Precise Positioning and Estimation of Crustal Movement in King Sejong Station, King George Island, Antarctica

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Abstract

King Sejong Station in King George Island plays a great role in the expansion of the human activities due to its geographical characteristics as an advance post and gateway to the mainland of Antarctica. This study addressed the precise positioning of King Sejong Station's GPS CORS (Continuously Operating Reference Station) and the estimation of the crustal movement of Barton Peninsula, King George Island. The GPS data for 32 months (January 2007 to August 2009) were used for the study, and the relative positioning method was used for precise positioning. The observation data of O'Higgins, which is closest to King Sejong Station, were used as the fixed points among the IGS (International GNSS Service) CORSs. Precise positioning with a maximum of ±0.0172 m RMSE was possible for the X, Y, and Z components. The precise point positioning (PPP) of the GPS data showed that Barton Peninsula is moving at a speed of 19 mm/year northeast (30° azimuth).

Keywords: *GPS, precise positioning, crustal movement, King Sejong Station*

1. Introduction

The Antarctic Continent, including the Antarctic Ocean, accounts for about 7% of the entire surface of the earth. Much of it is covered with ice and snow. Due to its severe natural environment, with the average temperature ranging from -35 to -15℃, and its geographic conditions, it is the least polluted place in the world and is thus an ideal site for many scientific researches.

Antarctica has been glaciated for some 34 million years, but its ice sheets have fluctuated considerably, driving changes in global sea level and climate throughout the Cenozoic Era. Variations in ice-volume can change global sea levels by tens of meters or more, and alter the capacity of ice sheets and sea ice to act as major heat sinks or insulators. So it is important for us to determine the scale and rapidity of the response of large ice masses and associated sea ice to climatic forcing. For that reason the Intergovernmental Panel on Climate Change (IPCC) has called for an assessment of the stability of the cryosphere in the face of rising CO2 levels (http://www.scar.org/media/pressreleases/). The call for an environmental protocol to the Antarctic Treaty came after scientists discovered large deposits of natural resources such as coal, natural gas and offshore oil reserves in the early 1980s (http://www.eoearth.org/article/Energy_profile_of_Antarctica).

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The unique environment of Antarctica has attracted the attention of many countries due to its scientific and economic values. Since the Antarctic Treaty took effect in 1961, 20 countries have placed 45 regular scientific stations in the continent to study its ecology and environment. The geographic data of the continent are also being examined as the bases of such studies. Such geographic data are essential for scientific activity, environment management, and sightseeing, as well as for the preservation of life in Antarctica.

GPS is an essential tool for applications that be required high positioning precision (Parkinson, 1996 ; Hasan, 2012; Hwang, 2012; Quadeer, 2012; Park, 2013). GPS have been used as a useful tool in investigating global plate motions and regional tectonic movements (Argus and Heflin, 1995; Larson et al., 1997). A number of tectonic studies using GPS have been done (Kato et al., 1998; Shen et al., 2000; Holt et al., 2000).

In this study, the GPS observation data of King Sejong Station for 32 months and the IGS CORS observation data for the same period were processed using the relative positioning method, to calculate the high-precision coordinate results of King Sejong Station's GPS CORS. In addition, the crustal movement of Barton Peninsula was monitored, and its speed was estimated via precise point positioning with the observation data.

2. King Sejong Station

King Sejong Station is located in Barton Peninsula, King George Island, making it strategic point for studying the behavior of energy particles from the space into the Earth's magnetic field. Its relatively mild climate in Antarctica attracts wide range of animals for breeding in summer. This is why many biologists want to visit the island for their researches. When it comes to geology, the northern Antarctic Peninsula including Bransfield Strait and the South Shetland Islands is the most active area until recently in geologic time. King George Island is one of the best places for studying the recent evolution of the land masses of Antarctica. Because the island is in subantarctic region and its surrounding sea is almost ice-free during the austral summer, it has become a favorite access to the Antarctic continent (http://www.kopri.re.kr/). Figure 1 shows the location of King Sejong Station in Antarctica.

