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GEO MAGNETIC MID-LATITUDE IONOSPHERIC GRADIENT DETECTION BY TIME-STEP METHOD

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Abstract:

The main challenge for GBAS is the instability of the local area ionospheric delay. Ionospheric delay gradients can damage an aircraft's landing system. Studying the ionosphere's spatial gradients is necessary to accomplish this because the approaching aircraft will receive statistics. This paper discusses the time step method to detect the ionospheric spatial gradients. This method allows estimating the ionosphere gradients at both short and long baselines. The Spatial gradients for GPS stations, p502 and p509 located at 32.982°N, 115.421°W and 32.890°N, 115.293°W respectively, are analyzed for the year 2021. The maximum gradients were observed in the month of May with 2.3307 mm/km for the station p509 and the minimum gradients are observed on 23 January 2021 with 0.0008 mm/km.

Index terms: Ground-based Augmentation System (GBAS), Ionospheric delay gradient, Time step method, baseline length selection, ionospheric spatial gradient

Introduction:

The variance in local area ionospheric delay is the primary obstacle to GNSS signal quality at airports [1]. Ground Based Augmentation System (GBAS) augments the satellite-based aircraft navigation system to provide service with improved accuracy and enhanced safety which is superior to the standalone satellite navigation. International Civil Aviation Organization (ICAO) [2] has suggested to install GBAS in place of the existing Instrumental Landing System (ILS) to improve performance at lower installation, maintenance and costs [3].

The GBAS ground facility comprises of three to four predetermined reference receivers, a Very High Frequency (VHF) Data Broadcast (VDB) transmitter and a Master Control Station (MCS). The Global Positioning System (GPS) receiver in the aircraft computes the location of the aircraft. The GBAS receiver receives the differential corrections from the GBAS ground facility. Most GNSS errors that an aircraft encounters in and around an airport can be corrected by GBAS.

The ionosphere exhibits significant temporal and spatial variations in total electron content (TEC) resulting in plasma bubbles and scintillations [4]. TEC is an important parameter in detecting and mitigating errors caused by exceptional ionosphere behaviour. The spatial gradients over mid-latitude regions have been detected in this paper. Spatial gradients are found at the stations p502 and p509 located at the geomagnetic coordinates of 39.42°N, 47.61°W and 39.38°N, 47.47°W respectively.

For GBAS operation, ionospheric parameters were studied in both quiet and disturbed events [5] [6] [7] [8]. The time step method [9], [10] requires TEC observations to estimate delay gradients at a single station at different time instants. For Ionospheric Pierce Point (IPP) selection, time index management was used. The ionospheric height baselines were appropriately adjusted for delay gradient estimation at each time interval. The GPS signal errors due to ionospheric delay between the user and the ground facility [11] is reduced by avoiding the affected satellites.

The indices of geomagnetic activity are excellent instruments for modelling and forecasting the ionosphere's behaviour. The mostly accepted metrics for measuring the intensity of geomagnetic activity are the Kp index and the Dst index over the low and mid latitude ionosphere [12]. The three-hourly quasi-logarithmic index known as the Kp index provides the planetary average value of geomagnetic activity. Its value, which runs from 0 to 9, is a direct reflection of the intensity of the ionospheric storm [13]. A Kp index range of 0 to 3 denotes a tranquil

ISSN: 2278-4632
Vol-13, Issue-05, No.01, May : 2023

ionosphere and a quiet geomagnetic field. When the Kp index is between 4 and 6, it suggests a moderate ionospheric storm, and when it is over 7, it signals a powerful one.

The hourly index linked to low magnetic activity is known as the Disturbance Amplitude Storm Time (Dst) index and is stated in units of nano Tesla (nT). A positive or negative number can be found in the DST index. The strength of the ionospheric storm increases with the magnitude of the negative value. Severe geomagnetic storms have been linked to solar-interplanetary characteristics such halo CMEs, as demonstrated by Tripathi et al. [14]. Due to their halo-like coronagraph images, CMEs that are ejected towards the Earth are known as halo CMEs.

