The First Results of Analysing GPS Observations at IEODO Ocean Research Station in Korea

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Key words : IEODO ocean research station (IORS), Global Navigation Satellite System Global Navigation Satellite System(GNSS), Ocean Crustal Deformation, Zenith Path Delay of Troposphere(ZPD)

SUMMARY

A GPS continuously operating reference station was installed at IEODO ocean research station (IORS) in 2009 to support marine geodetic research activities. IORS is an offshore fixed plant structure, constructed on a submerged rock where is located in 149Km southwest from the southernmost island of Korea. The society of IEODO research and GNSS and geodynamics research group at Universiti Teknology Malaysia have collaboratively commenced processing the IEODO GPS data to examine its potential applications for ocean crustal deformation and meteorological studies. To this end, an ultra-high precision of GPS processing scheme has been applied for deriving a time series of the station coordinates and spatiotemporal variation of zenith path delay of troposphere. The first results of the analysis are presented with the aim of their applicability to scientific research.

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1. INTRODUCTION

IEODO, a submerged rock within a Korean's territorial, is located in 149Km southwest from MARADO, the southernmost island of Korea (see, e.g., Figure 1). Its most shallow peak is about 4.6m below the sea level. IEODO stretches about 600m north-south and 750m east-west from its top while it makes steep slopes in south and east and rather gentle slopes in north and west.

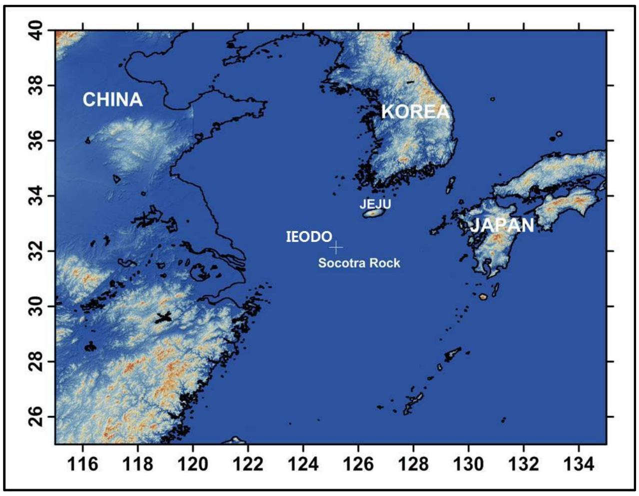

Figure 1. Geographical location of IEODO

In order to cope with natural disasters, such as earthquake and Typhoon, and ocean climate change, IEODO ocean research station (IORS), an offshore fixed platform was constructed on the rock in 2003 (see., e.g., Figure 2). It equips with the state-of-the-art ocean weather and environment sensing systems, and provides their observations in real-time mode for 24 hours a day. Furthermore, IORS has been used as a platform for maritime police and/or rescue works as well as a lighthouse to guide safe sailing for a quarter-million vessels a year. To support marine geodetic research activities, a GPS continuously operating reference station (CORS) was installed at the station in 2009 and has made its observations since then. While a

Trimble NetRS receiver and TRM 41249.00 antenna were initially established, they have been replaced by NetRS9 and TRM 55971.00 in January 2013. From standpoint of its application to scientific activities, the society of IEODO research has recently taken its first action to process the GPS data through international collaboration with GNSS and geodynamics research group (G&G) at Universiti Teknologi Malaysia. This project has focused on ultra-high precision of GPS analysis by BERNESE Version 5.0, scientific GPS data processing software, to estimate a time series of the station coordinates and zenith path delay of the troposphere (ZPD). This presentation provides preliminary results of the analysis which includes the coordinates and velocity vector with respect to IGS08 and temporal and spatial correlation of ZPD with the typhoon MEARI in 2011.

