A STUDY ON THE LOW-LATITUDE IONOSPHERIC SCINTILLATION USING DATASETS FROM GPS SCINDA RECEIVERS AND IONOSONDE INSTRUMENTS IN KENYA

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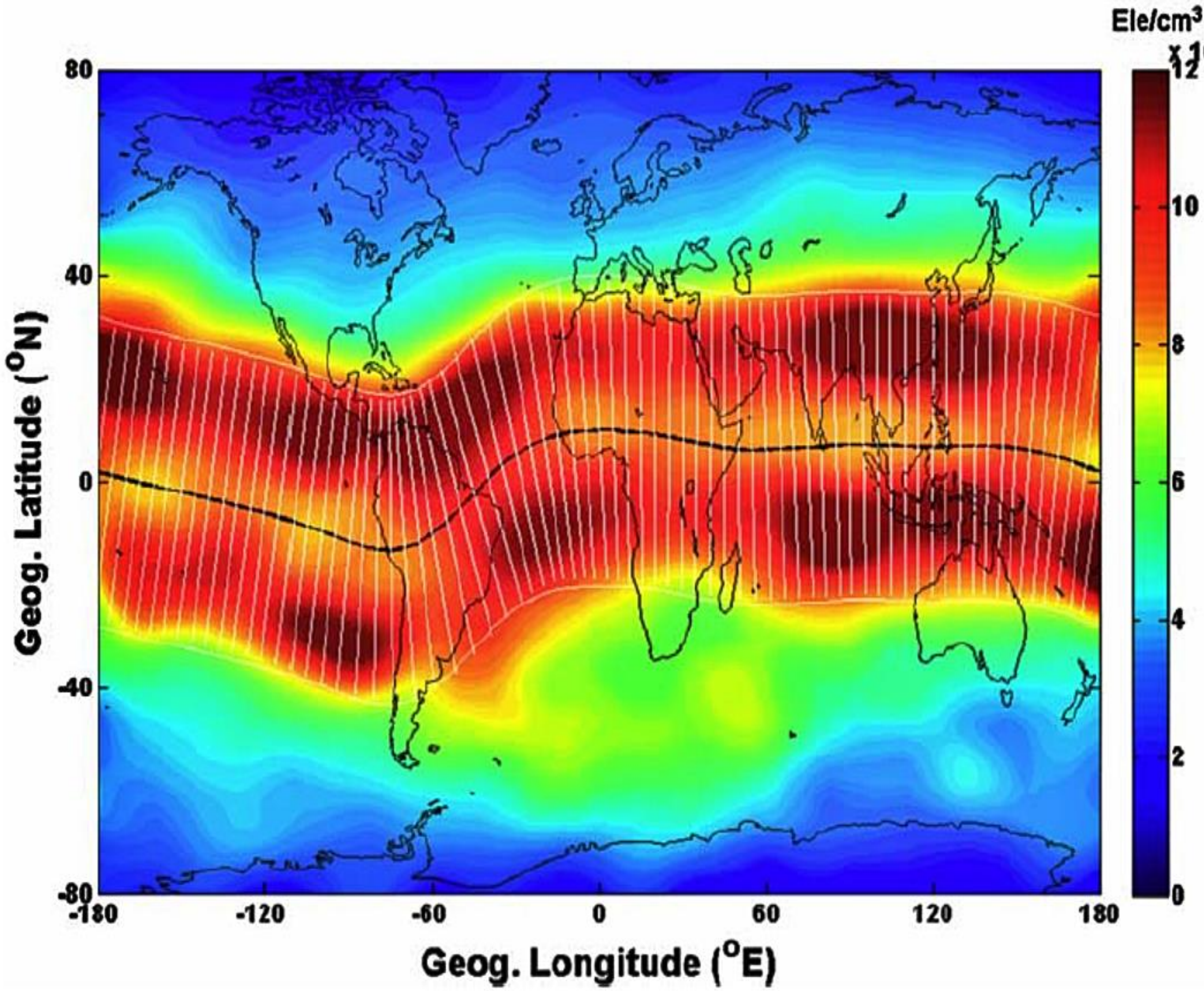
IONOSPHERIC VARIATION

- The global structure of the ionosphere is not homogeneous in terms of the electron density variation.
  - ➢ Variation in TEC values clearly depicts the occurrence of ionospheric irregularities.
  - ➢ Small-to-medium-scale density fluctuations in the ionosphere e.g. EPB and EIA.
  - ➢ Leads to Radio signal scintillation.



Geographical Regions of the Ionosphere (*Liu et al.,2009*)

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IONOSPHERIC EFFECTS

- The extent of ionospheric effect on Radio Signals depends directly on the concentration of the electrons (electron density) in the ionosphere.
- Major ionospheric effects on GPS signals:
  - ❖ **Range Error** – This is caused by time delay on signals which is as a result of Total Electron Content (TEC) density in the ionosphere.
    - Range Error = $\pm 40.3\ TEC/f^2$ (in meters)
    - Time delay = $40.3\ TEC/(cf^2)$ (in seconds)
  - ❖ **Scintillation** – This is due to rapid fluctuations in the signal amplitude and phase, caused by irregularities in the ionosphere.
- Scintillation activity varies with operating frequency, geographic location, local time, season, magnetic activity, and the 11-year solar cycle. (Doherty *et al.*, 2003)

OBJECTIVE

The objective of this study is to investigate the behavior of Ionospheric Scintillation in the low-latitude region during different geomagnetic conditions and it's effect on positioning and HF communication.

METHODOLOGY

DATA SOURCE:

- GPS Scintillation Network Decision Aid (GPS-SCINDA) receivers installed at Jomo Kenyatta University (37.01°E,1.09°S) and University of Nairobi (36.82° E, 1.28° S) have be used.
- GNSS scintillation receiver in Malindi – from INGV eSWua Website
- Ionosonde installed at the Luigi – Broglio Space Centre – NORISK project - from INGV eSWua Website

