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Korean National Report to IAG

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Korean National Report to the International Association for Geodesy, 2011

1. INTRODUCTION

It is the first national report of Korea to the International Association for Geodesy (IAG) and mainly includes the information on geodesy-related research and development activities in last four years. The ground-based and space-based infrastructures for geodesy have been rapidly increased from 2000, and some of these infrastructures are still under construction in Korea. Recently, many of important and fruitful results in this research field came by the unsparingly efforts of scientists, engineers and management staffs who are belong to the universities, research institutes, and Korean government.

There are several Korean universities related with geodesy including University of Seoul, Inha University, Ajou University, KyungIl University and etc. Korea Astronomy and Space Science Institute (KASI) and Korea Institute of Geoscience And Mineral Resources (KIGAM) are the main government-funded research institute for geodesy-related research works. In addition, Korea Aerospace Research Institute (KARI) and other government-funded research institutes are closely connected to the KASI, KIGAM and universities. In the case of government organization in Korea, the Ministry of Land, Transport and Maritime Affairs (MLTM) and National Geographic Information Institute (NGII) under MLTM are core organizations for geodesy. The ministry of Education, Science and Technology (MEST) and other government organizations are also involved in geodesy-related activities.

This document mainly provide the research works in geodesy of NGII, KASI, University of Seoul and Inha University over the 2008-2011 even though other institute and universities has their own activities for geodesy.

For the enlargement of geodetic infrastructures in Korea, many of research institutes and government organization put the budget for this purpose. Korean GNSS Network (KGN), which is consist of more than 100 Continuously Observing Reference Station (CORS), has been upgraded by changing the GNSS receiving system and related infrastructures in last few years. Especially, KASI had conducted several projects for hosting the (associate) analysis center of International GNSS Service (IGS) after official operating the IGS Global Data Center (GDC) from 2006. The construction of Korean SLR system (ARGO, Accurate Ranging system for Geodetic Observation) started in 2008 to make one 40 cm mobile SLR system (ARGO-M) and one 1 m fixed SLR system (ARGO-F). ARGO-M conducted by KASI will be integrated with all the sub-systems and tested at the end of this year. KASI had also acquired the official approval for operating the combination canter of the International VLBI Service for Geodesy and Astrometry (IVS) in Oct. 2008. In addition, NGII is constructing a dedicated geodetic 21m VLBI station at Sejong that is located in middle of South Korea from 2010. KOMPSAT-5 (KOrea Multi Purpose SATellite) will be launched at the end of Aug. 2011. It will be the first Synthetic Aperture Radar (SAR) satellite of Korea and provide not only SAR image for Geospatial Information System (GIS) but also the Radio Occultation (RO) observation data for GNSS meteorology.

As the necessity of the geophysical data is increased due to various scientific problems, NGII had completed the construction of the Unified Control Point (UCP) which covers the whole country with 10km by 10km spacing at the end of 2010. This basically collocate the position and gravity information so that efficient and reliable applications could be conducted. NGII is also conducting the gravity survey on the benchmarks to revise the Korean vertical datum which includes the re-definition of the origin and the change of the height system to orthometric by the end of 2011. At present, it is considered that a well constructed gravity network is available in Korea. The data quality of the recent data sets is good enough for the precision geoid development and orthometric height determination.

There are many research topics for the application of geodetic techniques in Korea. The research works for the determination of coordinate reference frame, Earth Orientation Parameters (EOP), crustal deformation, GNSS meteorology, DGPS & network RTK, Precise Orbit Determination (POD) of GNSS satellites and Vertical Datum Monitoring are described in this report

Korea has contributed to the IAG activities during the last decade. There are two IGS station, 4^{th} IGS GDC, 2nd IVS combination center and member institute of ILRS. Currently, Korea has one IGS governing board member-at-large and one Global Geodetic Observing System (GGOS) Steering Committee member-at-large. KASI is also the member agency of GGOS Inter-Agency Committee. The contribution to the IAG from Korean side will be more activated in next decade.

2. SPACE GEODETIC INFRASTRUCTURE

2.1 GNSS

The Korean GNSS Network has more than 100 permanent GPS reference stations including the two IGS stations (SUWN and TAEJ) that have been established since 1999. Several governmental agencies including the Korea Astronomy and Space Science Institute (KASI) in the Ministry of Education, Science and Technology (MEST), the National Geographic Information Institute (NGII) in the Ministry of Land, Transport and Maritime Affairs (MLTM), and other institutes and universities have operated the GNSS stations and related facilities. The KGN is distributed uniformly throughout the Korean Peninsula. The spatial resolution of the KGN is approximately under the 50 km, which provides high spatial resolution observations. The geographical distribution of the permanent KGN stations is shown in Fig. 2.1.

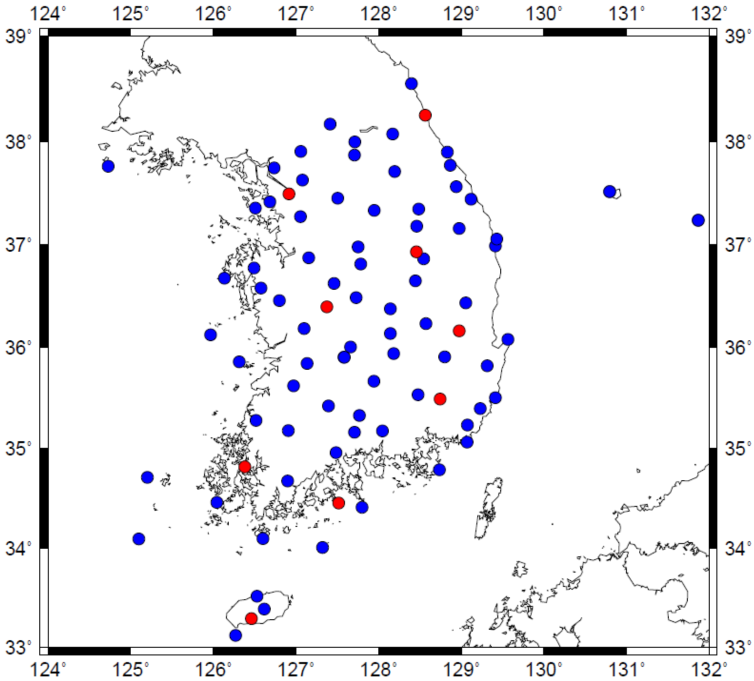


Figure 2.1 The geographical distribution of KGN.

Each reference station of the KGN is basically equipped with a geodetic dual frequency GPS receiver. The aims of the KGN are specified as the monitoring of local and regional crustal deformation, scientific research, cadastral surveys, providing geographic information, and transmitting the differential GPS & RTK data for a nationwide service through some specific communication link methods.

KASI is operating the IGS global data center (GDC) for the international scientific researches and applications from 2006. The KASI GDC archives and provides the Asia-Oceania regional GNSS data directly and also, archives and shares all the IGS data and products from more than four hundred worldwide IGS stations and IGS analysis centers *(http://gdc.kasi.re.k)* collaborated with other IGS GDCs.

In 2011, new permanent GNSS stations are planned to be constructed by KASI in the territories of Mongolia and the Federated States of Micronesia. The Mongolian and Micronesian GNSS stations are expected to provide a valuable GNSS data from the locations of north-east Asian area and southern Pacific Ocean. KASI will also replace the GNSS receiving system of their IGS station, TAEJ, from GPS only to Multi-GNSS capability including GPS, GLONASS, Galileo and QZSS in the middle of 2011. In addition, KASI will also apply to host a QZSS reference station of JAXA to participate the Multi-GNSS campaign under the umbrella of IGS.

Many interests in the research area of space geodesy by using GNSS technology have been given by science communities in Korea. Especially, KASI has been focused on the application of GNSS space geodetic techniques to terrestrial reference frames, time reference frames, space weather monitoring, and GNSS meteorology. Therefore, KASI is developing their own GNSS data processing and analysis software package with its own intrinsic models and techniques.

Recently, the international space geodetic community strongly requests the international cooperation to resolve the global agenda problems such as climate changes, natural disaster prediction, and monitoring of the changing Earth by using space geodetic infrastructures and technologies. Korean space geodetic community actively participates and contributes to the international activities of IAG and other international geodetic communities.

2.2 SLR

ARGO Program

KASI (Korea Astronomy and Space Science Institute) has preceded a governmental program named ARGO (Accurate Ranging system for Geodetic Observation) since 2008 to develop one mobile and one fixed SLR systems, ARGO-M and ARGO-F respectively.

ARGO-M, which will be completely developed in 2011, has the separate optical path that employs the 40cm receiving and 10cm transmitting telescopes. The system is a semi-automated and KHz laser ranging system with the single shot range precision of about one centimeter and NP precision better than 5 mm for LAGEOS satellite. ARGO-M is capable of tracking satellites with the laser retro-reflector array in the range of 300 to 25,000 km altitude and will provide 24 hour tracking coverage including daylight tracking. Some essential components effecting on ranging accuracy came from the foreign institutes, which include the timing system, photon detector, laser and optoelectronic controller developed by Graz station in Austria. The CDR (Critical Design Review) of ARGO-M was carried out on March 2011 and it is now in the phase on a fabrication and system integration. Table 2.1 show the performance and specifications of ARGO-M determined after the critical design review.

Table 2.1 Major specification of ARGO-M.

Item	Parameter	Characteristics and Specification
Telescope	Path type	Bistatic/coude path
	Primary mirror radius	200 mm
	Secondary mirror radius	45 mm
	Primary mirror F-ratio	1.5
	Transmitting beam divergence	5~200 arcsec
	Tracking & Pointing accuracy	<5 arcsec
	Field of view (full angle)	5 arcmin
Detector	Quantum efficiency	20%
	Rising time	100 ps~2 ns
	Field of view	90 arcsec
Laser	Wavelength	532 nm
	Pulse energy	2.8 mJ @2 KHz
	Pulse width	15 ps
	Repetition rate	2 KHz

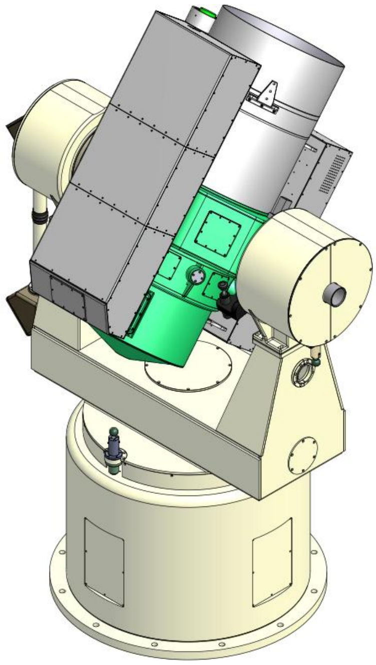


Figure 2.2 3-dimensional shape of ARGO-M system

ARGO-F, which is equipped with a telescope of 1 m diameter, has the common optical path and its development will actually begin from 2012 after ARGO-M completion. Its basic function is also laser ranging to satellites with the laser retro-reflector array and it can have an additional function such as lunar laser ranging, optical tracking using laser illumination, and space debris laser ranging. None of these additional functions are determined yet but KASI is going to make development strategies including these additional functions by 2011.

