Geodesy and Cartography
ISSN 2029-6991 / eISSN 2029-7009
2022 Volume 48 Issue 3: 177–184
https://doi.org/10.3846/gac.2022.14848

UDC 528.481

DETERMINATION OF THE MOTION BASED ON GNSS OBSERVATIONS BETWEEN 2000 AND 2021 BY USING THE IGS POINTS ON THE POLAR REGIONS

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Received 01 May 2021; accepted 02 September 2022

Abstract. People are fascinated today more than ever by the polar regions of the Earth. One reason for this is that wide expanses of the Arctic and Antarctic have not been explored and are therefore still viewed as frontier regions. Another is that they both have very diverse histories with regard to their origins and ice formation. Their numerous aspects still pose many puzzles for science today. The regions of the Earth designated as polar are those areas located between the North or South Pole and the Arctic or Antarctic Circles, respectively. The northern polar region, called the Arctic, encompasses the Arctic Ocean and a portion of some surrounding land masses. The southern polar region, called the Antarctic, contains the continent of Antarctica and areas of the surrounding Southern Ocean. In this paper three tests (2000, 2010 and 2021) of continuous GNSS data recorded by 8 permanent International GPS Service (IGS) stations in both Polar Regions have been processed by using CSRS-PPP Software for geodetic networks. The results also show that all GNSS provide good visibility with low elevation angles, whereas with high elevation angles, which might be needed due to natural barriers, the GLONASS and other satellites provides the highest number of visible satellites. Consequently, the mean motion of the study area was found approximately 7–15 cm for horizontal components (X–Y) and 6 cm for vertical components (Ellipsoidal Height) on the eight IGS points in the both poles.

Keywords: motion, IGS points, GNSS, static processing, Arctic, Antarctic.

Introduction

The regions of the earth designated as Polar Regions are those regions located between the North Pole or South Pole and the Arctic Circle or South Pole Circle, respectively. The Arctic region is called the North Pole, which covers the Arctic Ocean and part of the surrounding land. The Antarctic polar region is called Antarctica and includes the Antarctic continent and the surrounding area of Southern Europe. The diameter of each area is 5204 kilometres, because the Arctic Circle and the Antarctic Circle are 2602 kilometres away from their respective geographic poles. Therefore, do not confuse them with the floating magnetic poles on the earth. On the world map, the Arctic Circle is usually marked with a dotted line at 66°33′ north and south latitudes. The contour was originally determined based on the direction of the sun. Therefore, the Arctic Circle is defined as the latitude at which the sun is not accurately positioned for 24 hours during the summer solstice on June 21 each year. The winter solstice also occurs in the southern hemisphere. Therefore, the location of the Antarctic Circle is defined by the latitude at which the sun remains below the horizon for 24 hours. The 21st century is the century of the Polar Regions. Except for the remote land and ocean areas of the Arctic and Antarctica, there are few other natural landscapes that fascinate human beings. Today, most of the almost inaccessible ice and snow areas are undeveloped. In addition to fascination, the world also pays attention to the Polar Regions, because they act as cooling chambers, play a vital role in the earth's climate system, and greatly affect the global air quality and ocean circulation patterns. The subtle changes in its complex structure may have a profound impact. This is especially true for the large ice sheets in Greenland and Antarctica. They contain 99% of the ice on the earth. If they melt, global sea levels will rise. The melting of these two ice caps will raise water levels around the world by about 70 meters, and the long coastline of the earth will be submerged. Today, the effects of global climate change can be seen more clearly in the Polar Regions than anywhere else, especially in the Arctic regions. Since the middle of the 20th century, it has

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been warming up more than twice as fast as other parts of the earth, so it is regarded as an early warning signal of climate change. Therefore, meteorological services and scientists closely track events in high latitudes in real time, at least when satellites and measurement networks make observations possible (Gao et al., 2011; Linty et al., 2018; Reid et al., 2016; Haugg et al., 2001; Yastrebova et al., 2021).

The Arctic has become a challenging area not only due to bad weather, but also due to telecommunications and location restrictions. Many research groups have thoroughly studied the Arctic in this field. One of the challenges leading to the degradation of the positioning performance of the North Pole satellite is related to ionospheric disturbances, which cause satellite signal delays and flicker. The survey mainly shows that the performance of GNSS in the Arctic is not good. The geometry of the GNSS satellite constellation poses another challenge related to positioning. The motive is that the medium Earth orbiting (MEO) positioning satellites are seen at low elevation angles, which makes the sign grasp go through from the feasible blockage. In this study, we make contributions to the associated works on positioning in the Arctic region. The novelty of this work lies in the comparison of the overall performance of current positioning structures for the self-sustaining maritime area the usage of the simulation framework, which integrates the actual fashions of GNSS signals. Because GPS satellites are in an orbital plane of 55 degree inclination, not enough satellites are visible at high elevation angles for users in the Arctic. For this reason, VDOPs in the Arctic are worse (i.e., higher) than those close to the equator. Another approach would be to use multiple constellations, that is, some combination of GPS, Compass, Galileo and GLONASS. The significant improvement in the Arctic using two or more constellations. Multi-constellation augmentation helps improve the precision of existing GPS technologies by overlapping information gathered from multiple sources. This ensures that there is always coverage in satellite data no matter where the user moves. While this has been solved in most parts of the United States and Europe, the Polar Regions have unique geographical and atmospheric factors that can distort satellite imagery and signals (Gao et al., 2011; Linty et al., 2018; Reid et al., 2016; Jefrey, 2015; Haugg et al., 2001; Yastrebova et al., 2021).