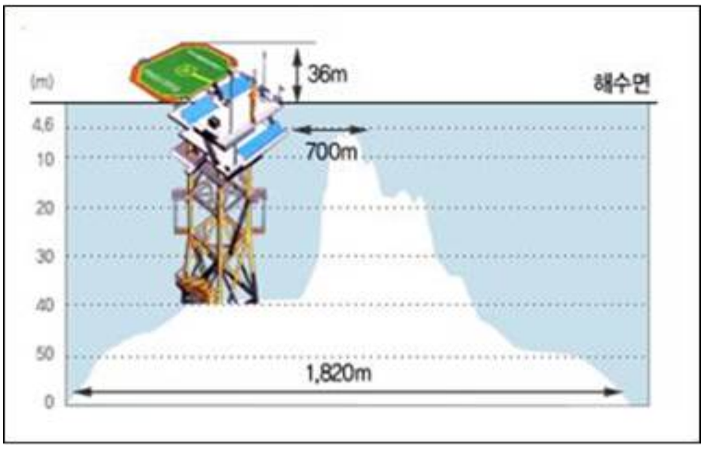

Figure 2. Layout of IORS installation

2. GPS DATA AND SOFTWARE USED

IEODO GPS station used to equip with Trimble NetRS receiver and TRM 41249.00 antenna but has been replaced by those of NetRS9 and TRM 55971.00 in January 2013. The operating condition of the station faces very harshness due to limited electric power supply and network connection. The GPS observations from 2009 to 2012 have been firstly examined to pick up possible data sets to be processed, revealing that only 398 days were available. This project has endeavoured to process all the available measurements with 13 KORS, CORS operated by National Geographical Information Institute of Korea, and 10 IGS (International GPS Services) stations to define the datum (e.g., IGS08).

The Bernese version 5.0 is selected as the main data processing software in this project. It provides several unique data processing tools useful to handle a huge number of GPS measurements (Gendt et al., 2005). For instance, the Bernese processing engine (BPE) automatically processes GPS observations according to predefined scripts, whereas the ADDNEQ2 module computes multi-session solutions with the statistically correct combination of a set of single-session solutions. In this project, the BPE is utilized to processes daily GPS raw measurements and the ADDNEQ2 estimates final solutions of coordinate and velocity vector referenced to IGS08.

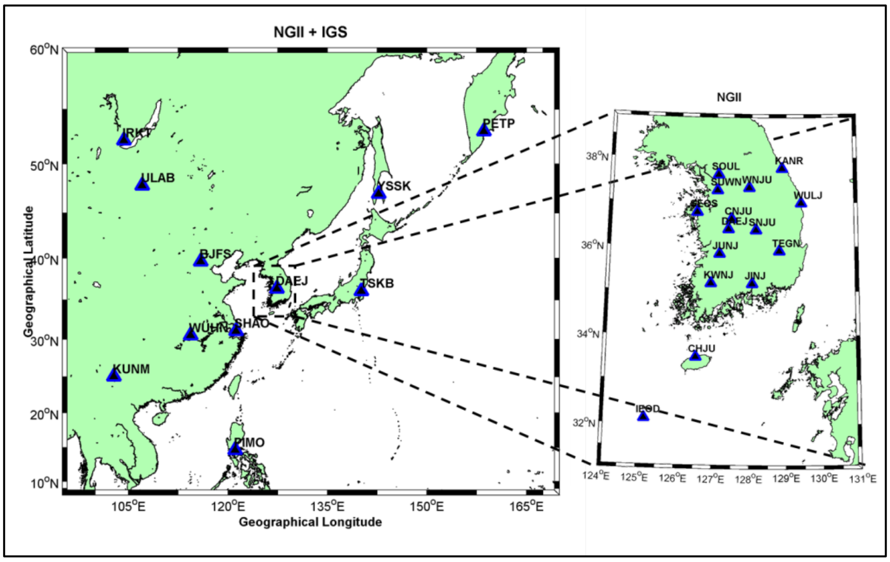

Figure 3. GPS CORSs used in the processing

3. COORDINATE AND VELOCITY VECTOR OF IEODO STATION

A GPS data processing procedure adopted in this project consists of two steps: (a) daily and; (b) final solutions. While the former processes raw GPS measurements, the latter is the combination of the daily normal equations by the sequential least-squares adjustments. The minimum constraints technique imposing Helmert constraints on coordinates and velocities of IGS reference sites was applied for the definition of the datum. Such an approach has been known as an optimum way that defines the datum of a geodetic network because small errors in the coordinates of a reference station do not distort the network geometry nor significantly degrade the datum definition (Altmanimi, 2003).