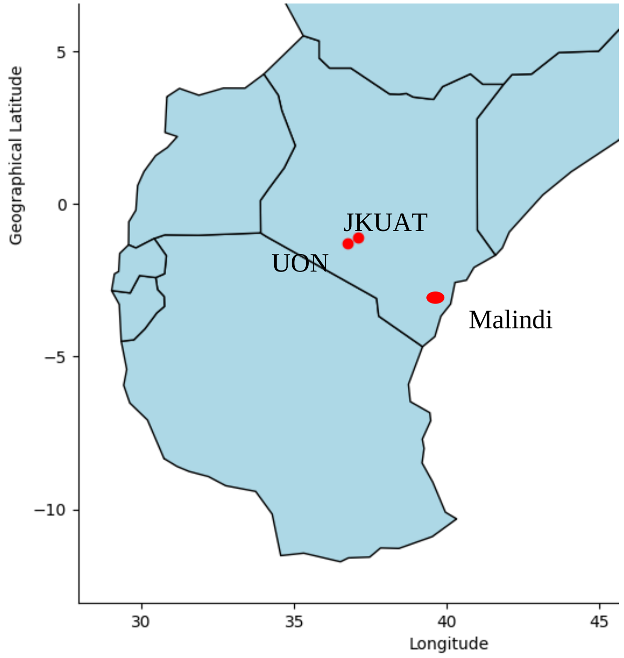

Figure 5: Data Sources

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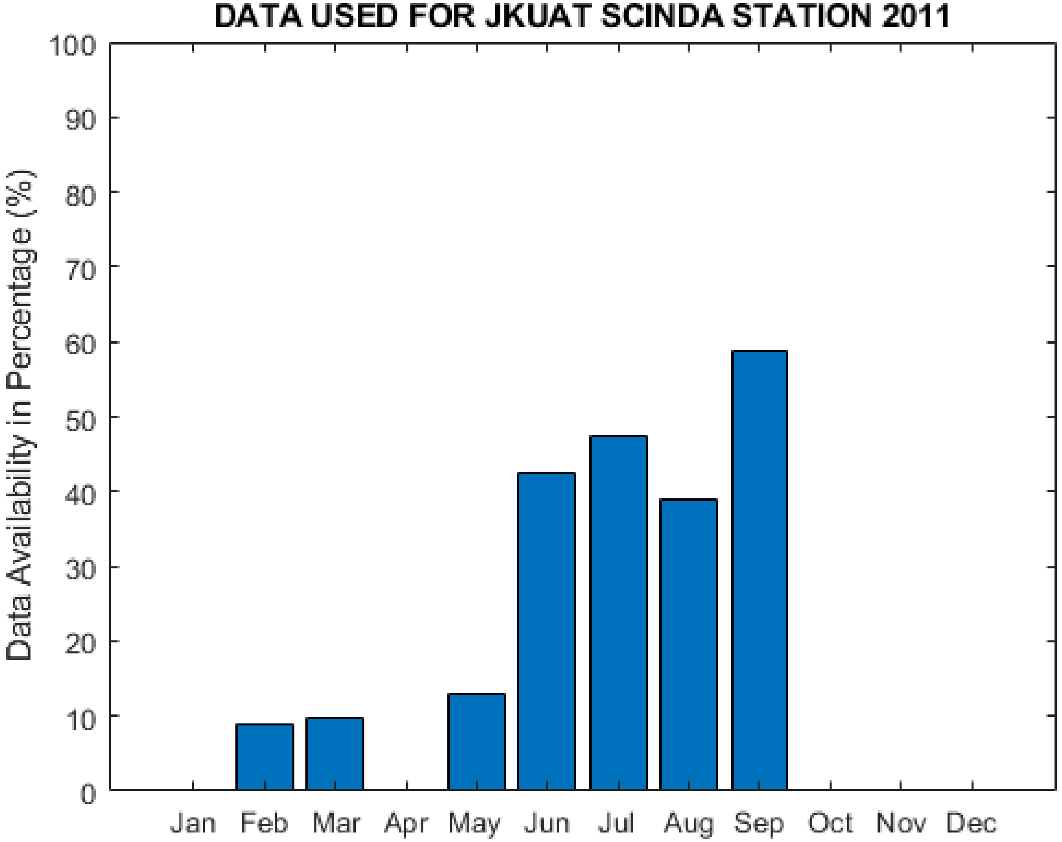
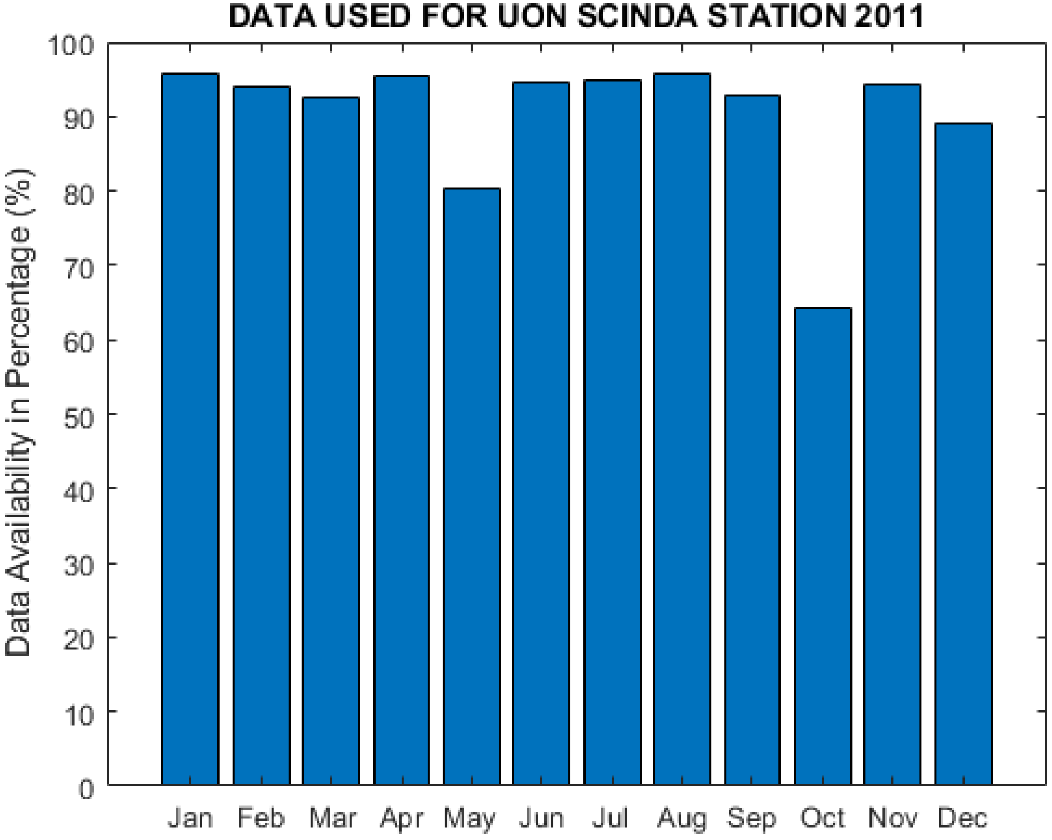
DATA AVAILABILITY

Only night time data was considered: Low-latitude ionospheric scintillation is limited to local night time hours.

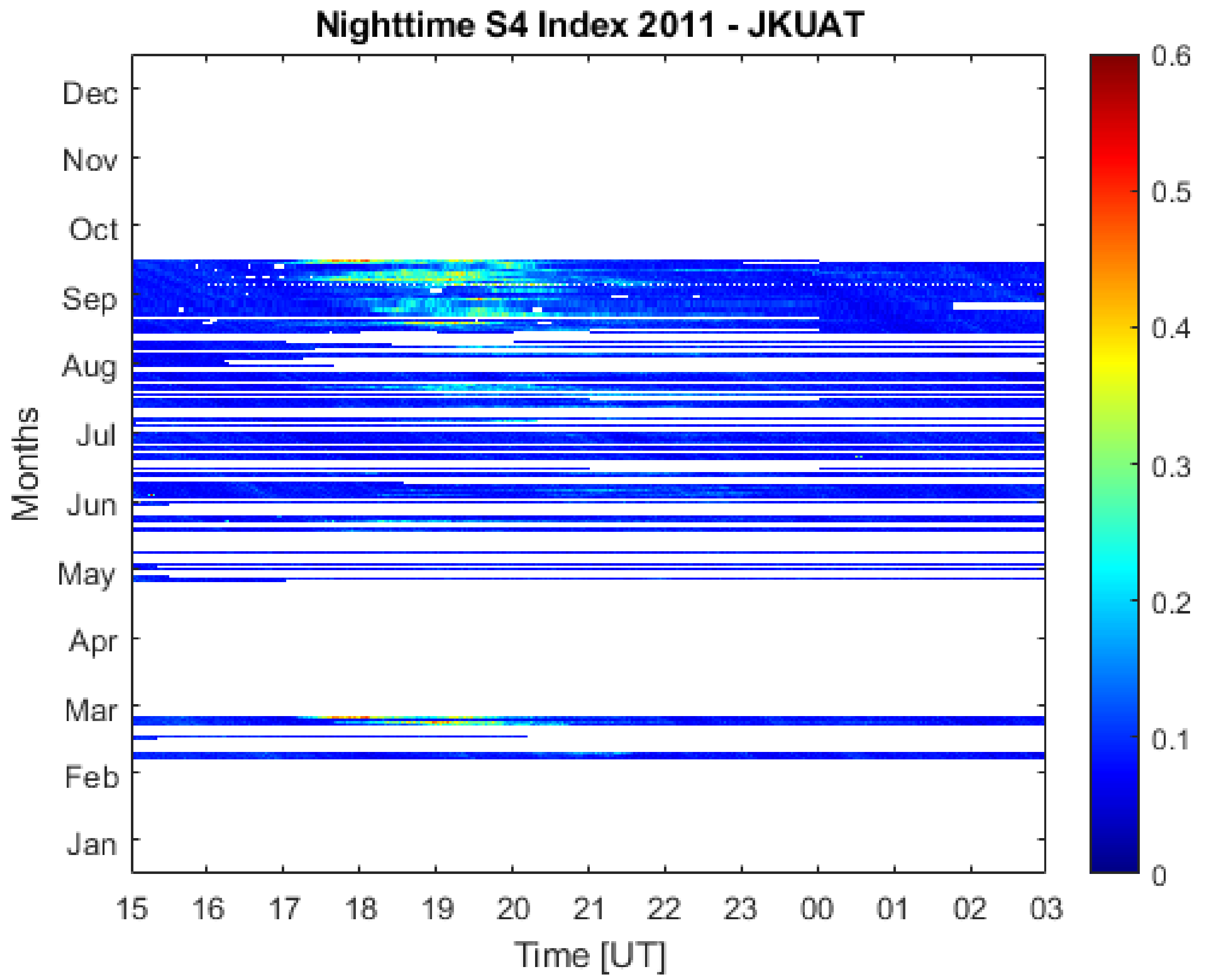
Resolution: 1 Minute, Elevation angle limit of 30° was applied.