The ionosphere is particularly active in polar areas, creating a more difficult environment to get a satellite signal. The Arctic region experiences a lot of ionospheric activity that fluctuates in intensity based on the solar cycle. Every 11 years, there is a rise in ionospheric activity which can produce beautiful aurora borealis but also causes a lot of problems with electronics in general. The researchers hope to gain more knowledge as to how the ionosphere more specifically affects satellites, and how to move around these obstacles to create satellite augmentation n in this area. GPS satellites are not impervious to ionospheric activity, which can cause signal scintillation, creating changes in the amplitude or phase of signals. This can cause errors in timing, which then translates to errors with positioning calculations. For Arctic applications, many solutions have been proposed. One such solution is the implementation of multi-channel L-band frequencies in satellite navigation systems. This would capture more data for positioning calculations and could overcome ionospheric interference if multiple frequencies are being used. The Arctic region, defined as the region above the Arctic circle (or 66.56 degrees latitude North), is known for being a challenging area, not only due to severe weather but also due to wireless telecommunication and positioning limitations. Many research groups have delved into the Arctic's research in this field. One of the challenges causing a reduction in the Arctic satellite positioning performance is related to ionospheric and tropospheric disturbances that cause random delays and scintillation of the satellite signals. These effects are even greater when the satellite is closer to the horizon. The survey mainly indicates that the GNSS performance in the Arctic is sub-optimal. The GNSS satellite constellation geometry, typically measured through the Geometric Dilution of Precision (GDOP) metric, causes another positioning-related challenge. The associated problem may be related to the constellation design of many medium Earth orbiting (MEO) positioning satellites and the affected time shifts. The satellite visibility from the low-elevation angles may be obstructed by location-specific conditions, and signals from high-elevation angles are unavailable due to time- and location-specific conditions. Moreover, the received signal suffers from possible blockages due to icebergs, hills, other vessels, etc., causing multipath (Gao et al., 2011; Linty et al., 2018; Liu et al., 2009; Reid et al., 2016; Jefrey, 2015; Haugg et al., 2001; Haugg et al., 2001; Yastrebova et al., 2021).

In this study, it has been applied GNSS techniques to investigate surface displacements on both poles. In this paper, the horizontal and vertical displacements originating from eight IGS points (on the South and North Poles) on 1 January 2021, 1 January 2010, and 1 January 2000 were investigated. For this aim, data of eight IGS stations (CAS, DAV, MAW, NYAL, PALM, SYOG, THU2 and TIXI) in the nearby North and South Pole points were used. Receiver Independence Exchange (RINEX) observation data of 8 IGS stations were obtained from IGS servers and analysed. Analyses and processing were carried out with CSRS-PPP Software and coordinate series and total displacements were computed by using the coordinate differences.

1. Description of experiment

Global Navigation Satellite Systems (GNSS) technique is widely used for geodetic and geodynamic modelling studies such as monitoring tectonic plate movements, earthquake observation, crustal deformation, etc., as it can produce high precision, low-cost and 3D positioning in a global coordinate system. GNSS can also be used to measure the relatively slow deformation of the ground that occurs during the time between earthquake and the other events. Figure 1a illustrated the North Pole Region and Figure 1b shows the South Pole and Antarctica region. Figure 2 shows all of IGS points on the earth.

As mentioned in the previous section, five IGS stations (CAS, DAV, MAW, PALM and SYOG) from IGS network in South Pole Region were used in this study (Figure 3). Moreover, the three IGS stations (NYAL, THU2 and TIXI) from IGS network of North Pole Region were used in this study (Figure 4). The (Receiver Independence Exchange) 24 hours of RINEX observation files with 30 second's interval were obtained from IGS servers for these three