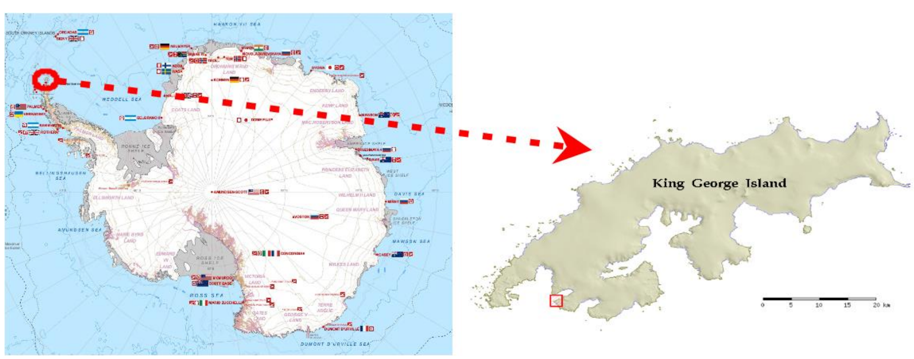

Figure 1. Location of King Sejong Station in Antarctica

In this study, GPS data for 32 months (January 2007 to August 2009) were used for the precise positioning of the study area and for the estimation of the crustal movement speed of Barton Peninsula. GPS receiver of King Sejong Station has changed in December 2009 and prepares registration in IGS. So, GPS data isn't provided to user after 2009.

The data in the thirty-second-interval RINEX format were used for the study, and the UZ-12 receiver and ASHTECH's ball microstrip antenna (ASH701945B_M SNOW) were used for the GPS observation.

3. Data Processing

In this study, the observation data of King Sejong Station's GPS CORS were processed via relative and precise point positioning by week, using Bernese GPS 5.0 (BSW 5.0).

The deviations occurring during GPS data processing due to physical movement of the earth must be removed using a proper model and this type of correction includes pole movement, atmospheric load (McCarthy, 1996). BSW5.0 eliminated these correction factors by using precise orbiting and all kinds of models provided by NASA JPL (NASA Jet Propulsion Laboratory), AIUB (Astronomical Institut Universität Bern) and IGS(International GNSS Service). The Saastamoinen model (Saastamoinen, 1972) and Niell mapping function (Niell, 1996) were used for the tropospheric delay. The setting was organized so that only the observation data with at least a 13° elevation angle could be processed, to prevent multipath. The precise ephemeris of Jet Propulsion Laboratory was used for the position information of the satellites, and the absolute calibration model was used for the antenna phase center offset calibration. The absolute calibration model can calculate the calibration value for the azimuth at very fine intervals and can provide calibration values for the L1 and L2 frequencies, respectively. Table 1 shows the methods and data for processing the GPS data.

Table 1. Parameters of Data Processing

Parameters	Description
Data Processing Methods	Relative Positioning, Precise Point Positioning
Satellite Ephemeris	Precise Ephemeris
Tropospheric Correction	Dry and Wet Niell Model
Earth Gravity Potential	JGM3
Sub-daily Earth rotation parameters	IERS2000
Nutation	IAU2000
Antenna Model	Absolute Model
Solar System Ephemerides	JPL DE200

Bernese Processing Engine (BPE) is an automated data processing program of which processing procedure is determined by Process Control File (PCF), and the user may adjust the option upon use of BPE or add or omit each script by a separate edit function. BPE has been used for Global IGS Network data processing at IGS Analysis Center and is also being use dat GSI(Geographical Survey Institute) in Japan currently for nationwide GPS network data processing purpose(http://www.geonet.org.nz/). As the BPE server has been started, it performs the following tasks:

1) The BPE server reads its input options. The input options contain the name of the PCF and the CPU Control File. The first file defines the sequence of tasks that will be executed and the second defines which hosts can be used.

2) According to the PCF and CPU file, the server starts the first client. The CPU file defines how a client is started.

3) The first task of the newly started client is to open the TCP/IP connection to the server. From the moment when the connection is accepted by the server, the client is permanently connected until it terminates.

4) After successfully establishing the connection between server and client, the server starts to send commands to the client and the client sends back its responses. The first

message from the server usually commands the client to run a specific user script. The last response from the client informs the server about finishing the user script. The last command from the server tells the client to disconnect and terminate.

