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ORIGINAL ARTICLE

Monitoring of Icelandic plate movement with GNSS method and GPS signal jamming effects in Iceland

Atınç Pırtı [1*], Ramazan Gürsel Hoşbaş [1] and Mehmet Ali Yücel [2]

[1]Department of Geomatic Engineering, Yildiz Technical University, 34220 Esenler, Istanbul, Türkiye
[2]Department of Geomatics Engineering, Canakkale Onsekiz Mart University, 17100 Canakkale, Türkiye

*atinc@yildiz.edu.tr

Abstract

Jamming is electromagnetic radiation or reflection that impairs the function of electronic instruments and equipment or communication tools. Intentionally disrupting or interfering with GPS signals, which are used for positioning, navigation, and timing, known as "GPS jamming", is accomplished using a radio frequency emitting device. On January 8, 2022 (the day of a NATO exercise), it was investigated how GPS signal jamming affected the position accuracy at three IGS points in Iceland. The obtained coordinate differences between kinematic processing and static processing reached values of about 0.5–10 meters for the MAYV, and HOFN stations in this study. In addition to GPS signal jamming effect in Iceland, horizontal and vertical velocity fields of the three IGS stations in Iceland covering a twenty-two year period (2000–2022) in this study. According to the obtained results, a motion of about 2cm–2.5cm per year (horizontal) and 0.1cm–2.1cm per year (vertical) was computed at the three IGS stations (HOFN, REYK, and MAYV) located in Iceland.

Key words: signal jamming, accuracy, GPS, GNSS, Iceland, motion

1 Introduction

It is essential to first describe how Global Positioning System, or GPS, works before discussing GPS jammers in more detail. GPS is a navigational aid that is used by civilians, businesses, and the military, with earth-orbiting satellites transmitting radio signals. The signals are received by the GPS receiver to calculate position using the trilateration method. Vehicle navigation and positioning systems, portable GPS tracking gadgets, mobile phones, and other devices all use GPS. Using a specified frequency, GPS transmissions are radio communications. In fact, GPS operates on two main frequencies, one of which (L1, 1575.42 MHz) is intended for the use by the general public rather than reserved specifically for military purposes, as is the other (L2, 1227.6 MHz). Due to the fact that GPS consists only of weak radio waves, it is possible to block or bend these signals using a GPS jammer; however, doing so requires specialized equipment and experience. GPS jamming is the technique of deliberately disrupting or interfering with GPS data used for positioning, navigation, and timing by use of a radio frequency (RF) transmitting device. These radio frequency transmitters are compact and easy to use. They send out RF signals at the same frequency as GPS signals. These externally emitted signals can interfere with GPS signals and cause reception problems, disabling GPS receivers or affecting their accuracy in determining position and time. As the signals travel a significant distance to reach GPS receivers, they become faint by the time they reach the earth's surface.

There has been a lot of research about the jamming of GPS signals. Borio et al. (2016); Borio and Gioia (2021); Faria et al. (2016); Fu et al. (2003); Marcus (2014); Pinker and Smith (1999) demonstrate the impact and detection of GPS/GNSS jammers on receivers. Gorski (2018) and Westbrook (2019) show that GPS jammers interfere with military operations. Glomsvoll and Bonenberg (2017); Goward (2017); Mizokami (2016); Staalesen (2018); Trevithick (2018) demonstrate that GPS signals are jammed in Black Sea, North Korea, Norway, Northern Sea and Syria, respectively. Hu et al. (2018) illustrates GNSS spoofing detection based on new signal quality assessment model. Martini (2016) demonstrated

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that China is jamming GPS satellites. Aghadadashfam et al. (2020); CRFS (2019); Dunnigan (2013); Mosavi et al. (2017); Moussa et al. (2017); Nilsen (2019); Staalesen (2018); Stopienski (2020); Wang et al. (2021) describe an anti-jamming system for GPS receivers.