TROS Operation in Korea

The memorandum of agreement (MoA) between Institute of Seismology, China Earthquake Administration (ISCEA) and KASI was concluded for a productive collaboration in the field of space geodesy in June 2008, which specially includes a collaborative operation of the Chinese transportable ranging observation system (TROS) in Korea. TROS was moved to Korea in August 2008 on the basis of MoA and it was scheduled to be operated for 12 months in KASI headquarter in Daejeon. After 4 days of TROS installation, KASI got the first pass of Ajisai satellite on Aug 26th, 2008. The observational data set of TROS in Korea could be not transferred to ILRS data center because the measurements are performed occasionally due to the bad weather.

Research works

The main applications of ARGO are precise orbit determination, space geodesy and space tracking. For the applications, the GEODYN II and KASI own programs will be used. For developing the SLR data processing program, KASI performed a preliminarily research to develop a precise orbital and geodetic parameter estimation system using SLR data, which was cooperated with ACL (Astrodynamics and Control Lab.) in Yonsei University.

The feasibility study of estimation system development was implemented and KASI are conducting its own precise orbit determination system. The orbit determination system is consisted of dynamic, measurement models, and estimation algorithms. The dynamic models include geopotential perturbation, gravity of planets, solid earth tide, ocean tide, dynamic polar motion, relativistic effect, empirical acceleration, atmospheric drag, solar radiation pressure, and earth albedo pressure. A tropospheric delay and satellite body-fixed offset of the SLR array phase center are also considered as measurement models. The least squares filter is used for estimation algorithm. KASI has a plan to operate the ILRS associated analysis center from 2015 by using the KASI own program and the ILRS analysis center from 2019.

International Collaboration

The Korea-China SLR workshop has been hosted by China and Korea in turns annually since 2005 for the following purposes:

i) contributing to the promotion of the relationship between two countries in the field of space geodesy,

ii) sharing the information with the various science and engineering groups for satellite laser ranging system and its applications.

This workshop is going to be closed from 2012 officially because the Western Pacific Laser Tracking Network (WPLTN) workshop was established in May 2011 and its first workshop will be held in Russia in 2012. KASI has worked with many institutes such as Graz SLR station, Shanghai astronomical observatory, NASA/GSFC and NASA/JCET to exchange research personnel and technologies related SLR during last 4 years.

2.3 VLBI

VLBI Network in Korea

Since early 2000s, Korea Astronomy and Space Science Institute (KASI) had undertaken the construction project of Korean VLBI Network (KVN). It consists of three 21 m radio telescopes, which are located in Seoul (Yonsei University), Ulsan (University of Ulsan), and Jeju Island (Tamna University). Although the main purpose of KVN is for radio astronomy, KASI also contemplates how to make use of KVN facility for geodesy.

Cho et al. (2006) simulated the impacts of KVN to International VLBI Service for Geodesy and Astrometry (IVS) networks. They divided two kinds of network, KVN-Asia as a local scale network and KVN-Pacific as a global scale network. The primary purpose of the simulation was quantitative evaluation of KVN impacts before and after the participation of KVN in the two networks. The precisions of the station coordinates were evaluating for KVN-Asia while Earth Orientation Parameters (EOP) was evaluating for KVN-Pacific. The simulation results showed that 50% and 20% of maximum improvements for KVN-Asia and KVN-Pacific were anticipated, respectively.

Even compact VLBI network is capable of determining the plate motion parameter accurately if the stations are located on stable sites. Kwak et al. (2006) estimated the expected precision of the Amurian plate motion parameters with the future Korean VLBI array. The results showed that Korean VLBI array would verify the existence of Amurian plate as far as the observation precision of 0.2-0.5mm/yr for station velocities is achieved.

Figure 2.3 Three stations of KVN

National Geographic Information Institute (NGII) is constructing a dedicated geodetic VLBI station at Sejong that is located in middle of South Korea from 2010. Ajou University cooperates on the construction of the Sejong VLBI station. The main purpose of the Sejong VLBI station is to establish and maintain national geodetic datum by participating IVS regular session.

IVS combination center

KASI was inaugurated as an IVS combination center in October 2008. KASI is currently preparing for regular operation. The mission of KASI IVS combination center is to create high quality combination products, to control the quality of the IVS Analysis Centers' results, to provide feedback to the IVS Analysis Centers, and to adhere to the IERS Conventions.

The combination of KASI is carried out in normal equation level, as does BKG/DGFI combination center. However, KASI decides to use different software, Bernese GPS S/W 5.0 that is originally developed for GPS data processing, to give reliability to the combination results through crosscheck. For last two years, KASI have investigated normal equation level combination and modified Bernese S/W to handle VLBI products. The inputs to the Bernese S/W are the Normal Equation (N.E.) Matrix and the N.E. vector from every daily Solution Independent Exchange Format (SINEX) file of the individual analysis centers of IVS. The outputs are daily SINEX files with combined station coordinates and Earth Orientation Parameters (EOP). Currently, KASI validates the modified Bernese S/W for this purpose.

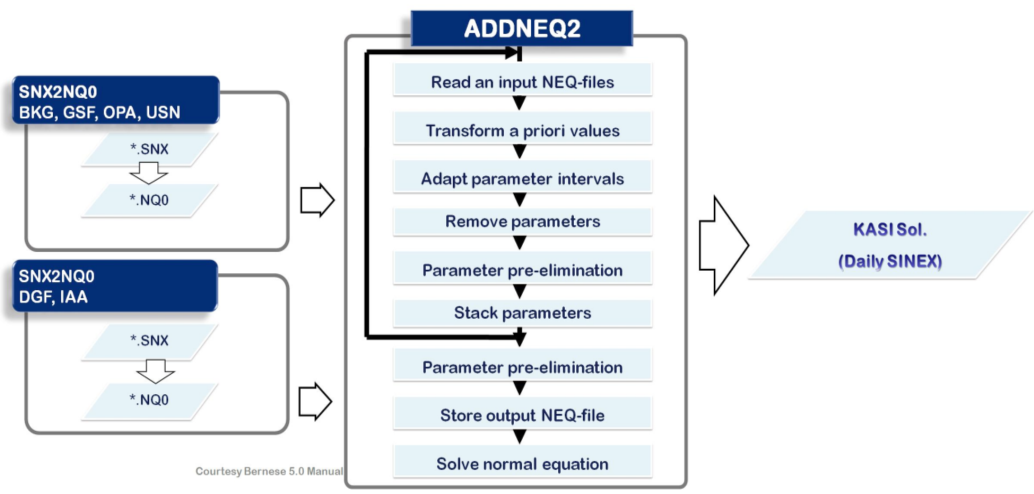


Figure 1.4 Combination processing flow of KASI

After completing the validation of modified Bernese S/W, KASI will establish the automated combination processing with the Bernese Processing Engine (BPE). This automated processing will produce an IVS combination solution for the whole period (1984 to present) easily and rapidly.

WVR calibration applied to geodetic VLBI observation

A fluctuation in the water vapor in the atmosphere is one of the largest sources of error of ground-based space geodetic techniques using radio frequencies such as VLBI and GPS. In order to achieve 1mm position accuracy, the goal of Global Geodetic Observing System (GGOS), the propagation errors of radio signal through troposphere should be calibrated.

As an approach to the calibration, KASI applies the data of the pointed water vapor radiometer (WVR) to VLBI data directly. Although a WVR is an ideal instrument for monitoring the water vapor content in the atmosphere, its benefits for geodetic VLBI have not been demonstrated so far. This research is expected to remarkably contribute to GGOS in near future.

GPS-VLBI Hybrid System

Kwak (2011) developed GPS-VLBI Hybrid System, as a novel observation method, to combine VLBI and GPS techniques in observation level and to estimate and remove atmospheric delays and clock errors that are main error causes in VLBI observation. The development was collaborated with National Institute of Information and Communications and Technology of Japan.

In the system, VLBI antennas and GPS antennas located at the same site, simultaneously receive signals from quasars and GPS satellites, respectively. Both signals are recorded and correlated in VLBI way. Kwak (2011) completed actual instruments of GPS-VLBI Hybrid System and carried out validation experiments of the system between Kashima-Koganei, 110km baseline. In the experiments, correlation fringes were simultaneously obtained from all GPS satellites on the sky and the feasibility of the GPS-VLBI Hybrid System was verified.

Furthermore, the 24-hour experiment was stably carried out and huge volume of data was acquired through VLBI system. Eventually, the practicality of the GPS-VLBI Hybrid System was ascertained. The correlation peaks of GPS signals with high signal to noise ratio from correlation processing were detected. If GPS signals are regarded as white noise signals, estimated group delay precisions of GPS data are similar to those of VLBI. However, from the actual analysis results with newly developed analysis software, the scatters of Observed−Calculated (O-C) were about 10 times bigger than expected thermal noise errors. Investigating the causes of these phenomena and improving the results are future tasks.

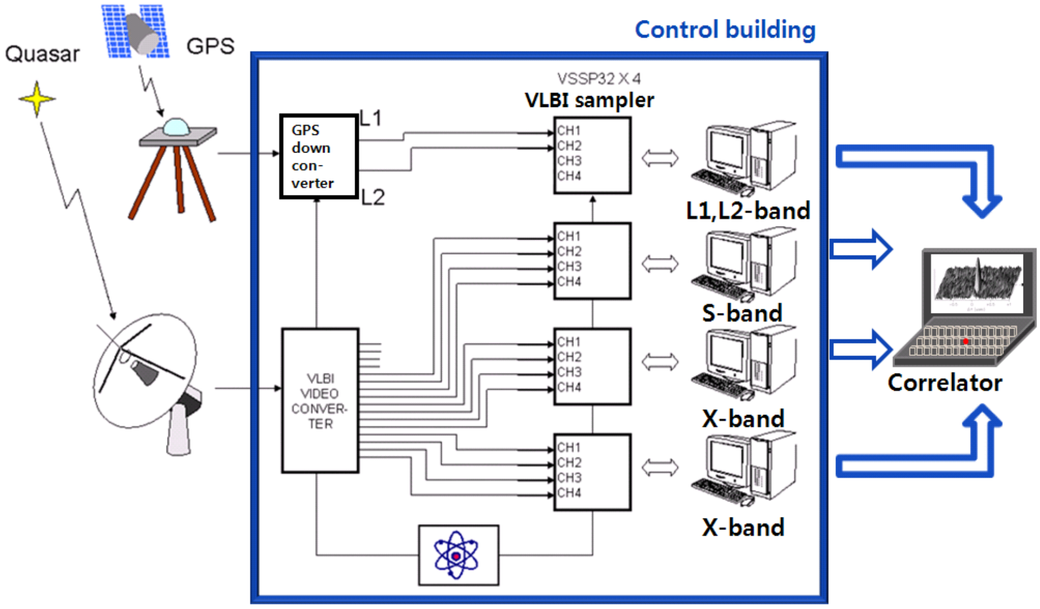


Figure 2.5 A block diagram of GPS-VLBI hybrid system

2.4 SAR and Radio Occultation

KOMPSAT-5 Mission

KOrea Multi Purpose SATellite (KOMPSAT) –5 has been developed since 2005. The primary mission of KOMPSAT-5 program is providing high resolution Synthetic Aperture Radar (SAR) images for Geographical Information System (GIS), ocean and land management, and disaster and environments monitoring. As the SAR image processing requires high precision orbit determination of the satellite, Atmosphere Occultation and Precision Orbit Determination (AOPOD) system is equipped on KOMPSAT-5 as a secondary payload (Lee et al., 2007).