5) In the way described above the BPE server keeps the information about all running clients. After finishing one client the BPE server decides whether new clients may be started. This means that steps 2)~5) are repeated until the entire BPE job finishes.

6) Server and clients report the information about their execution into several output files.

4. GPS Data Analysis

4.1 Precise Positioning of the GPS CORS in King Sejong Station

Before precise positioning of CORS in King Sejong Station, we analyzed data from the IGS stations in order to select reference station.

For experiment, IGS GPS observations have been collected from four stations that were close to the study area: OHI2 and OHI3 in O'Higgins, PARC in Punta Arenas, and RIO2 in Rio Grande. Figure 2 shows the IGS CORSs around King Sejong Station.

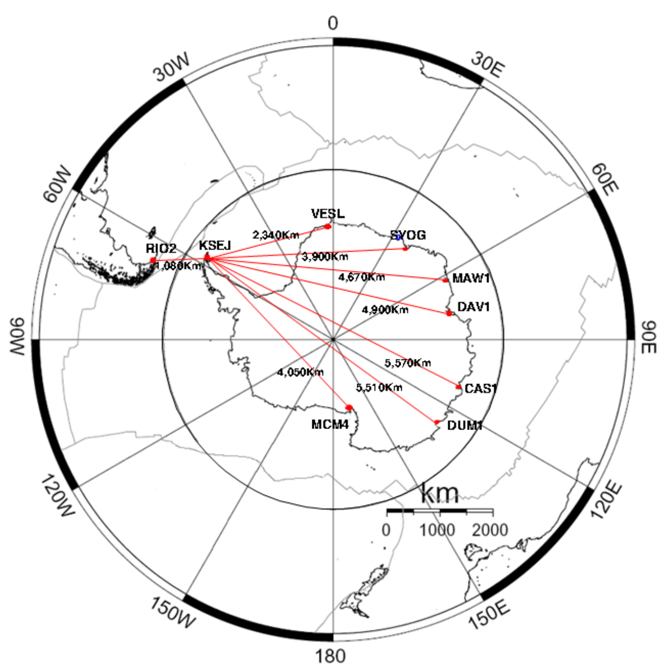

Figure 2. IGS CORSs around King Sejong Station

IGS announces the coordinate results of each CORS. Table 2 shows the coordinate results of OHI2, OHI3, PARC, and RIO2.

Table 2. Coordinate Information for Selected CORS (http://igscb.jpl.nasa.gov/)

Station ID	3D Cartesian Coordinate			Local Geodetic Datum	Reference Epoch
	X	Y	Z		
OHI2	1525811.7736	-2432478.2069	-5676165.5819	IGS05	2000-01-01 00:00:00
OHI3	1525808.9404	-2432478.7179	-5676166.2629		
PARC	1255992.4029	-3622975.0948	-5079719.3109		
RIO2	1429907.7509	-3495354.7664	-5122698.6572		

The four sets of data were used for the experiment that was conducted to select the reference station for relative positioning. When OHI3, which is 130 km away from the study area, was assumed to be an unknown point, the coordinate results according to the reference point were compared, with the three other stations (OHI2, PARC, and RIO2) as reference points. The GPS observation data for the first day of each month from January to December 2008 were used in the experiment. Table 3 shows the experiment results.

Table 3. Result of experiment

Case	OHI3			Reference Station
	ΔX(m) (RMSE)	ΔY(m) (RMSE)	ΔZ(m) (RMSE)	
I	-0.0042 (±0.0020)	0.0115 (±0.0039)	0.0133 (±0.0078)	OHI2
II	-0.0957 (±0.0136)	-0.0609 (±0.0264)	0.0868 (±0.0199)	PARC
III	-0.1019 (±0.0136)	-0.0585 (±0.0107)	0.0755 (±0.0158)	RIO2
IV	-0.0493 (±0.0067)	-0.0260 (±0.0133)	0.0485 (±0.0099)	OHI2 - PARC
V	-0.0532 (±0.0053)	-0.0245 (±0.0063)	0.0437 (±0.0081)	OHI2 - RIO2
VI	-0.100 (±0.0110)	-0.059 (±0.0176)	0.082 (±0.0156)	PARC - RIO2
VII	-0.067 (±0.0070)	-0.037 (±0.0119)	0.058 (±0.0101)	OHI2 - PARC - RIO2

Multiple reference points are generally used in relative positioning. In the experiment that was conducted in this study, however, the use of only OHI2, which is closer to the study area, led to better results in terms of both the deviation and RMSE compared to the use of multiple reference points, including PARC and RIO2, which are far from the unknown point (OHI3). Based on the results, OHI2 was selected to be the reference station for the precise positioning of King Sejong Station's GPS CORS.