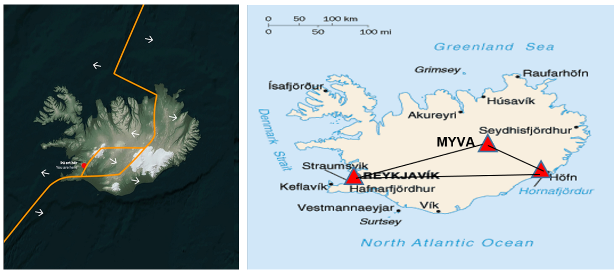
In this study, the power of jammers to affect GPS signals and suggestions to prevent the distortions are examined. Jamming with the GPS signals peaked in Iceland, especially on January 8, 2022, (between 00:00:00–24:00:00). Data from January 8, 2022 are examined, but also attempts are made to compensate for the jamming on January 8, 2022. In addition to the jamming effects, we investigate the motion of Iceland plate between 2000 and 2022 for three stations. The plate boundary between the North American and Eurasia Plates, which traverses Iceland, is strongly influenced by the island's hotspot. In this study, we give an overview of how plates spread, how fast they move relative to each other, and how the edges of plates change in Iceland. Relevant earlier reviews include those of Aerospace Security (2022); Árnadóttir et al. (2008); Halldorsson et al. (2013); Johannesson et al. (2018); Olafsson (2013); Vogfjoro et al. (2013); Pirti and Yucel (2022); Sigmundsson et al. (1995). For this aim, data (2000–2022) of 3 IGS stations were used in this study. Receiver Independence Exchange (RINEX) observation data of 3 stations were gained from the IGS Server. Analyses and Processing were performed with Topcon Magnet Tools v.7.3.0 software, and coordinate time series, total displacements were calculated by using the coordinate differences. A cut off angle of 10 degrees was selected.

Unfortunately, several adverse factors impede safe and accurate positioning in the Arctic. In particular, GNSS-based positioning and navigation face a number of limitations that cannot be easily overcome. This includes the ionospheric effects on satellite signals which in the Arctic are highly affected by an increased electron precipitation, which causes higher ionospheric variability reducing GNSS performance.

2 Materials and Methods

Iceland is a relatively young island, at least in terms of its geological history. A large plate made of solid rock is referred to as a tectonic plate. There are three tectonic plates at play in Iceland, as shown in Figure 1a. There is one micro-tectonic plate named Hreppafleki. As a result, the island experiences high levels of geothermal and volcanic activity. An excellent illustration of this is Thingvellir, in the southern region of Iceland, where the North American and Eurasian tectonic plates collide or, more accurately, drift apart. A tectonic plate drifts off from neighbouring tectonic plates, yet it approaches and engages with them where the borders of the plates meet, for example, underneath the island of Iceland. The tectonic plates are anchored to the continents, which move with them. Most earthquakes and volcanic activity on Earth are thought to be caused by tectonic plate interactions. Due to the island's position on the Mid-Atlantic Ridge, this occurs continuously, and Iceland is affected. Iceland experiences earthquakes frequently, mostly as a consequence of tectonic plate movements. Numerous Icelandic hot spring water flows might be impacted by earthquakes. This happened in June 2000 when two sizable earthquakes struck Iceland's southern region. Iceland has a lot of hot springs, and quakes can change how the water flows in many of them. Most earthquakes happen where tectonic plates meet, and Iceland is located exactly on top of one of these boundaries called the Mid-Atlantic Ridge. There are two main types of earthquakes in Iceland: those caused by tension released in the tectonic plates and those caused by the movement of magma (Bergerat et al., 2011; Björnsson and Einarsson, 1974; Einarsson, 1991; Gudmundsson, 2007; Sigbjörnsson and Ólafsson, 2004; Sigbjörnsson et al., 2007).

The Global Navigation Satellite Systems (GNSS) technique is often used for geodetic and geodynamic studies, such as: tracking the movement of tectonic plates, analyzing seismic events, observing crustal displacements, etc., because it can obtain higher



(a) (b)

Figure 1. Project area (a) and REYK, HOFN and MYVA IGS points located in Iceland region (b)

precision, lower cost, and 3D positioning in a global coordinate system. Kinematic surveys provide the highest production rate for all the GNSS methods. While rapidly generating coordinates, the precision obtained is not as high as by static techniques. This is because in kinematic techniques, most random measurement and GNSS system errors are absorbed in the coordinates. This can be contrasted with static methods, in which they are absorbed in the residuals after a network adjustment. Kinematic surveys can be post-processed or carried out in real-time, with the addition of a suitable communication link. It is critical, therefore, when using real-time solutions, that the GNSS receivers have the correct firmware loaded for the chosen real-time method. For the highest precision kinematic surveys, the methods of network: RTK, on-the-fly kinematic, and Post Processed Kinematic (PPK) can be used. The basic technique is the same as in the case of the static network RTK: to keep one receiver fixed at a known control station (base) while one or more other receiver(s) (rovers) move around the site following the same satellites. In this study, the data of three IGS stations (HOFN, REYK, and MAYV) in Iceland provides significant convenience. However, station data of this network with 30 seconds interval is archived and provides important contributions to reveal crustal deformations and displacements. The displacements of REYK, HOFN, and MAYV stations in this study were estimated by investigating the time series produced from yearly (2000–2022) solutions. REYK station is located on the southwest coast of Iceland. HOFN station is located on the west coast of Iceland. MAYV station is located on the middle part of Iceland, see Figure 1b.