AOPOD system consists of dual frequency GPS receiver and Laser Retro Reflector Array (LRRA). The Integrated GPS Occultation Receiver (IGOR) in AOPOD system will provide the GPS radio occultation data for GNSS meteorology and space science. KOMPSAT-5 will be launched on August 2011. Korea Astronomy and Space Science Institute (KASI) has been in charge of the development and hardware test of AOPOD system.

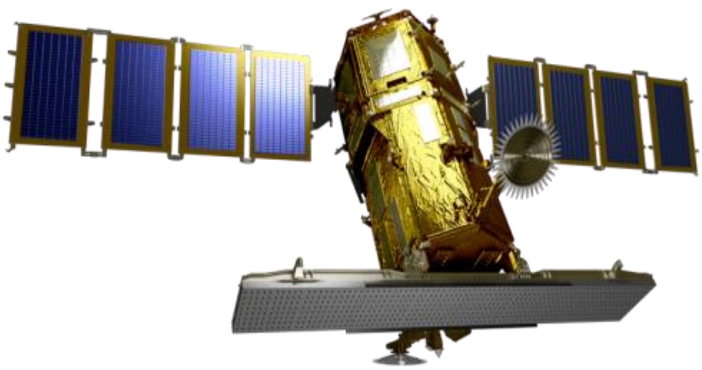


Figure 2.5 Image of KOMPSAT-5

KASI has also developed KASI Radio Occultation Processing System (KROPS) to retrieve atmospheric and ionospheric profiles from the GPS radio occultation data obtained by AOPOD system. Final products contain the vertical profiles of pressure, temperature and humidity in neutral atmosphere and electron density in ionosphere. Retrieval algorithms have been implemented and validated by comparing the results with ground and space based observations. Currently KROPS is under modification to improve the product quality. Products will be disseminated to international science communities via AOPOD Data center (http://aopodweb.kasi.re.kr)..

Research Works

Lee et al. (2007) examined the retrieval algorithm of the electron density profiles from the GPS radio occultation data using CHAllenging Minisatellite Payload (CHAMP) satellite data.

Retrieved electron densities were compared with International Reference Ionosphere (IRI) – 2001 model simulations, CHAMP Planar Langmuir Probe (PLP) measurements, and ionosonde observations. The results showed the substantial agreement between the retrievals and observations.

Choi et al. (2010) presented the operation concept of GPS radio occultation mission in KOMPSAT-5. IGOR operation phase and mode including the early stage after the launch of the satellite was introduced and parameter settings to collect the GPS radio occultation data were described.

Lee et al. (2011) investigated the winter anomaly of the ionosphere using the GPS radio occultation data from Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) satellites. The variations of the electron density during the solar minimum period were examined with the altitude, local time, latitude, longitude and hemisphere. The winter anomaly feature during low solar activity periods only occurred in the northern hemisphere and the intensity was variable with longitude. A more intense winter anomaly was likely to occur at longitudes closer to the magnetic pole. At northern middle latitudes, the winter anomaly occurred at the narrow altitude range near the F –peak height.

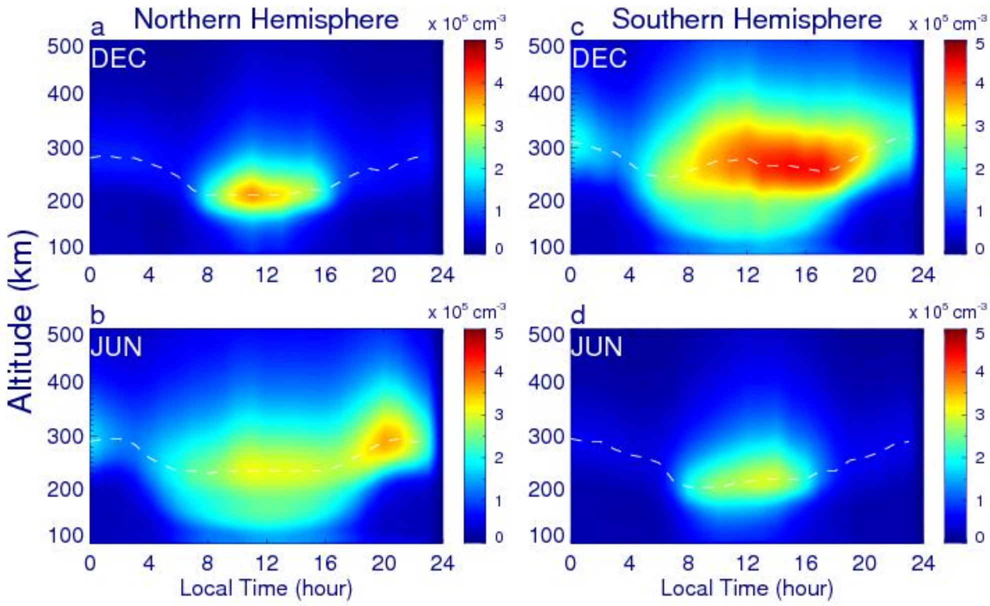


Figure 2.6 Diurnal and altitude variations of the longitude-mean Density at middle latitudes observed by COSMIC.

International Collaboration

KASI has been collaborated with international community for data processing and applications of the GPS radio occultation data for KOMPSAT-5 mission. In 2007, KASI and GeoForschungsZentrum (GFZ) Potsdam jointly developed retrieval algorithms of the electron density profile from GPS radio occultation data. The algorithm were implemented and validated with ionosonde observations and in-situ measurements from CHAMP satellite.

In 2008 and 2009, KASI was also collaborated with National Center for Atmospheric Research (NCAR) / High Altitude Observatory (HAO) for six month on the ionospheric research using the GPS radio occultation data. Global features of annual variation of the ionospheric F region were investigated by using COSMIC GPS radio occultation data as the preliminary run of KOMPSAT-5 data application.

KASI is currently discussing with University Corporation for Atmospheric Research (UCAR) for data processing and dissemination of the GPS radio occultation data from KOMPSAT-5 as the data from KOMPSAT-5 will be provided to National Oceanic and Atmospheric Administration (NOAA) for weather forecasting. UCAR COSMIC Data Analysis and Archive Center (CDAAC) is providing high quality atmospheric profiles for the data assimilation into the operational numerical weather prediction. KASI has a plan to improve the product quality upon this collaboration.

3. GRAVITY FIELD

The surveys on the gravity field have been conducted since 1960's in Korea. The utilization of the data however was relatively not active as there were no standardized procedures and regulations on the data acquisition, processing and maintenance. Furthermore, there was no facility for the instrument calibration so that the quality and reliability of the data were relatively poor.

As the necessities on the geophysical data is increased due to various scientific problems, the National Geographic Information Institute (NGII) of Korea decided to construct a good quality of geophysical data. In 2008, they placed an order for the construction of the Unified Control Point (UCP) which covers the whole country with 10km by 10km spacing. At UCP, not only the three dimensional position information, but also the gravity values are measured. This basically collocate the position and gravity information so that efficient and reliable applications could be conducted. The project establishing UCP was designed for three years and completed at the end of 2010.

Another ambitious project undergoing by NGII is the gravity survey on the benchmarks. The main purpose of this project is to revise the Korean vertical datum which includes the re-definition of the origin and the change of the height system to orthometric. The project is designed for three years and expected to be completed by the end of 2011.

As described above, the Korean gravity data can be categorized into two sets based on the data quality; one before 2008 (old data set) and the other after 2007 (new data set). At present, NGII well noticed the importance of the gravity data and initiated the processes to review the old geophysical data and reorganize it. In addition, they are about to set up the standardized procedures and regulations based on the international standards on the geophysical survey so that the quality of the data is secured and the precise and newest geophysical data is delivered to the users.

3.1 Data from UCP

The project on the UCP initiated in 2007 through the feasibility study and started to establish the control points from 2008 (Figure 3.1). It is designed to have spacing of 10km by 10km covering the whole country and mainly established in the plain area for easy access and maximum utilization. Total 1,200 points of UCPs are established and the precise three dimensional position, orthometric height, and gravity value are provided at each UCP. It is known that the information from UCP has the highest precision and consistency.

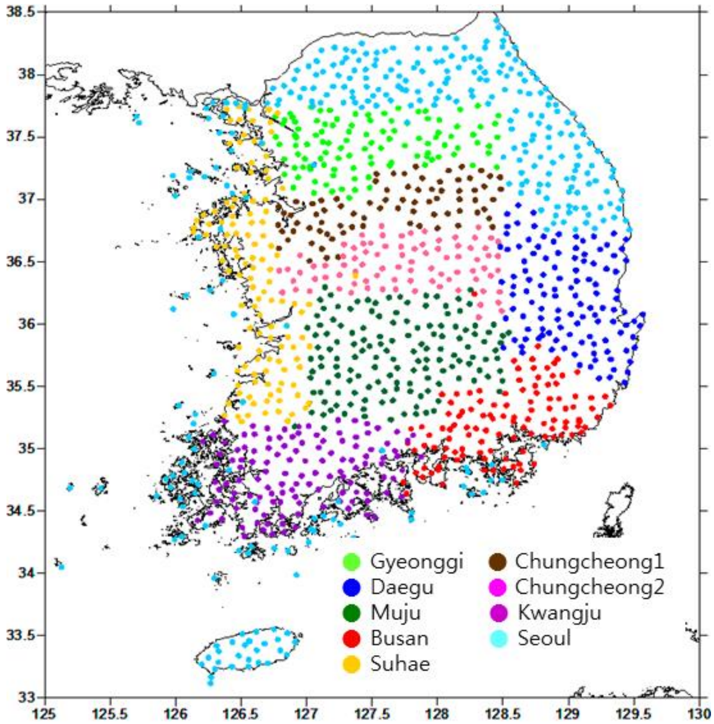


Figure 3.1 shows the distribution of the UCP.

As noticed, it shows highly regular distribution over whole country including some islands. Total 272 points from Chungcheong, Kyeongki area were established in 2008. Then, 614 points were established in Daegu, Pusan, Kwangju, Mooju, and Seohae area in 2009. Finally, 307 points at Seoul, Kangwon, and Jeju were established in 2010.

It should be mentioned that NGII maintains the gravity product delivered by surveying companies that conducted the project. Several companies were involved in that project so that some inconsistencies and errors are included in the gravity product. The reason for this could be found in many aspects. The main one, however, would be that not enough standardized procedures on gravity survey and data processing were established at that time. The problems we found in UCP data is summarized as follow.

a. No field book and report
b. No description on the calculation for drift and tidal correction
c. Inconsistencies between the instruments

Since the data has the above problems, of course, it should be re-processed in a consistent way to assess and verify the data quality.

