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CONTENTS

1. INTRODUCTION

In 2022, the first project in the national history of research and development was launched for establishing a regional navigation satellite system so called Korean Positioning System (KPS). It was designed to augment inter-operatibility with US-led GPS in terms of reliablity and integrity and will support region-wide positioning, navigation, and timing (PNT) services. KPS would be a milestone for promoting various applications like as autonomous navigation, precise agriculture, monitoring of disaters and natural hazards and so on.

During the last four years, Sejong Global Geodetic Observing System (GGOS) site has gradually got on a track of regular operation under close collaboration between National Geographic Information Institute (NGII) and Korea Astronomy and Space Science Institute (KASI). In the course of the collaboration, four radio telescopes of KASI and NGII have been periodically surveyed for local-tie measurements and determination of Invarient Points (IVPs). In accordance with the agreement between eight national institutions, data from domestic GNSS Network (KGN) which consists of 218 Continuously Observing Reference Station (CORS) are shared on web-based platform (http://www.gnssdata.or.kr). This national GNSS integrated data center has been operating by NGII for geodetic and public needs of real time GNSS data and its corrections since 2016. A seriese of researches on reference frame and Geoscience had been performed at KASI while NGII mainly focused on strengthening the role of geodetic VLBI facility as the national geodetic origin and improving the national geoid model Korea National Geoid 2018 (KNGeoid18).

NGII has also archived geospatial information of the polar regions particularly around three research stations in the Arctic (Dasan) and the Antarctic (King Sejong and Jangbogo). As the result, the first Korean version of polar map has been published based on precise digital topographic information, digital elevation model, and satellite images and so on. Such a polar surveying and imaging will be continued by using Compact Advanced Satellite 500 (CAS500)-1 operated by NGII which was launched in 2021.

2. R&D INFRASTRUCTURE

2.1 GNSS

For the GNSS-based geodetic surveying and an establishment of a positional reference system, NGII operates the GNSS CORS distributed with approximately 30 km interspace and a master control center as shown in Figure 2-1. The first of these is the SUWN IGS station, established in 1995. The CORS consists of GNSS receiver/antenna, dedicated communication lines, power management systems, and meteorological monitoring equipment for temperature and humidity and so on. The master control center comprises several components such as a real-time monitoring system of the CORS status, a real-time data calibration service (Networked Transport of RTCM via Internet Protocol: NTRIP) system, a GNSS data sharing system, and a precise positioning and displacement monitoring system.

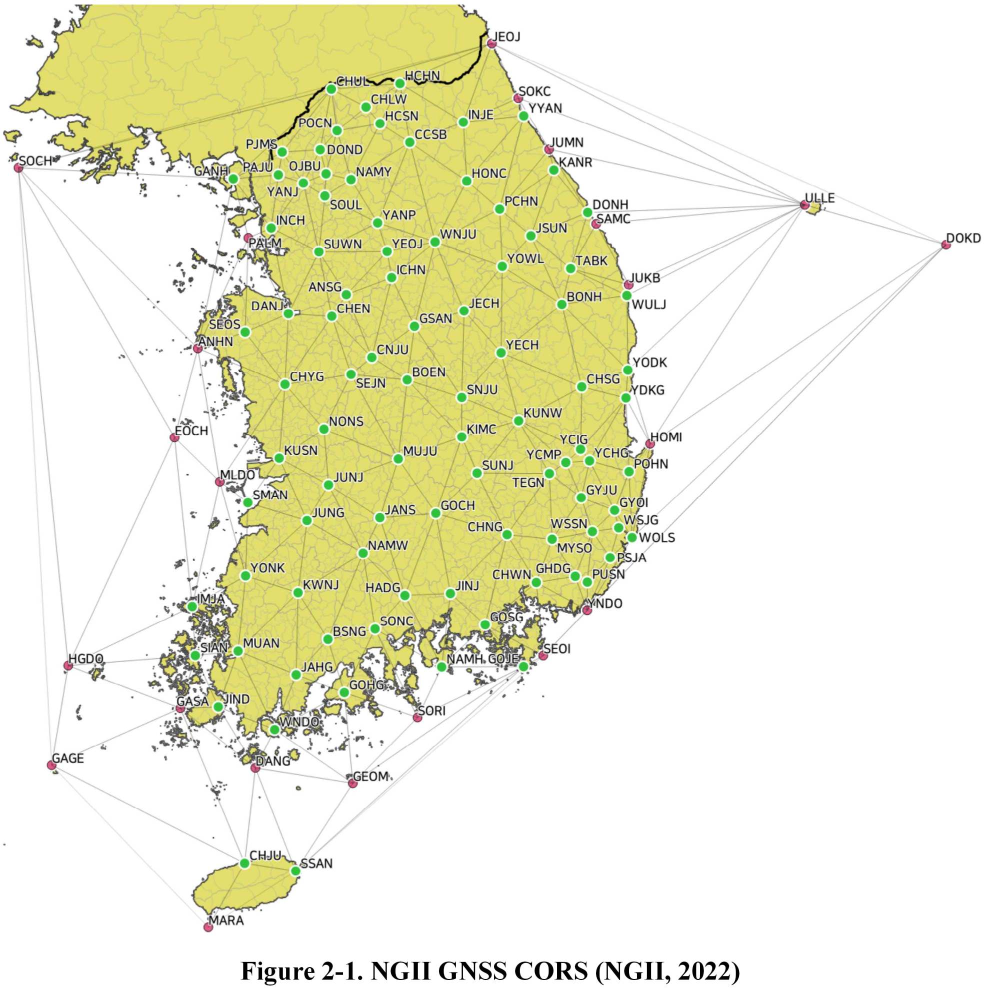

Figure 2-1. NGII GNSS CORS (NGII, 2022)

The CORS equips a high-end receiver for continuous observation of satellite signals such as GPS, GLONASS, Galileo and Beidou. Data observed at CORS are collected in real-time at the NGII GNSS master control center. The center monitors 92 CORS including 2 IGS stations (SUWN & SEJN) and provides the observation data with RINEX format to support precise positioning and various real-time calibration data services.

KASI is operating 11 CORS including one IGS station DAEJ. Two of these are located in the Chuuk Island of Micronesia (CHUK) and the Sainshand of Mongolia (SSND). The geographical location of the reference stations is shown in Fig. 2-2.

