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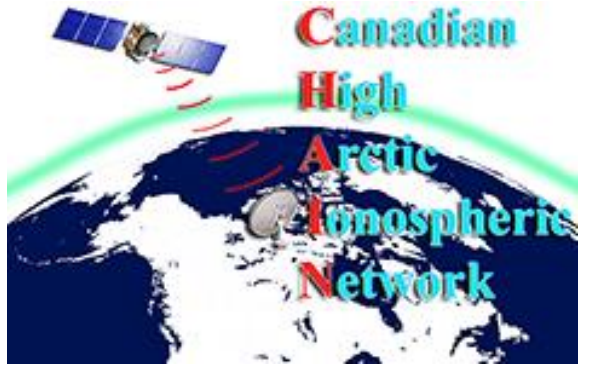


Climatology of GNSS scintillations at high latitudes

A. Kashcheyev & CHAIN team

Physics Department, University of New Brunswick, Fredericton, Canada

Outline

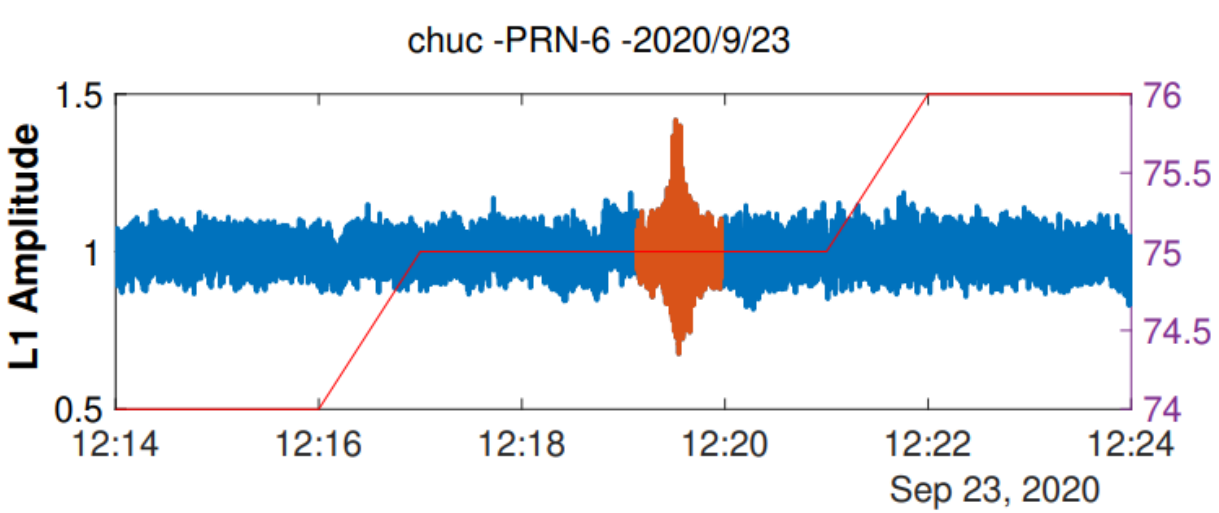
- Motivation
- Data description
- Dependency analysis
- Climatology
- Modelling efforts
- Conclusions