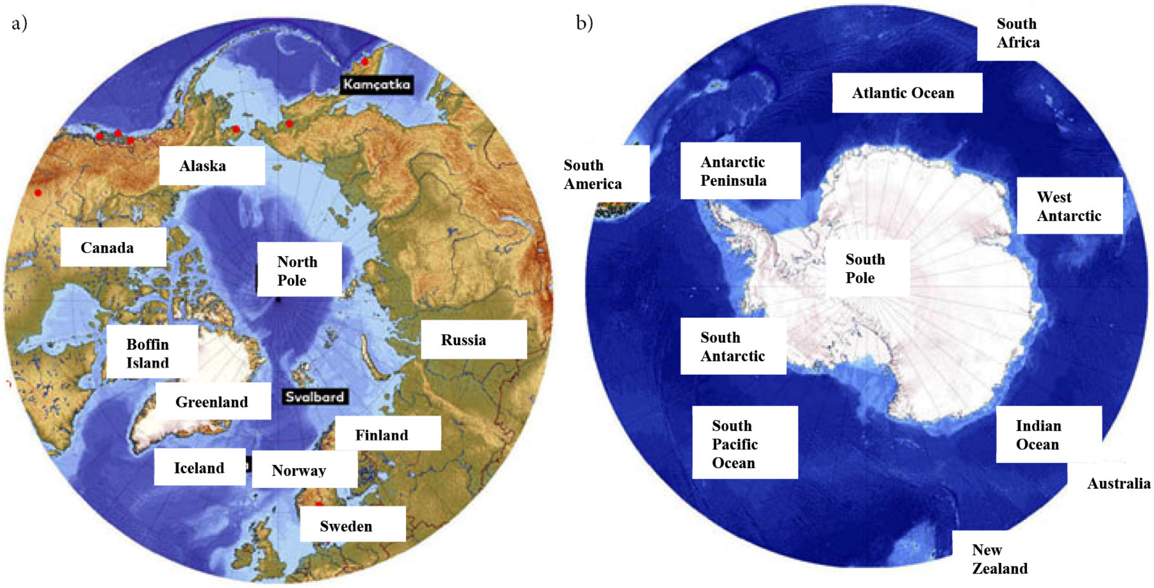

Figure 1. Map of the North and South Poles

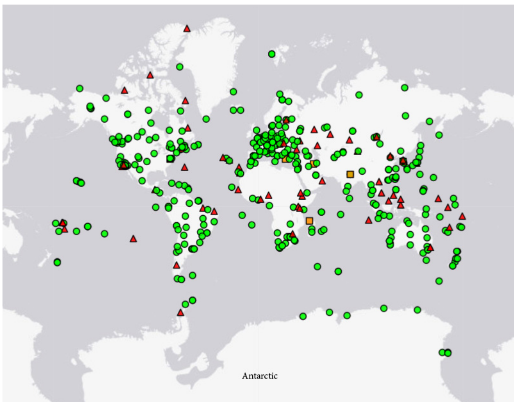

Figure 2. IGS points on the earth

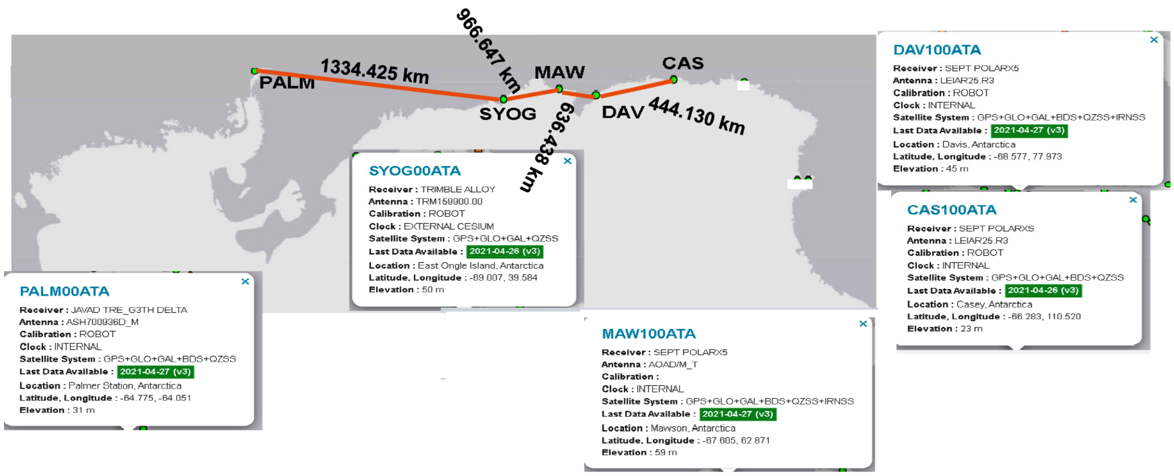

Figure 3. The specifications of the five IGS points nearby the South Pole Region (PALM, SYOG, MAW, DAV and CAS points)