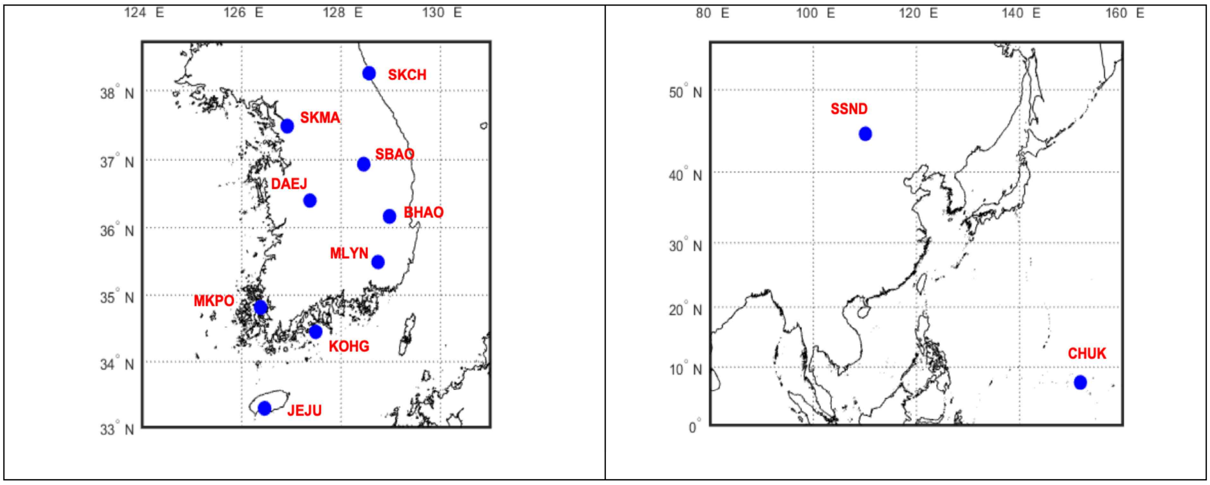

Figure 2-2. KASI GNSS CORS (KASI, 2022)

KASI is also operating the IGS global data center (GDC) that archives and provides GNSS data from the Asia-Oceania region. The KASI GDC also archives and shares all the IGS products from worldwide IGS stations and IGS analysis centers (ftp://nfs.kasi.re.kr, http://gdc.kasi.re.kr).

In addition, KASI has been operating a monitoring station (DAE2) of the Japanese Quasi-Zenith Satellite System (QZSS) signals since 2011. In international collaboration with the French space agency (CNES) and Institute Geographique National (IGN), KASI has been established REGINA (REceiver GNSS network for IGS and NAvigation) in South Korea for scientific purposes regarding the GNSS positioning and navigation. The REGINA GNSS station (GAMG) has been operated regulary since 2018 as an IGS station.

Korean Positioning System (KPS)

Figure 2-3. Overview of KPS Project (https://maily.so/sheldon/posts/0ee15081)

When KPS project is completed, Korea will be the seventh country to have its own satellite navigation system. It will comprise eight satelltes including three geosynchronous equatorial orbiters, the first planned to launch in 2027. And, with the remaining satellites to be released in consecutive years after that, it would be full operation by 2035. Such a system should improve significantly on the existing GPS in terms of accuracy, reducing the positioing error dramatically from 10 m to just 5 cm. (https://www.intralinkgroup.com/en-GB/Latest/Blog/December-2022/Opportunities-from-the-Korea-Positioning-System)

2.2 VLBI

Sejong Geodetic VLBI of NGII

Sejong geodetic VLBI of NGII, shown in figure 2-4, has been participated in International VLBI Service for Geodesy and Astrometry (IVS) campaign since 2014. As can be seen in Figure 2-5, approximately 1,400 hours of domestic and overseas observations are being made from 2019 to 2022. From 2020 onward, the ratio of domestic observations has been mostly constant.

Figure 2-4. VLBI Antenna at Sejong geodetic observatory of NGII

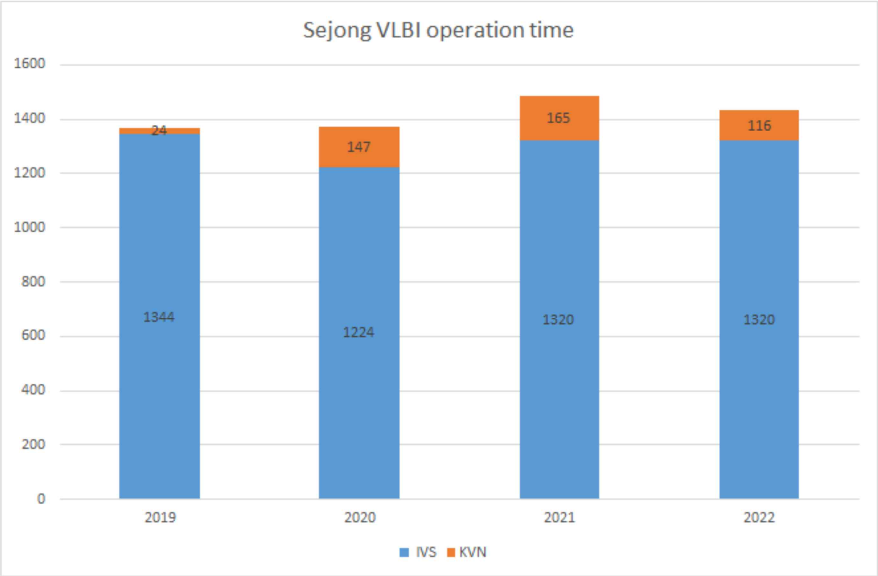

Figure 2-5. Annual observation hours for Sejong VLBI

The technical specifications of the Sejong antenna are presented in Table 2-1. The Sejong VLBI has a Cassegrain main reflector having a 22M diameter, and a total of four S, X, K, and Q band receivers. The S and X band receivers are mainly used for IVS observation, while the K and Q band receivers are used in observations for the KASI VLBI Network and the East-Asia VLBI Network (EAVN).