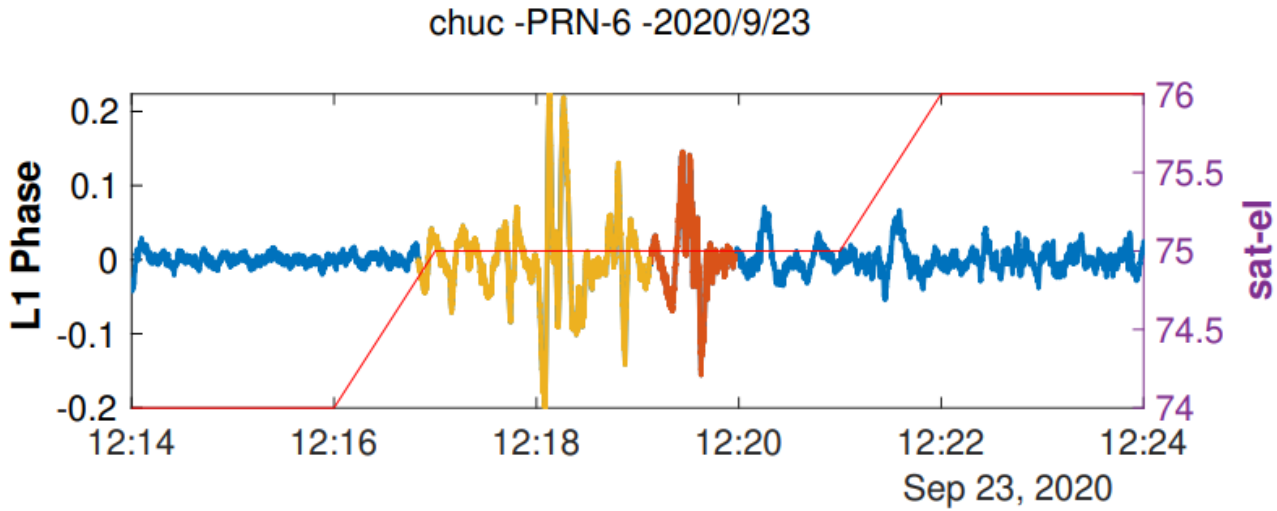
Scintillation: definition

RAPID

RANDOM

fluctuations in signal amplitude AND phase





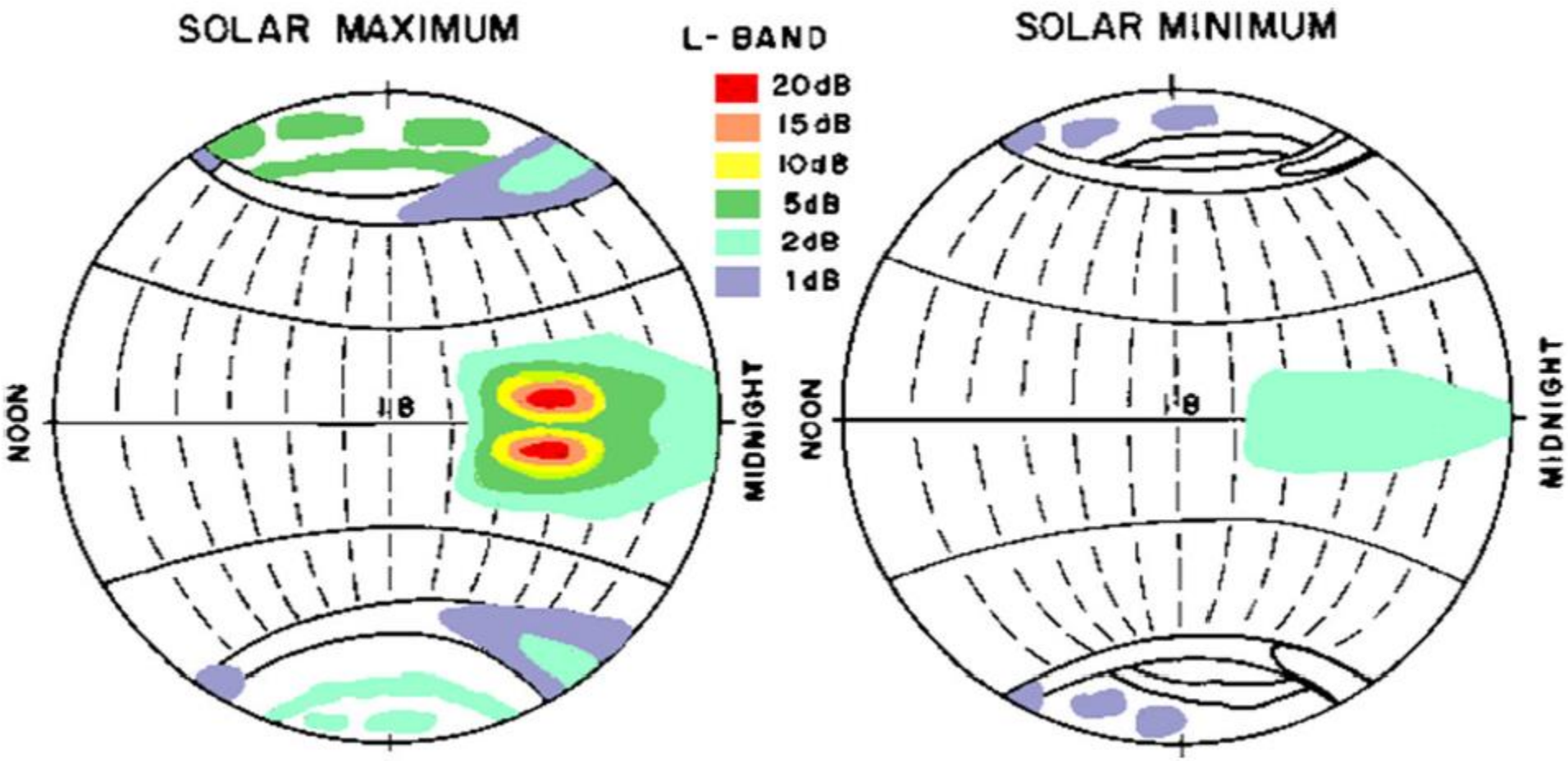
McCaffrey, A. M., & Jayachandran, P. T. (2019), Determination of the Refractive Contribution to GPS Phase "Scintillation", JGR

Scintillation: definition

$$S_4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}} \qquad \sigma_\phi = \sqrt{\langle \phi^2 \rangle - \langle \phi \rangle^2}$$

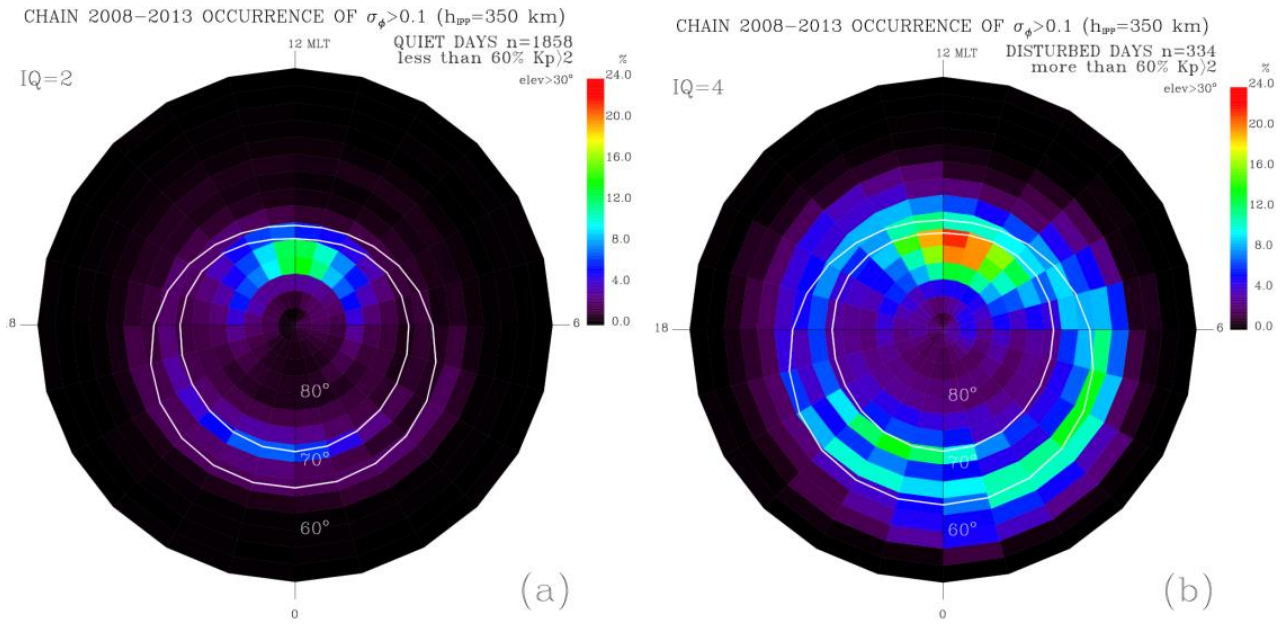
- Obtaining raw signal phase and amplitude
- Preprocessing (outliers, gaps, cycle slips identification & removal)
- High pass filtering
- Computing indices