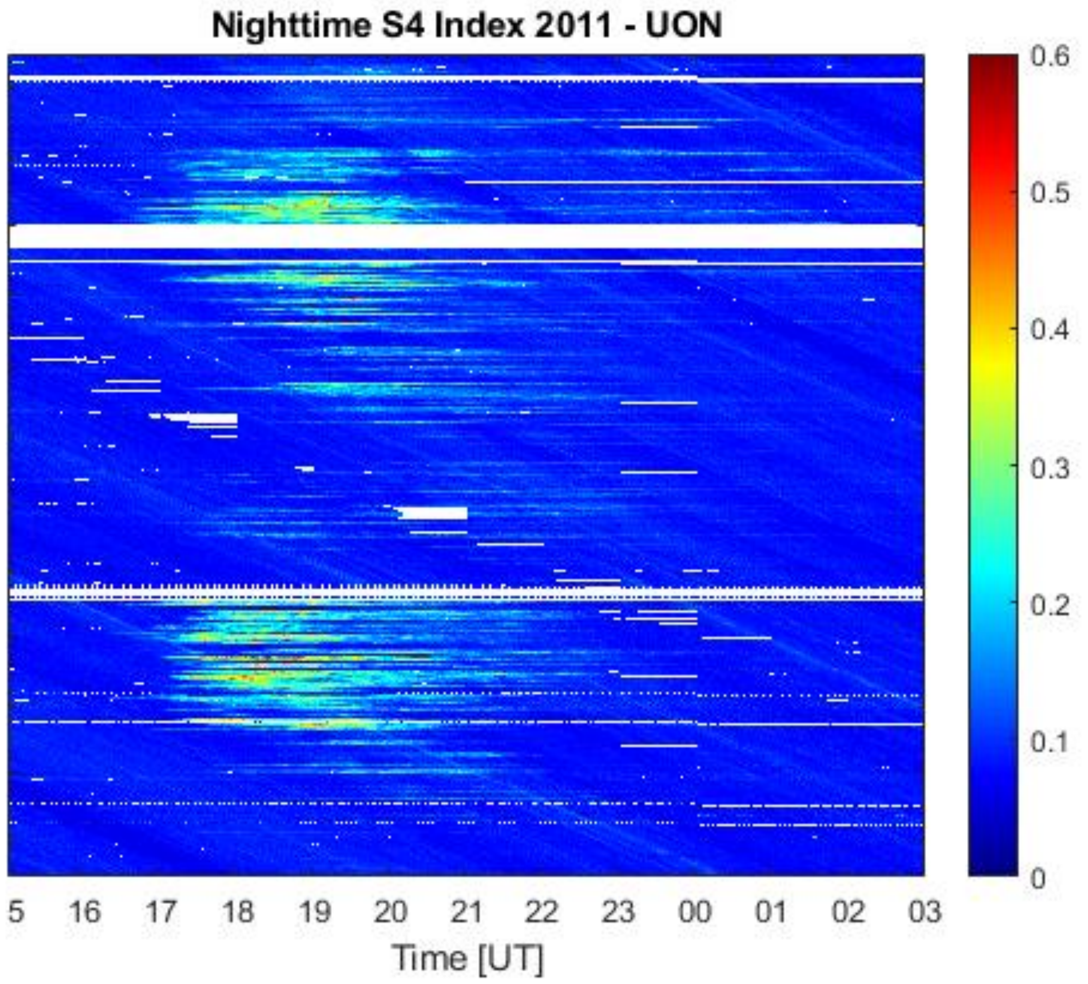




RESULTS AND DISCUSSION

Strong scintillation observed in the evening hours as from 20:00 to 00:00 local time.





Statistical analysis of S4 index distribution

- Only scintillation samples above noise-level threshold of 0.1 have been considered. Strong scintillation ($S_4 > 0.3$), moderate scintillation ($0.2 < S4 \leq 0.3$) and Low Scintillation ($0.1 < S4 \leq 0.2$) (Olwendo *et al.*, 2013, Amabayo *et al.*, 2013)

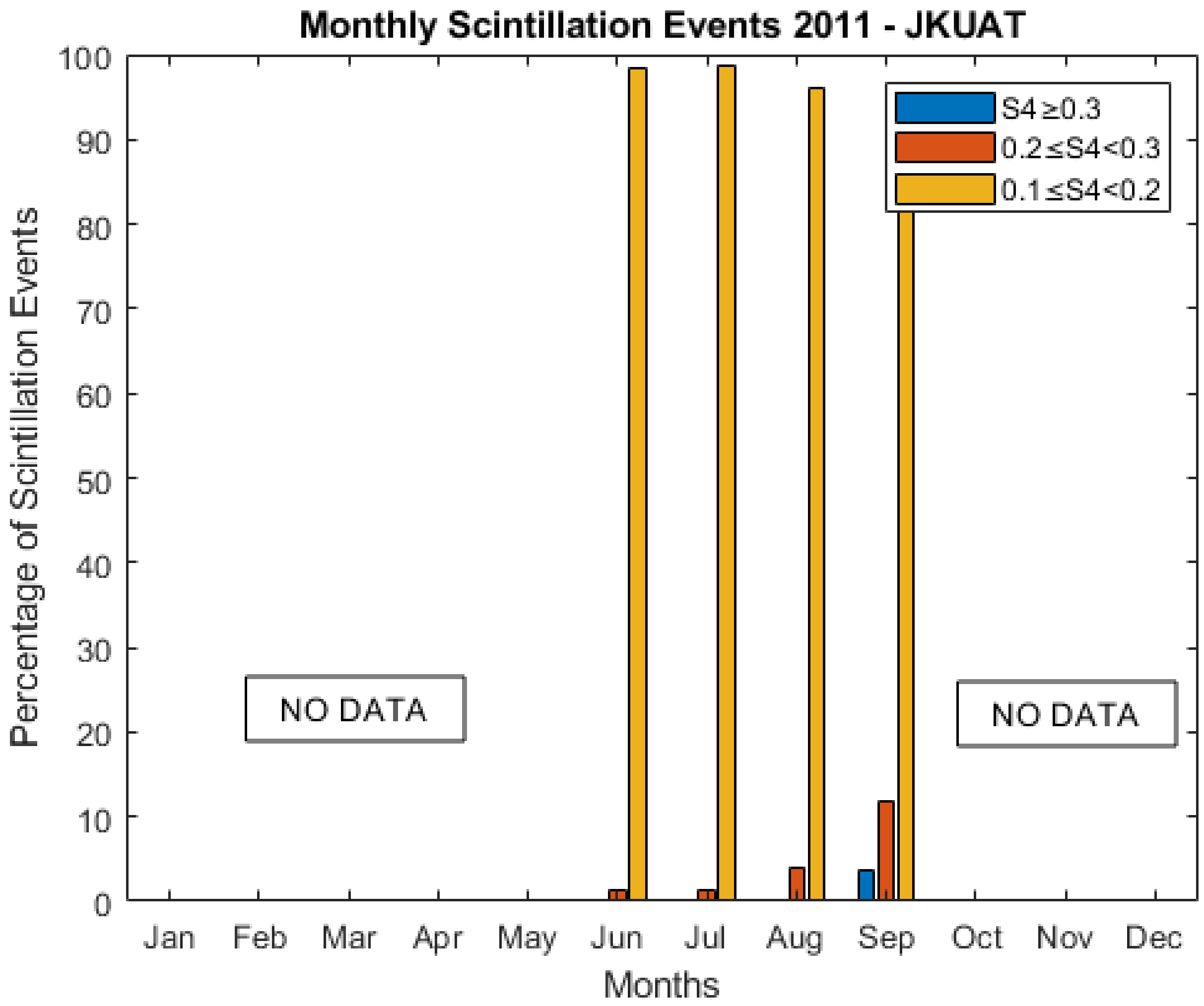
Scintillation levels of Data samples - JKUAT

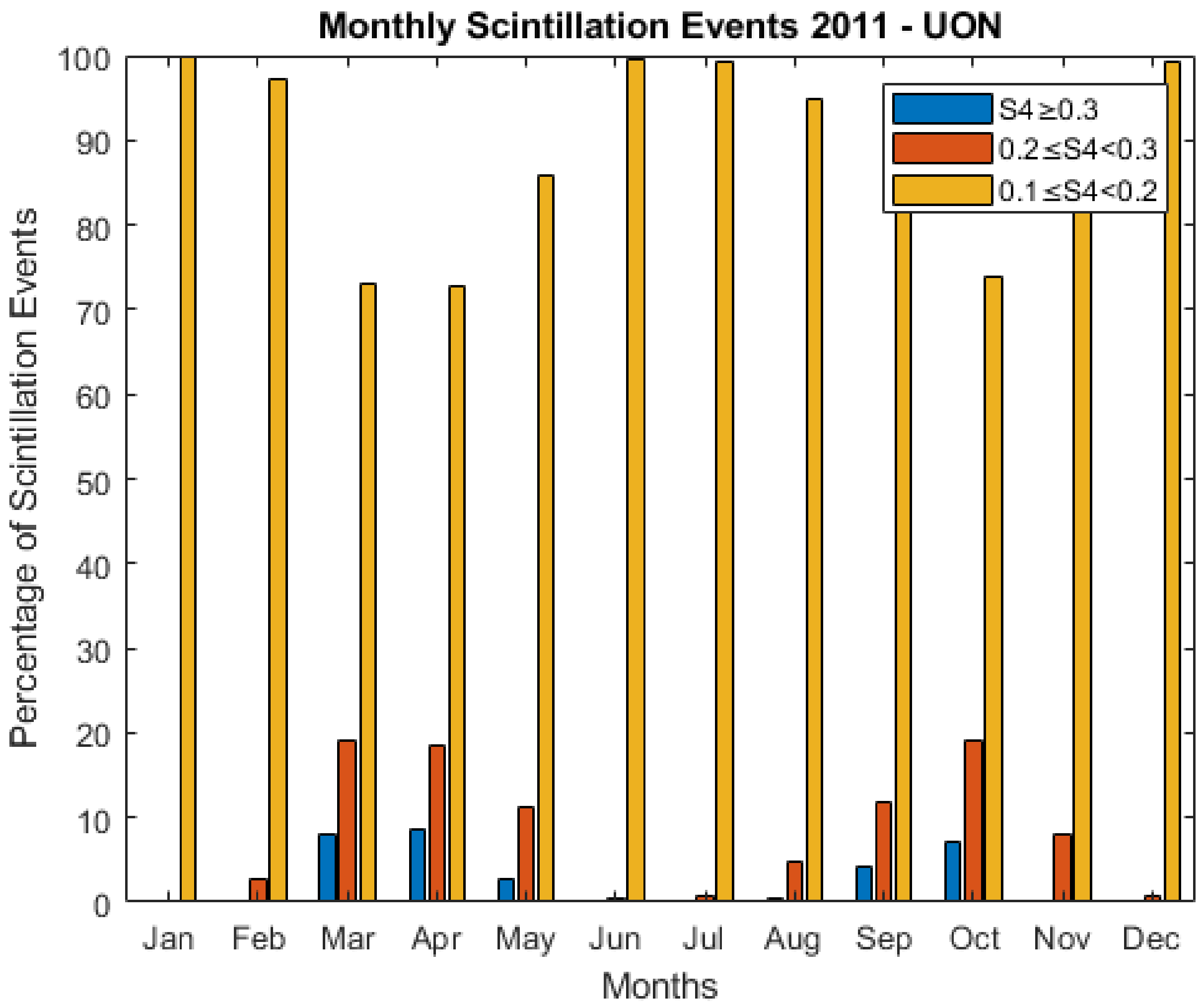
	Strong	Moderate	No Scint.	Total
January	0	0	0	0
February	0	1	337	338
March	134	202	719	1055
April	0	0	0	0
May	0	0	145	145
June	5	26	1859	1890
July	1	19	1374	1394
August	0	82	1966	2048
September	229	754	5359	6342
October	NO DATA			
November				
December				