Table 2-1. Sejong IVS Antenna Specifications

Parameters	Sejong VLBI
IVS letter codes	Sejong (KV)
CDP number	7368
DOMES number	23907S001
Location	127°.18′E 36°.31′N Elevation 177m
Diameter of main reflector	22m
Antenna type	Shaped Cassegrain
Aperture efficiency	about 60%
Pointing accuracy	0.0131°
Reflector surface accuracy	100㎛
Operation range	AZ: ±270° EL: 0 ~ 90°
Slew speed	5°/sec (AZ and EL)
FS Version	9.10.4
Data acquisition Recorder	K5 & DBBC3

Korean VLBI Network (KVN) of KASI

Korean VLBI Network (KVN; Figure 2-6) which comprises three identical 21-m antennas has been operating for 15 years. KVN is one of the active components of East Asia VLBI Network (EAVN). The baseline lengths of the KVN are 305~476 km. Each of antenna observes simultaneously at 22, 43, 86, and 129 GHz mainly for astronomical purposes like as monitoring star formation region, study on Active Galactic Nuclei (AGN), Astrometry and so on. Within a few months a new KVN antenna will be joined KVN. In 2021, an experiment for K-band Geodesy was carried out with collaboration of VLBI antennas in Asia-Oceania region like as Tianma, Urumqi, and Hobart. Preliminary result of the experiment shows ~32 ps WRMS for group delay ambiguity spacing.

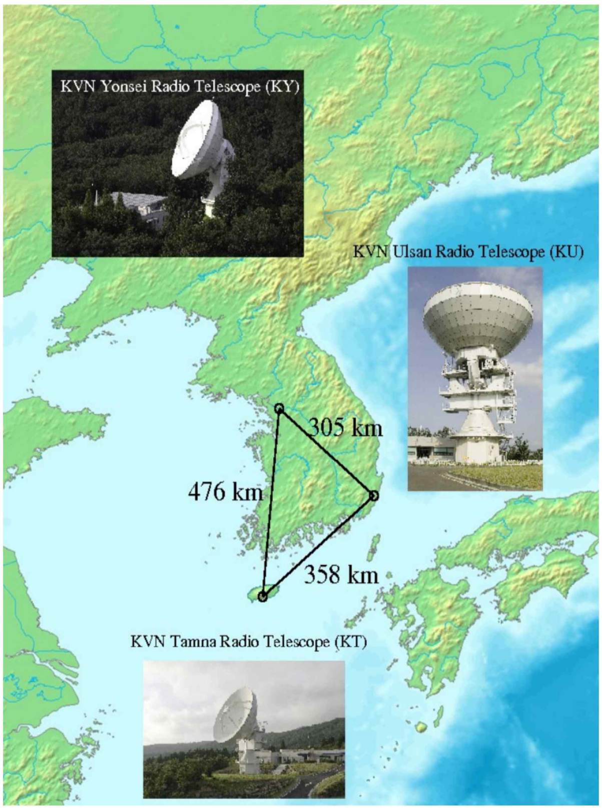

Figure 2-6. Korean VLBI Network (KVN) of KASI
(https://radio.kasi.re.kr/kvn/main.php)

KVN Reference Points

For Astrometry and Geodesy, it is important to determine an accurate reference position, often called the invariant point (IVP) of the radio telescope and to monitor the variation caused by crustal movement and gravitational deformation. Since the first IVP determination of Ulsan and Tamna telescope of KVN was done in 2017, the IVP survey has been conducted regularly. As can be seen in Figure 2-7 and 2-8, velocity vectors of three VLBI stations of KVN are within the normal range of estimates from GNSS in Korean Peninsula.

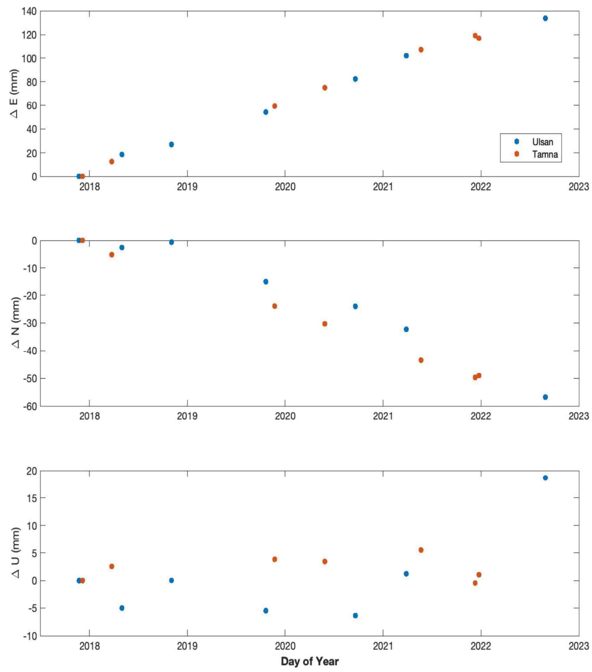

Figure 2-7. ENU components of KVN Ulsan and Tamna

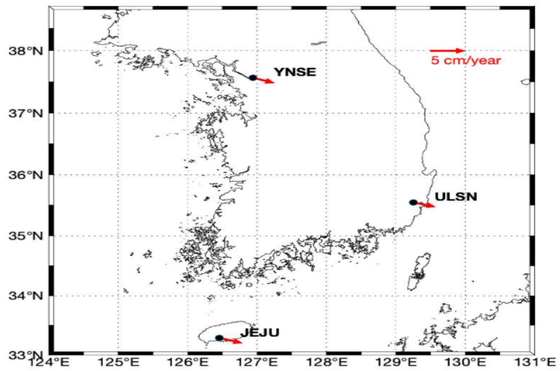

Figure 2-8. Velocity vectors of KVN stations

2.3 SLR

Sejong SLR of KASI

SLR, previous ARGO-M (Accurate Ranging system for Geodetic Observation-Mobile), near Sejong VLBI has been providing official data to ILRS since 2016. During the last four years, Sejong SLR has participated in ILRS campaign regularly as shown in Figure 2-9. Figure 2-10 shows the LAGEOS range precisions measured by ILRS network stations. IVP of Sejong SLR was determined by using of a pillar of NGII and three inhouse pillars in 2019 and 2020.