Methodology:

Ionosphere extends from 70 to 1000km from the surface of the earth. IPP is defined as the point of crossing of a GNSS signal from the satellite to the receiver with the ionosphere at a height of 350km (HIPP) from the surface of the earth. The latitude and longitude of IPP are calculated as shown in equations 1 and 2.

$$X_{IPP} = \sin^{-1}(\sin(Xg)\, cosR_{pp} + sinR_{pp} \cos(am)) \quad (1)$$

$$Y_{IPP} = Y_g + \sin^{-1}\left(\frac{sinR_{PP}\sin(am)}{cosX_{IPP}}\right) \quad (2)$$

Where,

$$R_{pp} = \frac{\pi}{2} - ea - \sin^{-1}\left(\frac{Ra\cos(ea)}{Ra+H_{IPP}}\right) \quad (3)$$

Where, ‘am’ is the azimuth angle and ‘ea’ is the elevation angle in radians. ‘Ra’ is the radius of the earth, HIPP is the height of the ionospheric thin shell [14]. Ionospheric spatial gradient can be calculated by Time step method [15]. The time step method consists of one satellite S1 and has one GNSS receiver R1 as shown in figure 1. There are two-time instants T1 and T2 at which the GNSS signals from each satellite are received. The distance between the IPP1 and IPP2 is ‘D’. It is defined as the difference in ionospheric delay between two consecutive time periods calculated from a single station and then divided by the IPPs at the two-time instants. GPS signals must travel longer distances at low elevation angles than at high elevation angles due to greater path loss. Signals at low elevation angles are corrupted by multipath propagation due to obstacles in the path. All ionospheric parameters have been calculated using elevation angles greater than 30 degrees.

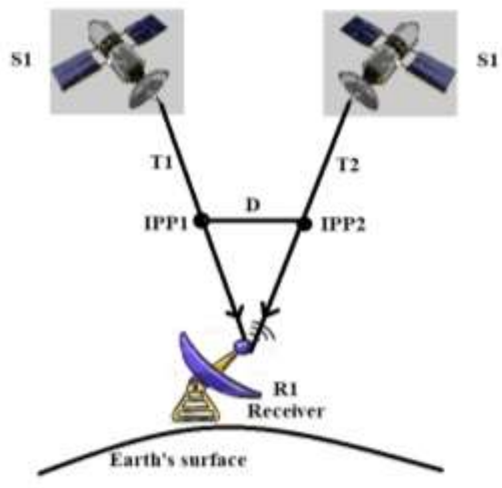

Figure 1: Time step method

Results and discussions:

The STEC values have been recorded at the GPS stations at p502 and p509 for the year 2021 to detect the ionospheric spatial gradients. The latitude and longitude of p502 station are 32.982

ISSN: 2278-4632
Vol-13, Issue-05, No.01, May : 2023

North and 115.421West. Similarly, for p509 station the latitude is 32.890 North and longitude is 115.293 West. The distance between the two stations is 16kms.

The spatial gradient for p502 from time step method is obtained for whole 2021 year. For the station p502 in the year 2021, observe that the spatial gradient is high in the month of May and September. The spatial gradient on 26 May 2021 has maximum value of 0.4466 mm/km and the spatial gradient in the month of September has the second maximum value which is 0.2451 mm/km on 28 September 2021 as shown in figure 2 and 4.

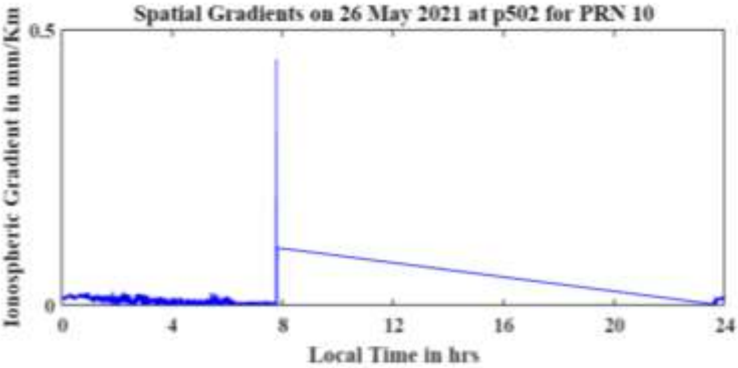

Figure 2: Spatial gradients on 26 May 2021 at station p502

The forecast of the maximum geomagnetic storms on 26 May and 28 September with the Kp index values is shown in the figure 3 and figure 5. The minimum geomagnetic storm i.e., calm day (23 January) shown in figure 7.