Thus, relative positioning was conducted with OHI2 as the reference point, for the precise positioning of King Sejong Station's GPS CORS. Table 4 shows the GPS observation data that were used in this study.

Table 4. GPS datasets used in this study

Location	ID	Date	Interval	Data Format
King Sejong Station	KSEJ	7 days in a month (2007. 01 ~ 2009. 08)	30 sec	RINEX
O'Higgins	OHI2	7 days in a month (2007. 01 ~ 2009. 08)	30 sec	RINEX

Precise positioning with a maximum of ±0.0172m RMSE was possible for the X, Y, and Z components, according to the relative positioning process. Table 6 shows the King Sejong Station GPS CORS coordinate results. The coordinate results were based on IGS05 as of January 1, 2000 (epoch 2000.0). The RMSE value of the Z component was larger than those of the X and Y components due to the characteristics of the GPS, particularly that the vertical component has a larger error than the horizontal component in the high-latitude region.

Table 5. Coordinate of CORS in King Sejong Station by Relative Positioning

X(RMSE)	Y(RMSE)	Z(RMSE)
1544165.9628 (±0.0070)	-2548888.4896 (±0.0080)	-5620212.4315 (±0.0172)

4.2 Crustal Movement of Barton Peninsula, King George Island

In this study, the crustal movement of Barton Peninsula, King George Island where King Sejong Station is located, was monitored, and the GPS observation data were processed using the PPP method, to calculate the movement speed. The PPP results showed that Barton Peninsula is moving in the direction where the X and Z components are increasing while the Y component is decreasing. Figures 3-5 show the crustal movement of Barton Peninsula in the direction of the latitude, longitude, and ellipsoidal height. The vertical axis represents the change in the coordinates, with the data on January 1, 2007 as zero, and the horizontal axis represents the observation date. The precise-point-positioning results by latitude and longitude showed that Barton Peninsula is heading northeast.