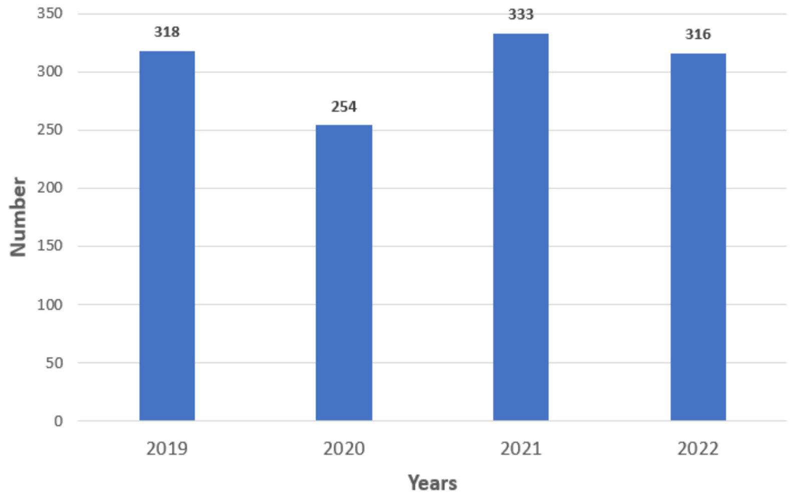

Figure 2-9. Annual observation satellites for Sejong SLR

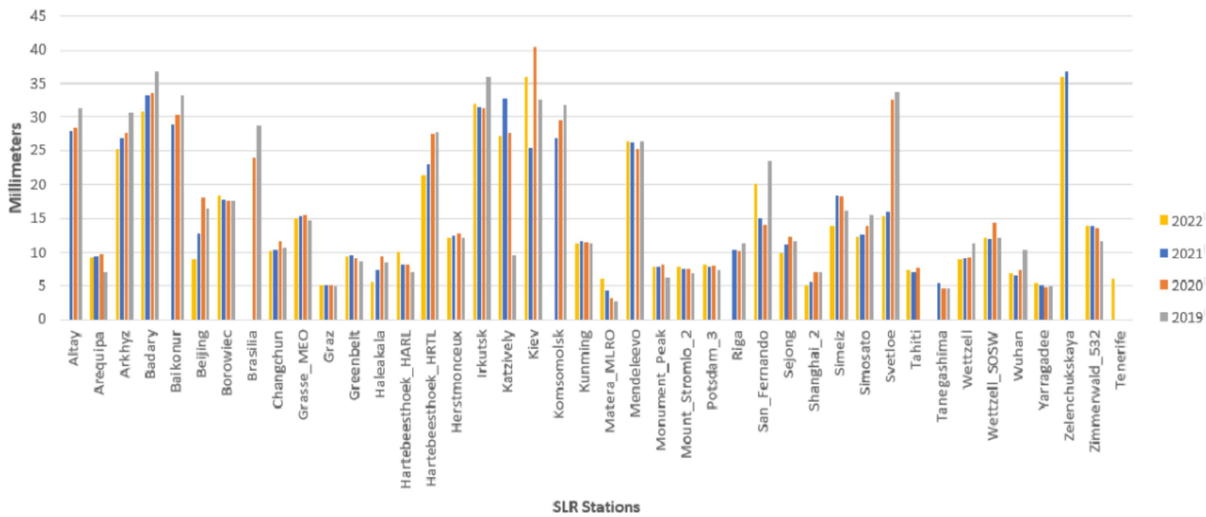

Figure 2-10. LAGEOS range precisions measured by ILRS network stations

2.4 GGOS

Local Tie at Sejong GGOS Site

GGOS sites are essential particularly for geodetic parameters like as ITRF and EOPs. Sejong GGOS site, certified in 2019, contains three network stations of IGS, IVS, and ILRS. VLBI and GNSS of NGII and nearby SLR of KASI have been contributing to determination of ITRF and EOPs. Since each technique utilizes independent space geodetic frame, their relative positions must be precisely determined to ensure the accuracy of the combining reference frame. NGII is installing a superconducting gravimeter system in the site.

As shown in figure 2-11, a polygonal network for the local tie survey at Sejong GGOS site was established in 2020. For the first step, reference points (IVPs; Invariant Points) of VLBI and SLR were determined by a least squares adjustment computation. Overall procedure to estimate the IVPs is shonw in figure 2-12.