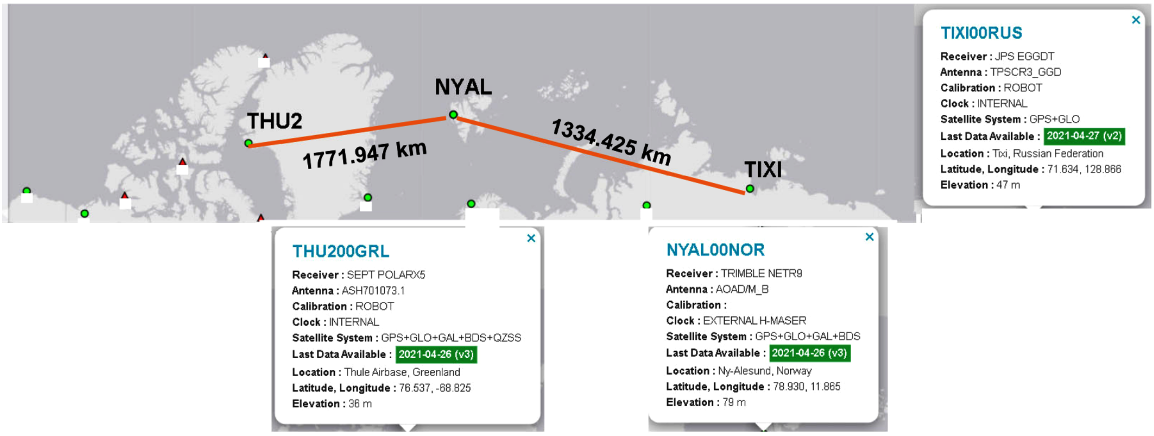

Figure 4. The specifications of the three IGS points nearby the North Pole Region (THU2, NYAL and TIXI points)

periods. 24-hour of RINEX observation files (01.01.2021, 01.01.2010 and 01.01.2000) from the 5 IGS stations in south pole region and the 3 IGS stations in north pole region were processed by using CSRS-PPP Software (static (24 hours-record interval-30 seconds)). From the solutions (24 hours), static processing results were obtained by using the ITRF 2014 epoch 2021.0, ITRF 2005 epoch 2010.0 and ITRF 2005 epoch 2000.0 coordinates estimated with a precision of 2–28 mm in the horizontal direction and 8–54 mm in the vertical direction, see Tables 1, 2 and 3. In order to make motion effect clearly (displacement) visible among the three periods, these data were analysed from January 1 of 2021, January 1 of 2010 and January 1 of 2000 (00:00:00-24:00:00 UTC Time).

As a result of the GNSS observations, it was observed that the horizontal displacement directions of five IGS points in South Pole Region between 1 January 2021 and 1 January 2000 were bigger than the other periods (between 1 January 2021 and 1 January 2010; between 1 January 2010 and 1 January 2000) results. During the first period (between 1 January 2021 and 1 January 2000), it was determined that the movement that occurred at five IGS points was in the X–Y directions (Figure 5). The time of the motion is very important for us to detect the displacement values. By comparing to the station coordinates of the five IGS points in South Pole Region by using static solutions before and after 2000 (1 January 2000), obtained the displacements. Where ΔX_{disp}, ΔY_{disp} and Δh_{disp} are the displacements, Xpost, Ypost, hpost, Xpre, Ypre and hpre indicate the average GNSS based positions estimated from before and after the year of 2000. The displacement values obtained for 5 IGS stations in South Pole Region according to the above procedure are presented in Figure 5. The horizontal displacement (X-Y) values for PALM IGS point are about 6–38 cm, see Figure 5. The vertical displacement (h) values for PALM IGS point are about 1.2–7.5 cm, see Figure 5. In addition, the height component was differed up to 4–127 mm at the five IGS points among three periods, see Figure 5. It indicates that the X components shows large values during period with changes varying from 5 mm to 38 cm and Y components changes varying from 1.5 cm to 15.4 cm. These five IGS stations in the South

Table 1. Standard deviation and coordinate values (ITRF 05, Epoch 2000.0) of the eight IGS points by processing static GNSS satellites (CSRS-PPP Software) in the South and North Pole Region

ITRF 05 (Epoch 2000.0)						
Name	Latitude (°)	Longitude (°)	Ell.Height (h) (m)	Std (Lat) [mm]	Std (Long.) [mm]	Std (h) [mm]
South Pole Region						
PALM	64°46′30,32625″S	64°03′04,04653″W	30,967	6	8	16
CAS	66°17′00,09256″S	110°31′10,93977″E	22,486	9	11	21
SYOG	69°00′25,04645″S	39°35′01,47861″E	50,006	9	11	29
MAW	67°36′17,15934″S	62°52′14,57596″E	59,161	10	12	23
DAV	68°34′38,36131″S	77°58′21,41012″E	44,431	25	28	54
North Pole Region						
TIXI	71°38′04,10631″N	128°51′59,10496″E	47,049	6	7	18
NYAL	78°55′46,50326″N	11°51′54,30334″E	78,481	6	6	21
THU2	76°32′13,37047″N	68°49′30,11816″W	36,120	8	9	25

Table 2. Standard deviation and coordinate values (ITRF 05, Epoch 2010.0) of the eight IGS points by processing static GNSS satellites (CSRS-PPP Software) in the South and North Pole Region