Scintillation: morphology/global picture

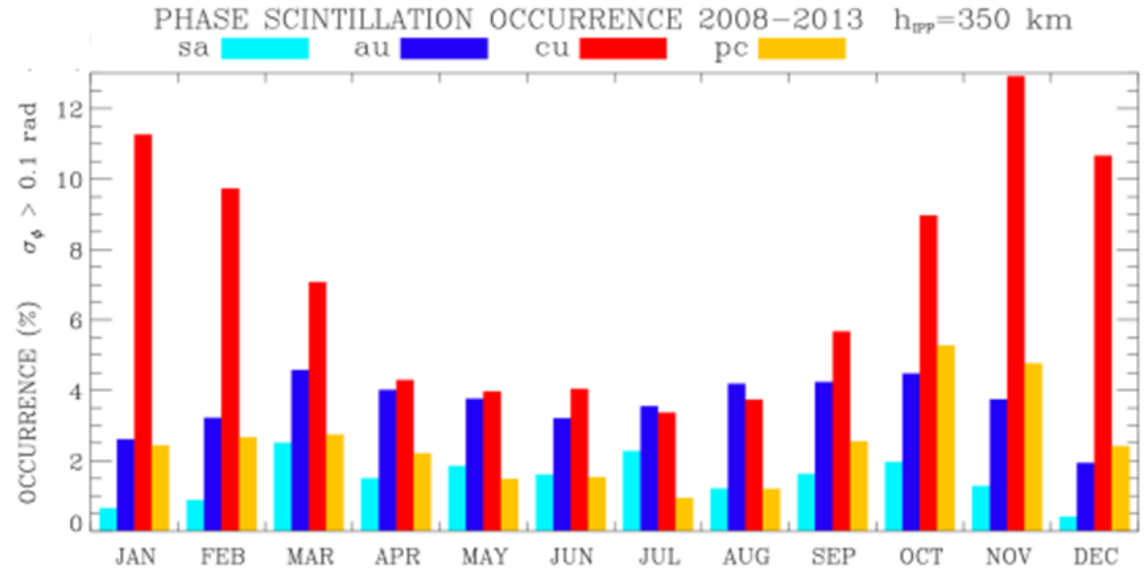


Global variation of amplitude scintillation fades at L band (after Basu et al. 1988, colored by Wernik)

Scintillation: morphology/global picture



The 2008–2013 phase scintillation occurrence maps for geomagnetically **(a)** quiet and **(b)** disturbed days

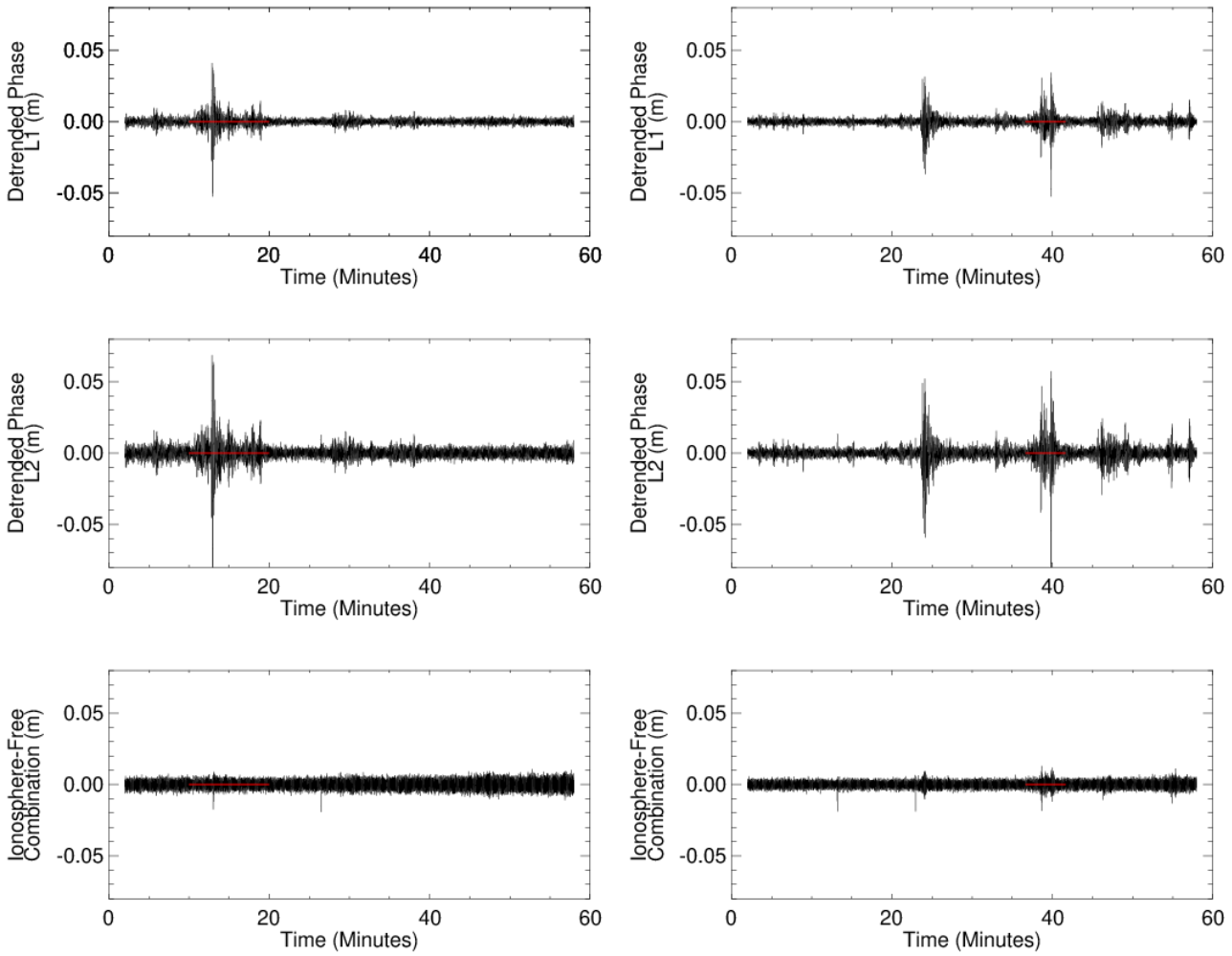


Monthly variation of phase scintillation occurrence in cu, au, pc and sa sectors for $h_{IPP} = 350$ km.