3.2 Data from benchmarks

The gravity survey on benchmarks are initiated in 2009 and designed for 3 years to establish the basis for the precise geoid development and the orthometric height system establishment. Total 1,408 points mainly from Kangwon and Kyeongsang area were measured in 2009. In 2010, 1,043 points were obtained from Kwangju area (Figure 3.2).

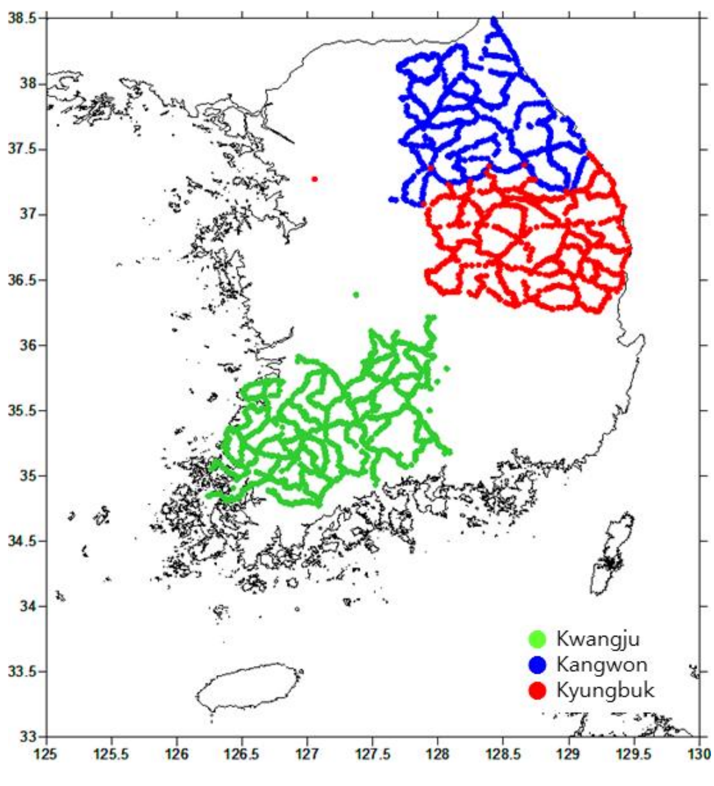


Figure 3.2. The distribution of gravity measurements on benchmarks

Since the regulations on the gravity survey was established in early 2010, still some problems were found in 2009 data which is summarized as follow.

a. No closure measurement
b. No back and forth measurement
c. No or erroneous writing in surveying record
d. No descriptions on the calculation

Again, it is necessary to re-process the data sets in a consistent way to assess and verify the data quality.

3.3 Standardization of the gravity data processing

It is clear that the data quality cannot be assessed unless a unified and consistent data processing is applied. Figure 3.3 shows the general procedure to generate the gravity anomaly from raw gravity measurement.

Figure 3.3 The procedure generating the gravity anomaly

Since many mathematical models are available in tidal and drift correction, a standardized method should be decided and applied. In addition, it is necessary to correct the instrument height correction up to the second order though the effect is not that large. This will assure the consistent processing in instrument height and free-correction.

3.4 Results of data re-processing

3.4.1 Re-processed results at UCP

Among the gravity measurements at UCP, the data from Daegu was not re-processed since the inconsistencies of instruments were found at raw data. In other words, two gravimeters were used at Daegu area and those instruments showed significant differences at common points. In this case, the re-processing is meaningless and a survey to identify the false instrument should be carried out. Other than that, no particular problems were occurred in re-processing except some outliers were removed from the data of Chuncheong area.

Table 3.1 shows the statistics of the free-air anomalies from the re-processing. Note that the overall precision is better than 0.05 mGal which is sufficient for the most of the applications.

Table 3.1. The statistics of the free-air anomaly for UCPs. Unit:mGal

	Free-air anomaly			Precision
	Range	Mean	STD.	
Whole	-14.565 ~ 101.188	12.119	11.684	
Kyeonggi a	-12.52 ~ 57.639	7.773191	14.13295	0.013
Kyeonggi b	-10.123 ~ 25.314	8.588	8.484	0.031
Chungcheong 1	-9.031 ~ 43.575	7.497	8.846	0.007
Chungcheong 2a	-9.868 ~ 30.045	10.219	8.787	0.027
Chungcheong 2b	-5.954 ~ 38.422	14.113	8.828	0.020
Seohae a	-4.499 ~ 34.019	5.805	8.184	0.010
Seohae b	-4.692 ~ 25.477	12.671	7.922	0.042
Seohae c	-3.702 ~ 26.109	12.587	6.844	0.013
Muju a	-8.906 ~ 22.789	7.172	7.091	0.007
Muju b	-7.94 ~ 101.188	13.271	16.791	0.005
Muju c	-10.84 ~ 58.775	11.134	14.693	0.003
Pusan a	6.75 ~ 37.05	21.825	7.209	0.009
Pusan b	3.86 ~ 30.50	23.404	8.348	0.023
Gwangju a	0.85 ~ 37.422	9.786	9.358	0.041
Gwangju b	3.699 ~ 34.399	13.992	7.398	0.036
Gwangju c	-0.592 ~ 47.594	14.616	7.577	0.031
Seoul a	-14.565 ~ 46.106	8.058	10.847	0.008
Seoul b	-9.415 ~ 92.318	27.496	18.474	

At the gravity survey of UCP, several common points were established between the neighbor areas for quality check. For example, five points were established as common points for Kyeongki and Chungcheong1 data sets. Therefore, comparing the results at common points would be the good analyzing methods.

3.4.2 Re-processed results at benchmarks

The analysis on the gravity values at benchmarks was performed in the same way we did for UCP. Table 3.2 shows the statistics of the data which shows the precision better than 0.04 mGal in all area.

Table 3.2 The statistics of the free-air anomaly for benchmarks. Unit:mGal

	Free-air anomaly			Precision
	Range	Mean	STD.	
Whole	-15.271 ～ 127.311	26.348	20.996	
Kangwon	-15.27 ～ 34.70	24.635	22.838	0.032
Kyeongbuk	-8.66 ～ 39.44	28.084	10.843	0.020
Gwangju	-13.87 ～ 85.445	11.376	13.496	0.007

When comparing the results at the common points between Kangwon and Kyeongbook area, an interesting bias about 0.230 mGal appeared both in the previous and re-processed results. Considering the long spacing of the measuring points and the mountainous terrain in Kangwon area, either large measurement errors or the errors in the height system is open to doubt. Therefore, it is recommended to conduct re-survey on those common points for further analysis. Looking at the differences between the previous and re-processed results, no systematic differences are shown (Figure 3.4). This means that the previous results were generated in a consistent data processing though it is different with that we applied.

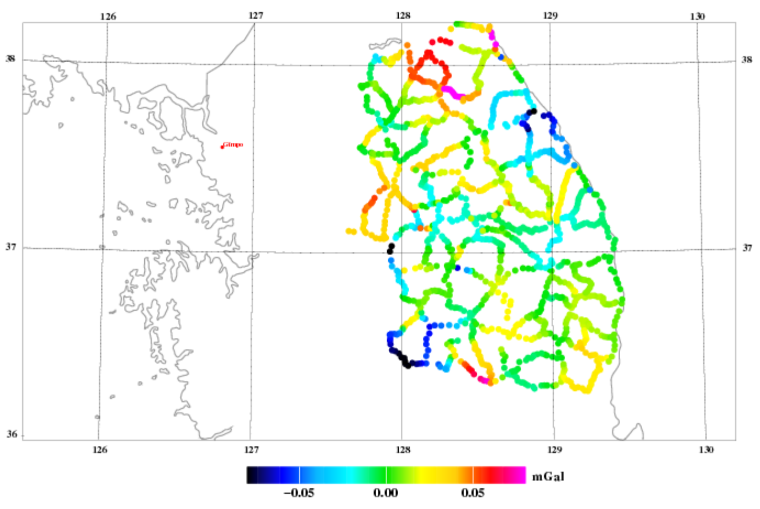


Figure 3.4. The differences between the previous and re-processed results at benchmarks.

3.5 Korean Geoid

From late 1990's, many studies on local geoid construction have been progressed in Korea. However, the precision of previous geoid has been remained about 15cm because of the problems on distribution and quality on gravity and GPS/Leveling data.

From 2007, new land gravity data and GPS/Leveling data have been obtained through the Korean Land Spatilaization Project, Unified Control Point and Gravity survey on Benchmark Project. The newly obtained data shows much better distribution and quality. In addition, the airborne gravity survey was conducted in 2008 to cover whole Korean peninsula.

Based on these new data sets, a precision geoid is calculated at the end of 2010. As a methodology, the general remove-restore approach was applied with the best parameters in order to produce a precise local geoid. The global geopotential model EGM08 was used to remove the low frequency components using degree and order up to 360, and the short wavelength part of the gravity signal was dealt with the SRTM (Shuttle Radar Topography Mission) data.

The parameters determined empirically in this study includes 0.5° and 110°~120° for Stokes' integral and Wong-Gore kernel, respectively, and 10 km for both Bjerhammar sphere depth and attenuation factor. The final gravimetric geoid in Korea ranges from 9 m to 34 m with a precision of 5.45 cm overall compared to 1,096 GPS/Leveling data (Figure 3.5).

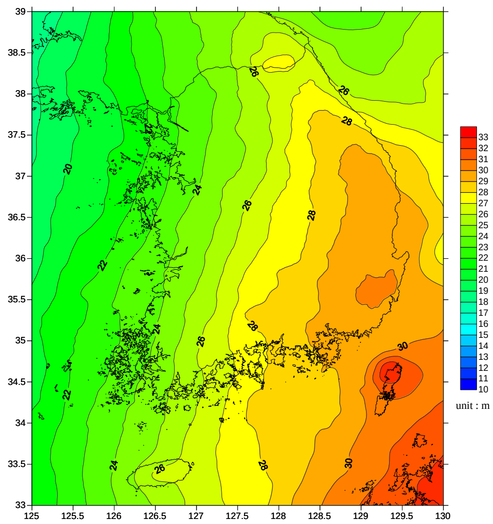


Figure 3.5. Gravimetric geoid in Korea

In addition, the Korean hybrid geoid produces 3.46 cm and 3.92 cm for degrees of fitness and precision, respectively, and better statistics of 2.37 cm for plain and urban area was achieved. The gravimetric and hybrid geoids are expected to improve further when the refined land gravity data are included in the near future.

3.6 Summary

The Korean gravity data can be categorized into two sets, one before 2008 and the other after 2007 and, the data from 2008 has relatively good quality and well maintained. In 2010, the verification on the data quality was performed with a standardized procedure and followings are concluded.

The UCP data sets showed some the instrumental problems and record problems at Daegu and Chooncheong2 areas. It could be, however, re-processed and utilized for any applications after some verifying survey and analysis. The survey on benchmarks showed some minor problems and enough to be used in the applications. However, the bias appeared at common points should be identified through re-survey and analysis.

