# Validation of Ionospheric Irregularities observed by the COSMIC satellites over the low latitude African region

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# The definition of S4 index

- The signal power fluctuation, $\delta P$ (probably due to ionospheric irregularities) generally follows a Nakagami-$m$ pdf with mean value of one and variance of $\frac{1}{m}$.

- The strength of amplitude fading due to scintillation is characterized using a parameter referred to as the $S4$ index, which is equal to the standard deviation of the signal power variation. That is,

$$S4 = \sqrt{\frac{1}{m}} = \frac{\sqrt{< I^2 > - < I >^2}}{< I >}, \tag{1}$$

  $I$ represents the signal intensity.

- Due to the properties of the Nakagami-$m$ distribution, the $S4$ index cannot exceed $\sqrt{2}$ (Ward et al. (2006), *Interference, Multipath, and Scintillation*, In *Understanding GPS Principles and Applications*)

# The Sources of S4 index used in the study

The S4 data during quiet geomagnetic conditions of the year 2011 were used.

**Sources of S4 data used in this study:**

- SCINDA receiver that operated at Nairobi, University, Kenya.
- COSMIC Data Analysis and Archive Center, Level 1b, S4 scintillation index (scnLv1 format).

# The Research Question

How can we make use of the COSMIC S4 observations along the links to GPS satellites?

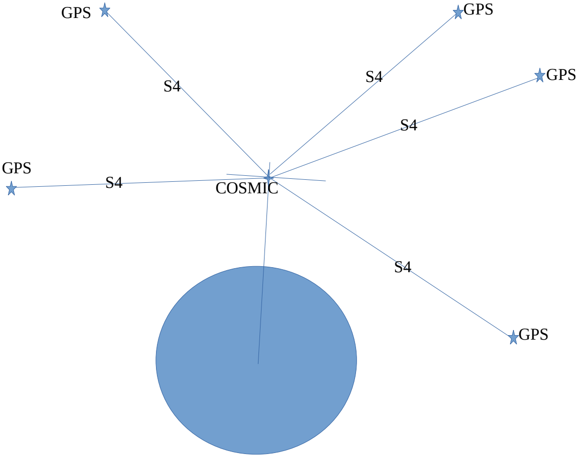



Figure: 1, COSMIC S4 observations

# The use of COSMIC S4 observations

Carrano et al. (2022), Real-Time Monitoring of Ionospheric Irregularities using Radio Occultation Data, *Presentation at ICTP, Trieste, Italy during African Capacity Building Workshop on Space Weather Effects on GNSS*.

- Under the COSMIC-2 Cal/Val program, they developed a Product to geolocate irregularities that produce scintillation of GPS and GLONASS signals
- Not all bubbles are detected: only those intersected by the RO ray-paths at F-region altitudes, and those for which RO S4 triggers download of high-rate data.
- RO scintillation is most often due to bubbles near the tangent point, but the spread of the distribution is significant. A bubble causing RO scintillation for COSMIC-2 can reside up to 200 km above the tangent point.

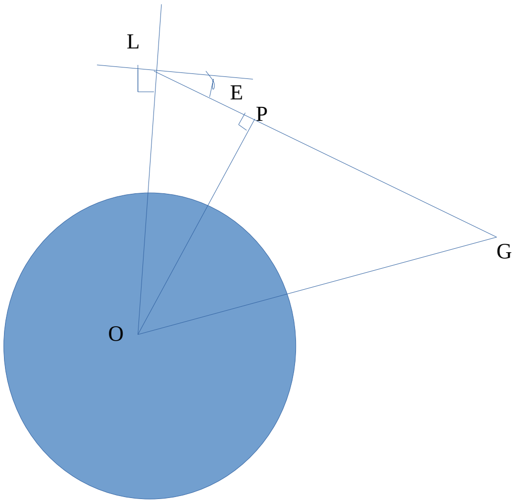



Figure: 1, Typical COSMIC S4 observation geometry

# COSMIC S4 observations ...

- Since the Cartesian coordinates of the GPS and LEO satellites are known from the scnLv1 files, distances, OL, OG, and LG can easily be calculated.
- The scnLv1 files also provide the elevation angles (E) of the GPS satellites as viewed from the LEO satellites.
- Therefore,

$$LP = OL \times cos(90 - E); \quad PG = LG - LP \tag{2}$$

- The distance OP was restricted $> 90$ km (including E region).