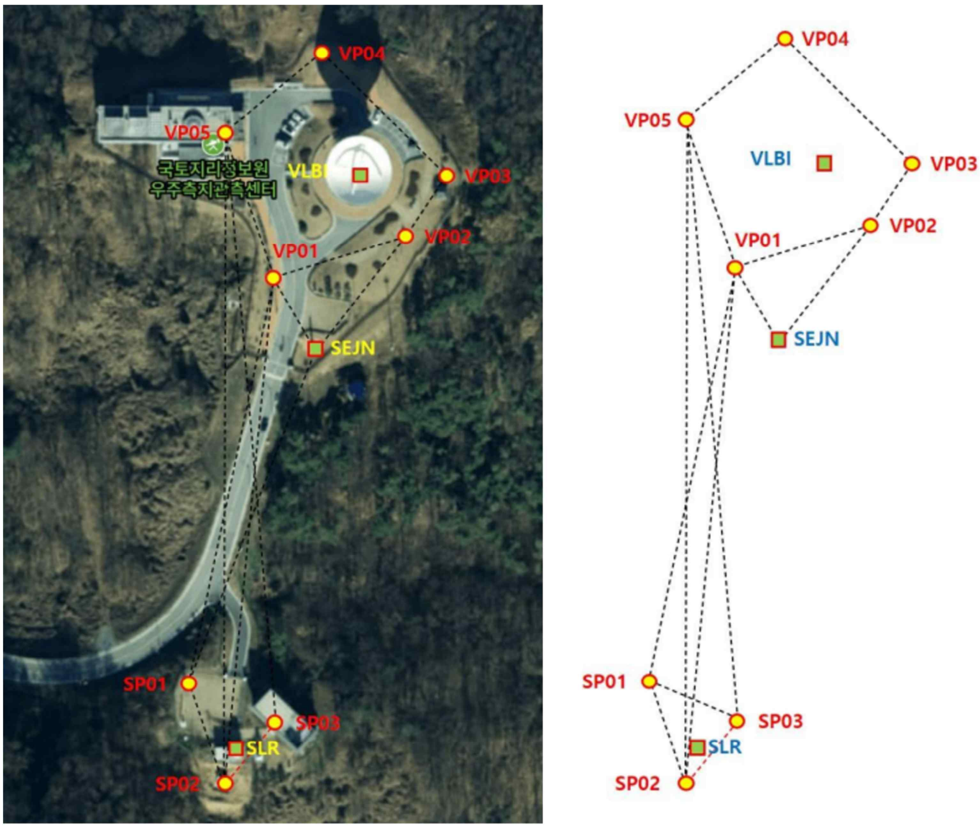

Figure 2-11. A polygonal network for local tie survey at Sejong GGOS Site

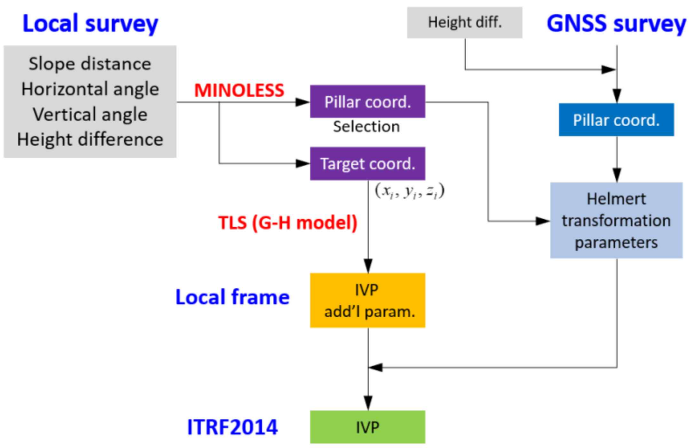

Figure 2-12. Estimation of IVPs of VLBI and SLR at Sejong GGOS site

The IVPs of VLBI, SLR, GNSS in ITRF2014 are shown in SINEX format as below.

```
%=SNX 2.10 NGI 20:320:00000 NGI 20:213:00000 20:290:00000 C 00009 2
*-------------------------------------------------------------------------------
+FILE/COMMENT
* File created by Space Geodetic Observation Center (Sejong, Korea)
* Matrix Scalling Factor used: 1.0000000000
* Contact: Dr. Sang-Oh Yi
-FILE/COMMENT
*-------------------------------------------------------------------------------
+SITE/ID
*CODE PT __DOMES__ T _STATION DESCRIPTION__ APPROX_LON_ APPROX_LAT_ _APP_H_
 7368  A 23907S001 C 22m VLBI               127 18 12.1  36 31 21.8   194.6
 7394  A 23907S002 C SLR telescope          127 18 10.5  36 31 15.6   176.5
 SEJN  A 23907M001 C Sejong, Korea          127 18 11.5  36 31 20.0   181.2
-SITE/ID
*-------------------------------------------------------------------------------
+SOLUTION/EPOCHS
*Code PT SOLN T Data_start__ Data_end____ Mean_epoch__
-SOLUTION/EPOCHS
*-------------------------------------------------------------------------------
+SOLUTION/ESTIMATE
*INDEX TYPE__ CODE PT SOLN _REF_EPOCH__ UNIT S __ESTIMATED VALUE____ _STD_DEV___
     1   STAX 7368  A    1 20:290:00000 m    2 -3.11008020807696E+06 3.219499E-04
     2   STAY 7368  A    1 20:290:00000 m    2  4.08206659196432E+06 3.979317E-04
     3   STAZ 7368  A    1 20:290:00000 m    2  3.77507675793716E+06 3.826499E-04
     4   STAX 7394  A    1 20:290:00000 m    2 -3.11010853233468E+06 3.448585E-04
     5   STAY 7394  A    1 20:290:00000 m    2  4.08217026709179E+06 3.742187E-04
     6   STAZ 7394  A    1 20:290:00000 m    2  3.77491176717258E+06 4.261244E-04
     7   STAX SEJN  A    1 20:290:00000 m    2 -3.11008202364000E+06 1.172608E-03
     8   STAY SEJN  A    1 20:290:00000 m    2  4.08209386772000E+06 1.311069E-03
     9   STAZ SEJN  A    1 20:290:00000 m    2  3.77502346280000E+06 1.395240E-03
-SOLUTION/ESTIMATE
*-------------------------------------------------------------------------------
+SOLUTION/MATRIX_ESTIMATE L COVA
*PARA1 PARA2 ____PARA2+0__________ ____PARA2+1__________ ____PARA2+2__________
     1     1  1.03651745632542E-07
     2     1 -1.02858525715112E-07  1.58349604655864E-07
     3     1 -9.02421567092604E-08  1.18349668677744E-07  1.46420979167617E-07
     4     1 -1.71330492690703E-08  2.09612864401804E-08  2.30417703320909E-08
     4     4  1.18927357005994E-07
     5     1  2.23283008340365E-08 -2.68544536142165E-08 -3.11558436135739E-08
     5     4 -8.00485797357568E-08  1.40039608419214E-07
     6     1  2.14808606812500E-08 -3.10192331434083E-08 -2.05934363025959E-08
     6     4 -3.52207212591083E-08  3.92250271544064E-08  1.81582036650376E-07
     7     1 -2.37959481003146E-08  7.75105070971902E-09  2.08168374548474E-09
     7     4 -1.50108852282661E-08 -4.51919980030846E-10 -2.66092921106388E-08
     7     7  1.37500999022128E-06
     8     1  7.44832416032474E-09 -2.90227883750650E-08 -5.75168753909832E-10
     8     4 -1.14330033285589E-08  7.11240274548213E-09  1.34283806928829E-08
     8     7  2.92019967284475E-07  1.71890246542599E-06
     9     1  6.96273362558317E-09 -8.10674068251707E-09 -3.99875716055758E-08
     9     4 -2.56034838433804E-08  2.56800740728770E-08 -4.75669993209187E-09
     9     7  4.71546896709947E-07 -1.16020550722159E-06  1.94669371547446E-06
-SOLUTION/MATRIX_ESTIMATE L COVA
%ENDSNX
```

3. R&D ACTIVITIES

3.1 REFERENCE FRAME

KASI R&D activities regarding Space Geodesy are focusing on reference frame and its applications. For the last four years, researches on reference frame have been conducted such as precise orbit determination of GNSS satellites and preparing of hybrid (GNSS & VLBI) reference frame realization.

Reference Frame

In 2020, a key technique for determination of regional reference frame based on 20 IGS stations and 11 KASI CORS has been developed with precision comparable to that of the final products of IGS. As shown in figure 3-1, weekly solutions from 2018 to 2020 show mm level accuracy compared with the IGS and CODE (Center for Orbit Determination in Europe) solution.