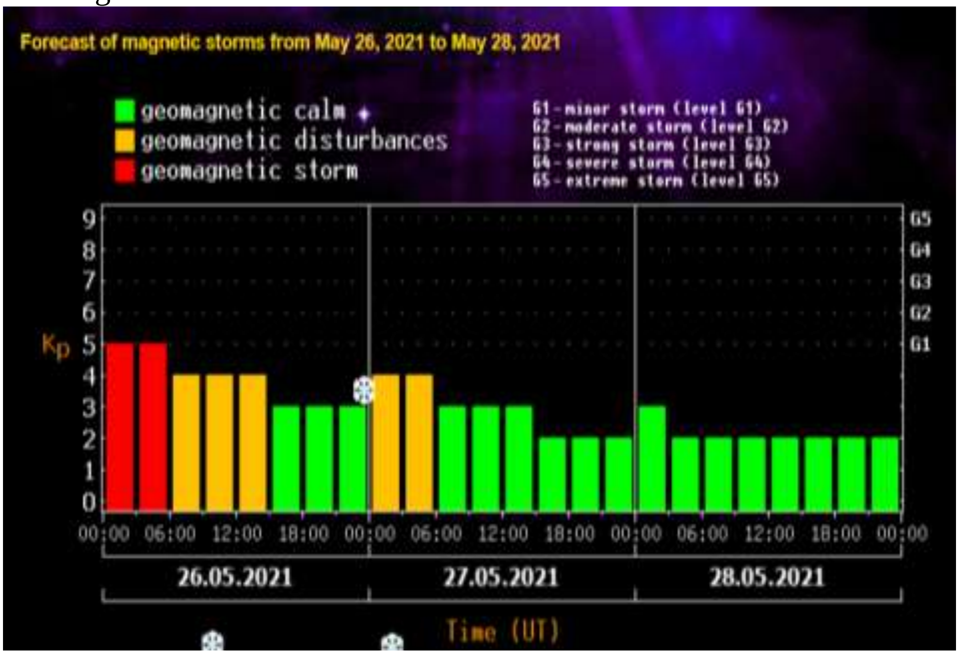

Figure 3: Forecast of geomagnetic storm on 26 May 2021

ISSN: 2278-4632
Vol-13, Issue-05, No.01, May : 2023

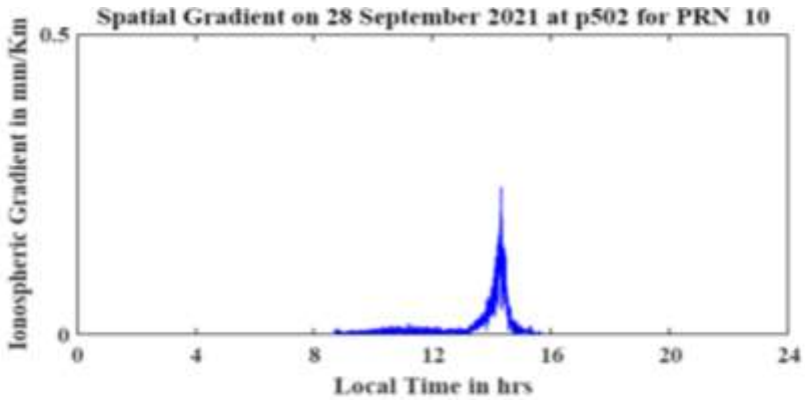

Figure 4: Spatial gradients on 28 September 2021 at station p502

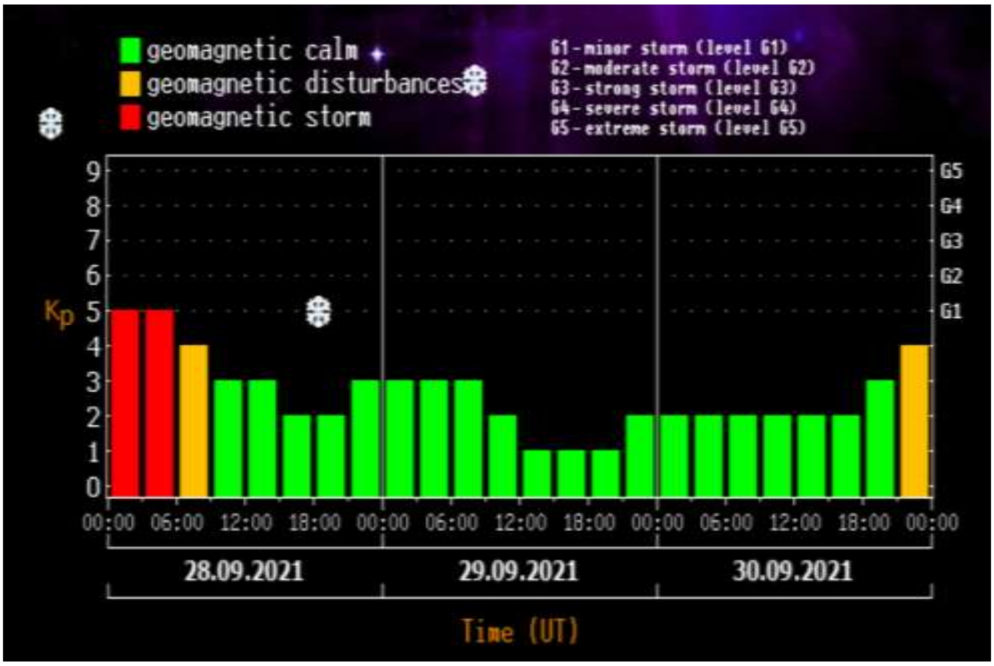

Figure 5: Forecast of geomagnetic storm on 28 September 2021

The minimum value is observed on 23 January 2021 which is 0.0008 mm/km as shown in figure 6.