Scintillation levels of Data samples - UON

	Strong	Moderate	No Scint.	Total
January	0	4	1722	1726
February	2	78	337	2960
March	511	1219	719	6418
April	642	1367	0	7391
May	61	237	145	2102
June	0	23	1859	4360
July	2	19	1374	2995
August	17	231	1966	4874
September	271	775	5359	6613
October	422	1121	4365	5908
November	6	490	5701	6197
December	3	37	4767	4807

- Graphical representation of the statistical analysis of the monthly distribution of scintillation samples through out the year. – Months with data below 40% were not considered since they may not produce an accurate representation of the monthly distribution of scintillation events.





- Monthly statistical analysis of scintillation events - defined as scintillation occurrence with S4 index values above noise –level threshold of 0.1 and sustained for at least 5 minutes.
- Some strong scintillation samples observed especially in the solsticial months were noted not to be sustained for 5 minutes and thus not considered as scintillation events

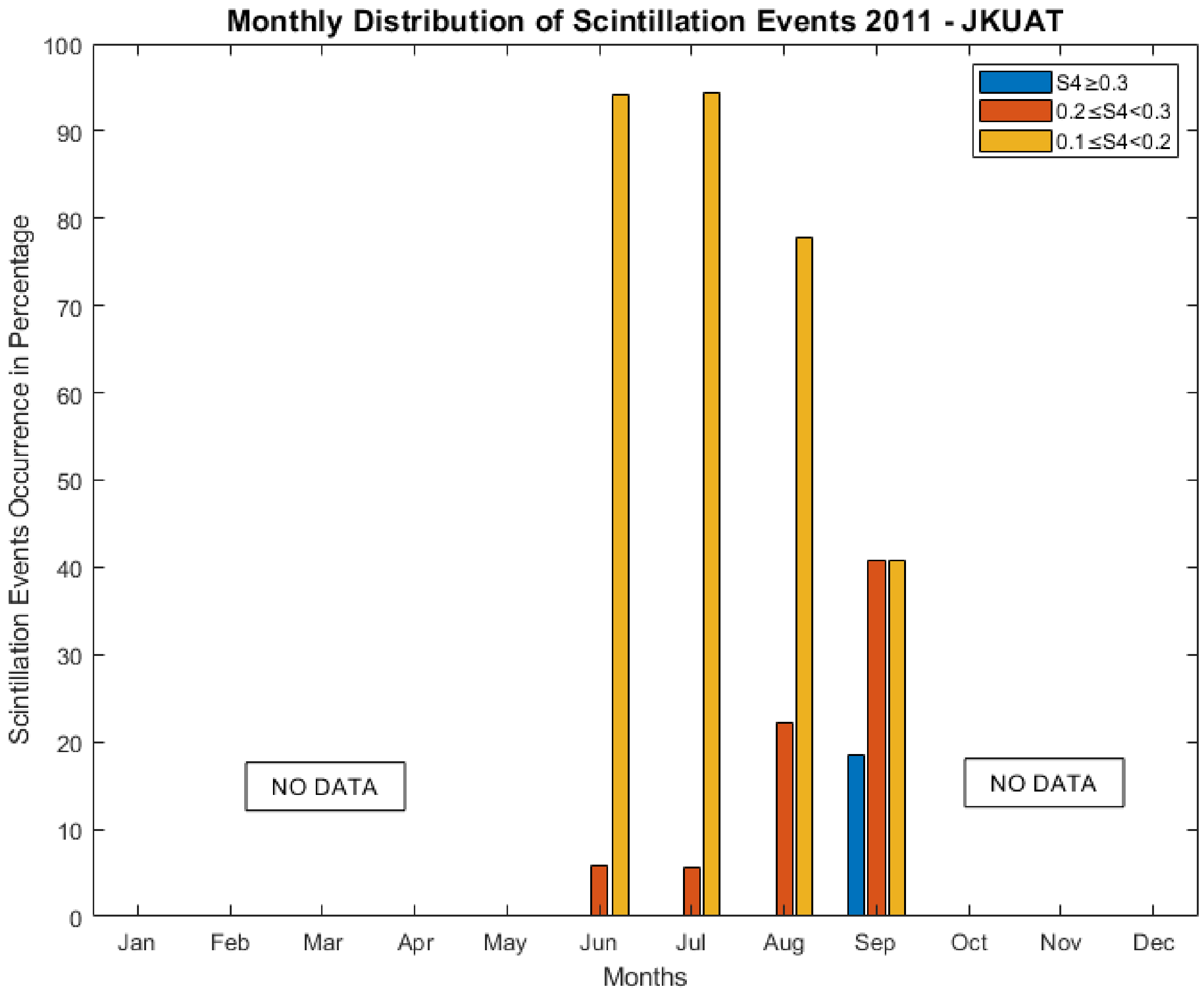
Scintillation Events Levels - JKUAT

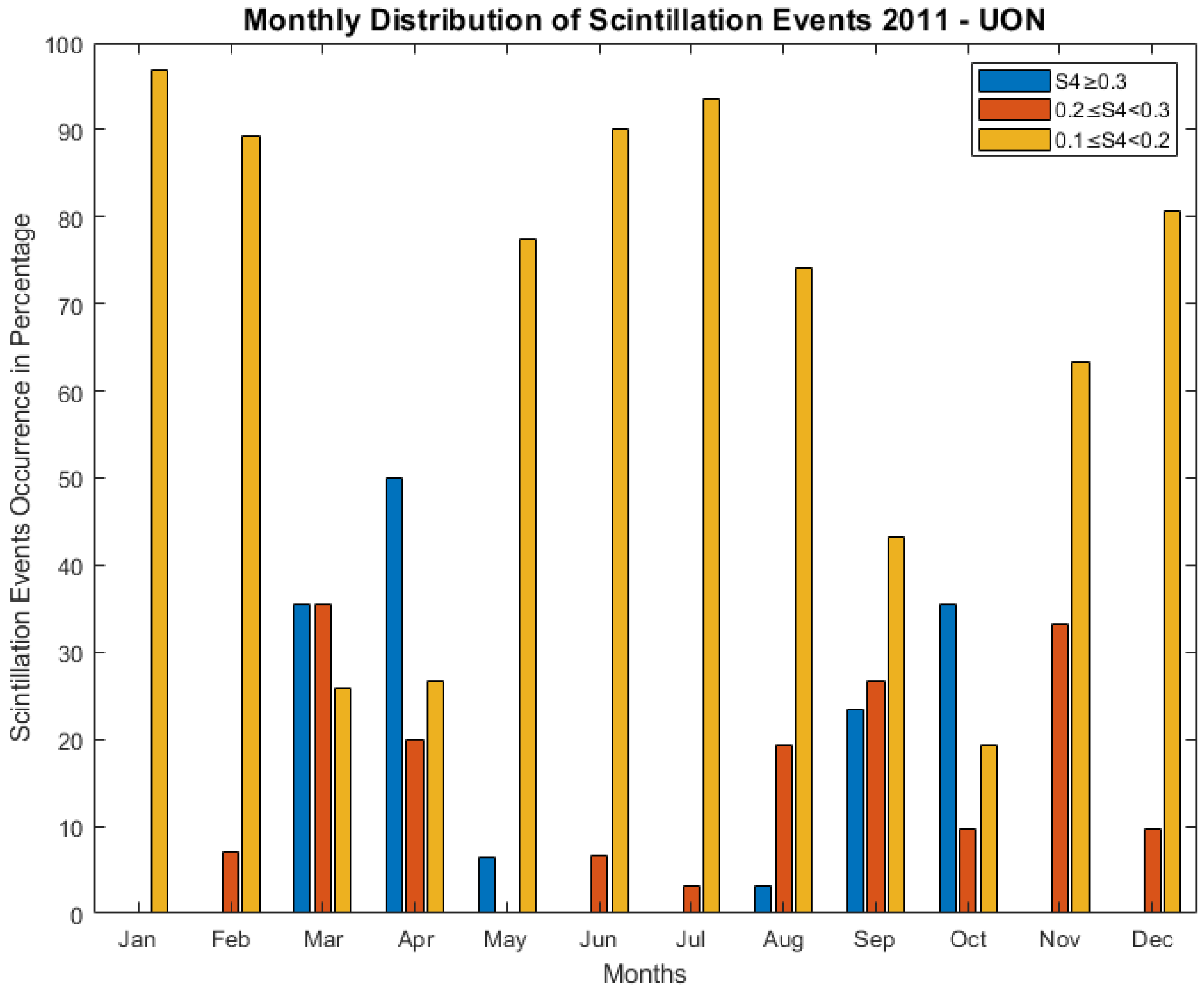
	Strong	Moderate	No Scint.	Total
January	0	0	0	**0**
February	0	0	3	**3**
March	3	0	3	**6**
April	0	0	0	**0**
May	0	0	5	**5**
June	0	1	16	**17**
July	0	1	17	**18**
August	0	4	14	**18**
September	5	11	11	**27**
October	NO DATA			
November				
December				