IGS final orbit and Earth orientation parameters were used in the processing. These IGS products were unfortunately referenced to 2 different geodetic reference frames (e.g., IGS05 and IGS08) during the period of the GPS observations from 2009 to 2012. It is well known that the same reference frame should be used for the ground stations during the analysis to ensure the best possible consistency (Boucher and Altamini, 1996). To this end, the IGS products were transferred to the reference frame to which the current IGS station coordinates aligned (e.g., IGb08). The tropospheric delays were estimated and the quasi-ionosphere free (QIF) strategy was employed for the ambiguity resolution (Dach et al., 2007). The absolute antenna phase centre variation (PVC) model for GPS receivers and satellites were applied for their corrections. Considering the amount of GPS data, the daily processing was automatically carried out by the BPE, resulting in a total of 398 solutions.

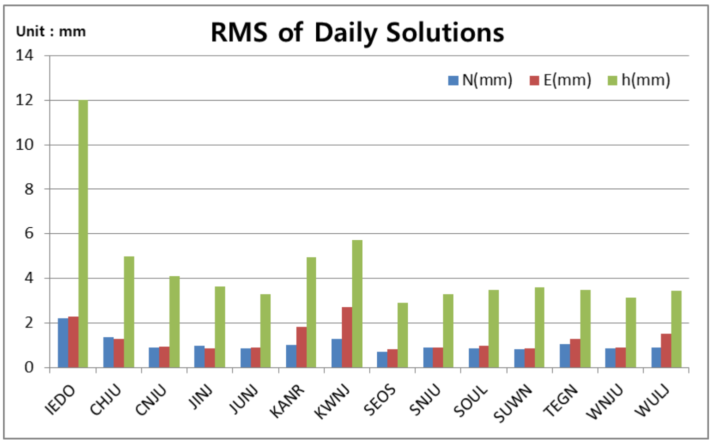

Figure 4. RMS of daily solutions

A series of network adjustments combining the daily normal equations was performed not only to access precision of the daily solutions but also to examine possible outliers, detecting nine days and removing them from the database. Figure 4 shows RMS (root-mean-squares) values of the daily solutions with respect to the combined adjustment. The values of the horizontal component range from 1 to 2 mm, whereas those of the vertical component are mostly around 5mm. However, it should be noted that the vertical RMS of the IEODO station is relatively larger than the others. This phenomena can be also observed in Figure 5, plotting vertical repeatability of the daily solutions, so that further investigation is required to identify the reason whether receiver and/or antenna malfunctioning, observation environment around the site or unexpected pillar displacements. To this end, a site visit is under schedule in near future. Figure 6 plots the time series of the coordinates, indicating consistent movement of the IEODO station toward southeast.

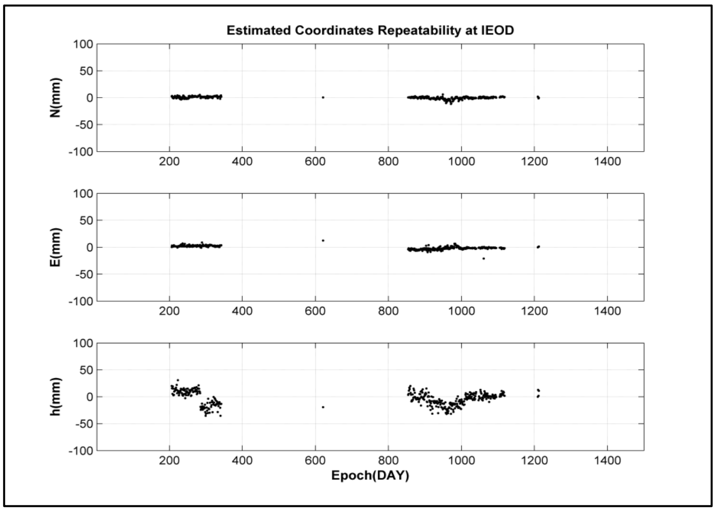

Figure 5. Repeatability of IEODO daily solutions (2009–2012)