At present, it is considered that a well constructed gravity network is available in Korea. The data quality of the recent data sets is good enough for the precision geoid development and orthometric height determination. The precision of recently developed gravimetric geoid is about 5 cm over the country and better than 3cm at urban and plain area in case of hybrid geoid.

4. APPLICATIONS

4.1 Reference Frame and Earth Orientation Parameters

One of the main research goals of KASI in space geodesy is to produce its own Terrestrial Reference Frame (TRF) and Earth Orientation Parameters (EOP) solution with high quality. It could be contributed to the international communities such as International VLBI Service for Geodesy and Astrometry (IVS), International GNSS Service (IGS), International Laser Ranging Service (ILRS), International Earth Rotation and Reference System Service (IERS) and Global Geodetic Observing System (GGOS), and to the domestic community.

As a part of an effort for those goals, KASI had conducted the combination project of major space geodetic techniques, GNSS, geodetic VLBI and SLR, so called GVS project, until 2010. KASI analyzed the data of each technique for itself, combined the products, and produced the combined TRF. That kind of combination will be practical when domestic stations or newly added geodetic stations need to be connected to International Terrestrial Reference Frame (ITRF). Furthermore, the combined products will contribute to establish the application model on natural hazard mitigation.

KASI developed automated data processing systems of individual techniques, GNSS, VLBI and SLR to produce individual products of each technique. In the case of GNSS, KASI constructed optimal network of global GNSS stations and selected 61 fiducial stations. The data processing software was Bernese GPS S/W 5.0. The data span the period of 2002-2007 for six years. The repeatability of positioning is 4.1mm, 5.0mm and 12.6mm for east, north and up components, respectively. The differences with respect to IERS C04 were 0.18mas, 0.35mas and 0.043ms for x-pole, y-pole and UT1-UTC, respectively.

In the case of VLBI, KASI analyzed TRF and EOP with CALC/SOLVE that is most popular analysis software for VLBI. The analyzed data are 1-year data during 2000. The repeatability of positioning is 7.5mm, 7.1mm and 7.3mm for east, north and up components, respectively. The difference with respect to IERS C04 was 0.27mas, 0.31mas and 0.019ms for x-pole, y-pole and UT1-UTC, respectively.

In the case of SLR, KASI processed SLR data and produced TRF and EOP with GEODYN-II/SOLVE. The data span the period of 2000-2008 for nine years. The difference with respect to IERS C04 was 0.29mas, 0.35mas for x-pole and y-pole, respectively.

KASI had also developed combination solution system with the final products from three space geodetic techniques, GNSS, VLBI and SLR. The combination was dedicated to TRF and conducted in product level. The combination of KASI focused on connecting domestic stations and newly added station to ITRF. The combined results were compared with the combined TRF by CATREF that IERS International Terrestrial Reference System (ITRS) center employs for its combination. The TRF differences of GNSS were 5.0mm, 5.6mm and 4.7mm for X, Y and Z components, respectively. The TRF differences of VLBI were 7.2mm, 3.7mm and 9.6mm for X, Y and Z components, respectively. The TRF differences of SLR were 18.1mm, 8.5mm and 16.8mm for X, Y and Z components, respectively.

KASI researched on the predicting the polar motions with an additional 500-day period component. The Chandler wobble and the annual wobble are two dominant components of Earth's polar motion. Several minor periodicities have been formerly reported, but their amplitudes were all estimated to be much smaller than the two components. KASI revealed that a formerly unknown polar motion component does exist (Figure 4.1).

The period of this component is about 500(493) days. Its amplitude is variable and is 20 mas in average. From the evidences founded, KASI speculates that this third largest component of polar motion is caused by resonance of an oscillating mode of Earth, possibly inner core wobble. According to KASI EOP prediction model, predicted polar motion including 500-day period component is about two times more accurate.

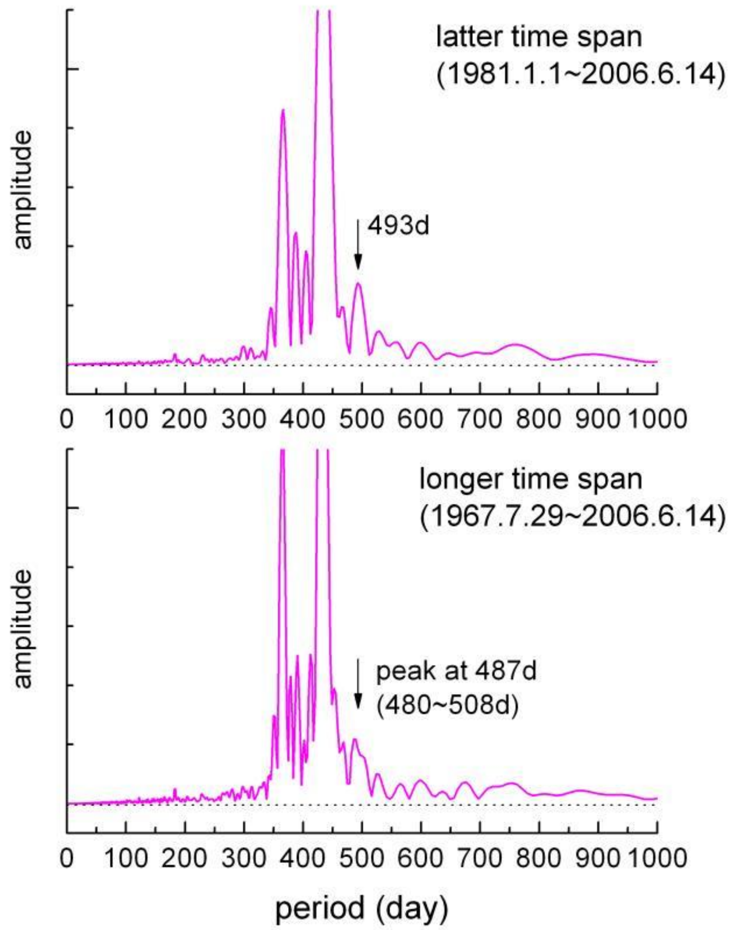


Figure 4.1 Two amplitude Fourier spectra of different polar motion time series.
(Two biggest peaks are annual and chandler components from the left, respectively.)

4.2 Crustal deformation

Korean peninsula has been known to be a very stable region because it is located on the inner rigid Eurasian plate and the earthquakes in Korea has shown much lower frequency and magnitude than neighbor active regions. However, the quantity of the deformations could not be known before the space geodetic technologies were introduced in Korea. After the well distributed and dense GPS network in Korea were installed, the precise movements of the overall Korean peninsula have been reported from 2001. Those studies reported that the internal movements of Korean peninsula are less than one centimeter per year and the accumulated strain rates per year are two orders of magnitude smaller than active tectonic regions such as plate boundaries (Park et al., 2001; Hamdy et al., 2005; Jin et al., 2006).

Since 2007, more reliable computations of deformations have been presented with the aid of long period data and improvements of GPS data processing techniques. NGII processed the GPS data of 53 permanent GPS stations in Korea from 1999 to 2006 and calculated strain rates (NGII 2007). Jin et al., (2007) analyzed the data of 85 continuous GPS stations and about 1000 campaign of Northeast Asia and suggested that the deformation in Northeast Asia can be described with several rotating blocks (Figure 4.2). Song and Yun (2008) computed strain patterns of Korean peninsula using the GPS observations of 9 continuous stations in Korea.

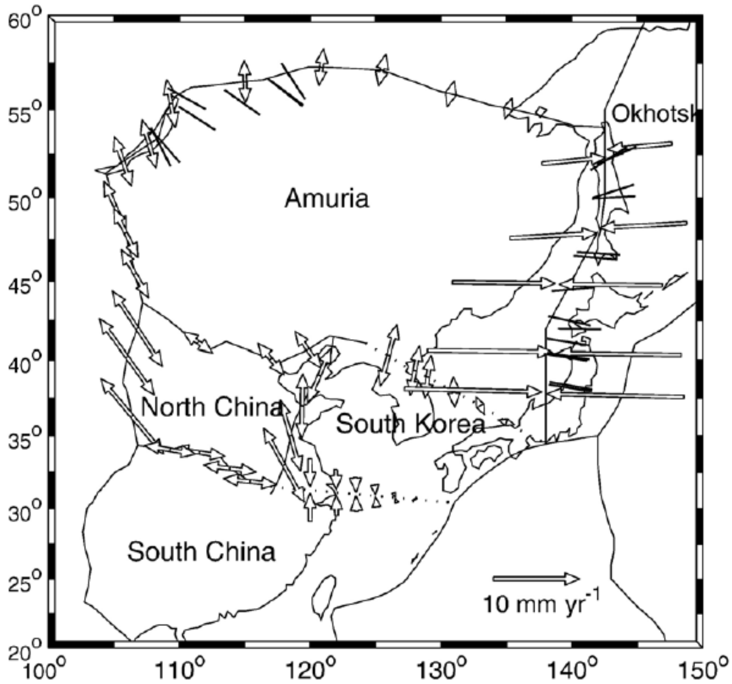


Figure 4.2 Relative motions at plate boundaries (Jin et al., 2007).

A number of studies have focused on vertical deformations of Korean peninsula. The ocean loading by ocean tides, which is the one of periodical vertical deformations, has been studied by using GPS data in Korea (Yun et al., 2007; Park et al., 2007; Won et al., 2009; Na and Baek 2011). These studies have extracted ocean tide loading constituents from GPS time series and compared with theoretical loading models (Yun et al., 2007; Park et al., 2007; Won et al., 2009), or re-analyzed theoretical procedures of ocean tide loading models and suggested modified Green's functions for more appropriated for the crustal structure of Korean peninsula (Na and Baek 2011).

The time series of the vertical component of continuous GPS stations were also analyzed to understand geophysical characteristics and to improve the repeatability (Kim and Park 2010). Kim and Park (2010) investigated the principal components of vertical time series of 14 continuous GPS stations in Korea. The first mode showed an average of 4.2 mm per year and the time series removed the first mode were improved by 34.8 %.

The crustal deformations by large earthquakes were also studied. Baek et al., (2010) analyzed the GPS observations of 25 IGS stations in South America to analyze 2010 Maule earthquake in Chile. The coseismic offsets and the propagating speed of surface waves were computed by kinematic processing. On 11 March 2011, Mw 9.0 earthquake struck Tohoku province in Japan. The earthquake deformed Japan islands as well as Korean peninsula. The observed coseismic displacements by continuous GPS network in Korea were from 1.0 cm to 5.4 cm (Figure 4.3). It was the first observation to detect coseismic displacements caused by earthquakes since continuous GPS networks have been installed in Korea. The strain analysis of the displacements suggested that the accumulated strains by internal deformation were released (Baek et al., 2011).