ITRF 05 (Epoch 2010.0)						
Name	Latitude (°)	Longitude (°)	Ell.Height (h) (m)	Std (Lat) [mm]	Std (Long.) [mm]	Std (h) [mm]
South Pole Region						
PALM	64°46′30,32284″S	64°03′04,03661″W	31,087	4	6	13
CAS	66°17′00,09565″S	110°31′10,94264″E	22,460	4	6	12
SYOG	69°00′25,04577″S	39°35′01,47530″E	50,000	4	6	14
MAW	67°36′17,16012″S	62°52′14,57368″E	59,125	4	4	13
DAV	68°34′38,36362″S	77°58′21,40688″E	44,395	4	6	12
North Pole Region						
TIXI	71°38′04,10302″N	128°51′59,12172″E	47,067	4	5	14
NYAL	78°55′46,50734″N	11°51′54,31906″E	78,547	5	5	17
THU2	76°32′13,37188″N	68°49′30,14800″W	36,156	4	5	15

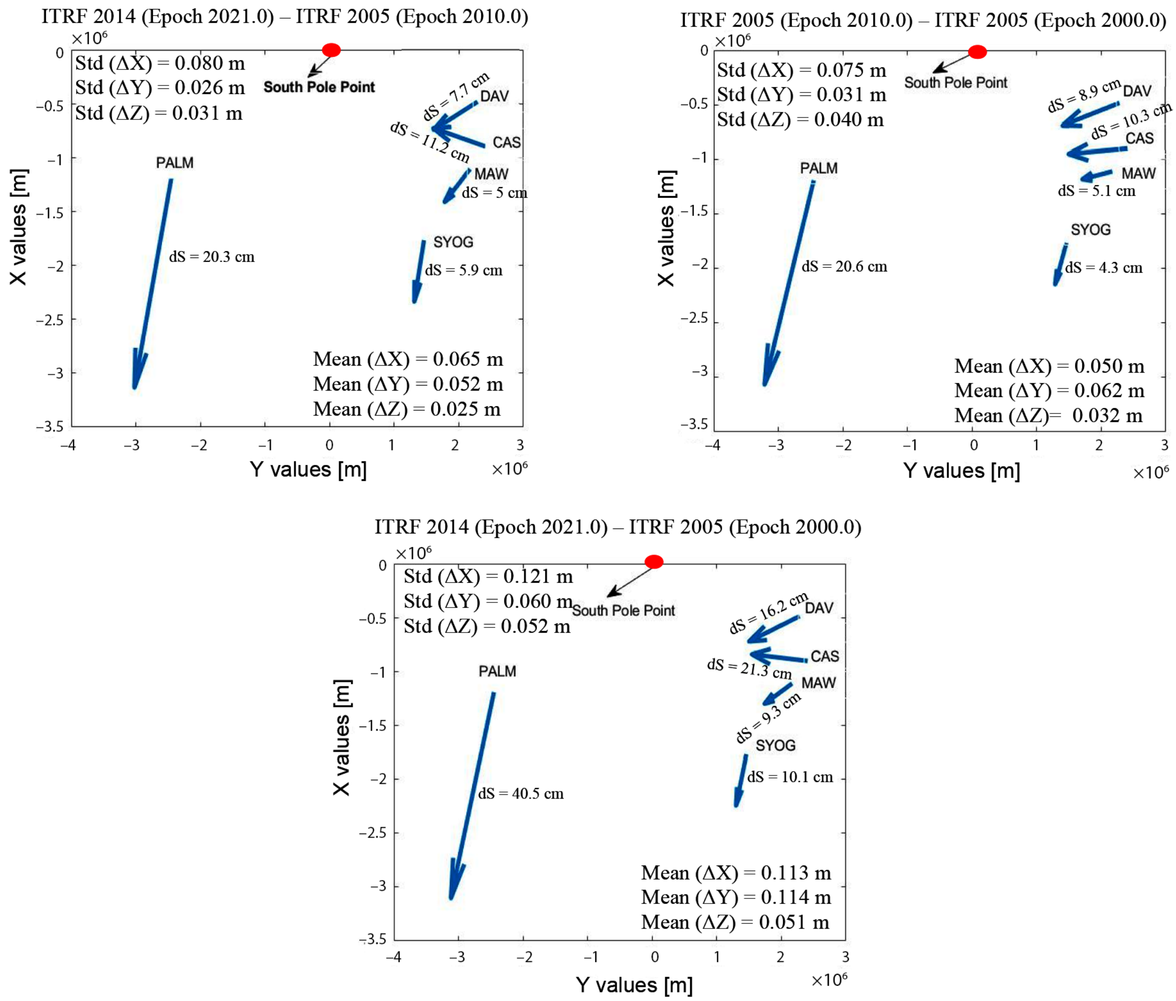

Figure 5. Horizontal displacement vectors (WGS 84 coordinate system) of the five IGS points (South Pole Region) among three periods (1 January 2021, 1 January 2010, 1 January 2000)