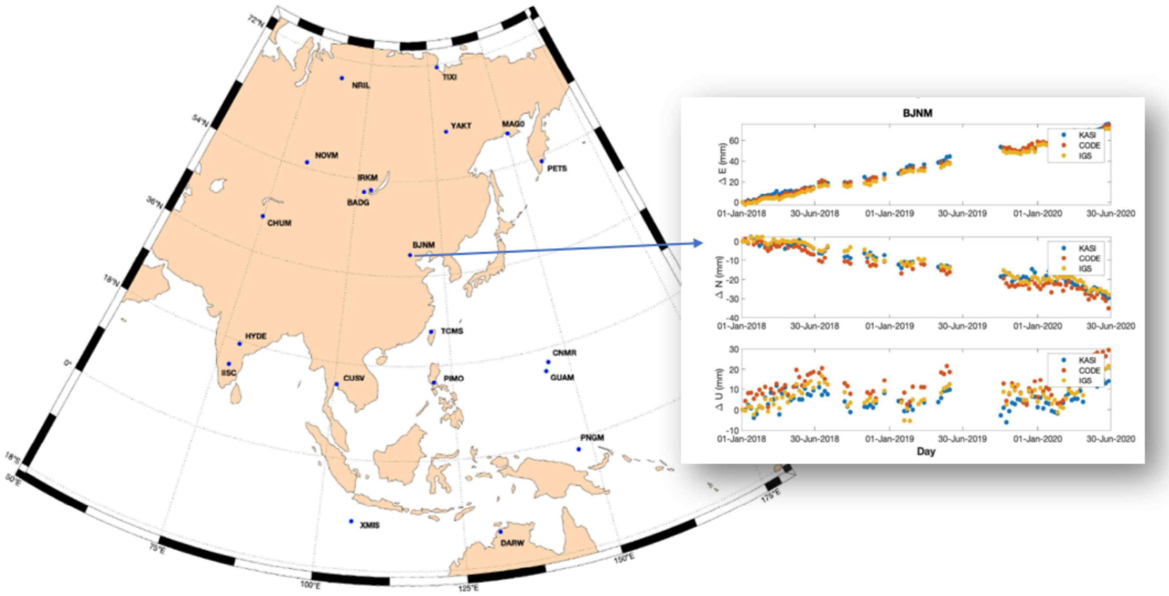

Figure 3-1. The regional GNSS network and its time series

In 2022, the regional GNSS network has been modified considering seven key criteria including GNSS and VLBI colocation. As shown in figure 3-2, 14 IGS sites 9 GNSS+VLBI sites were chosen in terms of long-term stability of time series and geometry of network.

Figure 3-2. Modified regional GNSS+VLBI network (red circles: GNSS+VLBI)

Figure 3-3 shows time series and its formal errors for AIRA of the regional network.

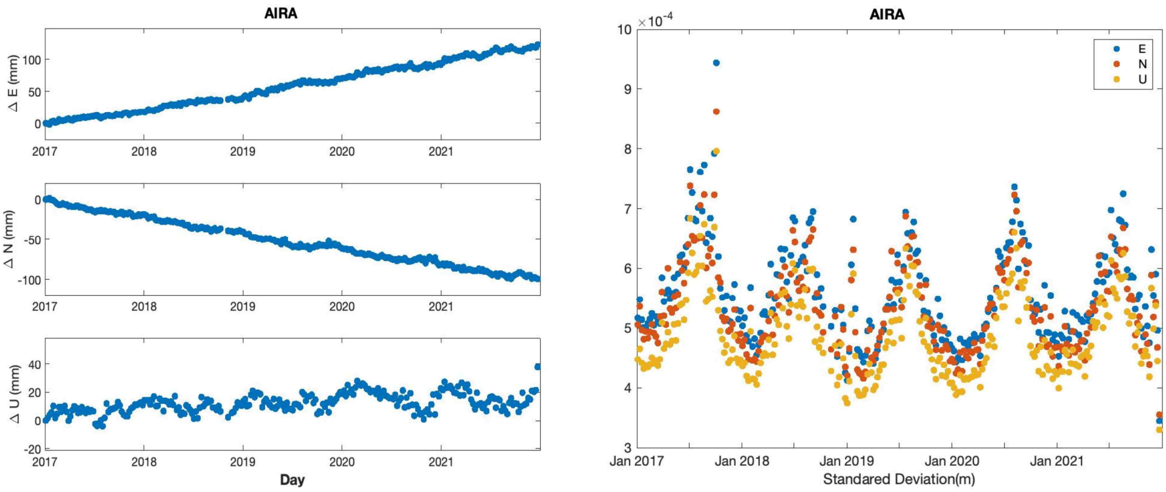

Figure 3-3. Time series and its formal errors for AIRA of the regional network

Geodetic VLBI Receiver for KVN

Since 2022, a new geodetic VLBI receiver dedicated to KVN has been developing. This receiver was designed to avoid radio frequency interference of S band of conventional geodetic VLBI and not to interrupt exisiting astronomical observation frequency band. It will cover C (6~8 GHz), X (8~9 GHz), Ka (28~34 GHz) band and can observe simultaneously. Figure 3-4 is the conceptual design of the C/X/Ka band feedhorn. The first receiver will be assembled in late of 2023.

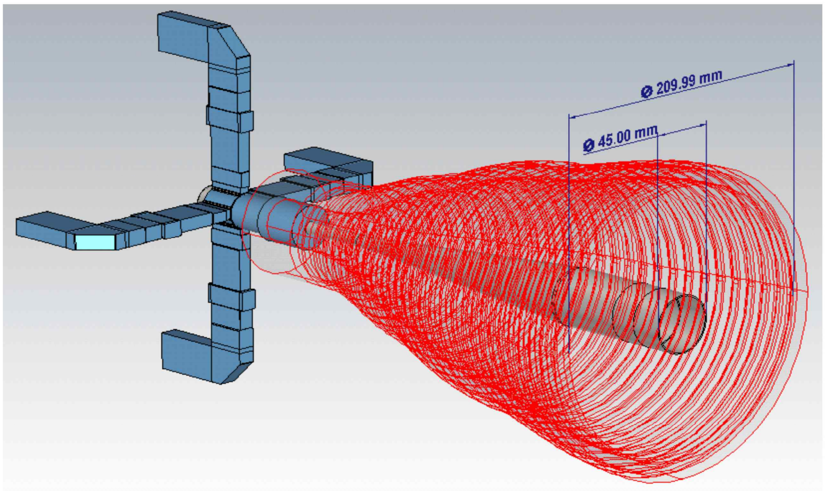

Figure 3-4. C/X/Ka band Feedhorn

In the future, a hybrid (GNSS+VLBI) type of reference frame determination will be reallized in Asia-Oceania region. It will provide a refernece frame to VLBI signal transmitter loaded satellites as well as KPS. KVN would also be participated in IVS or regional geodetic campaign and spacecraft tracking network.

3.2 IONOSPHERE MONITORING

KASI has been developing a near-real-time (NRT) ionospheric monitoring system, utilizing GNSS data from 40 stations. This system generates maps of Total Electron Content (TEC) and Rate of TEC (ROTI) every 15 minutes. Additionally, KASI is in the process of establishing a GNSS scintillation observation network along a meridional chain. This network encompasses two stations in Korea, one in Micronesia, and another in Antarctica. Apart from NRT ionospheric monitoring, KASI has also engineered a regional TEC prediction model employing a deep learning approach. By using a 20-year TEC dataset and combining Convolutional Long Short-Term Memory techniques and the Deep Convolutional Generative Adversarial Network–Poisson Blending (DCGAN-PB) method, this prediction model adeptly forecasts TEC values 24 hours in advance as shown in figure 3-5.

