is used for anlysis. For IRI-2016 data, they are download from IRI website. (IRI = International Reference Ionosphere)

Project Activites	**Responsible members**
1. Install dual-frequency GNSS receiver at YTU (Myanmar) Collect observational data for further analysis	KMITL, YTU
2. Install dual-frequency GNSS receivers at NUOL (Laos) Collect observational data for further analysis	KMITL, NUOL
3. Develop daily GNSS data products for disaster and Aviation • Study the Space Weather (SW) Data Format for Aviation • 2-D TEC map, ROTI data products • Analyze the loss-of-lock statistics and scintillation • Prediction model for iono parameters, GNSS parameters	KMITL, YTU, NUOL
4. Develop daily ionospheric data products: foF2, Spread F	KMITL, CMU
5. To support the new installation of VHF Radar Station at Chumphon, Thailand	KMITL (Chumphon), NICT
6. Seminar, Workshop	ALL

The figures below show the locations of NUOL and YTU, where new GNSS receivers are installed.

<u>National University of Laos (NUOL), Laos</u>



Yangon Technological University (YTU), Myanmar

(3) Findings and Outcomes

Figure 2 shows examples of the plots of critical frequency (foF2), the median values as well as Spread F occurrences. Typically, the HF communication outage is considered under two conditions: (1) when the observed foF2 values are below 30% of the median values or (2) when spread F events occur. In this plot, we show the variation of foF2 at Chumphon station in 2014, for instance.

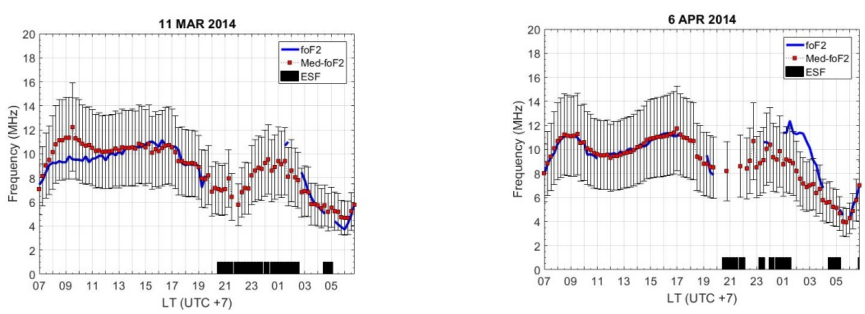


Fig. 2. Examples of the plots of critical frequency (foF2), the median values and Spread F occurrences

Figure 3 shows examples of the plots of Spread F occurrences in 2014. The reason we choose 2014 is because it is during the peak of solar cycle (repeating every 11-12 years). It can be seen that the occurrence rates of spread F (range-type) are up to 50% in March 2014.

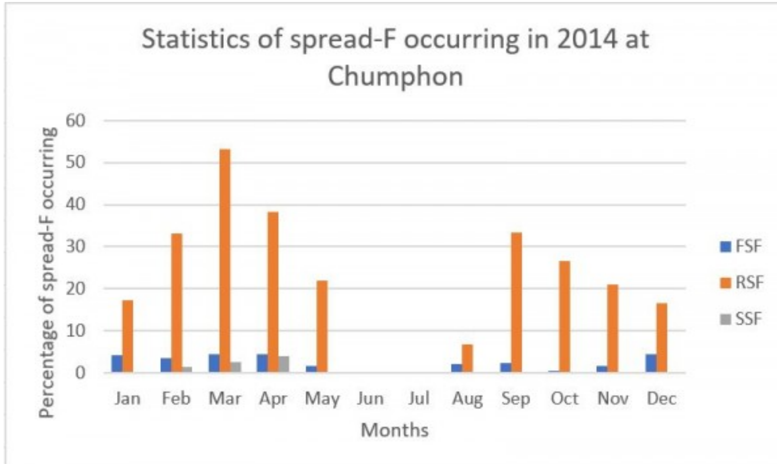


Fig. 3 Spread F occurrence rates at Chumphon station in 2014.