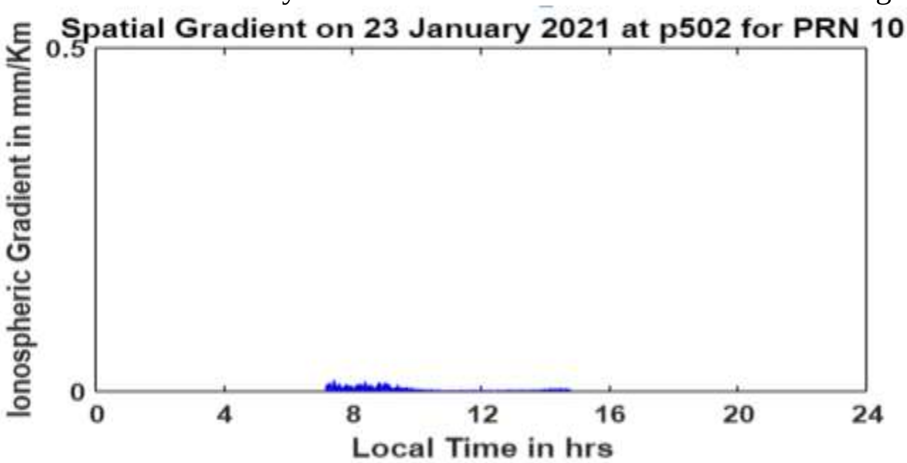

Figure 6: Spatial gradient on 23 January 2021 at station p502

ISSN: 2278-4632
Vol-13, Issue-05, No.01, May : 2023

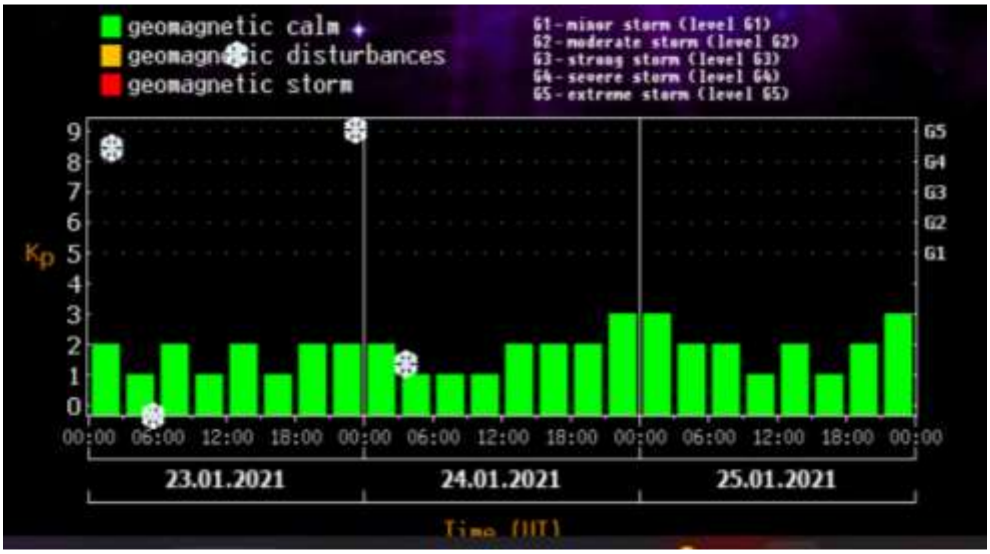

Figure 7: Forecast of geomagnetic storm on 23 January 2021

The overall values of spatial gradient in the year 2021 for the station p502 is shown in the figure 8. The minimum values are observed in the figure 9.

