Estimation of GNSS PWV in KOREA Peninsula for a Very Short-Term Weather Forecast

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Abstract

GNSS technology is highly useful for a very short-term weather forecast because information on moisture can be obtained from the GNSS data with high temporal and spatial resolution. In this study, GNSS precipitable water vapor (PWV) for Korea Peninsula region is estimated in near real-time i n order to utilize the PWV for practical applications. GNSS observation data are collected from nine permanent GNSS stations in the Korea Peninsu la. The number of the GNSS stations will be increased up to more than eighty in the near future. Zenith total delay (ZTD) is estimated using double-differenced carrier phase observations and Bernese GNSS software version 5.2. Then, PWV can be retrieved using a local mean temperature equatio n (MTE) for Korea Peninsula. As a result, the GNSS-PWV is estimated and provided to a user every 10 minutes. This PWV information will be utili zed as the initial value of a numerical weather model, and we expect that it will improve the reliability of a very short-term weather forecast, such as a torrential rain. Moreover, it is also expected that the PWV can provide useful information about a fog phenomenon.

1. Research Goal

Table 1. Main requirements

- PWV accuracy : < 2 mm
- Temporal res. : 10 ~ 15 min
- Spatial res. : 100 ~ 200 km → 10 ~ 30 km (in the next stage)

The Korea Astronomy and Space Science Institute (KASI) develops a GNSS-PWV information management system to apply the PWV to practical applications, such as the initial value of a numerical weather model, research on a fog phenomenon, or the Air Force operational weather. The technical requirements of the project are shown in Table 1. To meet the requirements, the GNSS-PWV information management system is built up using high-performance computers and Bernese GNSS software.

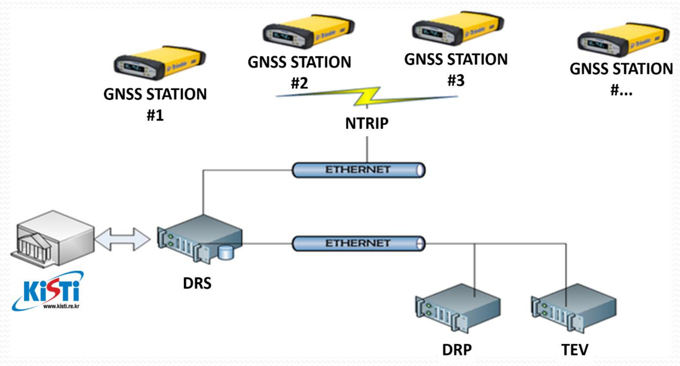

Figure 1. The architecture of the GNSS-PWV information management system

2. A GNSS-PWV Information Management System

The GNSS-PWV information management system developed by the KASI allows to estimate ZTD in near real-time, as well as in post-processing. The architecture and the specific features are shown in Figure 1 and Table 2, respectively. The system consists of a DRS, DPS, and TEV, which are divided functionally. The DRS receives data and provides information to a user. The DPS processes GNSS data and then estimates PWV. The TEV is in charge of redundancy of the DPS as well as a test and evaluation. This system was made of high-performance computers to process enormous data. For speedy collection of the data, NTRIP was adopted, thereby RINEX files are received from GNSS stations every 10 minutes. Finally, Bernese GNSS software version 5.2 produces a local network solution every 10 minutes. The main parameters set up in the Bernese are shown in Table 3. The GNSS observation data shifts every 10 minutes with a sliding time window of 24 hours. In conclusion, this system can meet the requirement for the temporal resolution.

Table 2. The GNSS-PWV information management system

Severs	DRS: **D**ata **R**eceive and Service **S**erver DPS: **D**ata **P**rocessing **S**erver TEV: **T**est and **EV**aluation (Redundancy)
The specification of DPS	Model: HP ProLiant DL360p Gen8 - 2 Intel Xeon E5-2640 (2.0GHz, 8-core) - 512GB SSD 4EA
# of stations	12 including 4 IGS stations → > 80 (in the near future)
Data collection	NTRIP, 10 min intervals
O/S	LINUX (Ubuntu 12.04 LTS)
Software	Bernese GNSS software version 5.2