Figure 4 shows examples of the plots of scintillation at Chumphon on 18 March, 2018. The S4 index values are plotted for L1 and L5 frequencies. On this day, the S4 values reach 0.3 and 0.35 for L1 and L5 frequencies, respectively. The L5 frequency is affected more than L1 counterpart evidently.

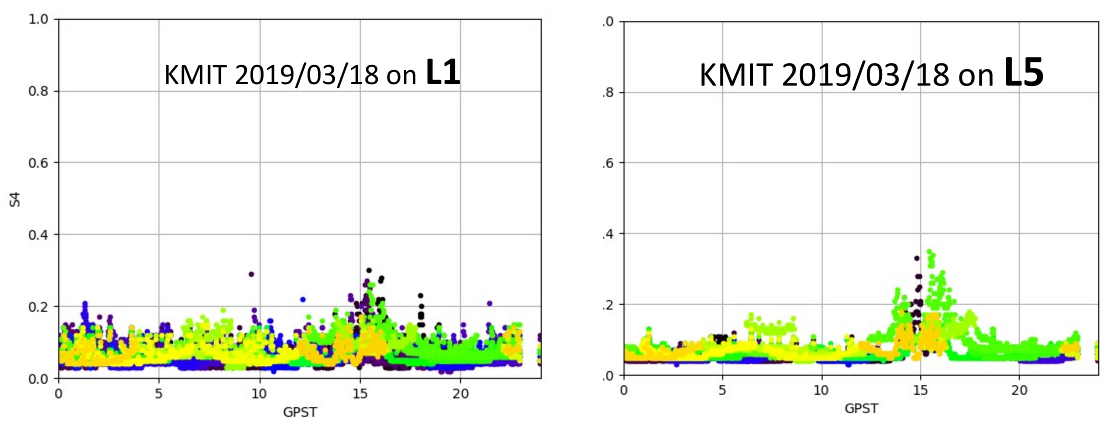
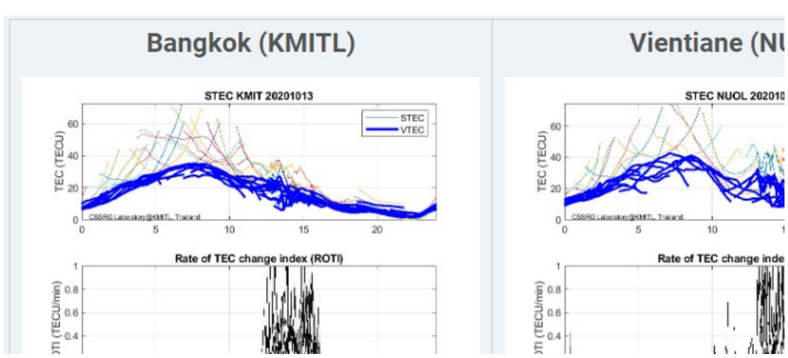


Fig. 4. Examples of the scintillation plots at Chumphon on 18 March, 2018.

Figure 5 shows examples of total electron content plots at 4 stations: Bangkok, Chaingmai, Vientiane (Laos) and Nakhon Ratchasima on 13 October, 2020.