3 Results

24 hour of RINEX observation files (8 January 2000–2022) from three IGS stations were processed by using Topcon Magnet Tools v.7.3.0 software (static, 24 hours-recorded interval-30 seconds, fixing REYK station). GNSS support improved with Advanced Epoch filtering allows measurement to be stored only when the specified number of epochs have been measured at the specified HRMS/VRMS values. Our aim in this study was to verify how much the GPS signals are affected by the jamming effect and to confirm to what extent the GLONASS/Galileo/Beidou/IRNSS multi-satellite combinations can resist signal jamming. From the solutions, static processing results were obtained by combining the Iceland-ISN93 coordinates estimated with in the standard deviations of horizontal component of 23–25mm and 55–56mm in the vertical component, as shown in Table 1. The data from January 8, 2022 (the day of the NATO exercise) were examined, but also attempts were made to compensate for the jamming on January 8, 2022. Local coordinates also allowed the digital designers to calculate a means around the finite limits of numerical representation.

Geographic coordinate systems also have some disadvantages over projected coordinate systems in ArcGIS, which feature a limite practicality for local or small-scale data, as they do not account

Table 1. IGS Points REYK, HOFN and MYVA coordinates (Iceland-ISN93) in the Barents Sea (static process, using GPS, GLONASS, Galileo, Beidou and IRNSS satellites)

Name	Grid Northing (N) [m]	Grid Easting (E) [m]	Elevation (h) [m]	Std (N) [m]	Std (E) [m]	Std (h) [m]
REYK	407354.574	356149.034	93.001	—	—	—
HOFN	423856.918	684151.592	82.851	0.024	0.025	0.056
MYVA	573231.570	597061.349	370.533	0.024	0.023	0.055

for the variation in the earth's surface , the effects of gravity or rotation.

As mentioned above, the reason of using HOFN and REYK points in this study is that these two points record GPS, GLONASS, Galileo, Beidou, and IRNSS signals. The satellite numbers responding to HOFN and REYK receivers are: 29(GPS), 22(GLONASS), 26(Galileo), 28(Beidou) and 2(IRNSS) satellites. However, the number of satellites with account of MYVA receiver is 29(GPS), 22(GLONASS), and 25(Galileo) satellites. Figures 2 and 3 were performed by using RTKLIB v.2.4.3 software. Figures 2a, 2d and 2g (left) depict the visibility of GPS satellites of HOFN station in an open sky simulation scenario. Figures 2j and 2k depict the discontinuity (Pirti and Yucel, 2022). Figures 2j and 2k clearly show GPS jamming effects of the GPS signals.

As can be seen in Figures 2c, 2f and 2i, the standard deviation and mean values of the horizontal coordinates are in the range of 4–8.3cm, and the standard deviation and mean values of the vertical components are in the range of 10.4–13.2cm. In Figure 2l the effect of signal jamming effect, especially for coordinates, reaches 0.5–5m. Due to this effect, the increase in standard deviation and mean values increased up to 3–5 times. Ocean tidal loading (OTL) is the displacement of the Earth's crust caused by the redistribution of sea water due to ocean tides. This affects geodetic measurements with GNSS, and can thus be observed with continuous GNSS measurements. OTL can also be modelled to remove its effect on geodetic measurements.

Figures 3a and 3g depict the visibility of GPS satellites of MYVA station in an open sky simulation scenario. Figures 3d and 3j depict the discontinuity. Figures 3d, 3j, 3e and 3k clearly show the jamming effect of the GPS signals. As can be seen in Figures 3c and 3i, the standard deviation and mean values of the horizontal coordinates are in the range of 3.7–8cm, and the standard deviation and mean values for the vertical components are in the range of 10.5–16cm. In Figure 2f and 2k, the effect of signal jamming effect, especially for coordinates, reaches 0.5–10 meters. Integer ambiguity could not be resolved enough accuracy due to jamming in the GPS signal at this time intervals. Due to this effect, the increase in standard deviation and mean values increased up to 5–10 times.

3.1 Investigation of Signal Jamming Effects on GLONASS, Galileo, Beidou and IRNSS Satellites especially for static and kinematic processing

It seems difficult to obtain the jamming effect from the static processing results. The number of GPS satellites observed via three points was obtained in the range of 9 to 15. However, for the GLONASS, Galileo, Beidou, and IRNSS satellites, this number remains in the range of 7–12, 7–13, 5–12, and 1–2 respectively. On January 8, PDOP values of satellites among three points were obtained in the range of 0.75–1.40.