Table 3. Main parameters for processing

Method	Network solution
Observation data	GPS/GLONASS, L1&L2
Observation window	24 hours
Data sampling rate (RINEX)	30 sec
Mapping function	GMF
Parameter spacing	1 hour (ZTD), 24 hours (gradients)
Rel. a priori sigma	2 mm (ZTD), 0.2 mm (gradients)
Tropo. time res.	300 sec

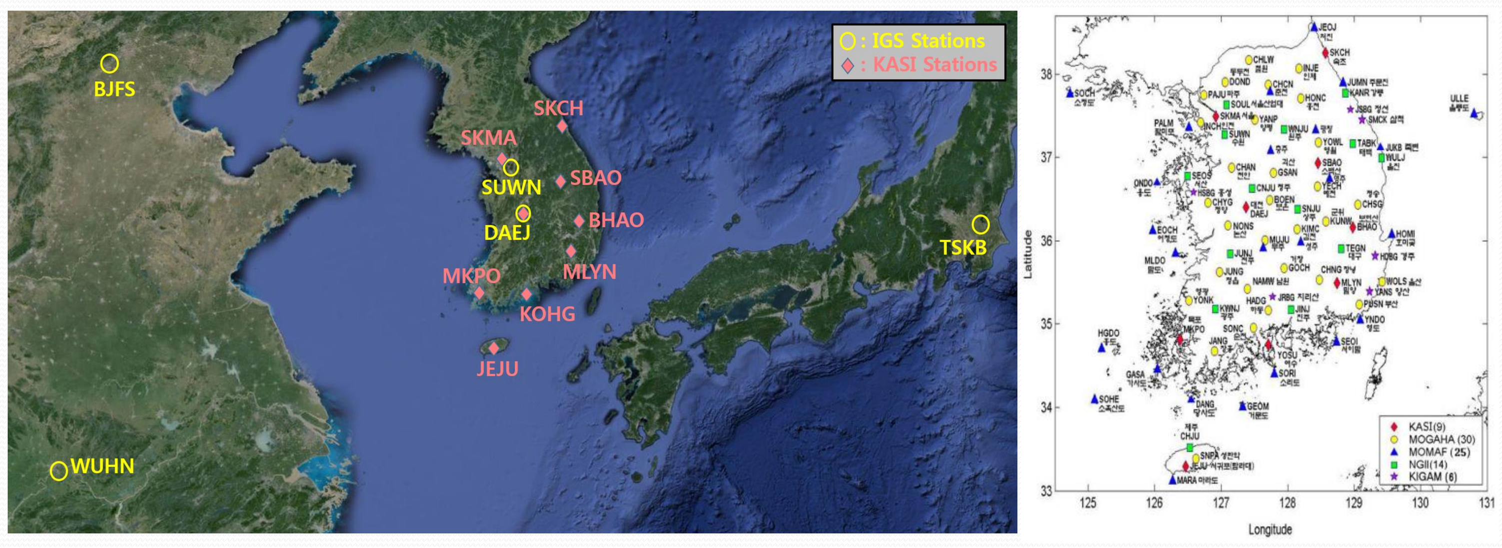

Figure 2. The network of GNSS stations in Korea Peninsula and the surrounding area (left), GNSS stations being added in the near future (right)

3. A Network of GNSS Stations

The KASI has the network of GNSS stations consisting of nine permanent GNSS stations in Korea Peninsula, which has spatial resolution of 100 ~ 200 km (the left side of Figure 2). To meet the requirement for the spatial resolution in the next stage as shown in Table 1, we have a plan increasing the number of the GNSS stations up to more than eighty in the near future (The right side of Figure 2). Then, the spatial resolution will be highly improved up to 10 ~ 30 km. In the current study, DAEJ is an only IGS reference station among the KASI's stations. Therefore, in order to define the local datum, GNSS observation data from four IGS stations - SUWN, BJFS, TSKB, and WHUN - around Korea Peninsula are added as shown in the left side of Figure 2.