Prikryl, P., Jayachandran, P. T., Chadwick, R., and Kelly, T. D.: Climatology of GPS phase scintillation at northern high latitudes for the period from 2008 to 2013, Ann. Geophys., 33, 531–545, https://doi.org/10.5194/angeo-33-531-2015, 2015

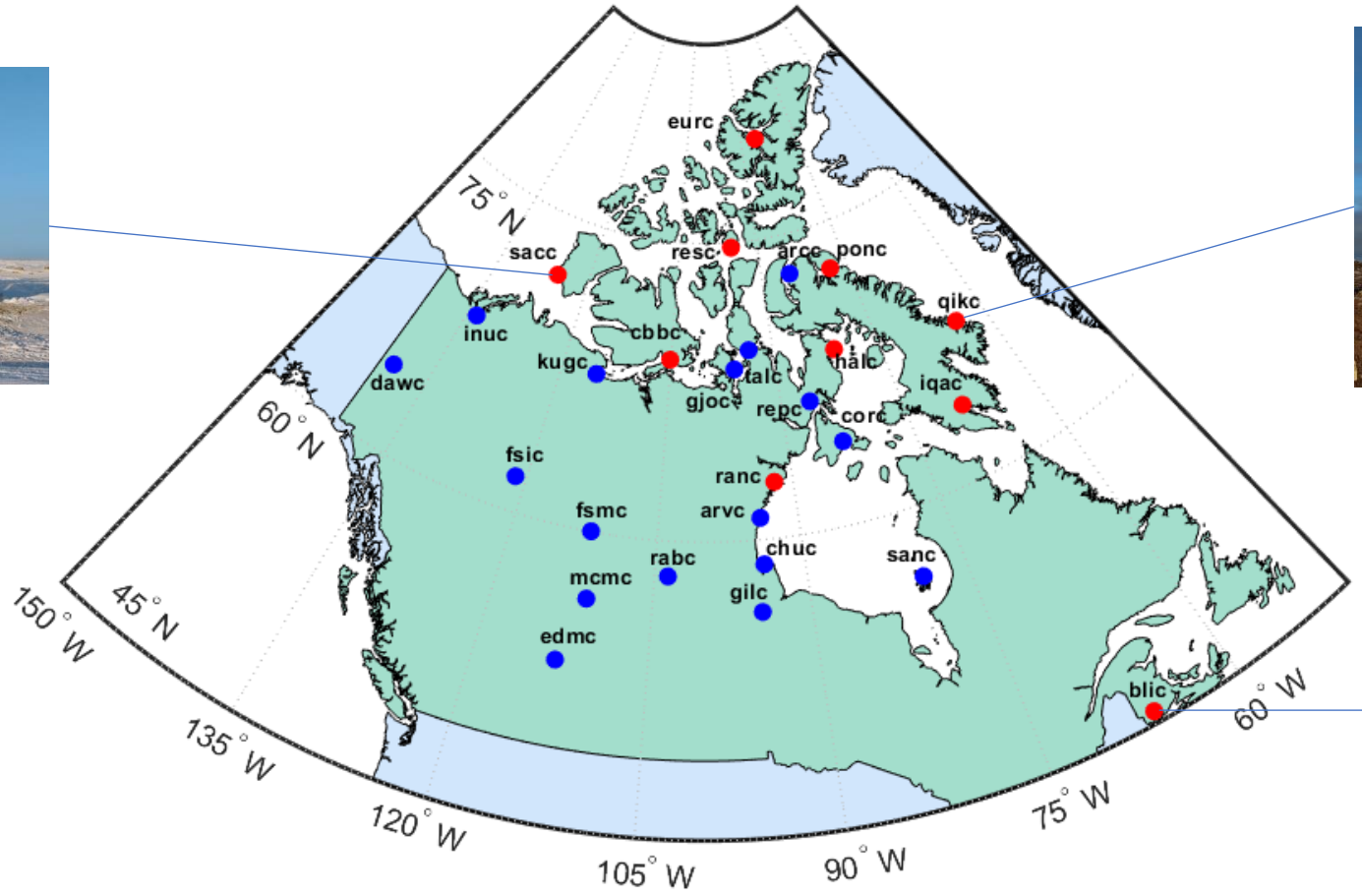
Scintillation: definition

$$\Phi_{IFLC} = \frac{\Phi_{L1} f_{L1}^2 - \Phi_{L2} f_{L2}^2}{f_{L1}^2 - f_{L2}^2}$$



McCaffrey, A. M., & Jayachandran, P. T. (2019), Determination of the Refractive Contribution to GPS Phase "Scintillation", JGR

CHAIN (Canadian High Arctic Ionosphere Network)



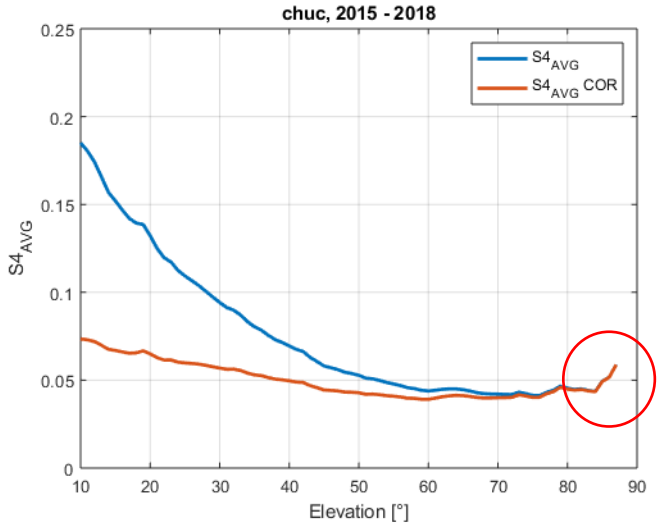
- GNSS Ionospheric Scintillation and TEC Monitor (GISTM) receiver (18)
- GISTM receiver & ionosonde (10)