- Computation of coordinates of the point P($XP$,$YP$,$ZP$) using known coordinates of L($XL$,$YL$,$ZL$) and G($XG$,$YG$,$ZG$):

$$XP = \frac{XL \times PG + XG \times LP}{LG}, \tag{3}$$

$$YP = \frac{YL \times PG + YG \times LP}{LG}, \tag{4}$$

$$ZP = \frac{ZL \times PG + ZG \times LP}{LG}. \tag{5}$$

# COSMIC S4 observations ...

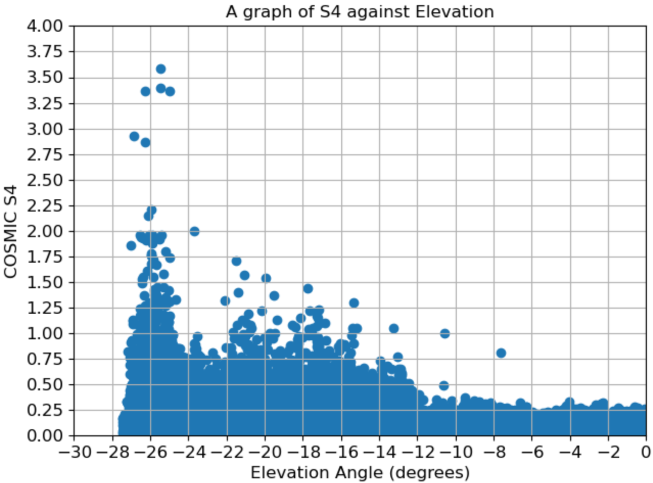



Figure: 2, Variation of COSMIC S4 as a function of elevation angle.

# COSMIC S4 observations ...

- The background value of COSMIC S4 $\sim 0.25$
- Significant values of COSMIC S4 ($> 0.25$) which might be associated with irregularities appear to occur at elevation angles of $< -11^{\circ}$.

# Correlation between COSMIC and SCINDA S4 over low latitude African region

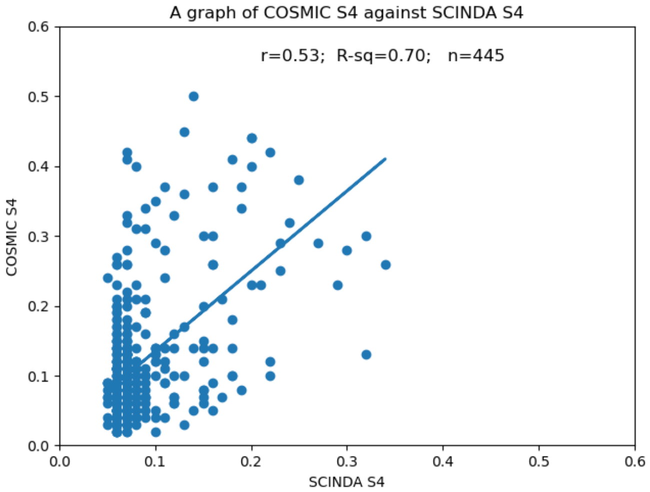



Figure: 3, A scatter plot of COSMIC S4 against SCINDA S4.

# Correlation between COSMIC and SCINDA S4 over low latitude African region ...

- The data presented are the hourly mean COSMIC and SCINDA S4 data which were separately determined during 18:00 - 24:00 LT.

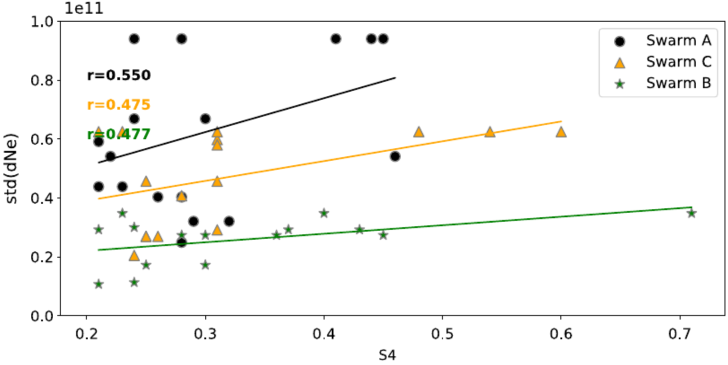
- A moderate positive correlation, possibly due to:

  (i) The long passes of some links between GPS and COSMIC satelites in the lower atmosphere. The COSMIC S4 might capture effects of the lower atmosphere which were excluded in SCINDA S4 by taking high elevation angle.

  (ii) The irregularities are patches which are not uniformly distributed over a location. Therefore, all satellites in the vicinity may not simultaneously measure high S4 values

# Comparison with previous studies

Aol et al. (2020), Ionospheric irregularities and scintillations: a direct comparison of in situ density observations with ground-based l-band receivers, *Earth, Planets and Space*.