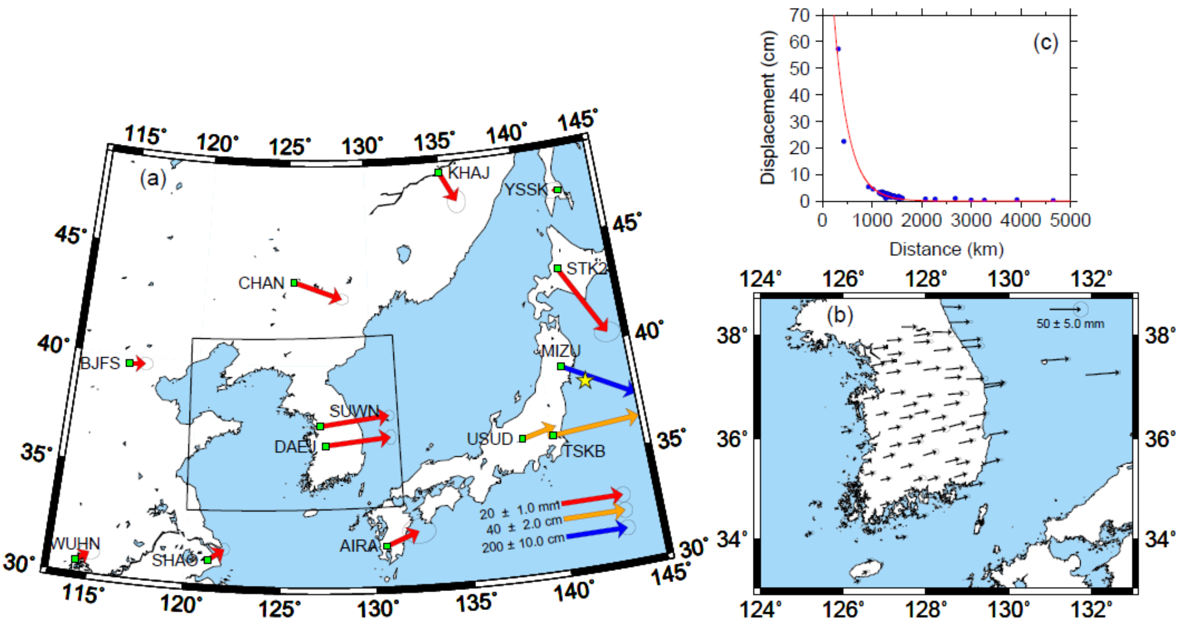


Figure 4.3 The coseismic displacements by the 2011 Tohoku earthquake in Northeast (Baek et al. 2011).

It is very important to monitor continuously crustal deformations although Korean peninsula has shown stable characteristics to date. This region has historical records of large earthquakes and there are several nuclear power plants which can be damaged by the deformations. For continuous and stable monitoring of surface deformations, GPS technology is very useful. About 90 continuous GPS stations were installed in South Korea; some stations were installed near the possible active faults in Korea. Korea

KASI carried out the related project, "Development of continuous monitoring technologies for torrential rain, radio interference, and tectonic deformation based on GPS" from 2008 to 2011. In this project, KASI developed the daily monitoring system of 18 continuous GPS stations composed of 10 domestic stations including two IGS stations (DAEJ and SUWN) and eight aboard IGS stations in northeast China, Japan islands, and Taiwan. The near real time monitoring technique was also investigated; the kinematic coordinates at every 30 seconds were validated with the particularly designed external device to measure actual displacements (Baek et al. 2009).

The experiment showed that it was possible to detect the abrupt displacement of 1 cm with 10 minutes latency. Korea Institute of Nuclear Safety (KINS) is developing the integrated site monitoring system for the nuclear facilities from 2009 (Lee et al. 2011). After the establishment of this system, it will continuously collect the displacements of faults, water level, and seismic waves, etc., near the nuclear facilities and provide significant information for the safety of nuclear power plants.

4.3 GNSS Meteorology

Troposphere

KASI has automatically produced GPS Precipitable Water Vapor (PWV) from Bernese software and compared with Integrated Water Vapor (IWV) from Microwave Water Radiometer (MWR) at 10-minute interval and PWV from radiosonde at two times per one day. Using KASI GPS PWV processes techniques, Lee et al. (2010) carried out the research for the fog detection using GPS observations.

Inha University and KASI examines the precision and accuracy of the GPS PWV and positioning with the three tropospheric mapping functions. The three mapping functions tested are Niell Mapping Function (NMF), Vienna Mapping Function 1 (VMF1), and Global Mapping Function (GMF). The precision of height estimation was improved when VMF1 and GMF was used instead of NMF.

To improve the Numerical Weather Prediction (NWP) model, KASI and Korea Meteorological Administration (KMA) have cooperated for application of GPS tropospheric PWV that is measured from KASI GPS network of 9 sites. KMA has been collecting the GPS data that are measured from Korea local GPS network of 90 sites to increase the temporal and spatial resolution of NWP since 2010.

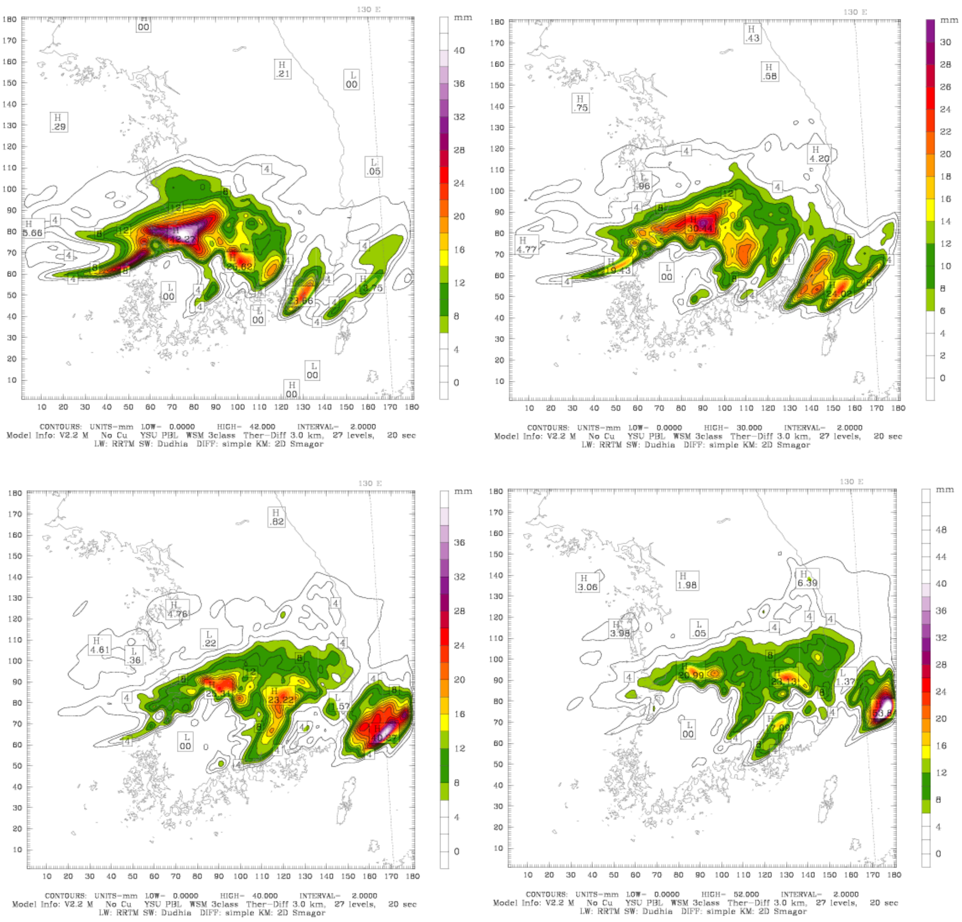


Figure 4.4. Results of the numerical weather prediction model
that is assimilated with GPS PWV in Korea using KASI GPS network

Ionosphere

At 10-minute interval, KASI has provided the 2-D GPS Total Electron Content (TEC) map and its ASCII data to monitor the variations of the ionospheric electron density for space weather. Also, it is provided that the Differential Code Bias (DCB) of GPS receiver and satellite to eliminate the instrument error in GPS TEC estimation with 1 week through KASI ftp service.

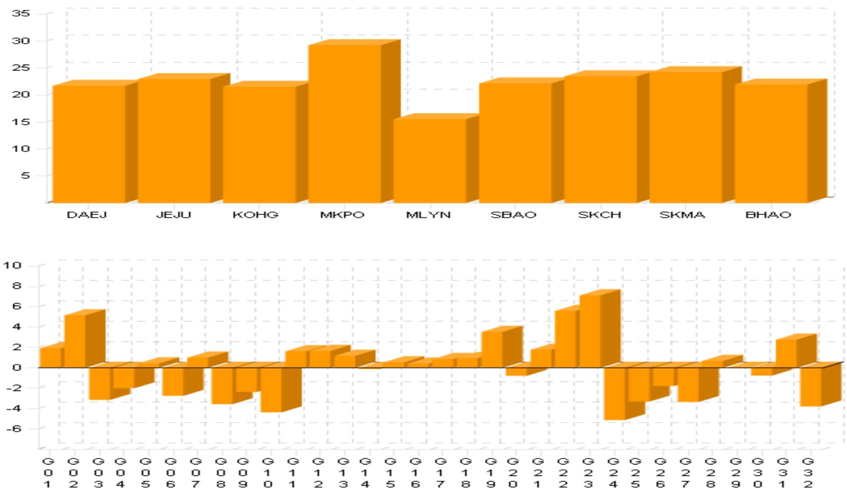


Figure 4.5. DCB values of KASI GPS sites (upper) and satellites (lower) from KASI

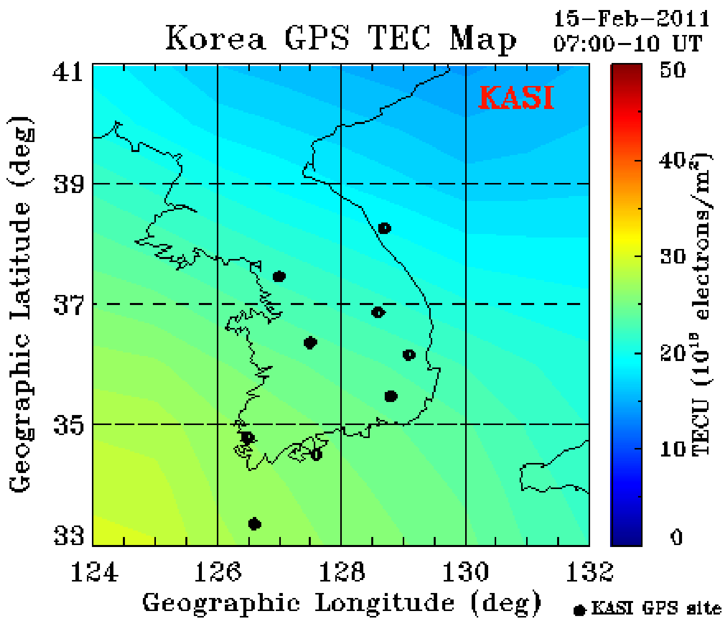


Figure 4.6. Response of the regional GPS TEC map over Korea Peninsula on 15 February 2011 when the X-class solar flare was erupted. The GPS TEC was increased above ~80% .

KASI and KOPRI (Korea Polar Research Institute) have been studied the ionosphere in Antarctic using GPS TEC. KOPRI has operated the GPS site at King Sejong station in Antarctic Peninsula and is also constructing the new GPS site at the new Korea Antarctic station on Cape Burks in the western Antarctic to research the geodetic effects of global warming and space weather in aurora region with KASI.