Scintillation Events Levels - UON

	Strong	Moderate	No Scint.	Total
January	0	0	30	**30**
February	0	2	25	**27**
March	11	11	8	**30**
April	15	6	8	**29**
May	2	0	24	**26**
June	0	2	27	**29**
July	0	1	29	**30**
August	1	6	23	**30**
September	7	8	13	**28**
October	11	3	6	**20**
November	0	10	19	**29**
December	0	3	25	**28**

- Graphical representation of monthly statistical analysis of scintillation events





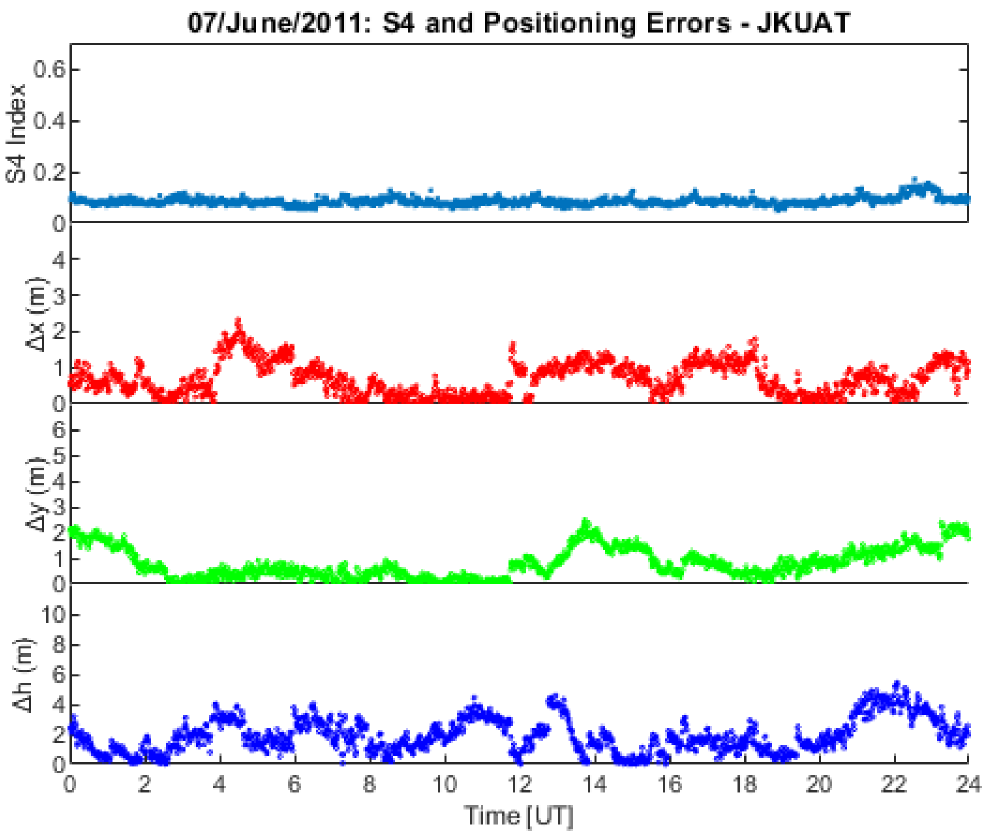
- These results show that the predominant amplitude scintillation (S4) events have a seasonal pattern of variation, the S4 index is relatively higher during equinoctial months of March-April and September-October. Consistent with, Olwendo *et al*., 2013, Abiriga *et al*., 2021, Ondende *et al*., 2022, Uluma *et al*., 2021).

- The post-sunset irregularities are attributed to electrical processes in the evening time equatorial ionosphere, which trigger EPBs through the RTI process. (Basu *et al*., 1976)

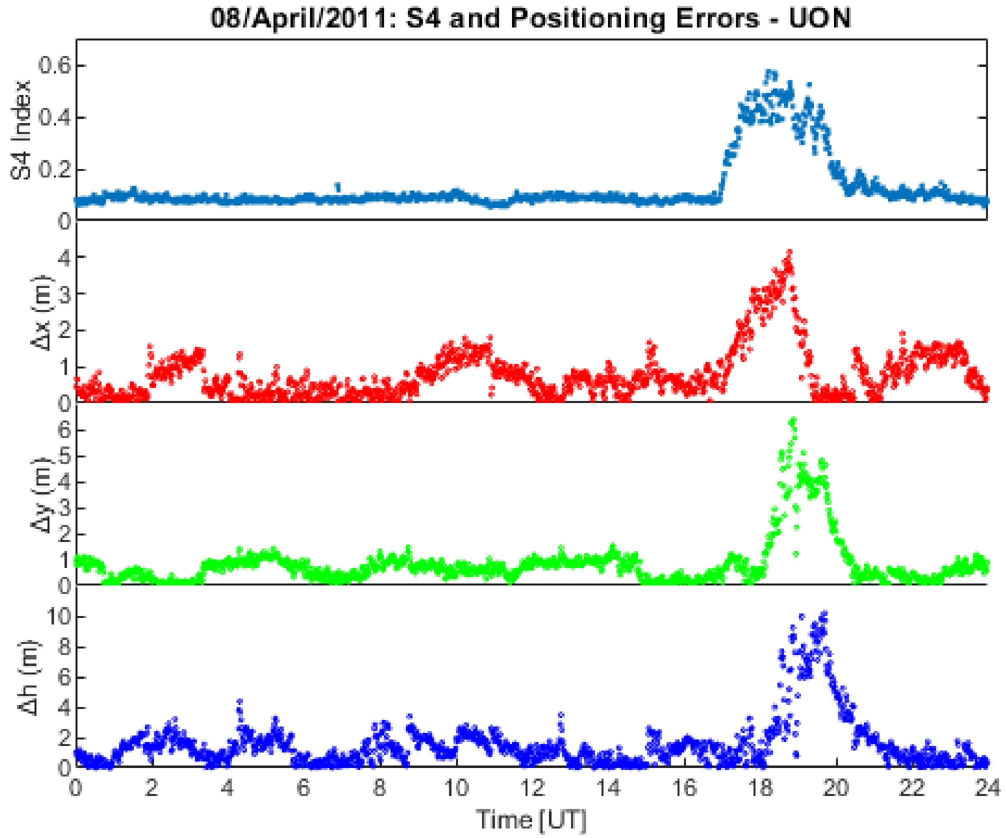
Impact on Positioning

- Δx, Δy, Δh represent errors along the longitude, latitude and altitude respectively.