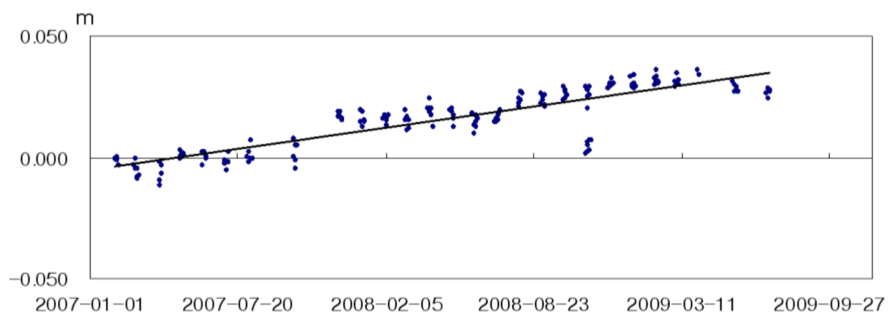

Figure 3. Movement of Barton Peninsula – Latitude

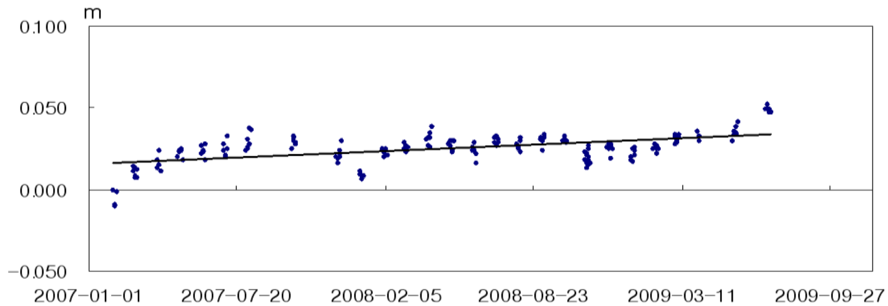

Figure 4. Movement of Barton Peninsula – Longitude

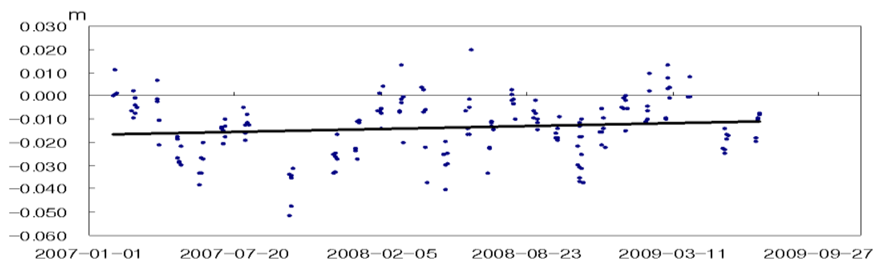

Figure 5. Movement of Barton Peninsula - Ellipsoidal height

In this study, the processing result for each session was combined by ADDNEQ2 module to calculate the movement speed of the King Sejong Station. ADDNEQ2 was developed in order to calculate Multi-session Solution from statistical combination of independent Normal Equation Solution which is created as a result of processing each session. The movement speed of GPS CORS can be calculated from such combination as long as a Normal Equation Solution exists over a certain period (Dach *et al.*, 2007). After reading the normal equation file, the system is expanded (station coordinate parameters are added). The resulting system of normal equations is singular. However, it is possible by changing the validity interval. The length of the new interval covers the entire analyzed period (*e.g.*, one year). The resulting normal equation system may then be stacked together with the other systems. Stacking of many normal equation systems referring to different epochs removes the singularity.

To estimate the crustal movement speed, the normal-equation solution of each session, which was created via PPP processing, was processed according to the free-network-solution method over the entire research period, using the ADDNEQ2 module. The crustal movements of Barton Peninsula were 0.0166, - 0.0088, and 0.0049 m/year in the X, Y, and Z directions, respectively, and 16.5, 9.6, and 2.3 mm/year in the latitudinal, longitudinal, and ellipsoidal-height directions. This is equivalent to the speed of 19 mm/year northeast (30.19° azimuth). The RMSE ranged from ±0.1 to ±0.3 mm/year for each component. It was somewhat large in the Z and ellipsoidal-height directions because the error of the vertical component was larger than that of the horizontal component due to the characteristics of GPS. Table 7 shows the crustal movement of Barton Peninsula and Figure 6 shows its movement direction and velocity.

Table 7. Crustal movement of Barton Peninsula

Velocity (mm/year)							Azimuth (from N)
X (RMSE)	Y (RMSE)	Z (RMSE)	Latitude (RMSE)	Longitude (RMSE)	Ellipsoidal height (RMSE)	Speed	
16.6 (±0.1)	-8.8 (±0.2)	4.9 (±0.3)	16.5 (±0.1)	9.6 (±0.1)	2.3 (±0.3)	19.0	30.19°

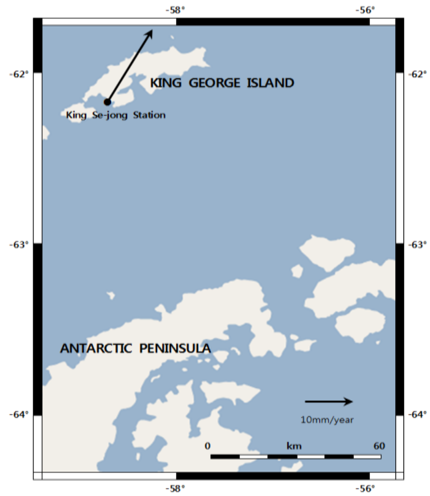

Figure 6. Movement Direction and Velocity of Barton Peninsula

5. Discussion

Geodetic measurements of crustal movements in Antarctica are an important input for the characterization of the present-day geodynamics of the continent, as well as providing supporting information and elements of validation with respect to the principal active tectonic structures in the area. The existing relative velocities between the Antarctic plate and the neighboring plates changed in time, as demonstrated by the irregular shape of ridges around the Antarctic plate.