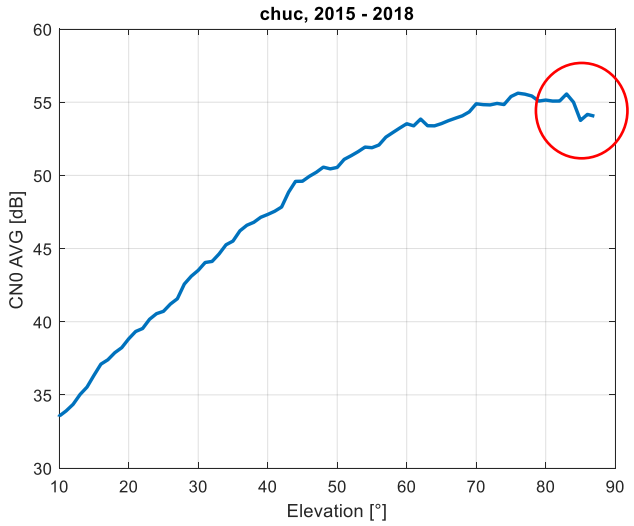
http://chain.physics.unb.ca/chain/

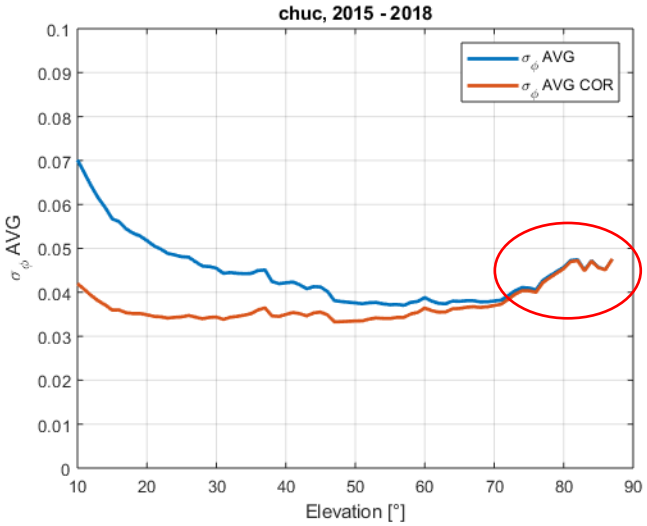
Data description

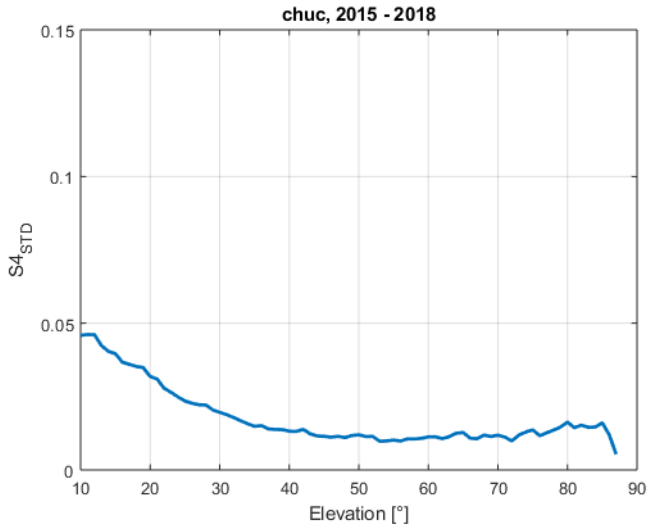
- Septentrio PolaRxS PRO, years 2015 – 2019, 15 stations
- Novatel (GSV4004B), years 2008 – 2019, 8 stations
- 50 Hz phase and amplitude raw data on L1
- S_4 (intensity, 0.1 Hz cutoff 6th, order Butterworth filter)
- σ_φ (phase, 0.1 Hz cutoff 6th, order Butterworth filter)
- Mean, standard deviation, min and max

Elevation angle dependence





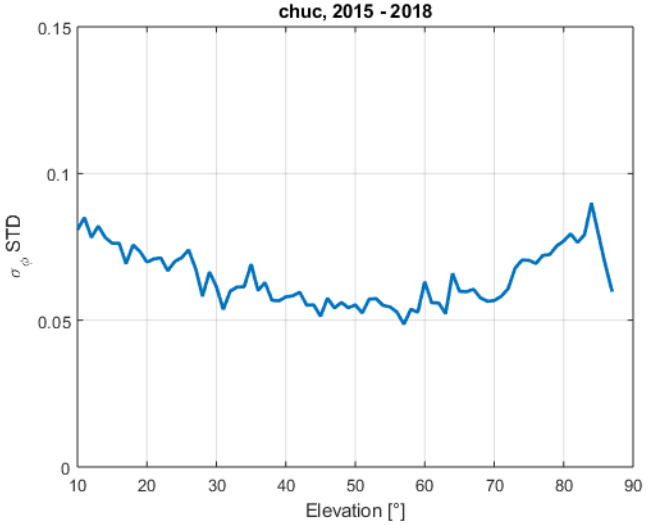




$$S_{4\,COR} = S_4 / F(\theta)^{0.9}$$

$$\sigma_{\varphi\,COR} = \sigma_\varphi / F(\theta)^{0.5}$$

$$F(\theta) = 1 / \sqrt{1 - \left(\frac{R_e \cos\theta}{R_e + H_{IPP}}\right)^2}$$