No Scintillation: S4 Index = 0.1 (Background levels)
Horizontal Errors up to 2m, Vertical Errors up to 4m

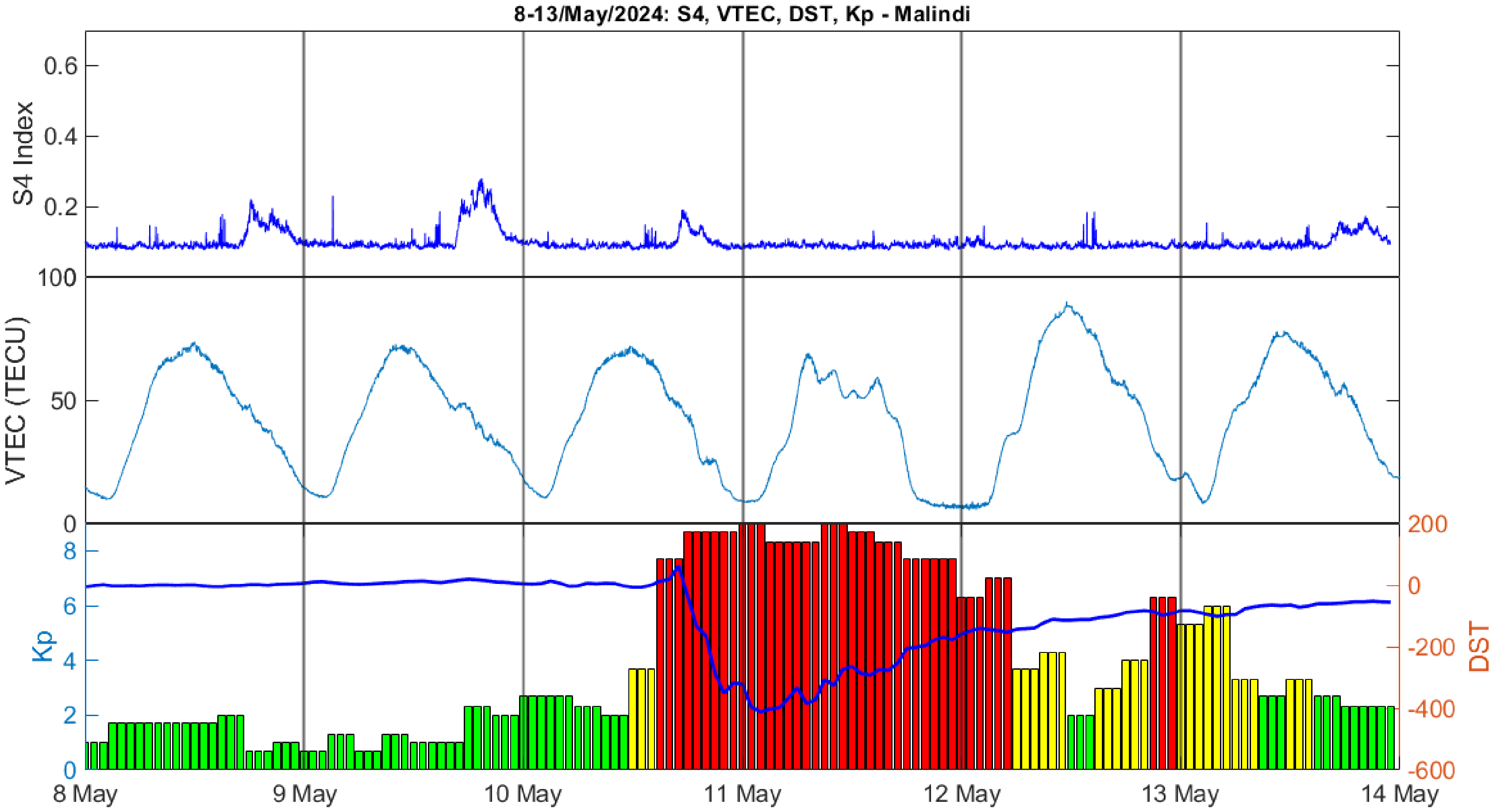


Strong Scintillation: S4 Index = 0.57
Horizontal Errors up to 7m, Vertical Errors up to 11m



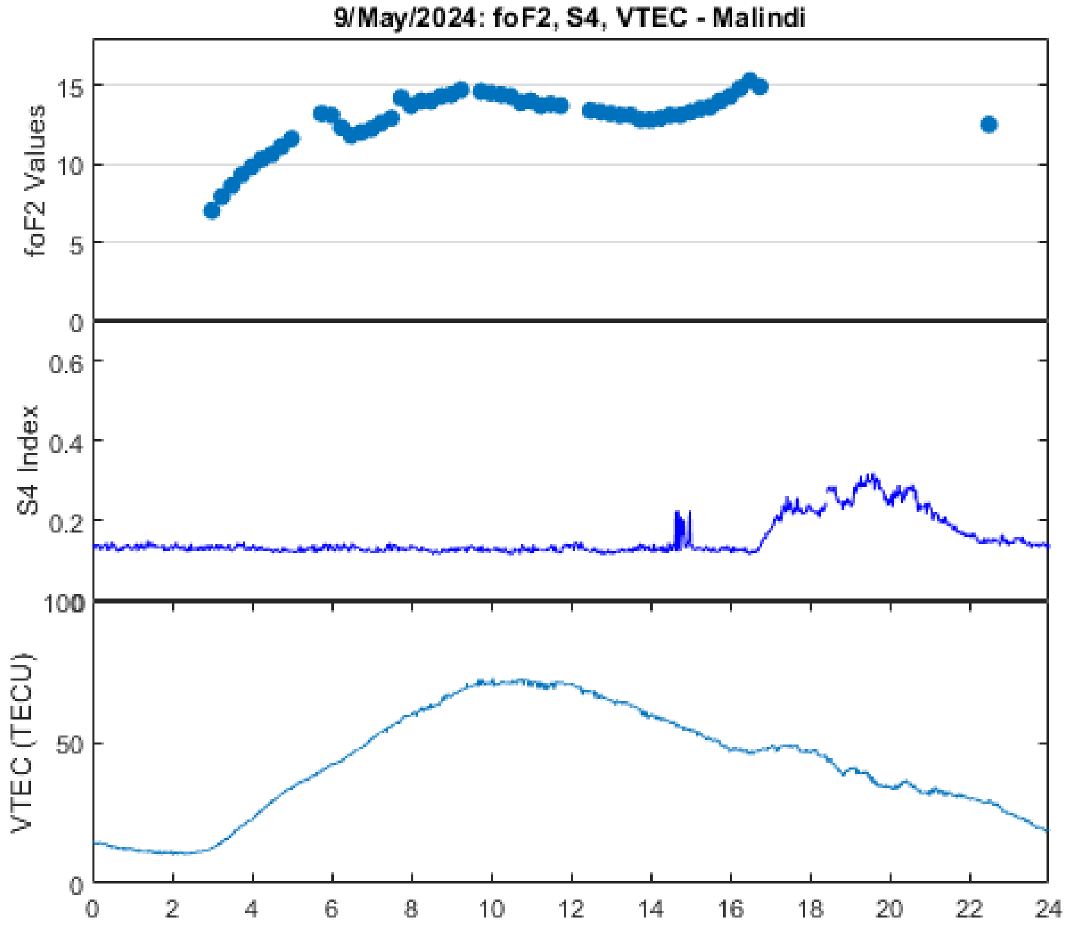
Scintillation during Geomagnetic Storms

The 10th – 11th May 2024 Geomagnetic Storm caused a negative ionospheric storm phase; caused by changes in neutral composition that leads to decrease in the O/N_2 density ratio due to atmospheric disturbances (Goncharenko *et al.*, 2007, Huang *et al.*, 2005, de Abreu *et al.*, 2010, 2014).