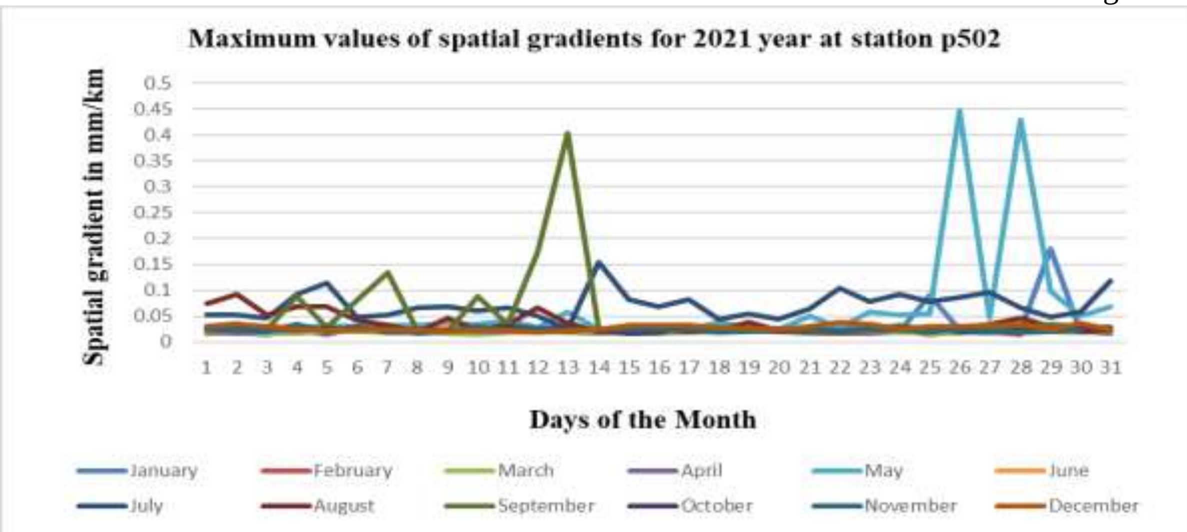

Figure 8: Maximum values of spatial gradients for station p502 for the year 2021

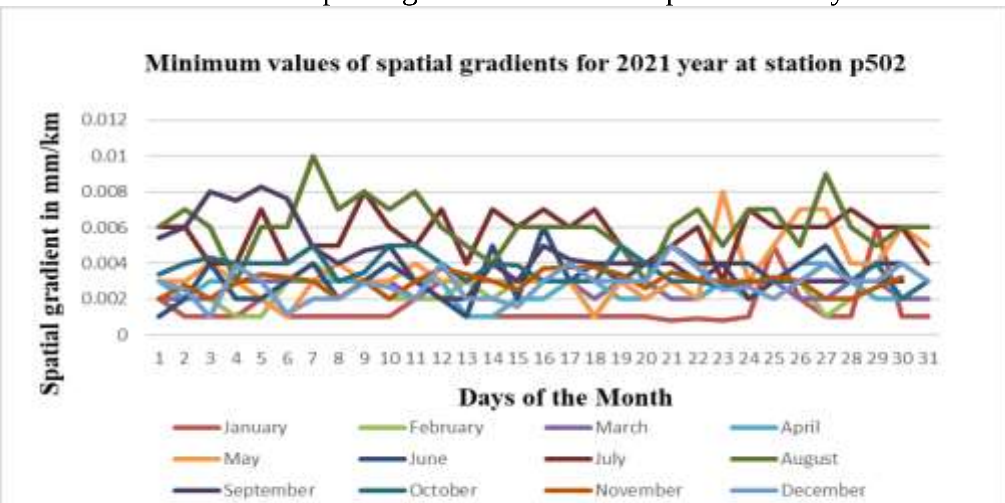

Figure 9: Minimum values of spatial gradient for station p502 for the year 2021

For the station p509 in the year 2021, observe that the spatial gradient is high in the month of May and September. On 22 May 2021, the maximum gradient is of 2.3307 mm/km and on 13