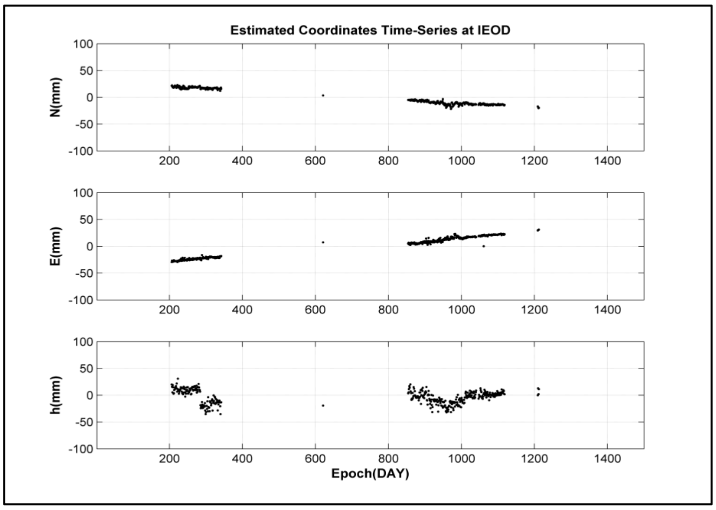

Figure 6. Daily solutions of IEODO (2009–2012)

A final adjustment to estimate the IEODO's coordinate and velocity was carried out and tabulated in Table 1. The velocity vectors of all the stations determined by the adjustment are presented in Figure 7. It can be seen from the results that trend of the station deformation of the IEODO has good agreement with that of the Korean Peninsula.

Table 1. Station Coordinates and Velocity Vectors estimated by this research

No.	Station	Geographic coordinate system(Reference epoch 24/10/2010)			Velocity Vector		
		Latitude	Longitude	Ellipsoid Height(m)	N(m)	E(m)	h(m)
1	IEDO	32-07-21.926644	125-10-57.212996	55.6778	-0.0137	0.0207	0.0023
2	CHJU	33-30-50.131902	126-31-47.360538	50.3500	-0.0137	0.0208	0.0004
3	CNJU	36-37-36.816978	127-27-40.425792	93.4975	-0.0129	0.0261	0.002
4	JINJ	35-10-23.110168	128-02-58.836367	122.0234	-0.0109	0.0248	-0.0006
5	JUNJ	35-50-36.423764	127-08-06.458161	77.1572	-0.0122	0.0241	0.0013
6	KANR	37-46-15.335778	128-52-05.629402	57.0575	-0.0128	0.0327	-0.002
7	KWNJ	35-10-42.147934	126-54-36.860750	71.6397	-0.011	0.0227	0.0037
8	SEOS	36-46-35.069429	126-29-39.138284	52.2813	-0.0127	0.025	0.0036
9	SNJU	36-22-44.988738	128-08-40.126164	111.6009	-0.0119	0.0264	0.001
10	SOUL	37-37-46.893969	127-04-47.015869	59.1179	-0.0134	0.0262	0.0024
11	SUWN	37-16-31.849493	127-03-15.273205	82.2596	-0.0134	0.0265	0.001
12	TEGN	35-54-22.699999	128-48-07.091079	106.3940	-0.0099	0.0278	-0.0014
13	WNJU	37-20-13.941986	127-56-49.527056	180.2202	-0.0124	0.0284	0.0016
14	WULJ	36-59-31.111771	129-24-46.791885	80.7643	-0.0108	0.0325	0.0006

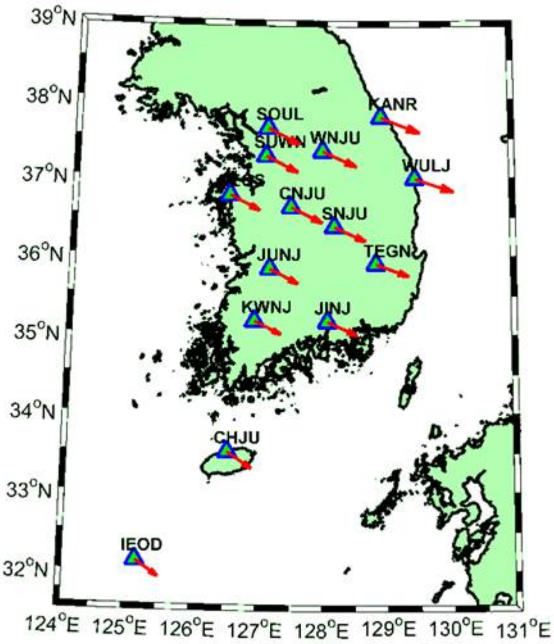

Figure 7. Map of the station velocity vectors estimated by this research

4. ZENITH PATH DELAY DURING EVENT OF TYPHOON

A typhoon is a meteorological phenomenon brining heavy rain and strong winds, which is a main natural disaster in Korea. Recording the variation in the atmospheric water vapour during the passage of typhoon is particularly important as it is the main source of precipitation and a dominant constituent of energy resources related to typhoon dynamics (Frank, 1977). GPS enables to provide a relatively inexpensive and effective way to remotely sense atmospheric water vapour (Davis et al., 1985; Dick et al., 2001). This can be implemented by analysing a delay of the satellite signals while propagating into the lower atmosphere. The delay is represented as the zenith path delay (ZPD) which can be separated into a dry and a wet component. Because zenith wet delay (ZWD) contains information on atmospheric water vapour profile and temperature, it can be converted to precipitable water vapour (PWV) through application of an appropriate function with a regionally weighted mean temperature model.