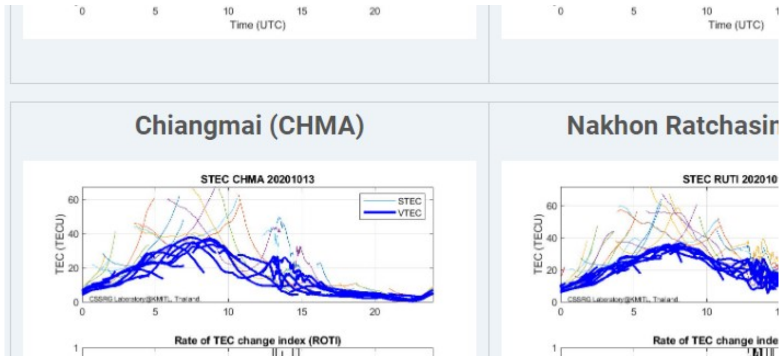
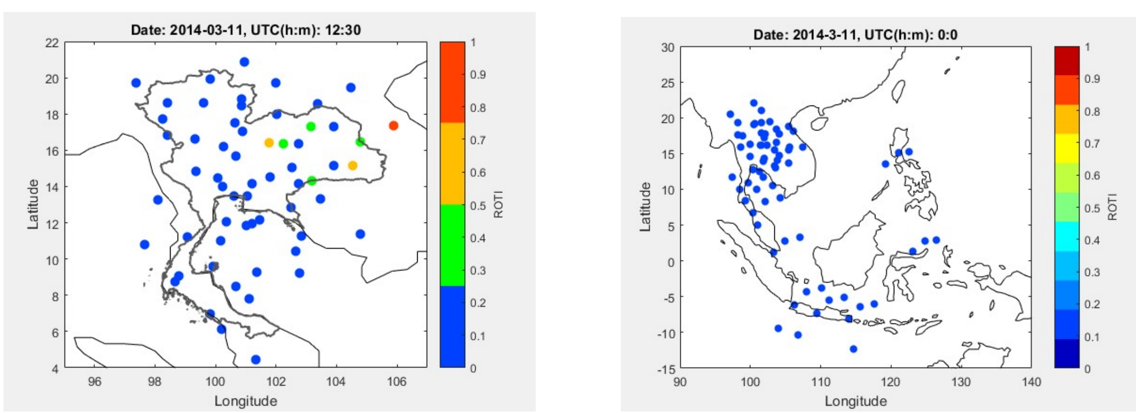


Fig. 5 shows TEC and ROTI plots at 4 stations on 13 October, 2020.

The total electron content (TEC) is computed by the difference between code pseudoranges at L1 and L2 frequencies. On the other hand, the rate of TEC change index (ROTI) is the standard deviation of TEC from the mean values. It indicates the disturbances in the ionosphere. From this figure, we see that ionospheric disturbances occur at all stations. Although it is not as severe at Chiangmai (CHMA) station as others.

Figure 6 shows examples of 2-D ROTI maps over Thailand and partial region of ASEAN. This type of map is used to show disturbances from the top view.



(a) (b)

Fig. 6. Examples of 2-D ROTI maps over (a) Thailand and (b) partial region of ASEAN

Figure 7 shows examples of the maximum usable frequency (MUF) Map when the transmission is set at Udonthani province. It indicates the required frequencies for transmission with HF propagation from the northeastern part of Thailand. Specifically, we use the Lockwood algorithm to convert the foF2 values produce this map.

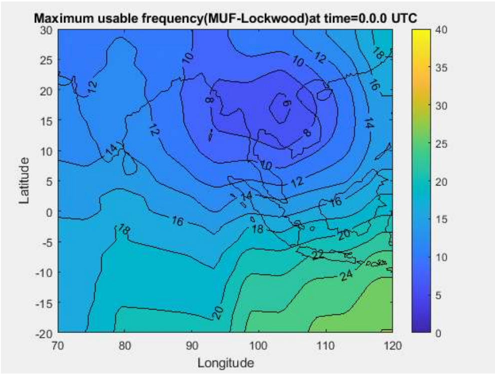


Fig. 7 shows examples of the maximum usable frequency (MUF) Map

The findings potentially impact the area of HF communication, ionospheric study, air navigation and precise positioning such as those used in autonomous vehicles. For air navigation, GNSS-based standards such as GBAS (ground-based augmentation system) and satellite-based augmentation system (SBAS) require the correction of ionospheric delays as well as prior warning of ionospheric disturbances. For precise positioning such as real-time kinematics (RTK) or ppp-RTK, accurate local ionospheric delays impact the convergence rates of positioning fix. For MUF maps, it is useful to aeronautical communication, military communication and navy usage.

(4) Broader Impact

The impacts of this project are as follow.