Elevation angle dependence

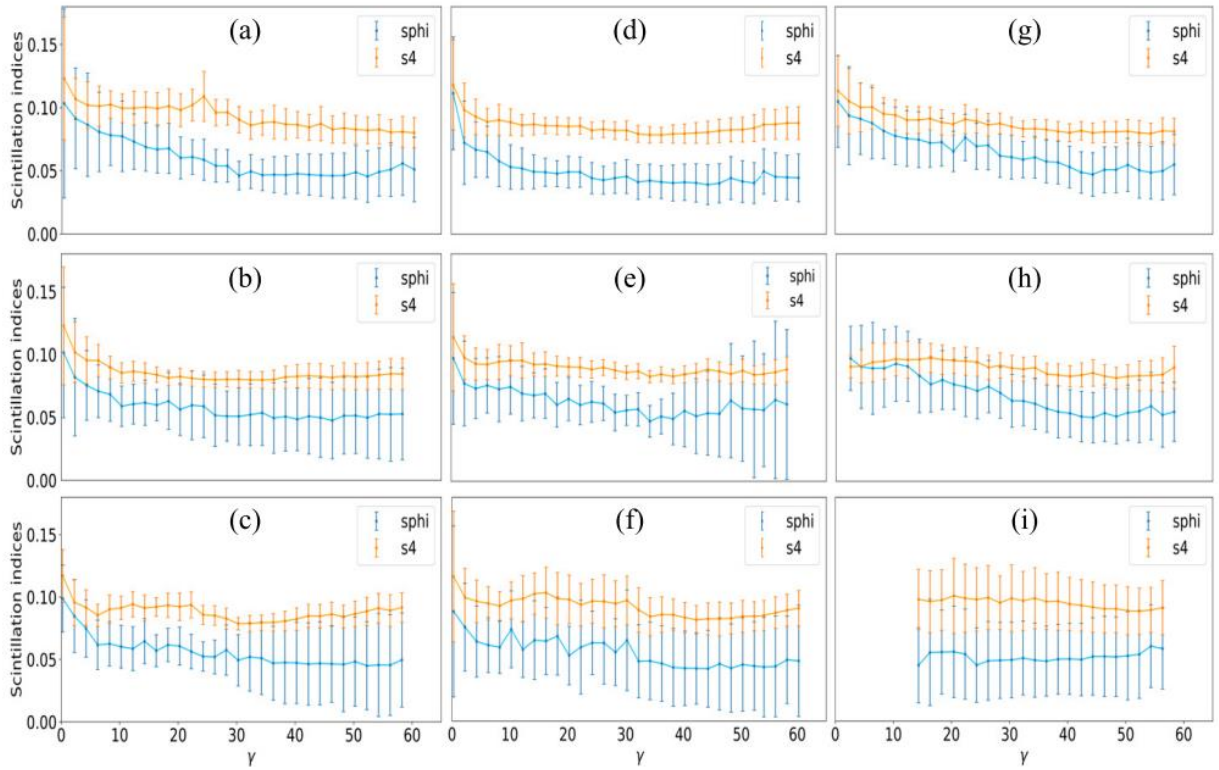
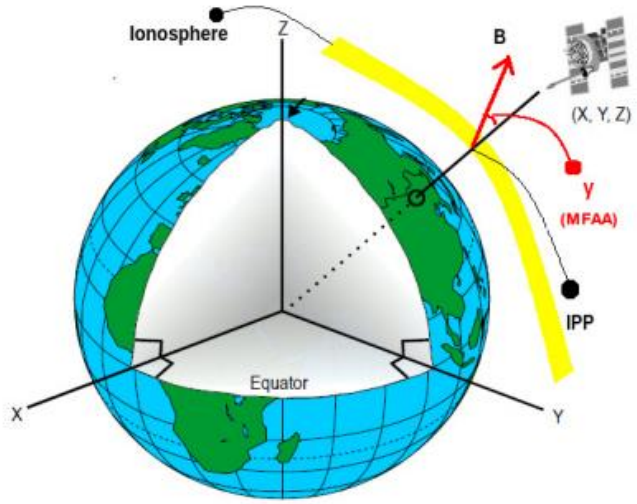


Fig. 4. Variation of scintillation indices with MFAA for nine stations spanning a period of seven years between 2014 and 2020. Plots are arranged in ascending orders of geographical latitudes starting at 56.65° and ending at 71.99°.

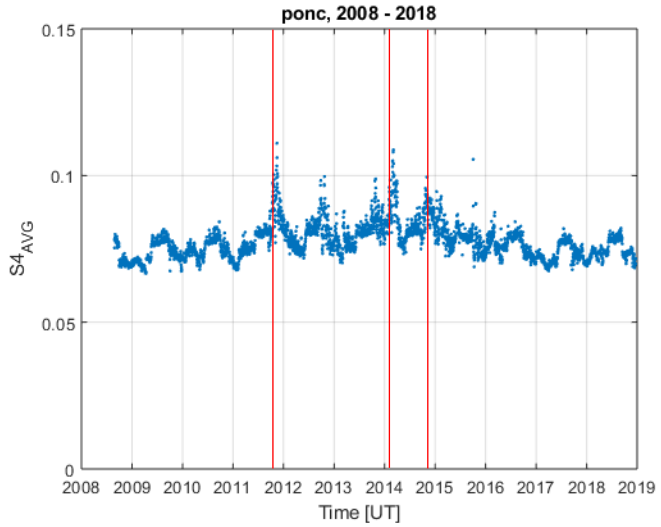


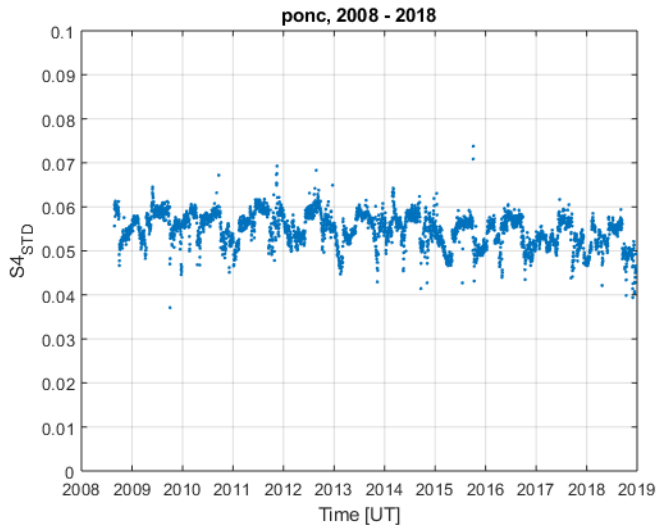
Magnetic field aligned angle (γ) is the angle between the satellite–receiver line of sight (LOS) vector and the geomagnetic field vector at the ionospheric pierce point (IPP) at 350 km

M. Madhanakumar, A. Kashcheyev and P. T. Jayachandran, "On the Dependence of Amplitude and Phase Scintillation Indices on Magnetic Field Aligned Angle: A Statistical Investigation at High Latitudes," in IEEE Geoscience and Remote Sensing Letters, vol. 19, pp. 1-5, 2022, Art no. 2502105, doi: 10.1109/LGRS.2021.3115668