Table 3. Standard deviation and coordinate values (ITRF 05, Epoch 2010.0) of the eight IGS points by processing static GNSS satellites (CSRS-PPP Software) on the South and North Pole Region

ITRF 2014 (Epoch 2021.0)						
Name	Latitude (°)	Longitude (°)	Ell.Height (h) (m)	Std (Lat) [mm]	Std (Long.) [mm]	Std (h) [mm]
South Pole Region						
PALM	64°46′30,31903″S	64°03′04,02529″W	31,155	2	2	8
CAS	66°17′00,09902″S	110°31′10,94363″E	22,496	3	2	8
SYOG	69°00′25,04471″S	39°35′01,47100″E	50,008	4	4	8
MAW	67°36′17,16087″S	62°52′14,56990″E	59,124	2	2	8
DAV	68°34′38,36575″S	77°58′21,40336″E	44,397	2	2	8
North Pole Region						
TIXI	71°38′04,09886″N	128°51′59,14096″E	47,063	2	2	9
NYAL	78°55′46,51264″N	11°51′54,33868″E	78,643	2	2	10
THU2	76°32′13,37368″N	68°49′30,18287″W	36,227	2	2	9

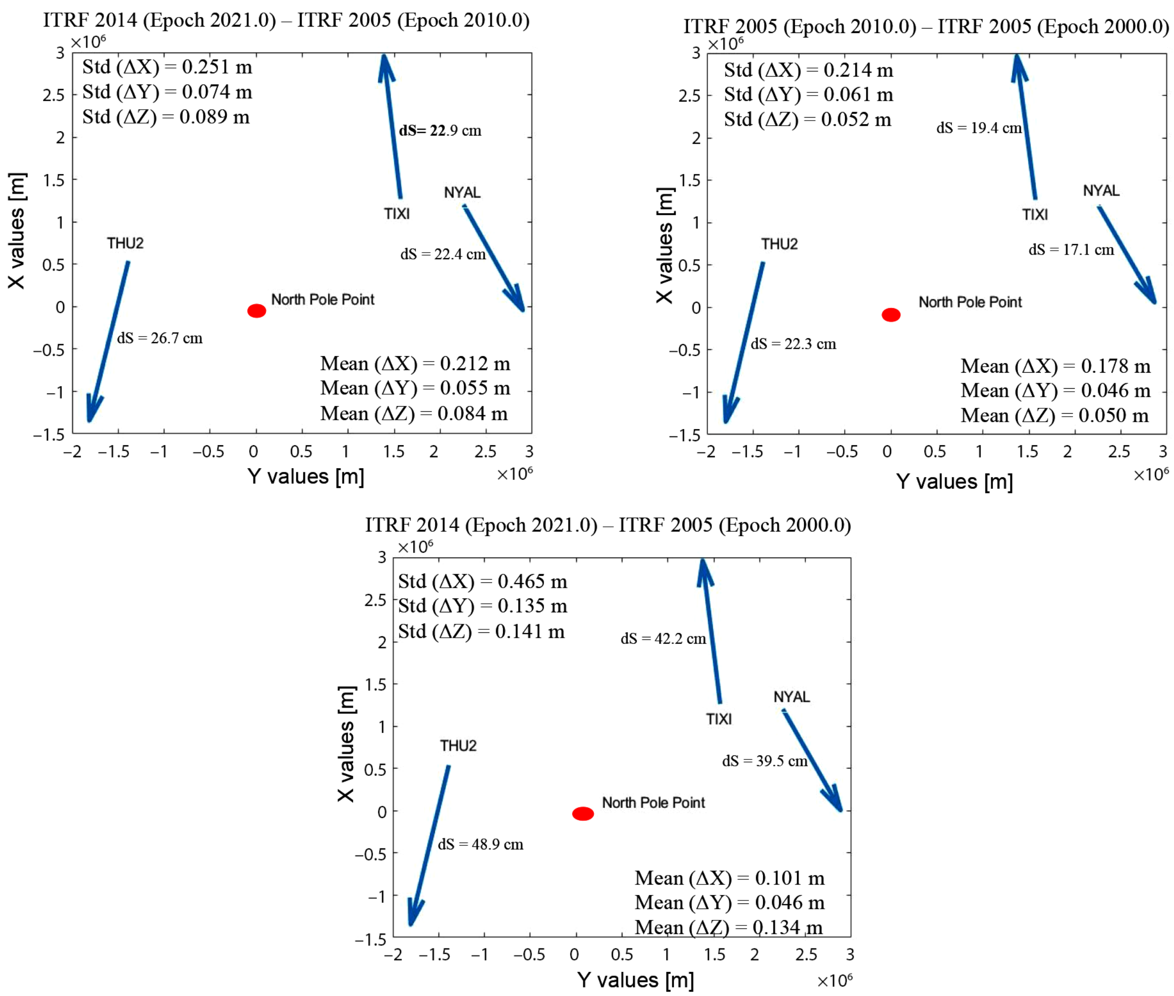

Figure 6. Horizontal displacement vectors (WGS 84 coordinate system) for three IGS points (North Pole Region) among three periods (1 January 2021, 1 January 2010, 1 January 2000)

Pole Region, where significant movement is obtained since they are closest to the South Pole point, are presented in Figure 5 for the horizontal directions ((X) and (Y) values in WGS84 system). Figure 5 shows the standard deviations and mean values of the coordinate differences between the three points among the three periods.