September 2021, the second maximum gradient is 0.2844 mm/km as shown in the figure 10 and 11.

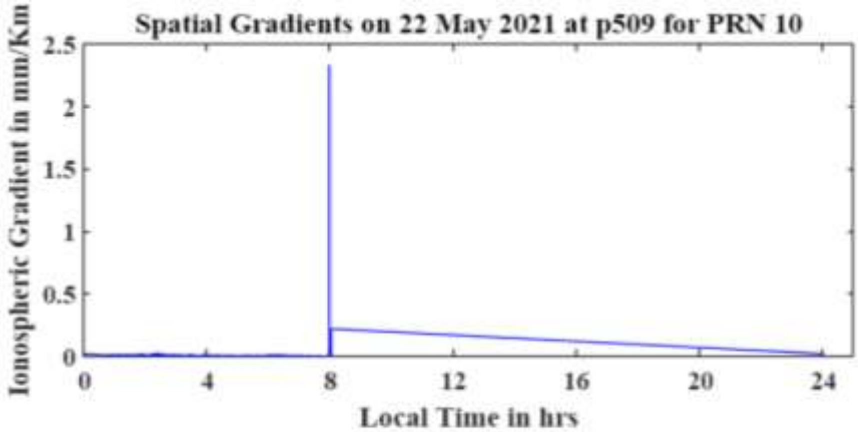

Figure 10: Spatial gradients on 22 May 2021 at station p509

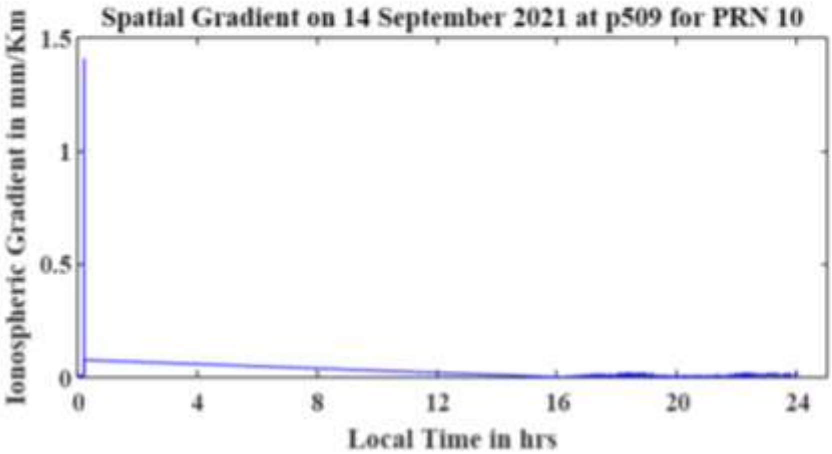

Figure 11: Spatial gradients on 14 September 2021 at station p509

The minimum value is observed in the month of April and May which be of 0.001 mm/km spatial gradient as shown in figure 12.