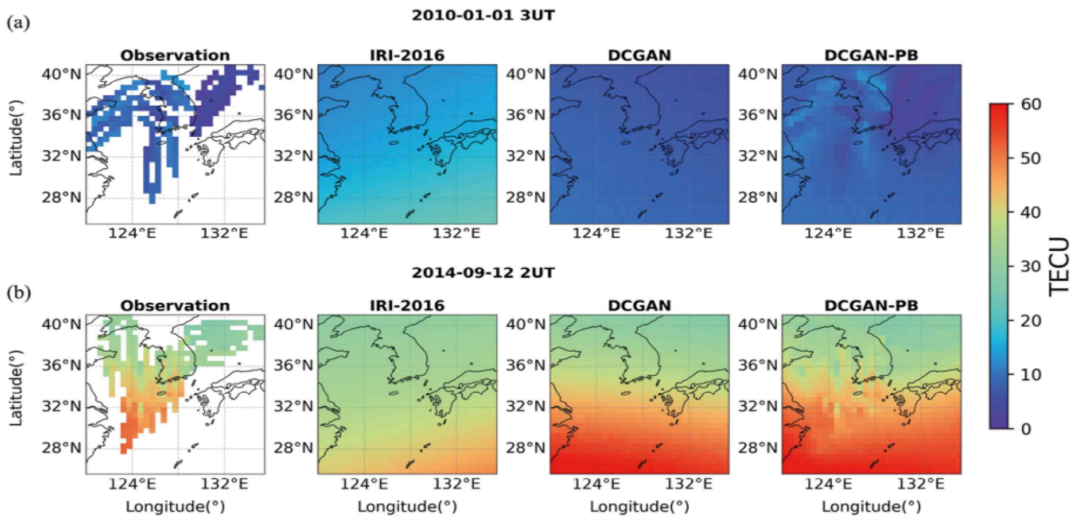

Figure 3-5. Visualization depicting the reconstruction of TEC maps using the DCGAN-PB method

Using this advanced ionospheric monitoring system, KASI successfully observed perturbations in the ionosphere caused by the significant volcanic eruption of Hunga Tonga-Hunga Ha'papi on January 15, 2022. The eruption, characterized by high-pressure, high-velocity forces, generated atmospheric waves that propagated globally, impacting the ionosphere. KASI's ionospheric monitoring system identified two distinct types of ionospheric perturbations. Firstly, transient TEC modulations coincided with surface air pressure perturbations. Secondly, pronounced irregular TEC perturbations and L-band scintillations were observed in the southern region of Korea. These phenomena are interpreted as the poleward extension of equatorial plasma bubbles.

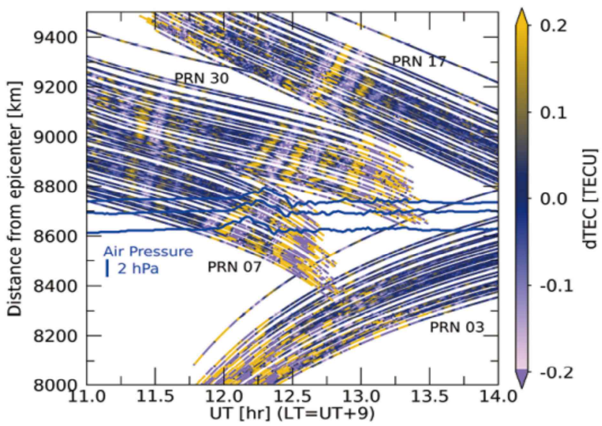

Figure 3-6. Alterations in both surface atmospheric pressure and ionospheric TEC due to the eruption of the Hunga-Tonga volcano

3.3 GEOSCIENCE

The Eurasian plate including Korea has known to be geologically stable, but the recent significant events, such as the 2011 Tohoku-Oki, the 2016 Gyeongju, the 2017 Pohang, and other events near Lake Baikal, strongly suggest the need for monitoring crustal motions on the Korean peninsula. Considering the improvement of methodologies and the increasing accuracy of observations that have been used for studying the geophysical processes including the plate motion and earthquake events, an effective analyze for the geodetic effects (surface displacement and gravity changes) on the Korean peninsula has been done in 2023.

Studies using surface displacements from GNSS stations on the Korean peninsula, including a station managed by NGII, demonstrated correction methods for the seasonal variations due to the global water mass load changes and long-term motions due to the post-seismic effect of the 2011 Tohoku-Oki earthquake. Figure 3-7 and 3-8 show that the periodic signals in a 1-year cycle were mostly estimated by the global water mass changes, and additional speed of plate motion could be effectively reduced by using the predictions from a viscoelastic earth model.

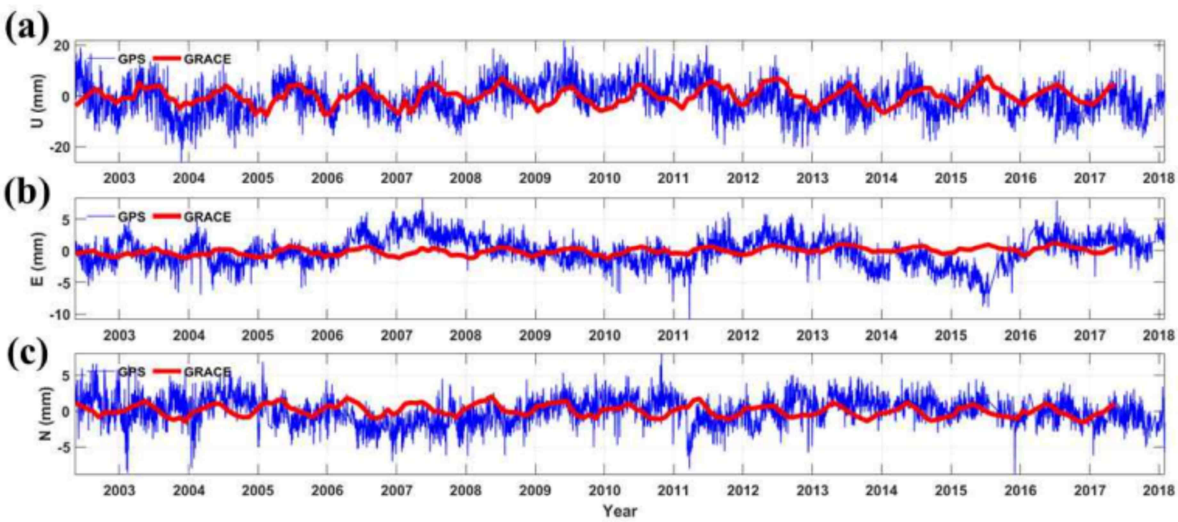

Figure 3-7. NEU components time series of SUWN IGS site

The study also suggested that the combination of the earth model test, GRACE satellite gravimeter data, and GNSS observations would provide a useful tool for understanding the domestic groundwater storage of Korea.