- Enhance better understanding of ionospheric disturbance in magnetic equator and low-latitude region, particularly, ASEAN region.
- Useful ionospheric disturbance detection for aviation and HF communications, prevalent, in aviation and communications in disaster situation, especially, along the coastal areas.
- Better disturbance characterization is required to determine performance of high-accuracy GNSS system used in other industries such as precisioned agriculture and autonomous driving.
- Regional data collection is important for long-term study and useful to global model improvement (such as IRI model and IGS model).

(5) Future Developments

Future developments of this project will move into the following directions.

- Utilization of artificial intelligence on disturbance detection and warnings (ROTI, foF2, spread F and hybrid usage)
- Keogram and transformation of mappings
- Effects of disturbances on navigation standards (GBAS CAT II-III), multi-GNSS and

disturbance warning based on aeronautical constraints.
- Region-wide plasma bubble detection.
- Improvement of international IRI model

(6) Social Contribution

International publications:

No	**Paper title:**	**Author names**	**Affiliation**	**Name:**	The date	Venue
1	Spread F Prediction Model for the Equatorial Chumphon Station, Thailand	P. Thammavongsy, P. Supnithi, W. Phakphisut, K. Hozumi, T. Tsugawa	KMITL, NICT	Journal of Advances in Space Research	Vol. 65, 2020, pp. 152-162	
2	Study of topside scale height based on NeQuick topside formulation and their comparison with ionogram-derived scale height in 2014 at Ascension Island	P. Jamjareegulgarn, P. Supnithi, T. Tsugawa, K. Hozumi	KMITL, NICT	IRI 2019 Workshop	9-13 Sept. 2019	Nicosia, Cyprus
3	Comparison of Spread-F probability and the IRI-2016 model during descending solar cycle in 2016 at the equatorial Chumphon station, Thailand	P. Thammavongsy, P. Supnithi, P. Kenpankho, K. Hozumi, T. Tsugawa	KMITL	IRI 2019 Workshop	9-13 Sept. 2019	Nicosia, Cyprus
4	The Statistics of Equatorial Spread-F and Effects on Critical Frequency at Chumphon, Thailand	P. Thammavongsy, P. Supnithi, W. Phakphisut, K. Hozumi, T. Tsugawa	NUOL, KMITL, NICT	(SICONIAN 2019)	15-16 Nov, 2019	Palembang, Indonesia
5	Performance of GAGAN Satellite-based Augmentation System in Thailand Region	S.Sophan, W.Phakphisut, L.Myint, P.Supntihi	KMITL	ITC-CSCC 2020	3-6 July, 2020	Nagoya, Japan (online)
6	Improvement of Kalman Filter for GNSS/IMU Data Fusion with Measurement Bias Compensation	N.Nilchan, P.Supntihi, W. Phakphisut	KMITL	ITC-CSCC 2020	3-6 July, 2020	Nagoya, Japan (online)

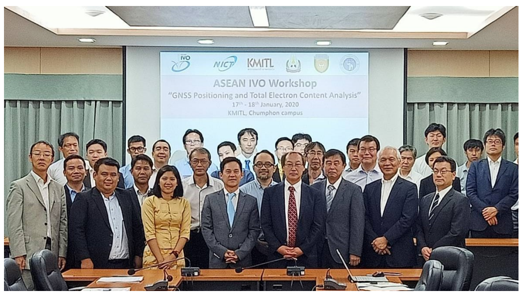
7	The disturbance effects on single-frequency GPS positioning at low-geomanetic latitude stations in Thailand	N.Tongkasem, L. Myint, P. Supnithi, K.Hozumi	KMITL, NICT	ITC-CSCC 2020	3-6 July, 2020	

Exhibitions

Space Weather Knowledge, National Science and Technology Fair in November 2019, 2020

Workshops

1. GNSS Positioning and Total Electron Content Analysis Workshop, Chumphon, Thailand (17-18 January, 2020)



2. Research Seminar on GNSS and Ionosphere Seminar (30 October, 2020)