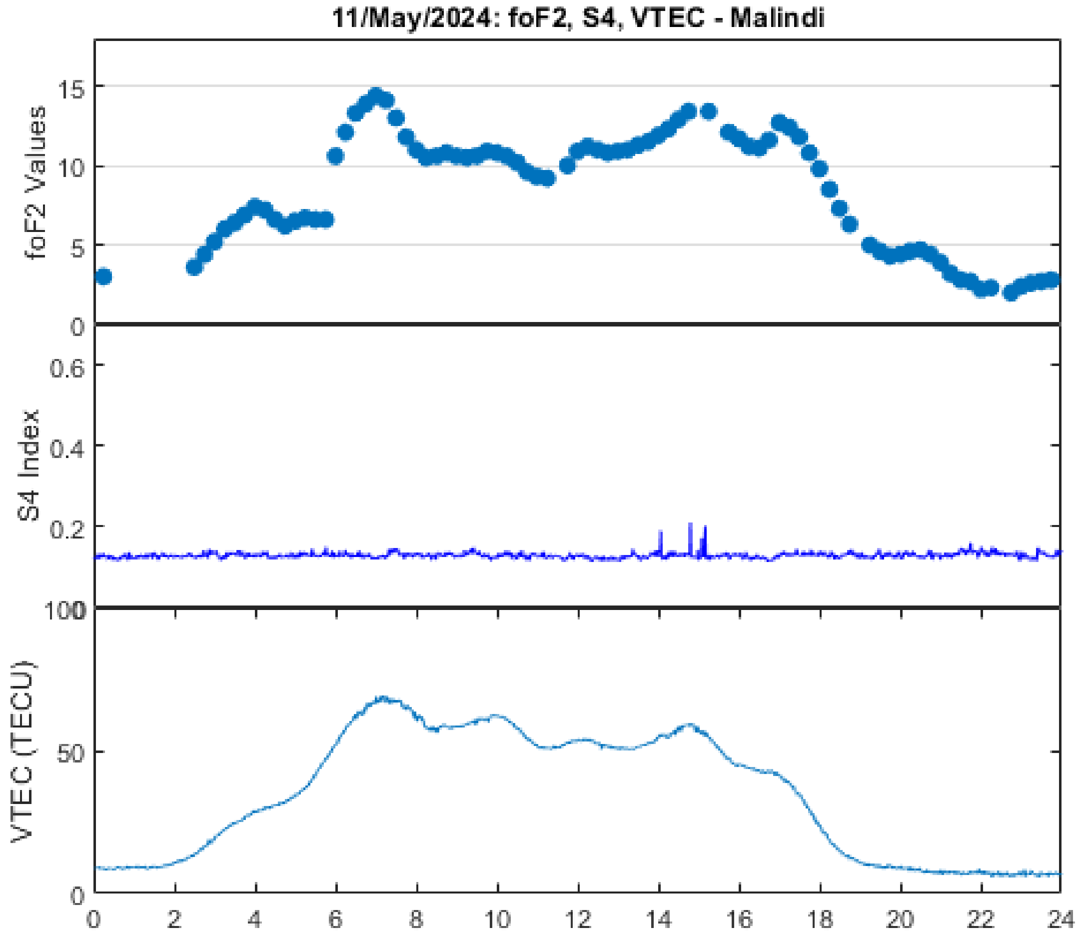


Impact on HF Communication

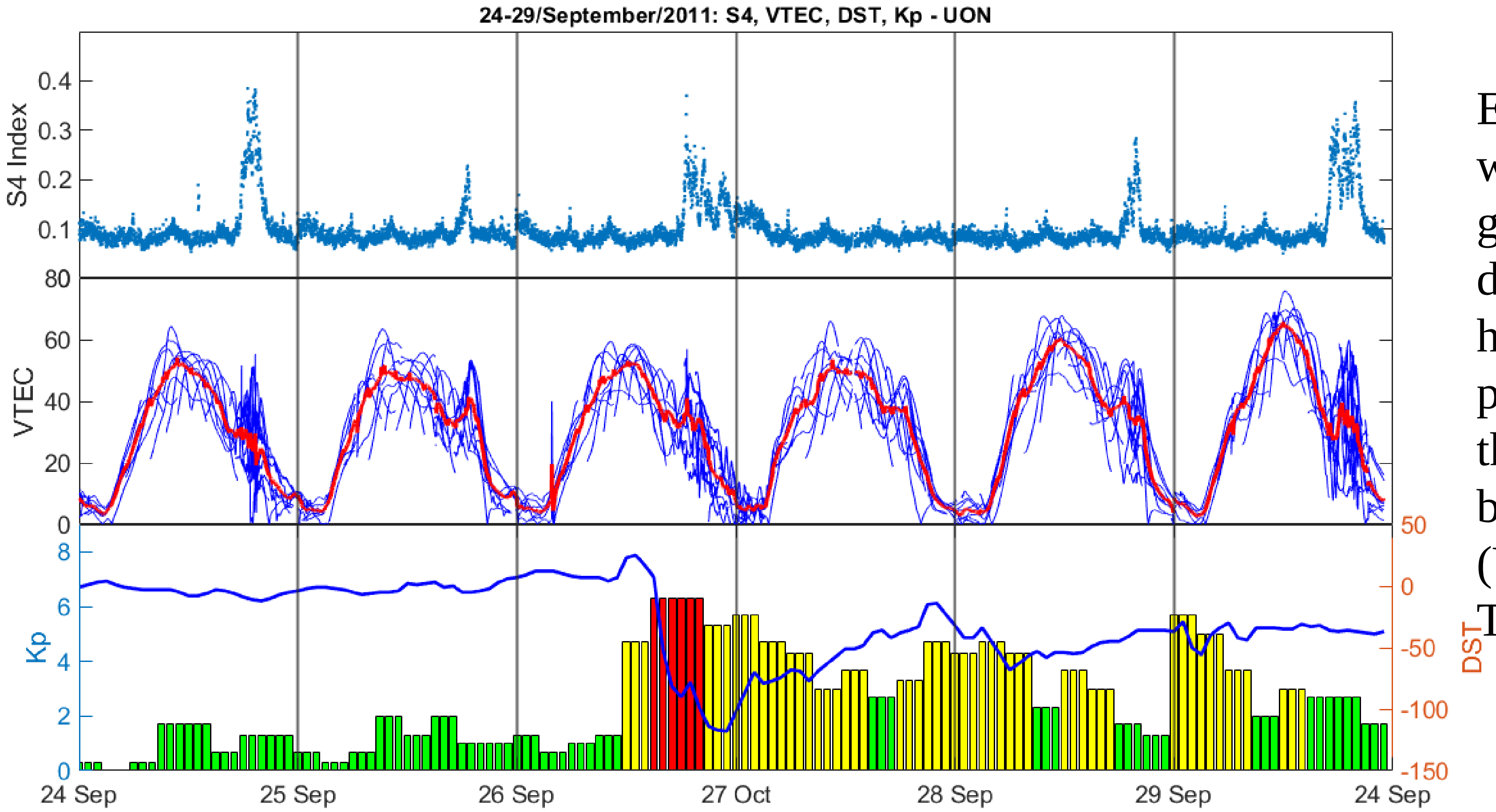
Significant Scintillation: S4 Index = 0.3
Complete absence of echoes during scintillation hours



No Scintillation: S4 Index = 0.1 (Background Levels)
Reduced foF2 values during daytime – Negative Ionospheric Storm

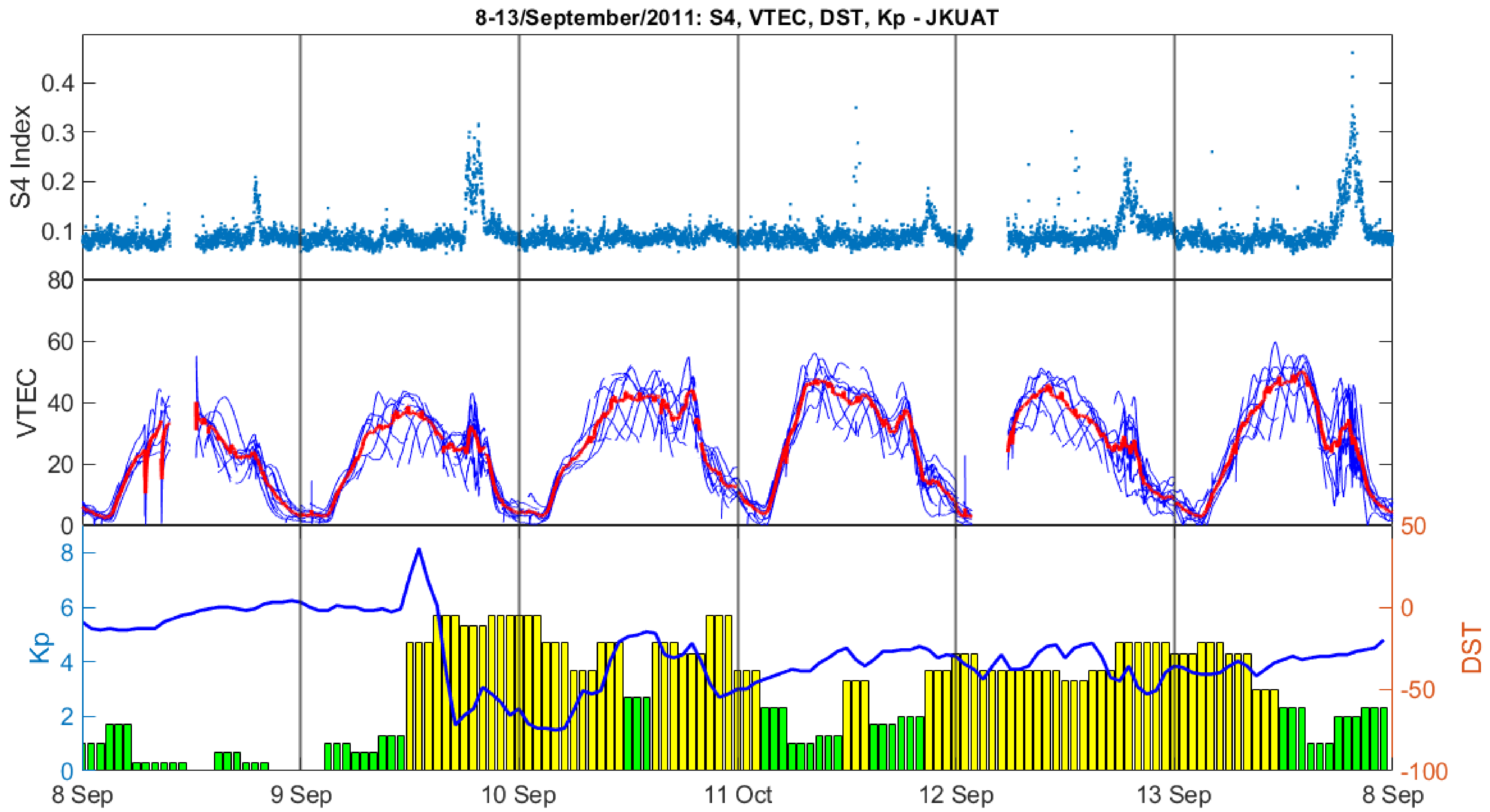


Scintillation during Geomagnetic Storms



EPBs are more likely to occur when there is a strong positive gradient in vertical plasma density, and hence the features of higher plasma density and large plasma drift are more favorable to the occurrence of the EPBs, and by extension, scintillation.
(Yi *et al.*, 2023, Tsunoda, 1985, Tsunoda *et al.*, 2015)