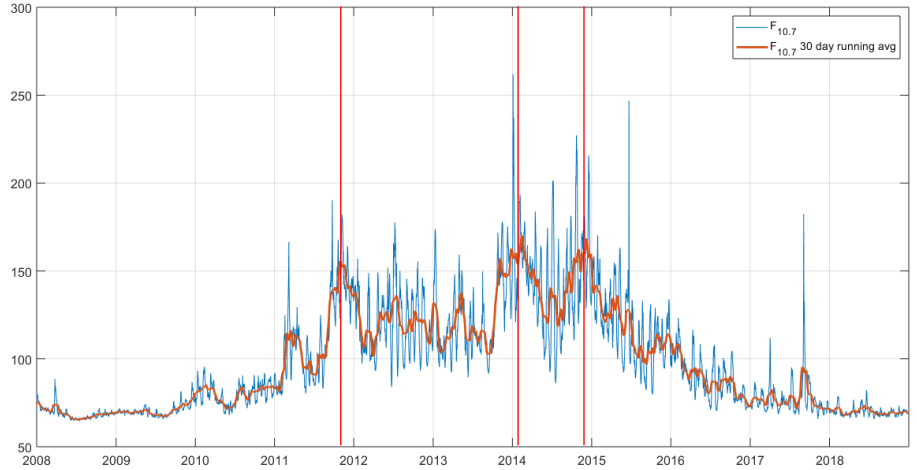
Long-term trends: Solar cycle

S_4

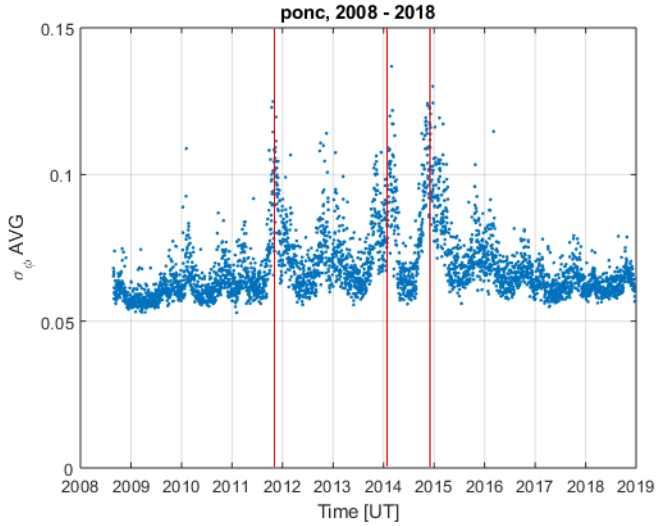


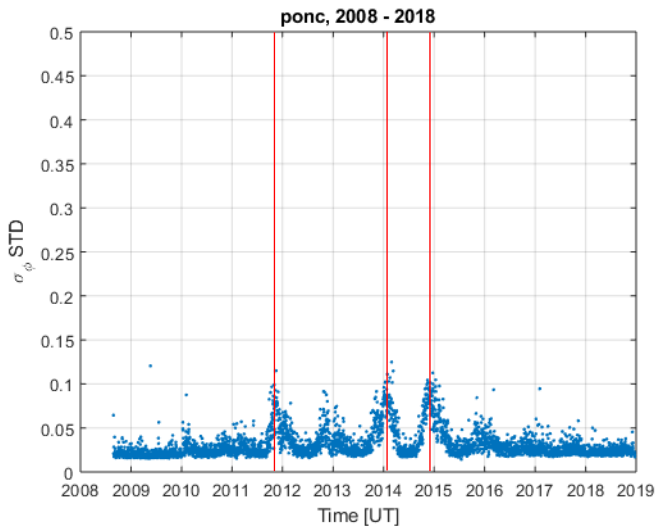


$F10.7$



σ_φ

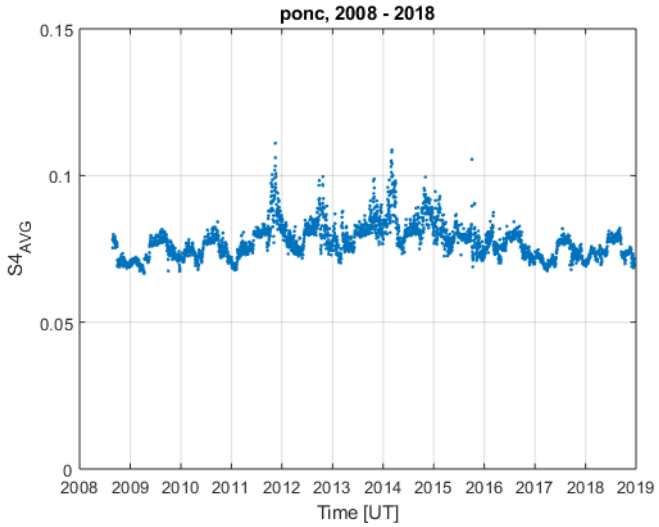


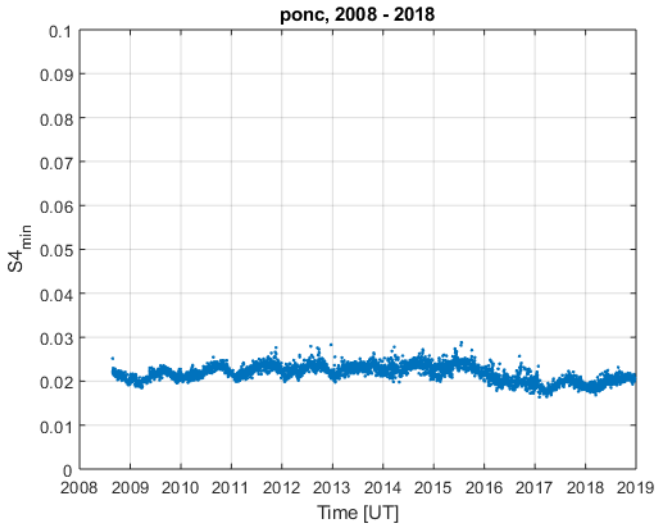


- S_4 and σ_φ correlate well with F10.7
- The correlation is present in both S_4 and σ_φ AVG, but not in S_4 STD
- Annual fluctuations are apparent