Coordinate differences (between kinematic and static processing) were measured in order to make this jamming effect more evident and to eliminate it. Since the kinematic process includes real-time position determination and broadcast ephemeris information is used, the jamming effect on the GPS signal is evident from the coordinate differences in the kinematic processing results (Figures 2 and 3). In the same situation (jamming), when GLONASS, Galileo, and Beidou satellites were analysed for kinematic processing instead of GPS satellites; therefore great improvements were obtained in the standard deviation and mean values (Figures 4 and 5). In this study, the advantages of selecting GLONASS, Galileo, and Beidou (GGB) processing as an alternative method in the regions with GPS jamming effects are presented. The obtained results between the kinematic processing and static processing of two points on 8 January 2022 by using GPS-only satellites and fixing REYK station are shown in Figures 4 and 5. The standard deviation values of the coordinate differences of HOFN station, obtained on January 8, 2022, between 00:00–24:00 hours, are 0.040m–0.294m, and the mean values are approximately 0.031m–0.333m, as shown in Figure 7. Figures 7b and 7c show that the standard deviation and mean values of the coordinate differences led to an increase in accuracy level (Pirti and Yucel, 2022).

The obtained results between the kinematic processing and static processing of two points on 8 January 2022 by using GPS-only satellites and fixing REYK station are shown in figures 4 and 5. The standard deviation values of the coordinate differences of MAYV station, obtained on January 8, 2022, between 00:00–24:00 hours, are 0.039m–1.491m, and the mean values are approximately 0.028m–0.547m, as in Figure 7.

GLONASS, Galileo, Beidou, and IRNSS satellites were affected by signal jammers as well as GPS satellites between 00:00–24:00 hours on January 8, 2022. For GLONASS it occurred although Galileo satellite signals are also more resistant to interference and jamming. The jammer transmitted noise, with the correct level of JSR (Jammer to Signal Ratio), is able to increase the noise level in the radar receiver worsening the SNR (Signal to Noise Ratio) and impeding the correct detection of the echo signal. SNR can be calculated using different formulas depending on how the signal and noise are measured and defined. The most common way to express SNR is in decibels (dB) , which is a logarithmic scale that makes it easier to compare large or small values. Other definitions of SNR may use different factors or bases for the logarithm, depending on the context and application. The SNR has been applied to multiple fields, such as: quality control, image processing, medicine, and business. For example, in quality control, the SNR shows the degree of the predictability of the performance of a product, or process, in the presence of noise factors. In image processing, the SNR of an image is usually computed as the ratio of the mean pixel value to the standard deviation of the pixel values over a given neighbourhood. SNR is usually expressed in decibels, which is a logarithmic unit that compares two power levels. For example, if the signal power is 10 watts and the noise power is 1 watt, the SNR would be 10dB. The probability density function for the log-normal is defined by the two parameters μ and σ, where $x > 0$: μ is the location parameter and σ the scale parameter of the distribution. These two parameters should not be mistaken for the more familiar mean or standard deviation from a normal distribution.