KASI and KOPRI are developing the new reference map model to validate the Global Ionospheric Map (GIM) model using ground-based GPS TEC with ground-based GPS TEC and the altimetry TEC from TOPEX/Jason satellites (Jee et al., 2010). This study shows the GIM errors exist in the region of equatorial ionospheric anomaly and the southern hemisphere.

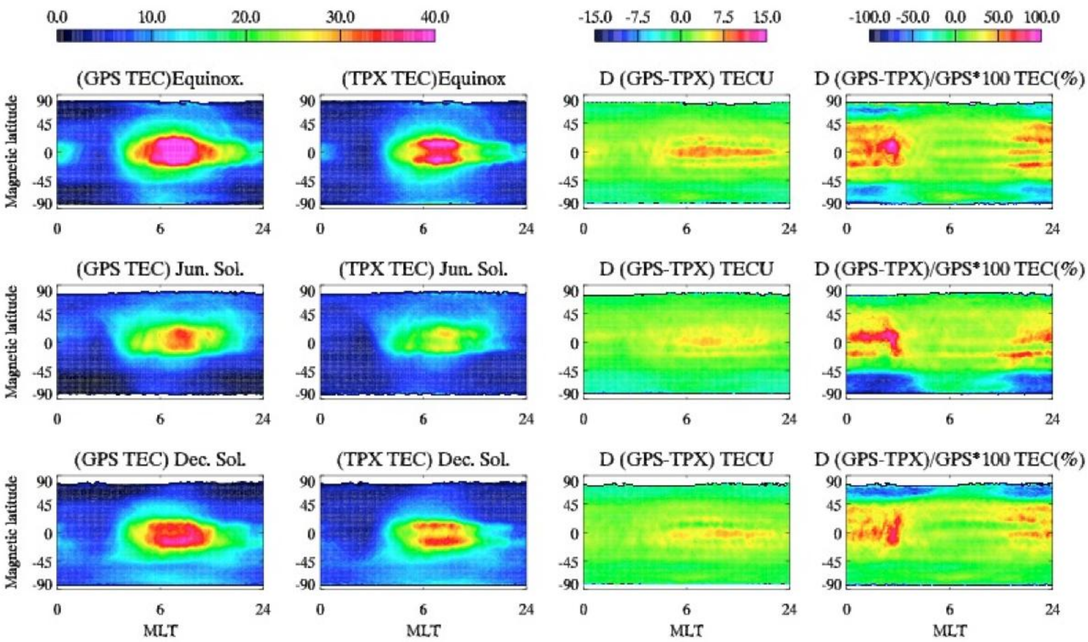


Figure 4.7. Comparison of global GPS TEC map and TOPEX TEC

4.4 DGPS & Network RTK

The Ministry of Land, Transport and Maritime Affairs (MLTM) is in charge of GNSS augmentation system in Korea and supporting research and development (R&D), implementation and operation. To provide more accurate and reliable positioning and timing services to Korean nationwide users, MLTM is implementing Korean NDGPS (Nationwide

DGPS). MLTM is currently planning to the modernization efforts that include a high-accuracy NDGPS (HA-NDGPS) system, to enhance the performance and provide more accurate positioning information with integrity.

The Seoul National University (SNU) has proposed a new way of improving Differential Global Navigation Satellite System (DGNSS) service using combination of multiple Satellite Based Augmentation System (SBAS) information. To verify the feasibility of the SBAS integration using multiple SBAS combination, the two other SBAS systems, Korean WADGPS Test Bed (KWTB) and MTSAT Satellite based Augmentation System (MSAS) are examined (Yun et al., 2008). SNU has been also implementing and testing of wide-area reference stations (WRS) and wide-area master station (WMS).

The Korea Aerospace Research Institute (KARI) has been developing the enhanced GNSS augmentation system for air navigation to meet ICAO standard since 2009. KARI has implemented a feasibility study for the Ground-Based Augmentation System (GBAS) implementation (Lee et al., 2009) and operation in Kimhae airport. KARI presented a test-bed schedule and activities related with installation of GBAS or SBAS, ground and flight evaluation scheduled for 2008. Recently KARI is acting as a major contributor of the International GBAS Working Group (IGWG) that serves the purpose to discuss technical and operational topics like GBAS integrity analysis, ionospheric data collection, operational safety assessments and so on.

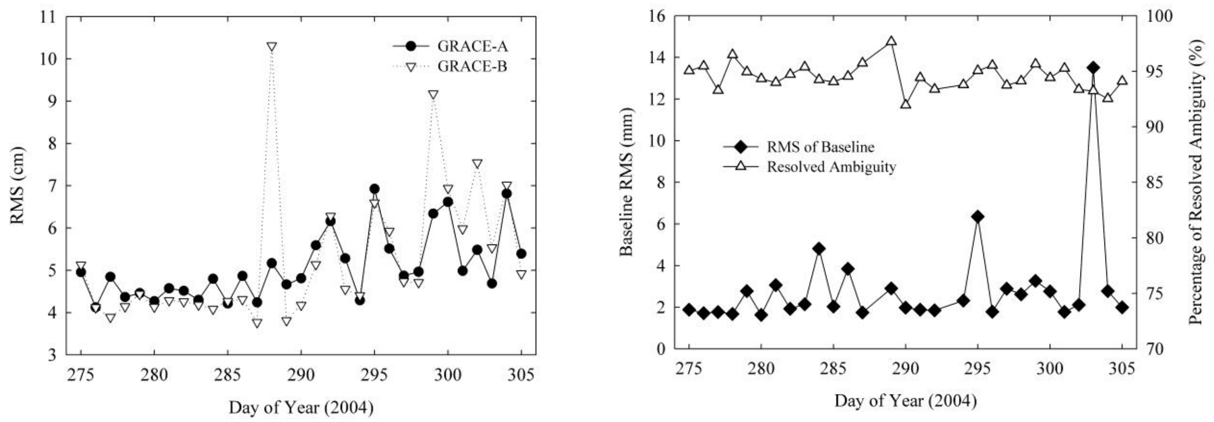
The aim of GPS network RTK (real-time kinematic) is to minimize the influence of the distance dependent errors such as ionosphere error, troposphere error within the boundary of GPS network. The atmospheric effects, especially the ionosphere, are the crucial factors for real-time high accuracy positioning using the network RTK. Network RTK positioning allows centimeter level accuracy in kinematic positioning. Precise positioning can be performed relative to a single or multiple reference stations, employing network-derived ionospheric corrections. KASI researchers have developed network RTK method using KGN for GPS L1 users. The ionospheric correction plays a key role in this method. The correction data derived from a GPS network is very useful in helping to understand network RTK. Network RTK system of KASI supports an accuracy of centimeter level in kinematic positioning for GPS L1 users (Choi et al., 2009). For several years KASI researchers have developed approaches which are suitable for the ionospheric TEC modeling over regional or global areas (Choi et al., 2009, Choi et al., 2010). These models are useful for improving the positioning accuracy.

Precise Point Positioning (PPP) is a method that performs precise position estimation using a single GPS receiver. That is, PPP estimates a single receiver position without any reference station or baseline. The largest difference between network RTK and PPP is the way that the satellite and receiver clock error are handled. It is increasingly used in various researches including monitoring of crustal movement, maintaining an international terrestrial reference frame, and etc. KASI researchers have been implementing the project named as 'Development of High Accuracy GNSS Data Analysis Engine'. This includes some items: development of GNSS data analysis software, precise orbit determination (POD). Since 2009, KASI has been developing its GNSS software package. In this project, the software is designed not only to run in PPP mode, but also to be able to estimate orbit, clock and tropospheric parameters.

4.5 POD (GNSS & SLR)

The researches related to Precision Orbit Determination (POD) in South Korea can be categorized to two areas. One is POD for Low-Earth-Orbit (LEO) satellites based on GPS and SLR measurements and their applications to space environments, and the other is POD of GPS satellites themselves. Currently, there is no institute to generate precise ephemeris of GPS satellites. However, a project is carried out by KASI for developing high precision GNSS data processing software that includes POD capability of GPS satellites. There are two institutes that perform the research for the POD of LEO satellites and their applications based on GPS and SLR measurements, KASI and Electronics and Telecommunications Research Institute (ETRI). In this section, the research status of the two institutes is described.

KASI has participated in the Korea Multi-Purpose Satellite-5 (KOMPSAT-5) Program by providing the GPS receiver system for radio occultation as a second payload. Related this project, KASI has been developing POD system for KOMPSAT-5 using the modified version of Bernese 5.0. The POD performance tested for GRACE shows that the rms (root mean square) error is about 4~7 cm (Roh et al. 2008). The results also show that there are radial biases in both GRACE satellites due to imprecise sensor offset information. Baselines determination between two GRACE satellites were also conducted using double differenced GPS measurements based on the kinematic and reduced-dynamics methods. The rms error of the estimated baseline is about 2~3 mm and the dependency on the ionosphere's irregularity are found (Roh et al. 2009).



(a) (b)

Figure 4.8 RMS Error of GRACE-A and B and their baseline (Roh et al. 2009)

A study for analyzing atmospheric properties using SLR-based POD results for LEO satellite was performed. The POS results for Starlette satellite based on SLR data shows that the achieved rms error is about 1.93 cm is improved about 35% through optimal combination of the drag coefficient estimation (Jeon et al. 2011). In this study, the SLR-based POD results were achieved using GEODYN II software.

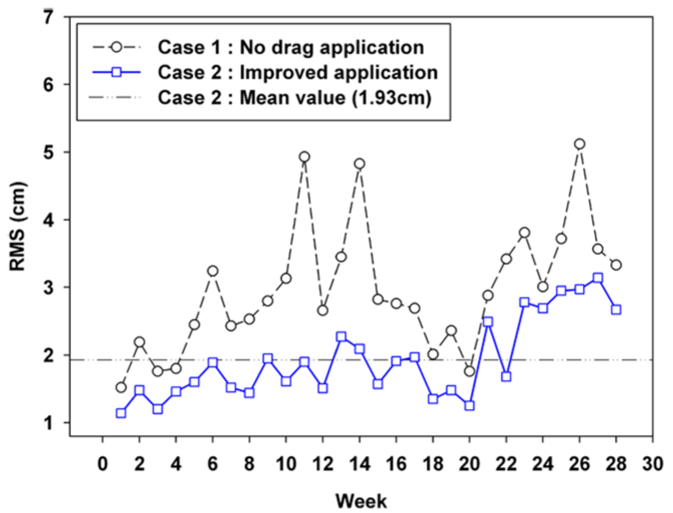


Figure 4.9 Orbital RMS residuals with the improved gravity and drag application option (Jeon et al. 2011).