# Comparison with previous studies ...

Olwendo et al. (2019), Comparison of ground based ionospheric scin- tillation observations with in situ electron density variations as measured by the Swarm satellites, *Radio Science*.

| | | **Agreement** | | **Disagreement** | |
|---|---|---|---|---|---|
| 2016 | Number of Events | S4>0.2 & RODI>0.02 | S4<0.2 & RODI<0.02 | S4>0.2 & RODI<0.02 | S4<0.2 & RODI>0.02 |
| February | 16 | 4 | 1 | 4 | 7 |
| March | 17 | 7 | 3 | 3 | 4 |
| April | 18 | 7 | 2 | 2 | 7 |
| May | 14 | 9 | 0 | 0 | 5 |
| June | 17 | 1 | 3 | 5 | 8 |

# Local time and Seasonal Variations of ionospheric irregularities

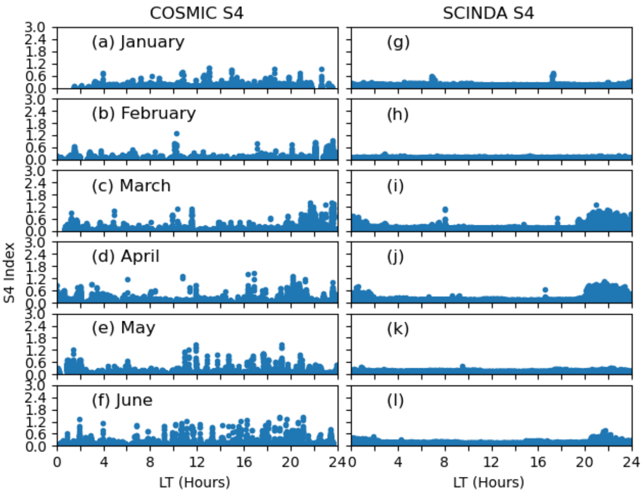



Figure: 4, Presents COSMIC and SCINDA S4 against LT during January - June 2011.

# Local time and Seasonal Variations of ionospheric irregularities ...

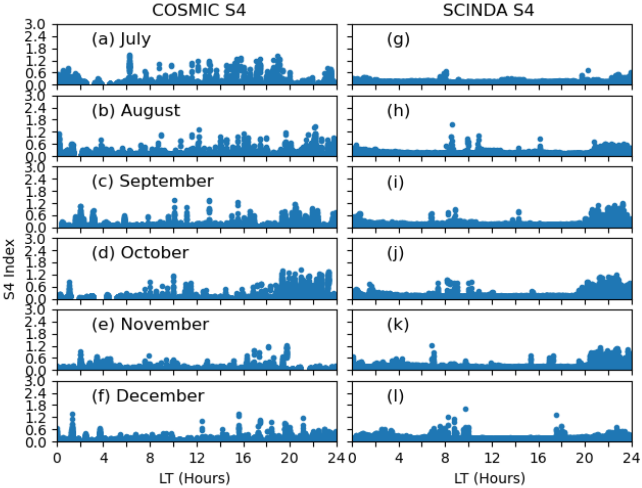



Figure: 5, Similar to Figure 4, but for months of July — December 2011.

# Local time and Seasonal Variations of ionospheric irregularities ...

The figures show that the values of SCINDA S4 $>$ background value mainly exist after sunset and before mid-night in equinox months of March, April, August, September, and October.

Moreover, the SCINDA S4 data depicts significant occurrence of ionospheric irregularities during the stated local time period in November.

Although the COSMIC S4 data appear to be noisy, the local time and seasonal patterns of occurrence of the majority of the cases of COSMIC S4 data $\geq$ the background value are similar to that of SCINDA data.

Figures also show several cases of high COSMIC S4 in solstice months of May, June, and July, particularly during the day (10:00 - 18:00 LT).

# Conclusions

- The COSMIC S4 data were validated using the SCINDA S4 data measured by the SCINDA receiver which operated at Nairobi University, Kenya.
- For the cases of GPS satellites with elevation angle $< 0^\circ$ as observed by the COSMIC satellies, a geo-location of the COSMIC S4 data associated with the link was proposed at the tangent point.
- There was a moderate positive correlation (r $=$ 0.53) between COSMIC and SCINDA S4 data, with $R^2 = 70$ %.
- Both data sets depict that scintillation occurs mostly after sunset and before midnight in the seasons of March and September equinoxes.

# Acknowledgements

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- GFZ Potsdam (Kp data)

  The GPS-SCINDA system is a network of ground based receivers established by the Air Force Research Laboratory in collaboration with Boston College.

- COSMIC Data Analysis and Archive Center provided the scnLv1 files from which COSMIC S4 data were obtained

# Thanks for your Attention