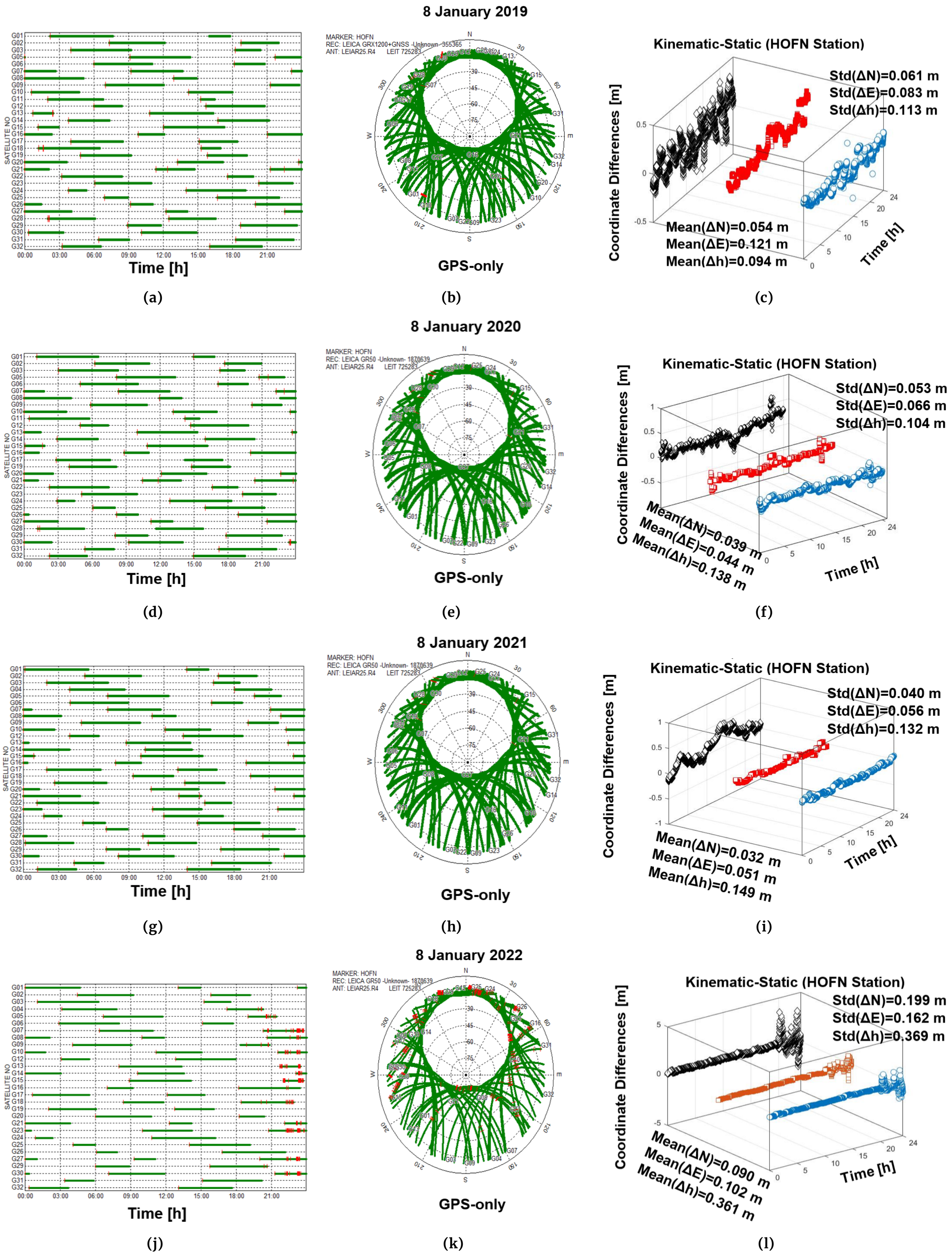


Figure 2. GPS satellite visibility plot of HOFN point in Iceland during the presence of jamming GPS signals (8 January 2022 – 24h, (a, d, g, j)) and skyplot (b, e, h, k); coordinate differences, standard deviation and mean values of HOFN station (processed GPS-only by fixing REYK station) in Iceland region on 8 January 2019, 2020, 2021 and 2022 (c, f, i, l)