The present tectonic setting of the Antarctic plates is the result of a complex geological evolution started from the Gondwana breackup that moved the Antarctica continent to a polar location (Lawver *et al.*, 1992; Meert, 2003). Boundaries of Antarctic plate are characterised mainly by divergent margins with the exception of the subduction zone of South Sandwich and South Shetland Island (Antonio *et al.*, 2006).

Especially, King George Island plays a great role in the expansion of the human activities due to its geographical characteristics as an advance post and gateway to the mainland of Antarctica and many research stations were located.

There are several studies that estimate crustal movement of Antarctic plate (Amalvict *et al.*, 2007; Bouin and Vigny, 2000; Altamimi *et al.*, 2002). And we compare our research with previous study. On the other hand, there are no IGS CORS in King George Island and limited analysis of crustal movement has been performed about King George Island region.

In this study, crustal movement of Barton Peninsula compared with previous. Table 8 shows the crustal movement of Antarctic Peninsula in previous study (Altamimi *et al.*, 2002). Figure 7 shows velocity field in Antarctic Peninsula.

Table 8. Crustal movement of Antarctic Peninsula in previous study

Station ID	Latitude(N)	Longitude(E)	Velocity (mm/year)	
			North	East
ELE1	-61° 28’ 50.6”	-55° 37’ 52.9”	0.0157	0.0034
ESP1	-63° 23’ 42.3”	-56° 59’ 45.9”	0.0116	0.0114
MAR1	-64° 14’ 41.8”	-56° 39’ 25.1”	0.0108	0.0097
NOT1	-63° 40’ 27.1”	-59° 12’ 29.5”	0.0119	0.0098
OHIG	-63° 19’ 14.6”	-57° 54’ 1.2”	0.0118	0.0103
PALM	-64° 46’ 30.3”	-64° 03’ 4.0”	0.0144	0.0117
PRA1	-62° 28’ 39.1”	-59° 39’ 1.0”	0.0174	0.0042
SPR1	-64° 17’ 43.2”	-61° 03’ 6.8”	0.0124	0.0096

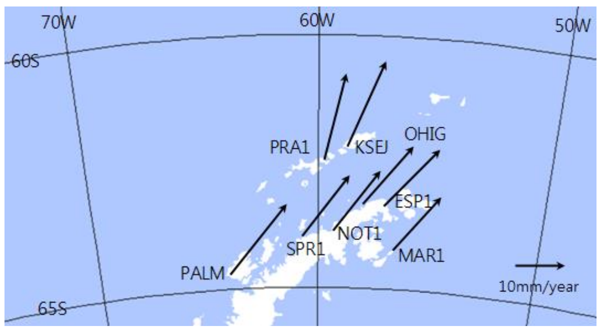

Figure 7. Velocity Field in Antarctic Peninsula

As for the movements of the Antarctic Peninsula itself, other study (Altamimi *et al.*, 2002) has found results similar to ours. Thus, we are able to confirm that the KSEJ motion properly represents crustal movement. The GPS receiver of King Sejong Station has changed in December 2009 and prepares registration in IGS. If GPS data will prove through IGS, precise and latest analysis about crustal movement will be available.

The coordinate of King Sejong Station’s CORS and the crustal movement speed of Barton Peninsula can be used as the basic data for relevant studies on positioning or crustal movement in Antarctica.

6. Conclusion

In this study, the observation data of King Sejong Station’s GPS CORS for 32 months were processed using the relative-positioning method, to calculate the precise coordinate results based on the IGS05 datum. In addition, the crustal movement of Barton Peninsula was estimated via precise point positioning and statistical processing with the observation data.

For King Sejong Station’s GPS CORS, the precise coordinate results with a maximum of ±0.0175m RMSE were obtained for the X, Y, and Z components.

The crustal movement of Barton Peninsula was monitored via precise point positioning, and the crustal movement speed was estimated to be 19 mm/year northeast by statistically processing the precise-point-positioning results.

It is expected that the coordinate results of King Sejong Station's GPS CORS and the crustal movement speed of Barton Peninsula can be used as the basic data for relevant studies on positioning or crustal movement in Antarctica.

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