Considering the geographical location of the IEODO GPS station, an entrance of typhoons to Korean Peninsula (see, e.g., Figure 1), it has a great potential to contribute improvement of a Typhoon weather forecast if the GPS processing would provide the WVP in accurate. Hence, a preliminary attempt has been made in this project to analyse the ZPD during an event of the typhoon MAERI in 2011. Figure 8 shows trajectory of the typhoon from its creation to dissipation (e.g., 22nd to 27th June; Day of Year (DoY) 173 to 178). While the daily GPS data was being processed, the ZPD was simultaneously estimated at 1-h intervals for each station from DoY 169 to 179.

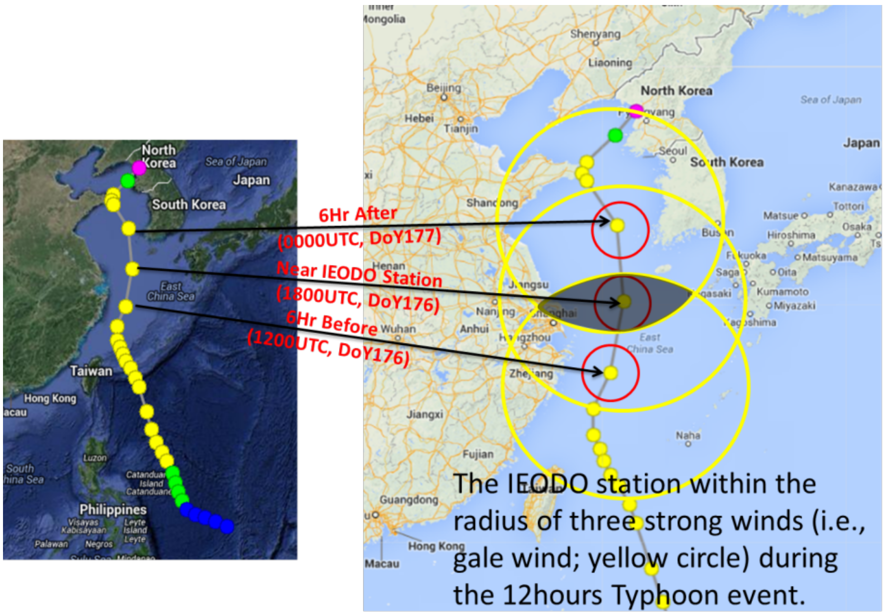

Figure 8. Trajectory of typhoon MEARI (http://agora.ex.nii.ac.jp)

Figure 9 plots temporal variation of the values at the GPS stations in Korea including IEODO. The ZPD has high magnitudes before and during the typhoon's passage. It can be understood from the results that its increase is induced by the water vapour in the atmosphere which is highly related with the typhoon's energy. Figure 11 illustrates spatiotemporal variation 6 hours before and after the typhoon's passage near the IEODO. Note that the plot is interpolated from the hourly GPS ZPD estimation, confirming that the ZPD is sensitive to geographical location as the typhoon moves northward.