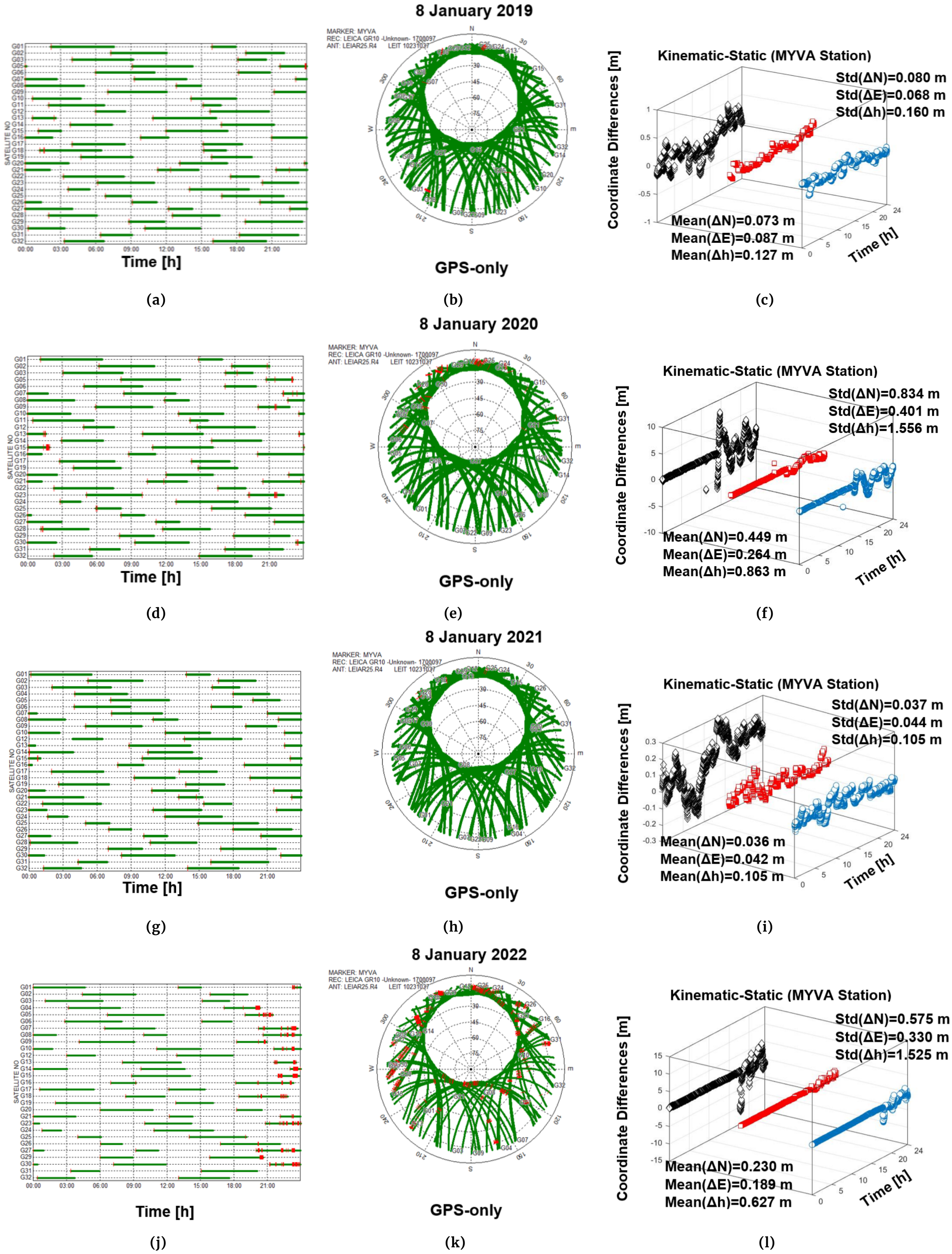


Figure 3. GPS satellite visibility plot of MYVA point in Iceland during the presence of jamming GPS C/A code signals (8 January 2022 – 24h, (a, d, g, j)) and skyplot (b, e, h, k); coordinate differences, standard deviation andmean values of MYVA station (processed GPS-only by fixing REYK station) in Iceland region on 8 January 2019, 2020, 2021 and 2022 (c, f, i, l)

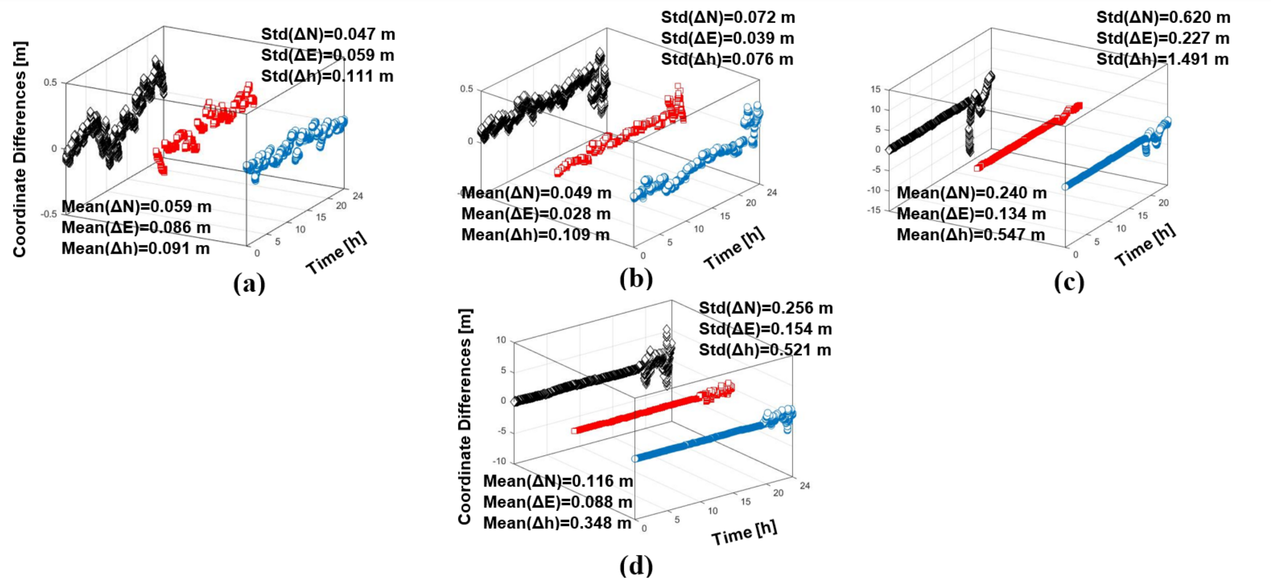


Figure 4. Coordinate differences, standard deviation and mean values of HOFN station (processed GLONASS/Galileo/Beidou/IRNSS-only by fixing REYK station) in Iceland region on 8 January 2019, 2020, 2021 and 2022