ETRI has developed ETRI-GPS-Precise-Orbit-Determination (EGPOD) software for the KOMPSAT-2 (Lee et al., 2005). Since EGPOD was developed, it is continuously upgraded and tested for various cases, namely, single or double frequency and single, double differenced observations, and reduced-dynamic and dynamic approaches (Hwang et al., 2011). EGPOD is now preparing KOMPSAT-5 POD that is scheduled to launch August 2011 at Russia. The major upgrade of EGPOD is the capability to process SLR measurements, because KOMPSAT-5 will carry laser reflector as well as dual frequency GPS receiver for radio occultation measurements and laser (Hwang et al., in press).

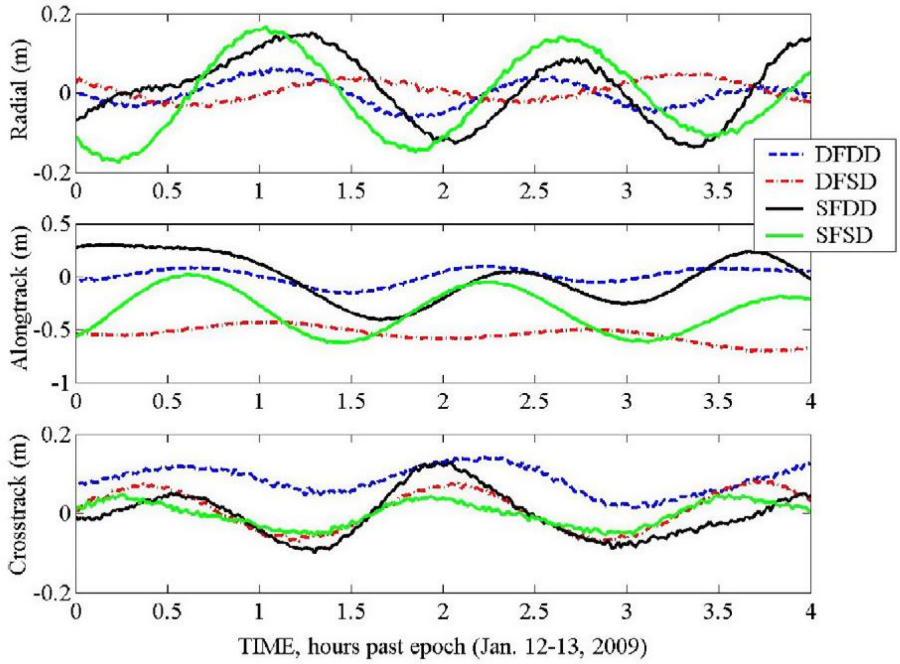


Figure 4.10 POD performance results for SAC-C (Hwang et al., 2011).

4.6 Vertical Datum Monitoring

From August 2005, the government organization Korea Hydrographic and Oceanographic Administration (KHOA) has initiated a monitoring project of tide gauge (TG) stations for the purpose of precisely establishing a national vertical datum. As of June 2011, 11 TG sites out of the total of 38 are equipped with permanent GPS equipments. The site name and specifications of the hardware are listed in Table 4.1 with the installation dates. Figure 4.11 depicts the locations of the 11 stations.

Table 4.1 List of the TG station with GPS equipments in Korea

Site ID	Latitude N. (D-M-S)	Longitude E. (D-M-S)	Installation date	GPS Receiver	GPS Antenna
ICNW	37-27-07	126-35-32	2005.07.26	Ashtech UZ-12	ASH701945E_M
CJUN	33-31-40	126-32-36	2006.10.18	Ashtech UZ-12	ASH701945E_M
SHON	38-12-25	128-35-40	2007.12.06	POLARX2e	ASH701945E_M
PUSW	35-05-47	129-02-07	2007.12.06	POLARX2e	ASH701945E_M
MKPW	34-46-47	126-22-32	2007.12.07	POLARX2e	ASH701945E_M
HUPO	36-40-39	129-27-12	2008.12.03	POLARX2e	TRM55971.00
YNKN	35-25-34	126-25-14	2008.12.05	POLARX2e	TRM55971.00
TNGY	34-49-40	128-26-05	2008.12.13	POLARX2e	TRM55971.00
POHN	36-02-50	129-23-02	2009.11.28	Trimble NetRS	TRM41249.00
DAES	37-00-27	126-21-10	2009.12.01	Trimble NetRS	TRM41249.00
DAEH	34-40-55	125-26-36	2009.12.03	Trimble NetRS	TRM41249.00

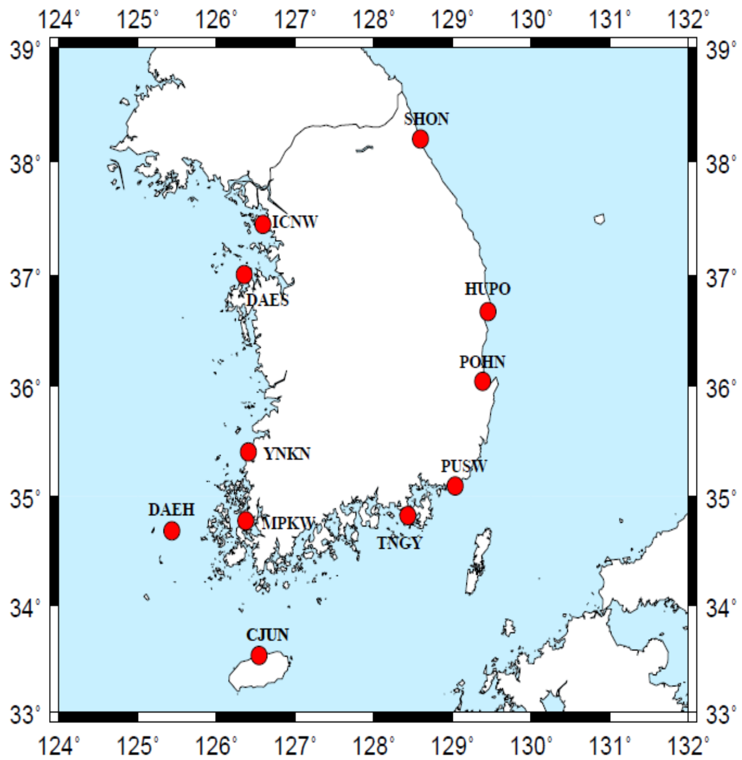


Figure 4.11 Geographical distribution map of TG+GPS station in Korea.

Figure 4.12 shows the GPS antenna installed at the CJUN station. Like CJUN, all the 11 GPS antennas are located right at the TG. Thus the vertical motion detected by continuous GPS height time series can be utilized to correct sea level variations for the crustal deformation. As the next step for the TG monitoring, KHOA is preparing for participation in the IGS (International GNSS Service) TIGA (TIde GAuge Benchmark Monitoring) project.

Figure 4.12 CJUN TG station with GPS antenna.

Figure 4.13 shows the vertical uplift rates of the Korean peninsula derived from 53 permanent GPS sites. All the stations processed have been operated since year 2000. The average uplift rate is around 2 mm/year, even though there are areas showing slighlty higher velocities, especially in the eastern, western, and southwestern parts.

To compare the crustal uplift rates from GPS, we also computed vertical velocities due to Glacial Isostatic Adjustment (GIA). When the old version of ice model (ICE-3G) was used the uplift velocities are in the range of 0.2 - 0.4 mm/year. However, with the updated ICE-5G, the rates are higher. The new rates ranges from 1.1 - 1.4 mm/year (refer to Figure 4.14). Possible causes of the discrepancies between GPS-based and GIA-computes rates are under investigation.

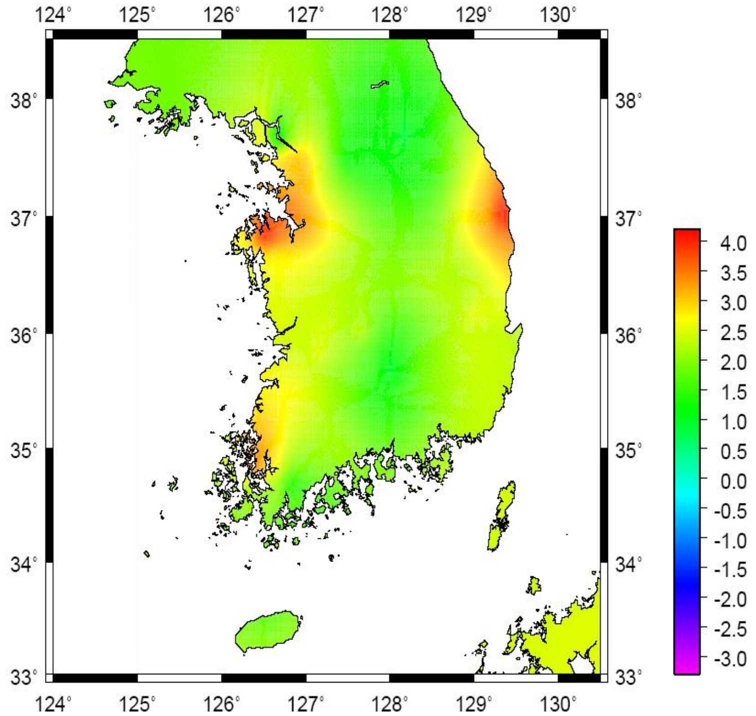


Figure 4.13 The vertical uplift rates of the Korean peninsula derived from 53 permanent GPS sites.

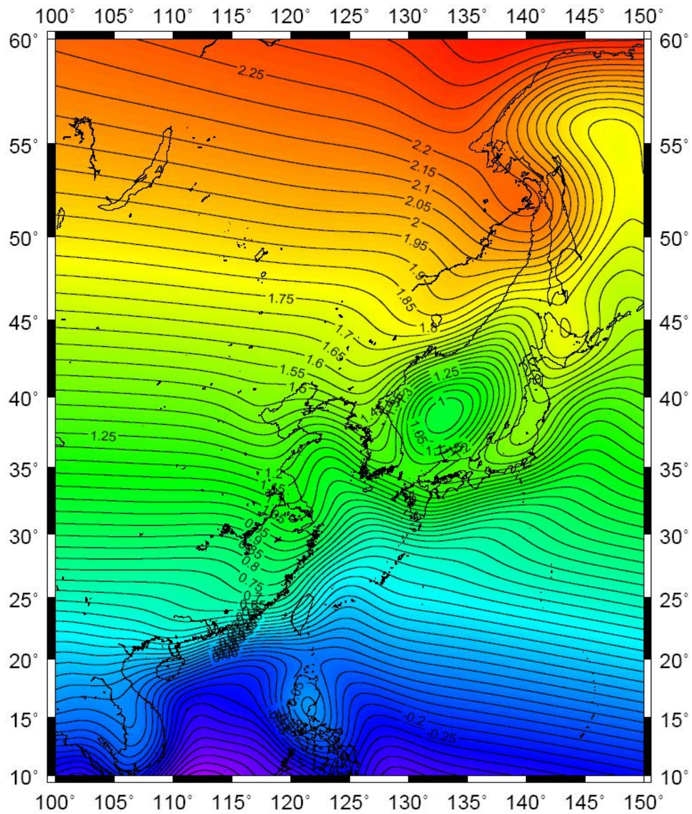


Figure 4.13 the discrepancies between GPS-based and GIA/ICE-5G-computes rates

Korean National Report to the International Association for Geodesy, 2011

PUBLICATION LISTS

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