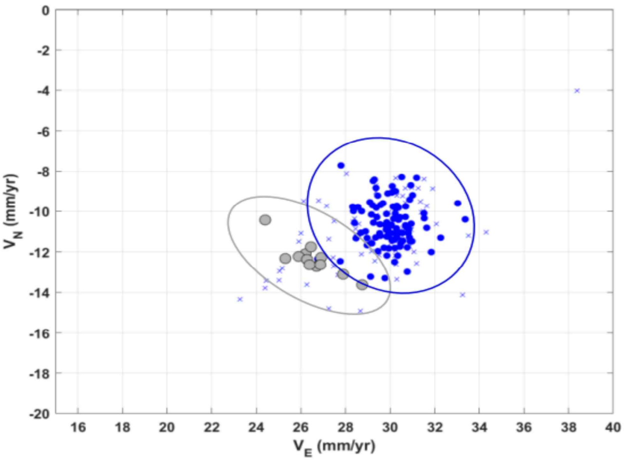

Figure 3-8. Horizontal veolcity vector changes of domestic GNSS network before (gray) and after (blue) 2011 Tohoku-Oki earthquake

Secondly, in the studies using SAR satellite observations, the accuracy of surface displacement estimates was improved by additionally reducing the atmospheric phase delay effect due to WRF atmospheric model. The improved estimates of crustal motions near Baikal rift zone were compared with GNSS observations as shown in figure 3-9. To overcome a limited spatial coverage of the traditional geodetic measurement such as GNSS, SAR interferometry technique was introduced to detect local-scale surface deformations of Korea. The results based on high-resolution SAR images were compared with the former estimates inferred from Sentinel-1 SAR images to re-evaluate the precise surface deformation rates, which additionally identified multiple locations indicating significant subsidences.

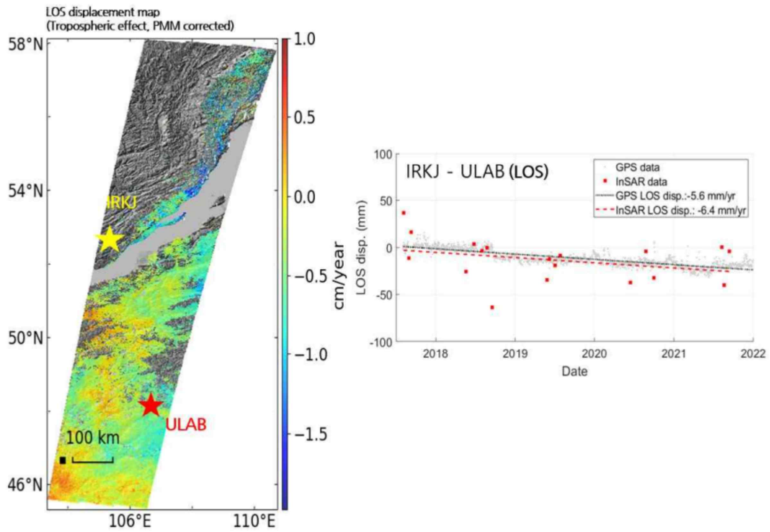

Figure 3-9. A Case of Baikal Rift Zone:
Differences of ground displacement (Line of Sight) between IRKJ and ULAB based on GNSS and InSAR

3.4 A MAP OF THE POLES

NGII published a report which titled 'A map of the poles: A view from satellites' in 2022. It is the outcome of a seriese of tasks on establishment of database for the polar regions particularly around research stations in the Arctic (Dasan) and in the Antarctic (King Sejong and Jangbogo) areas. Figure 3-10, 3-11, and 3-12 show King Sejong station, Jangbogo station, and Dasan station respectively.

Figure 3-10. The combined map of King Sejong station in the Antacrtic

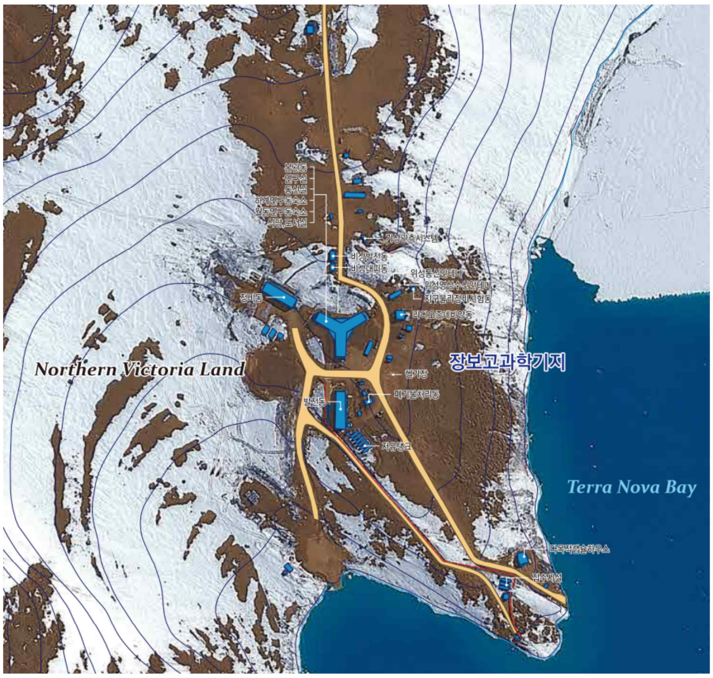

Figure 3-11. The combined map of Jangbogo station in the Antacrtic

Figure 3-12. The combined map of Dasan station in the Arctic

These are the combined version of various information from surveying, digitized topograph and elevation, orthophotograph, and a list of place name. It will be used for R&D activities on the regions, natural resources exploration, monitoring of climate change and space weather and so on. Such a polar surveying and monitoring will be continued by using Compact Advanced Satellite 500 (CAS500)-1 operated by NGII which was launched in 2021.

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