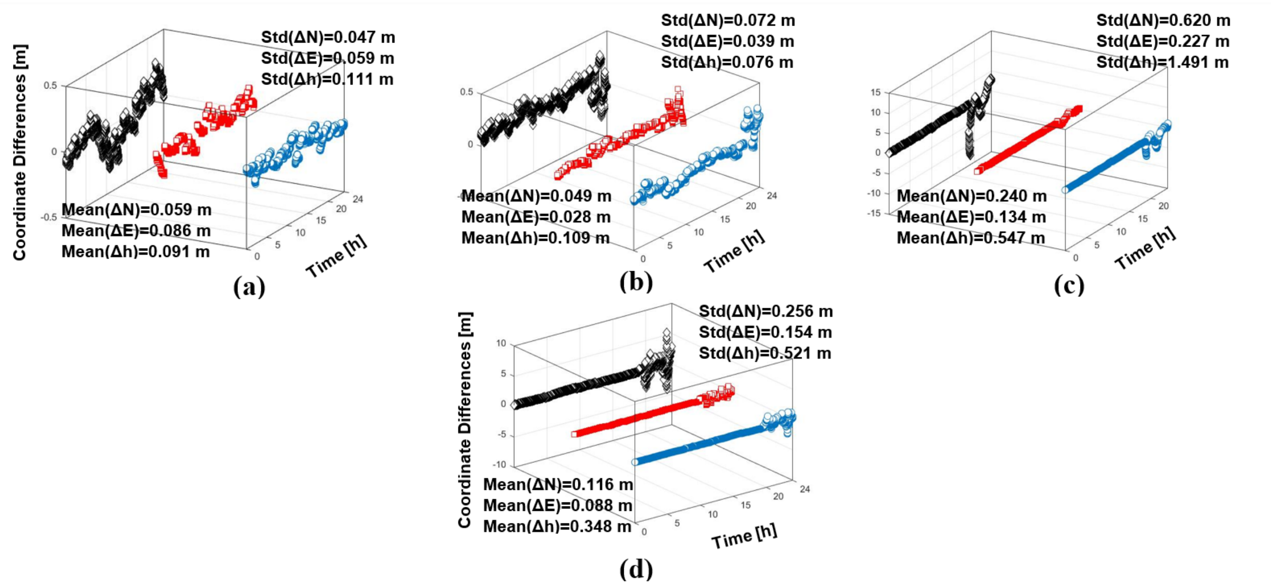


Figure 5. Coordinate differences, standard deviation and mean values of MYVA station (processed GLONASS/Galileo by fixing REYK station) in Island region on 8 January 2019, 2020, 2021 and 2022

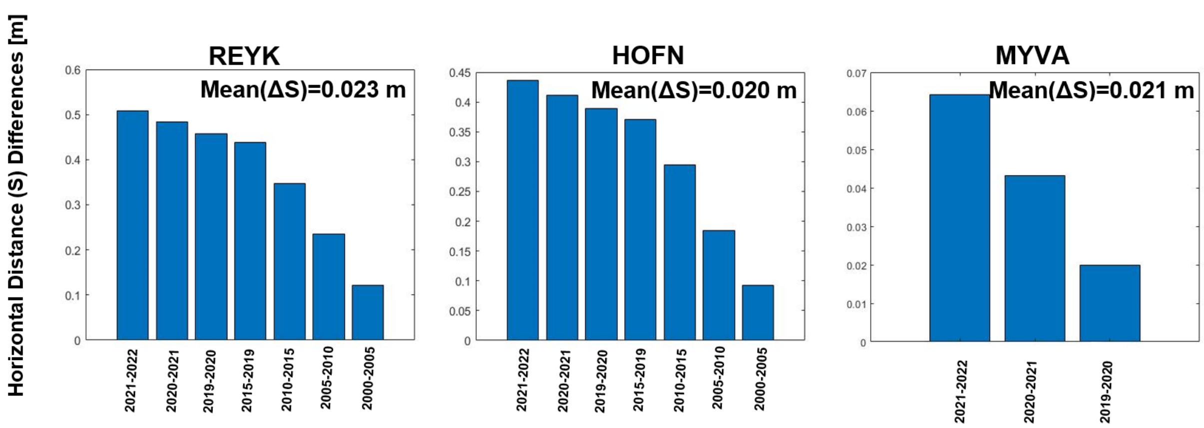


Figure 6. The horizontal displacements graphic of three IGS stations (REYK, HOFN and MAYV (8 January)) between 2000 and 2022 years