Scintillation during Geomagnetic Storms



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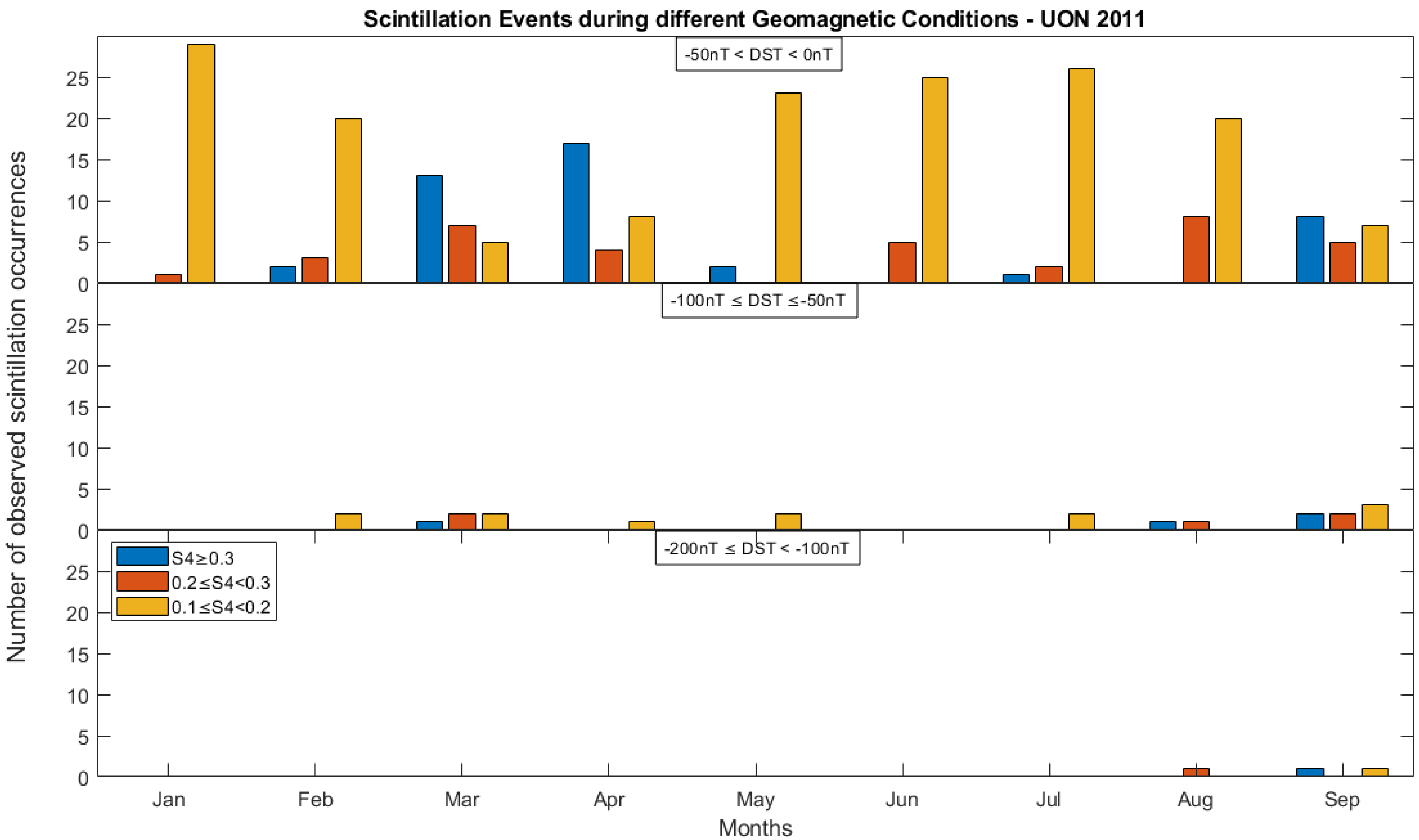
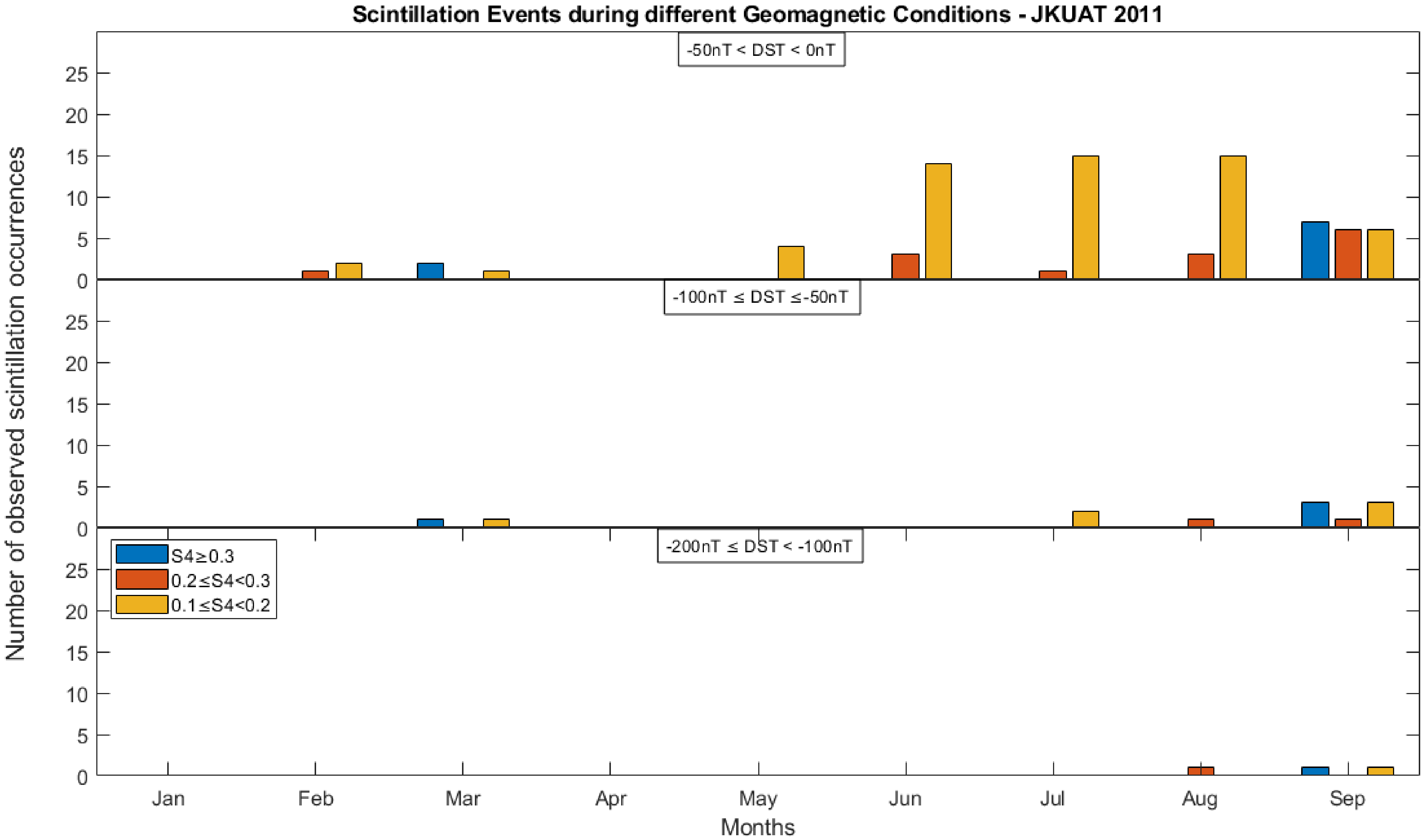
Scintillation during Geomagnetic Storms



There's a negative correlation between Scintillation occurrence and Geomagnetic storms intensity

Scintillation during Geomagnetic Storms



CONCLUSION

- There’s a direct correlation between increase in scintillation levels and increase in positioning errors.
- At background scintillation levels there still exists slight positioning errors in the nighttime, of up to 4m.
- Great intensity storms inhibit ionospheric irregularities: There exists a negative correlation between ionospheric irregularities and intensity of geomagnetic storms.

THANK YOU!