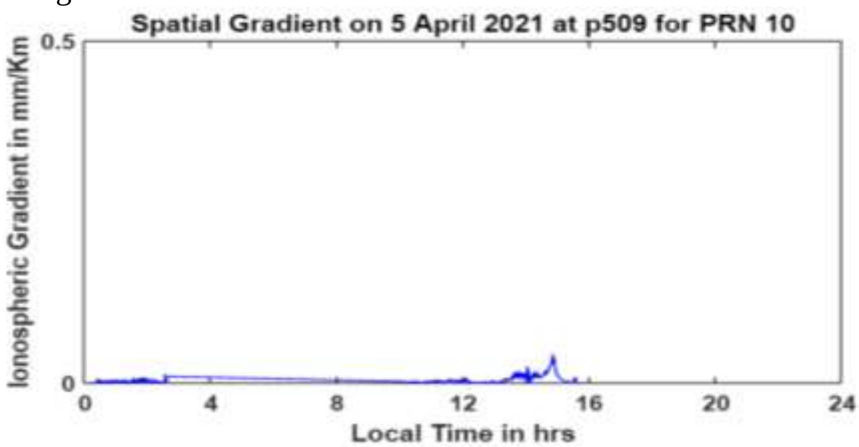

Figure 12: Spatial gradients on 5 April 2021 at station p509

The overall maximum and minimum values of spatial gradient for the station p509 in the year 2021 is shown in the figure 13 and 14.