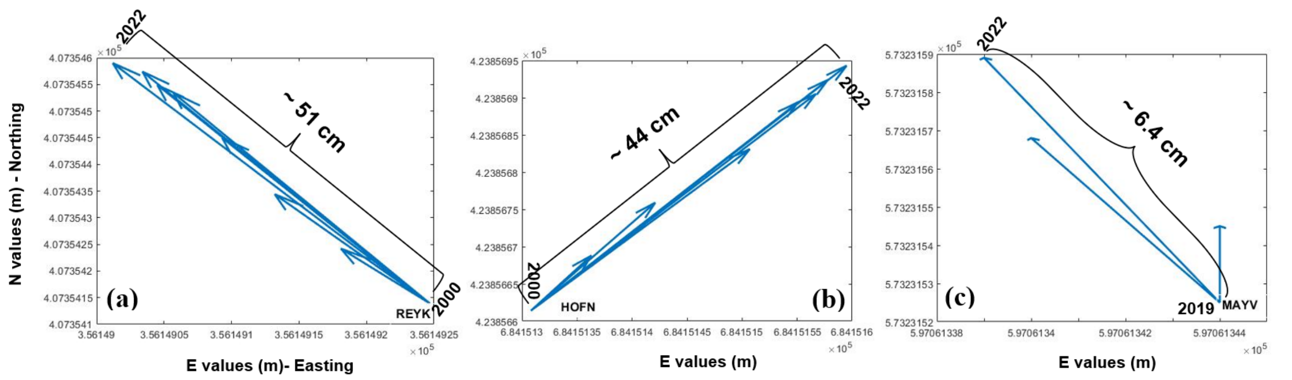


Figure 7. Horizontal Coordinate (Northing (N) and Easting (E) values on Iceland-ISN93 time series obtained from three IGS stations (REYK (a), HOFN (b) and MAYV (c) during monitoring twenty-two (2000–2022) year periods

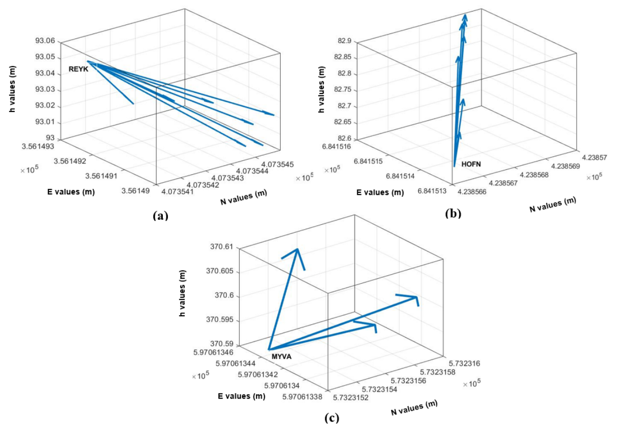


Figure 8. Iceland plate-induced 3D displacement vectors for three IGS stations among twenty-two years

3.2 Horizontal and vertical Displacements of three IGS stations (HOFN, REYK and MYVA) in Iceland

As can be seen in Figure 6, the mean displacement motions of the REYK, HOFN, and MAYV stations were calculated annually as 2cm–2.3cm, as a result of the process of the surveys performed during a 22-year survey period. Three IGS stations from IGS network used in this study time series belonging to three stations are illustrated in Figures 6, 7 and 8 for horizontal and vertical directions. In order to make displacements effect clearly visible in the time series, these data were analysed from January 8, 2000–2022. During the period 2000–2022, the motion that occurred at REYK, HOFN and MYVA stations was determined.

In Figure 8, between the coordinates of the REYK, HOFN, and MYVA points obtained by kinematic processing and the coordinates obtained by static processing are compared. By using the GNSS observations of displacements in three dimensions for the three IGS points, are shown in Figure 8. The vertical displacement values of HOFN IGS point are in the region of 25.2cm for twenty-two years; as in Figure 8b. The vertical displacement values of MYVA and REYK IGS point are about 1cm–3cm, as in Figures 8a and 8c. We compared our results with existing publications or analysis centres such as https://www.bigf.ac.uk/. Our obtained results were consistent with the other authors' values – horizontal components approximately 2cm–2.3cm per year (Sigbjörnsson and Ólafsson, 2004; Sigbjörnsson et al., 2007) .

4 Conclusion

This research analysed GPS signal jamming, which is expected to occur in Iceland, utilizing static-kinematic processing GPS measurements from three points (REYK, HOFN, and MYVA). These jamming effects on GPS signals have an impact on location accuracy, particularly for kinematic processing. The changes in coordinate discrepancies at position HOFN station, particularly between 00:00 and 24:00 hours on January 8, 2022, when GPS signals were subjected to the most significant jamming impact, reached around 0–10 meters. If the GPS signal is interfered with, we modify the path. In this study, the accuracy of the three-dimensional coordinates was not reached at a satisfactory level by employing GLONASS/Galileo/Beidou signals. It is proposed that the jamming that may occur in GPS signals cannot be eliminated by using GLONASS/Galileo/Beidou/IRNSS satellites combinations. Meanwhile, the horizontal and vertical displacements of three IGS stations (REYK, HOFN and, MAYV stations) between 2000 and 2022 years were 2cm–2.3cm per year and 0.1cm–1cm peryear, respectively.

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