4. Estimation of GNSS-PWV in Korea Peninsula

An estimated GNSS-PWV should meet the accuracy requirement of Table 1. However, because there is no proper reference, such as radiosonde observation data, we indirectly assess the accuracy of the PWV. First, ZTD estimates obtained in post-processing (PP) mode using the GNSS-PWV information management system are compared to IGS final troposphere products. Although the IGS products are not true, they are used as the reference in the current study. Then, ZTD estimates obtained in near real-time (NRT) mode are compared to the post-processed ZTD estimates for the nine KASI stations. Finally, GNSS-PWVs are retrieved from the near real-time solutions using several MTEs respectively, and then they are compared to each other.

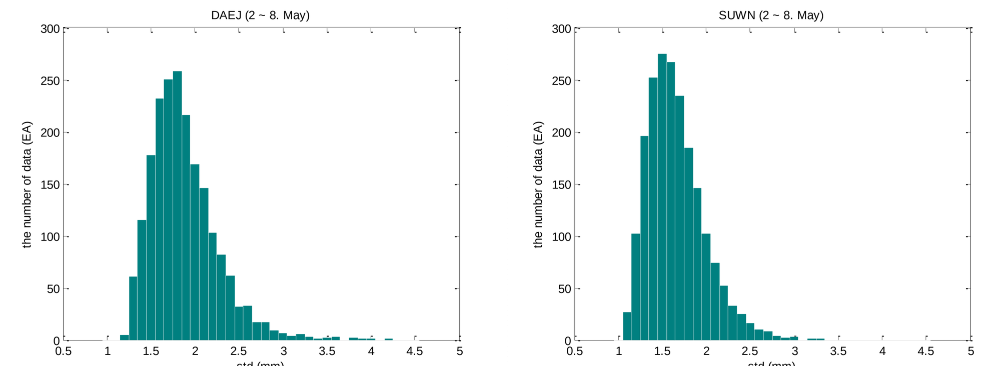

Figure 3. The histogram of the standard deviations for the ZTD (left: DAEJ, right: SUWN)

4.1 Post-processed ZTD estimates

ZTDs were estimated in PP mode for the time period of 2014-05-02 00:00 UTC to 2014-05-08 00:00 UTC. As shown in Figure 3, the standard deviation is centered around 1.6 mm. The ZTD estimates were compared to IGS final troposphere products for two IGS stations - DAEJ and SUWN - in Korea Peninsula. The results over seven days are shown in Figure 4. The mean, standard deviation, and RMS of the differences are in Table 4. In conclusion, the overall mean difference was 0.54 ± 7.12 mm with an average RMS of 7.14 mm in ZTD.

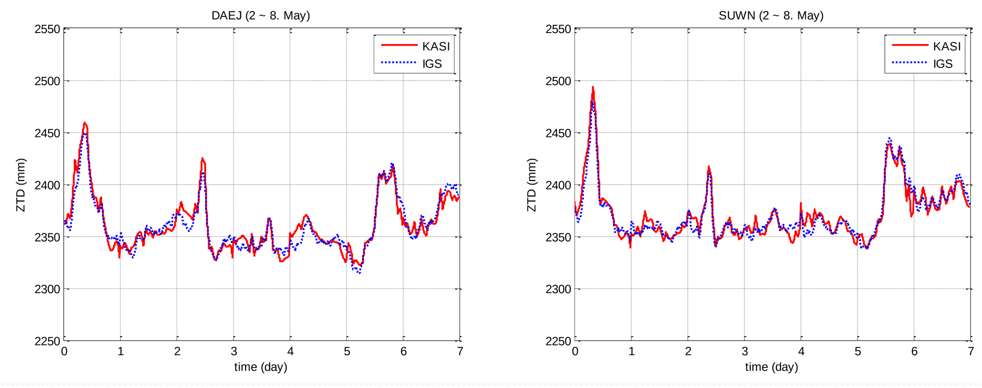

Figure 4. The comparison with IGS final troposphere products for the time period of 2014-05-02 UTC to 2014-05-08 UTC (left: DAEJ, right: SUWN)

Table 4. Statistics for the comparison with IGS products

Station	Mean (mm)	Std. (mm)	RMS (mm)
DAEJ	0.60	7.54	7.56
SUWN	0.48	6.70	6.71

4.2 Near real-time ZTD estimates

To assess the accuracy of ZTDs estimated in NRT mode, they were compared to the post-processed ZTD estimates for nine KASI stations. Compared with PP mode, the ambiguity resolution scheme of the NRT mode was simplified (see Table 5).