As a result of the GNSS observations, it was observed that the horizontal displacement directions of three IGS points in North Pole between 1 January 2021 and 1 January 2000 were bigger than the other periods (between 1 January 2021 and 1 January 2010; between 1 January 2010 and 1 January 2000) results. During the first period (between 1 January 2021 and 1 January 2000), it was determined that the movement that occurred at the three IGS points was in the X–Y directions (Figure 6). The time of the motion is very important for us to detect the displacement values. By comparing to the station coordinates of the five IGS points on South Pole by using static solutions before and after 2000 (1 January 2000), obtained the displacements. Where ΔX_{disp}, ΔY_{disp} and Δh_{disp} are the displacements, Xpost, Ypost, hpost, Xpre, Ypre and hpre indicate the average GNSS based positions estimated from before and after the year of 2000. The displacement values obtained for 3 IGS stations in North Pole Region according to the above procedure are presented in Figure 6. The horizontal displacement (X–Y) values for three IGS points are about 2.3–46 cm, see Figure 6. The vertical displacement (h) values for three IGS points among three periods are about 1.5–21.5 cm, see Figure 6. It indicates that the X components shows large values during period with changes varying from 13 mm to 46.1 cm and Y components changes varying from 2.4 cm to 15.4 cm. These three IGS stations in the North Pole Region, where significant movement is obtained since they are closest to the North Pole point, are presented in Figure 6 for the horizontal directions ((X) and (Y) values in WGS84 system). Figure 6 shows the standard deviations and mean values of the coordinate differences between the three points among the three periods.

By using the GNSS observations of the five IGS point's three dimensional displacement directions in South Pole Region are shown in Figure 7. The time series of coordinate differences of the five IGS points confirm that there is a strong bias of about 38 cm in the horizontal components and about 13 cm in the height components. These ΔX and ΔY components for five IGS points change between 7 mm and 38 cm on 1 January 2021, 1 January 2010, 1 January 2000 (00:00:00–24:00:00 UTC Time, see Figure 7). Figure 7 shows the standard deviations and mean values for the five IGS points in South Pole Region during the time period. The coordinate differences (Northing (X), Easting (Y)) of the five IGS points were not good in general with standard deviation and mean values less than 11 cm. The standard deviation and mean values of the height component were about 4 cm.

By using the GNSS observations of the three IGS point's three dimensional displacement directions in North Pole Region are shown in Figure 8. The time series of coordinate differences of the three IGS points confirm that there is a strong bias of about 46.1 cm in the horizontal components and about 21.5 cm in the height components. These ΔX and ΔY components for three IGS points change between 23 mm and 46.1 cm on 1 January 2021, 1 January 2010, 1 January 2000 (00:00:00–24:00:00 UTC Time, see Figure 8). Figure 8 shows the standard deviations and mean values for the three IGS points in North Pole Region during the time period. The coordinate differences (Northing (X), Easting (Y)) of the five IGS points were not