ISSN: 2278-4632
Vol-13, Issue-05, No.01, May : 2023

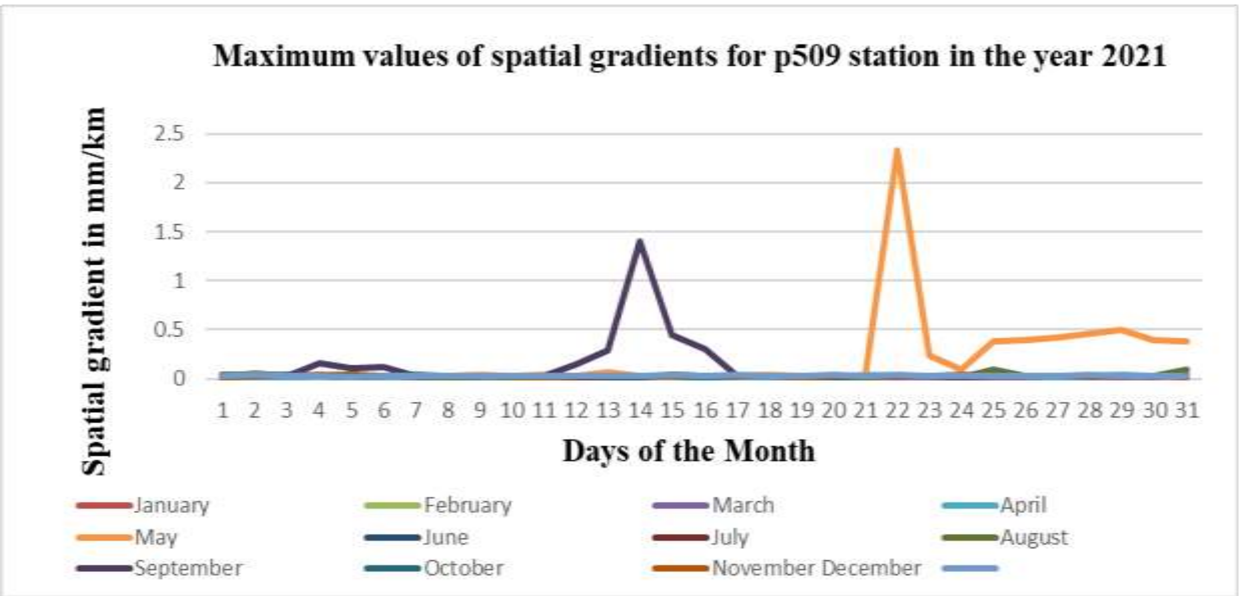

Figure 13: Minimum values of spatial gradient for station p502 for the year 2021

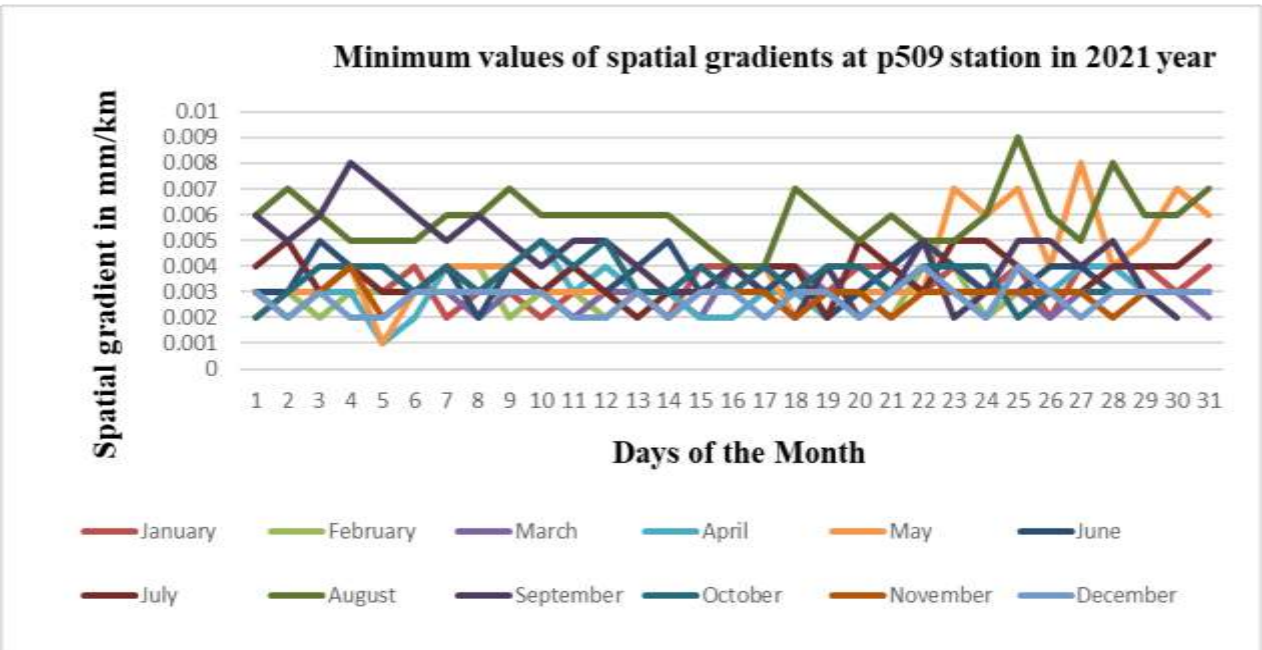

Figure 14: Minimum values of spatial gradient for station p509 for the year 2021

By observing the amplitude scintillation (S4) and phase scintillation the ionospheric disturbances can also be detected. The rapid fluctuations in amplitude and phase due to the scattering nature of the medium occurs when a radio signal from a GNSS satellite passes through a disturbed ionosphere. These fluctuations are called scintillations and, they show the amount of inconsistency in the radio signal.

Conclusion:

GBAS systems provide spatial corrections to the GNSS data, increasing location accuracy in civil aviation. Ionospheric error is the most challenging to reduce of all the errors that a GNSS signal undergoes. In this study, it aims to identify the spatial gradients by using single frequency time step method in the low latitude regions at the p502 and p509 stations over the year 2021. To find the ionospheric spatial gradients, the IPPs were calculated. The spatial gradients for stations p502

ISSN: 2278-4632
Vol-13, Issue-05, No.01, May : 2023

and p509 indicate a strong ionospheric disturbance during the month of May. The approach employed in this paper is simple but effective in evaluating ionospheric gradients.

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