Table 5. Main differences between NRT mode and PP mode

Mode	Orbits and ERPs	Ambiguity
Post-Processing	IGS Final	Combined*
Near Real-Time	IGS Ultra-rapid	QIF

*: Select an optimized method among Sigma (L5/L3), QIF, and Sigma (L1&L2) by considering a baseline

Figure 5 shows ZTDs obtained from NRT mode and PP mode respectively. In Figure 5, the green lines mean the difference in the estimates. The statistics are shown in Table 6 in detail. Consequently, the overall mean difference was -0.44 ± 3.60 mm with an average RMS of 3.63 mm in ZTD.

Table 6. Statistics for the differences between near real-time and post-processed ZTD estimates

Station	BHAO	DAEJ	JEJU	KOHG	MKPO	MLYN	SBAO	SKCH	SKMA
mean (mm)	-0.55	-0.33	-0.25	-0.39	-0.31	-0.61	-0.50	-0.60	-0.46
std. (mm)	3.53	3.89	3.48	3.47	3.48	3.50	3.47	3.79	3.80
RMS (mm)	3.58	3.90	3.48	3.49	3.50	3.55	3.50	3.84	3.82

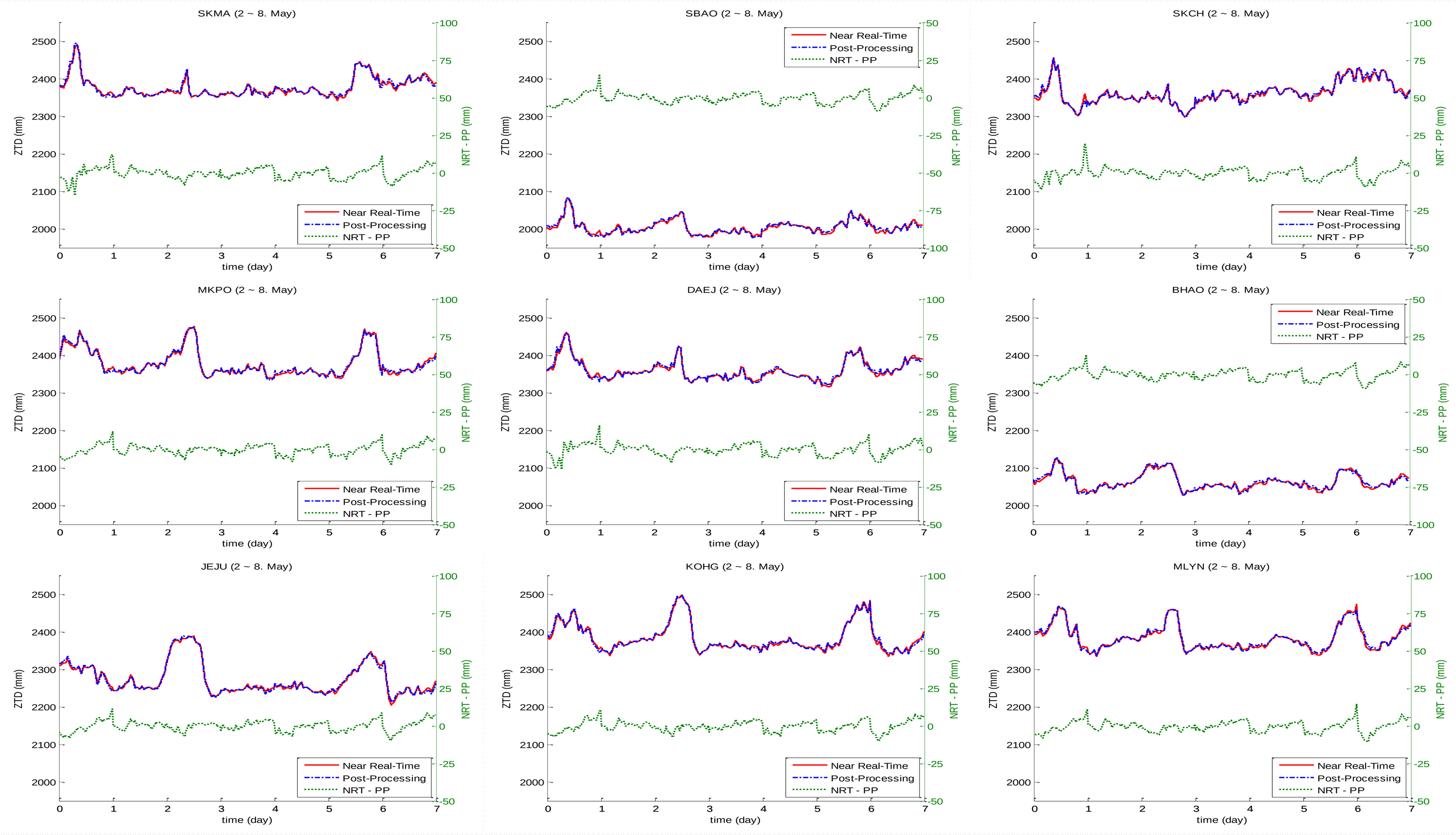

Figure 5. ZTDs estimated in NRT mode and PP mode for nine KASI's stations for the time period of 2014-05-02 UTC to 2014-05-08 UTC

4.3 GNSS-PWV estimates

As a final step, GNSS-PWV was retrieved from the near real-time ZTD estimates using several MTEs. For this study, a MTE derived by Ha et al. (2006) was adopted as a local MTE for Korea Peninsula. MTEs derived by Bevis et al. (1992) and Mendes et al. (2000) were also used to compare with the local MTE. Figure 6 shows GNSS-PWVs using the three MTEs respectively and the differences between the local MTE and the other MTEs. The RMS for the nine KASI's stations are shown in Table 7. The maximum RMS is less than 0.05 mm.

Table 7. The RMS of the PWV differences between the local MTE and the other MTEs

MTEs	Station	BHAO	DAEJ	JEJU	KOHG	MKPO	MLYN	SBAO	SKCH	SKMA
Ha – Bevis	RMS (mm)	0.02	0.05	0.05	0.03	0.04	0.05	0.04	0.04	0.04
Ha - Mendes	RMS (mm)	0.01	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.02