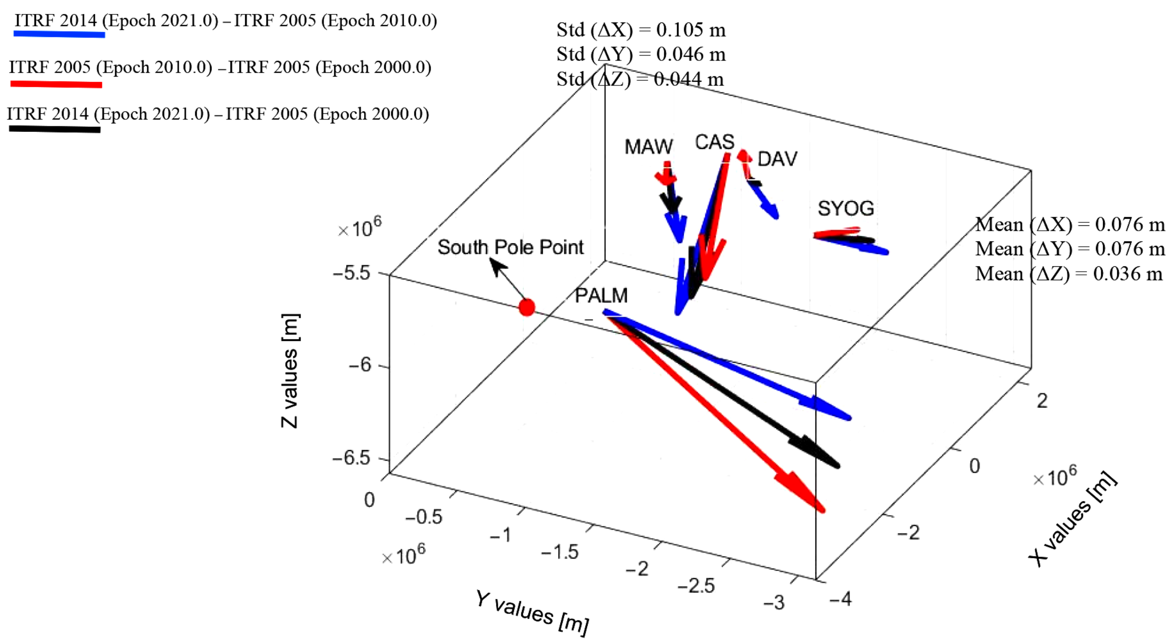

Figure 7. The three dimensional displacement vectors (WGS 84 coordinate system) for five IGS points in South Pole R

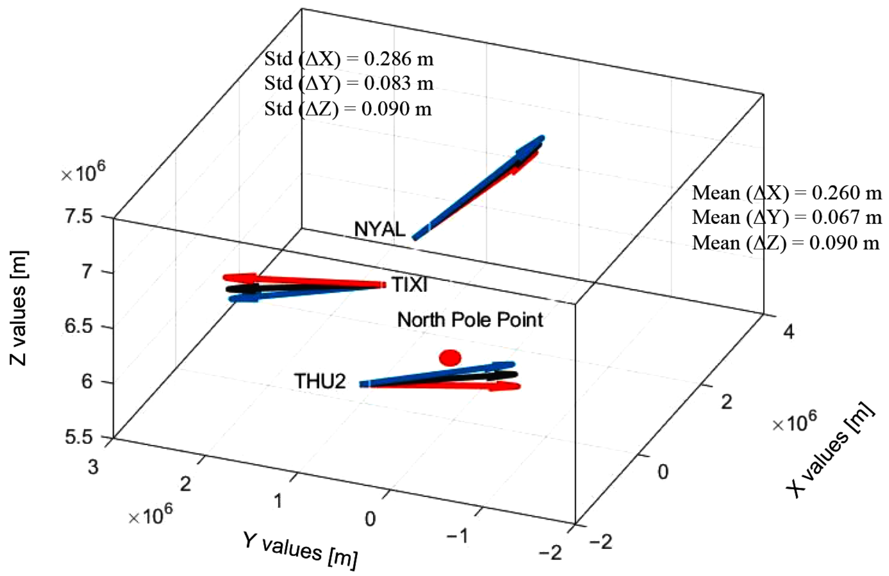

Figure 8. The three dimensional displacement vectors (WGS 84 coordinate system) for three IGS points in North Pole Region among the three periods

good in general with standard deviation and mean values less than 30 cm. The standard deviation and mean values of the height component were about 9 cm.

Conclusions

The North Pole (Arctic) and South Pole (Antarctic) region has faced a growing interest due to the potential in an exploration of natural resources (According to estimates, almost half of the world's remaining oil accumulation lies under the ice in the northern part of the Arctic Circle) and marine transportation, including autonomous vessel navigation. Accurate positioning can be achieved by the simultaneous utilization of a number of positioning systems. As can be seen from the results obtained from five IGS points in the South Polar Region in this study, the horizontal motion that occurred at these points in 21 years was generally attained a maximum of 40.5 cm and an average of 20 cm towards the equatorial direction. In this study, as can be understood from the results obtained from three IGS points in the North Polar Region, the horizontal motion in two of these points in 21 years was generally obtained in the direction of the equator with a maximum of 49 cm and average of 43.5 cm. As can be understood from the results obtained for the five IGS points in the South Polar Region in this study, the vertical movement in three of these points (PALM, CAS, SYOG) in 21 years generally tended to increase. The largest increase was observed at the PALM point and was obtained around 19 cm. As can be seen from the results obtained for three IGS points in the Arctic region in this study, the vertical movement at these points in 21 years has generally entered an increasing trend. The greatest increase was observed at NYAL point and was obtained around 16 cm. The average increase value in vertical direction of three IGS points was obtained around 9.4 cm. In the investigations made a while ago, it was concluded that the Antarctic region was also melting. The reason for this is not natural processes, but the effects of global warming. If one day all the ice in the South Pole melts, experts say sea and ocean levels will rise by 60 meters. Interestingly, the reason why the Arctic region melts faster is that it is submerged in water and thus ocean currents accelerate the process, while the Antarctic region is located on the rock so that it is not affected.

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