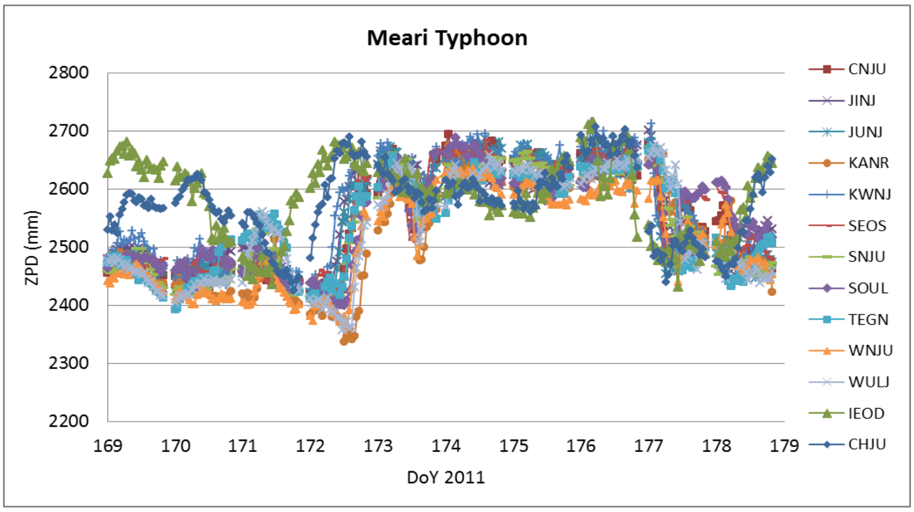

Figure 9. Temporal variation of ZPD at 14 GPS stations in Korea

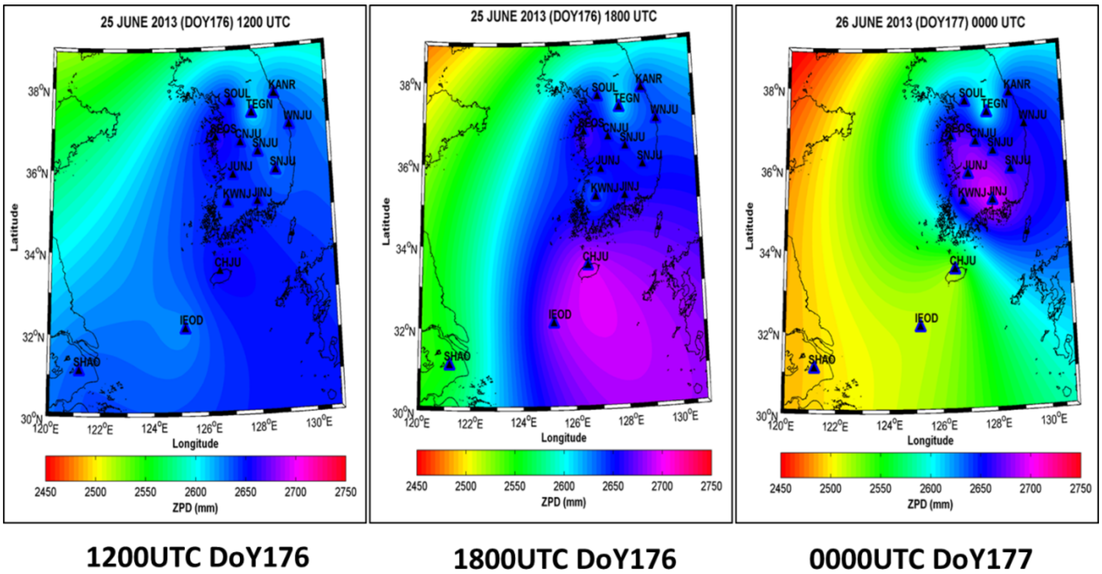

Figure 10. Spatiotemporal variation of ZPD during passage of Typhoon MEARI

5. CONCLUDING REMARKS

IEODO GPS data has been processed in this project together with 13 KORS and 10 IGS stations by the Bernese software; a total of 398 days of observations was analysed. The daily normal equations are combined though the sequential least squares, producing the final solution to estimate the station coordinates and velocity vectors. The precision assessment of the daily solutions has revealed few millimeter-level in the horizontal and mostly 5 mm in vertical component, respectively. However, it is of importance to observe that the vertical precision of the IEODO is relatively less than the others, so further investigation is highly required to identify an actual source. In addition, the estimated velocity vector of the IEODO has similar trend with those in the Peninsular, which is toward southwest with magnitude of 25mm/year. In addition, a time series of the ZPD was preliminarily analysed together a trajectory of the typhoon MEARI from DoY 173 to 178 in 2011, indicating that the values increase before and during the passage of the typhoon and decrease rapidly after it passed. Results of the spatiotemporal analysis of the ZPD revealed that the value has high sensitivity to geographical location of the typhoon. Not that this project has only focused on the ZPD itself, so that derivation of PWV from GPS will be carried out in near future to investigate its performance with a comparison of radio-sonde observations and other meteorology sensors.

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