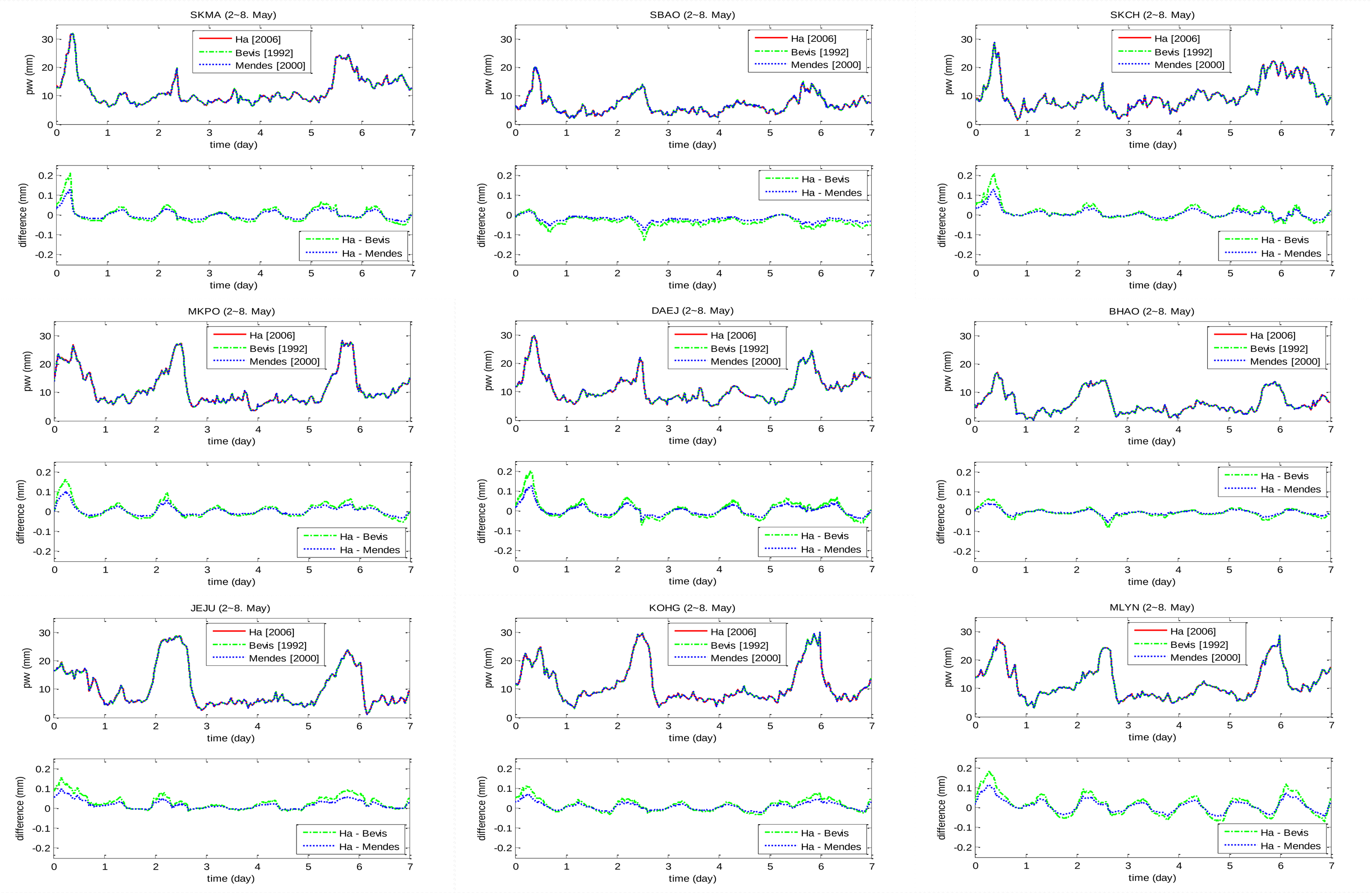

Figure 6. GNSS-PWVs for the nine KASI's stations for the time period of 2014-05-02 UTC to 2014-05-08 UTC

4.4 Accuracy assessment of GNSS-PWV

The average RMS of 7.14 mm and 3.63 mm in ZTD was found between the post-processed ZTDs and IGS products, and the near real-time ZTDs and the post-processed ZTDs, respectively. The average RMSs can be approximately converted into an error of GNSS-PWV by considering the typical ratio of zenith wet delay and PWV. In the current study, the ratio is defined as 6.5. Then, the error of GNSS-PWV is about 1.66 mm. Even if the maximum RMS of 0.05 mm for the difference of the MTEs is additionally considered, the error is less than 2 mm in PWV. In conclusion, the accuracy of the GNSS-PWV meets the requirement for the PWV accuracy of Table 1.

5. Conclusions and Future Works

The developed GNSS-PWV information management system allows to estimate GNSS-PWV in near real-time and provide the information every 10 minutes. The current network of GNSS stations has spatial resolution of 100 ~ 200 km but it will be improved up to 10 ~ 30 km soon. Finally, we found that the expected error of the GNSS-PWV estimates is less than 2 mm in PWV by means of the indirect assessment for the accuracy. These results meet the requirements of Table 1 well. The ultimate goal of this research is to utilize the GNSS-PWV for practical applications.

5.1 Plans for future applications

- Applying the GNSS-PWV to the initial value of a numerical weather model for very short-term torrential rain forecast.
- Utilizing 3-D distribution of water vapor for the Air Force operational weather

5.2 Future works

- Compare the GNSS-PWV with radiosonde observations for the accuracy assessment.
- Develop a new optimized local MTE by using long-term meteorological data.
- Research on a 4-D tomographic water vapor model using a dense network of GNSS stations.

Acknowledgements

This Research has been performed as a collaborative research project of Building Response System for National-wide Issues Based on High-performance Supercomputer supported by the KOREA INSTITUTE of SCIENCE and TECHNOLOGY INFORMATION (KISTI)

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