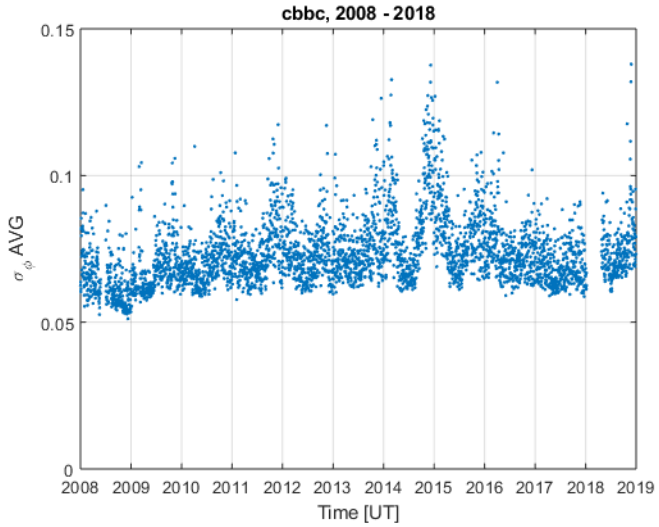
Long-term trends: annual cycle

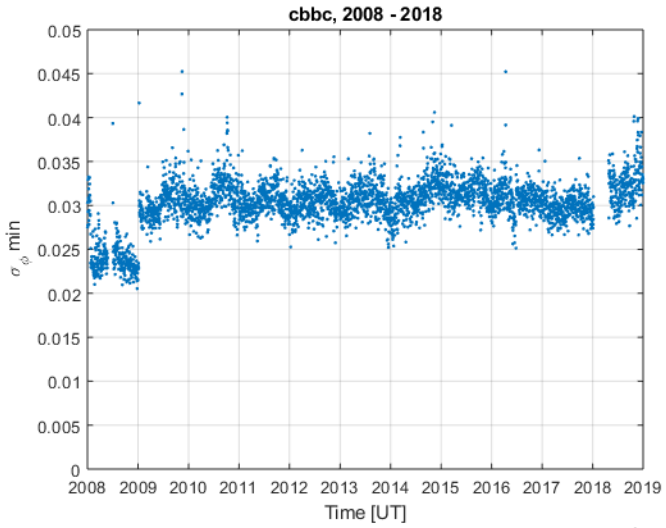
S_4





σ_φ

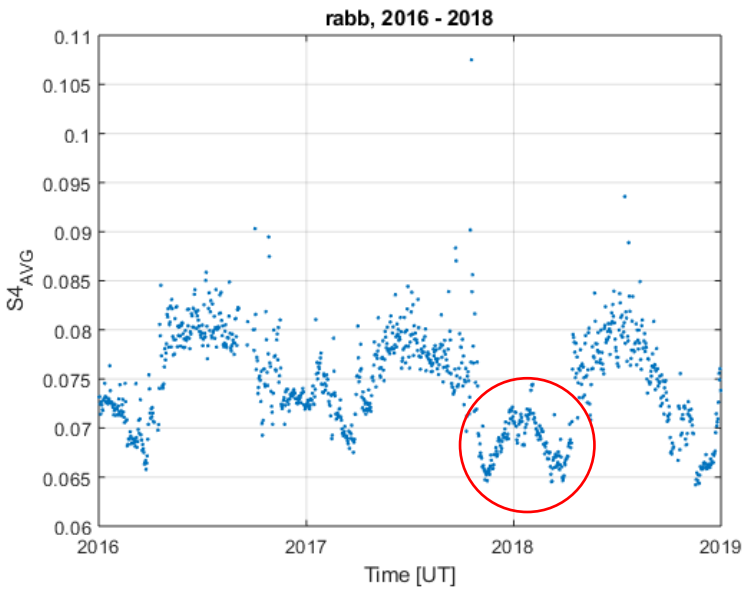




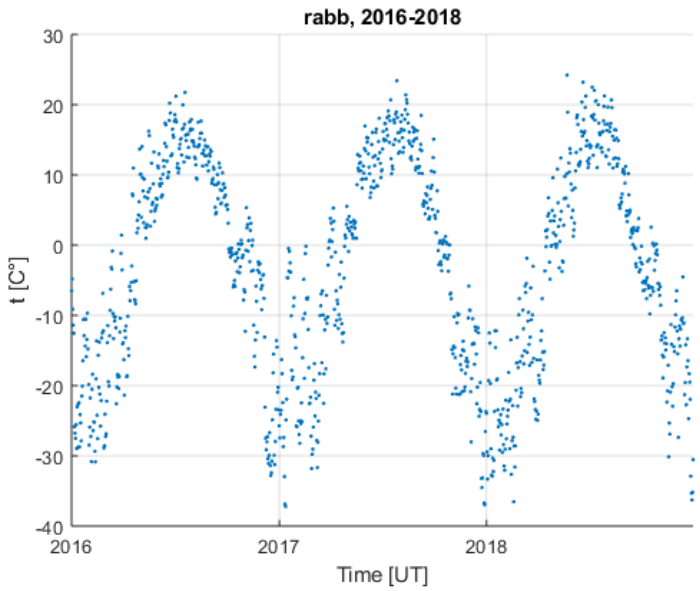
- Annual fluctuations are present in S_4 and σ_φ
- They are more prominent in S_4

Ambient temperature dependence

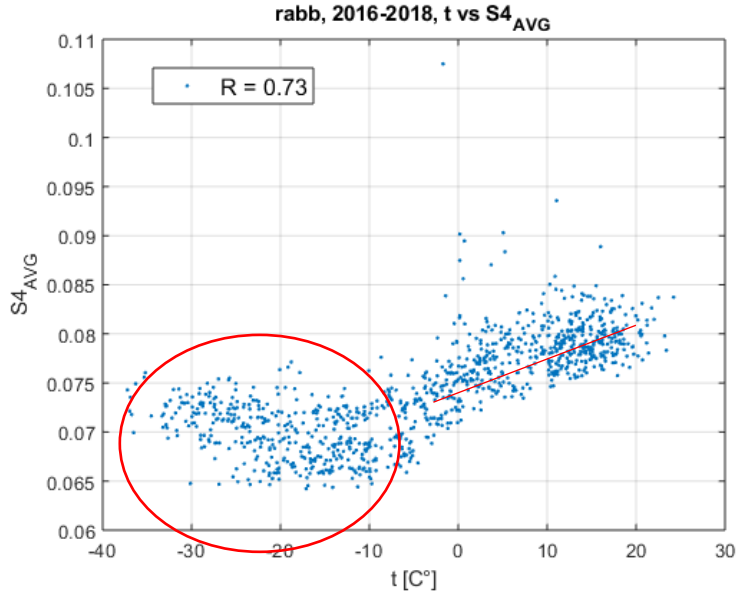
S_4

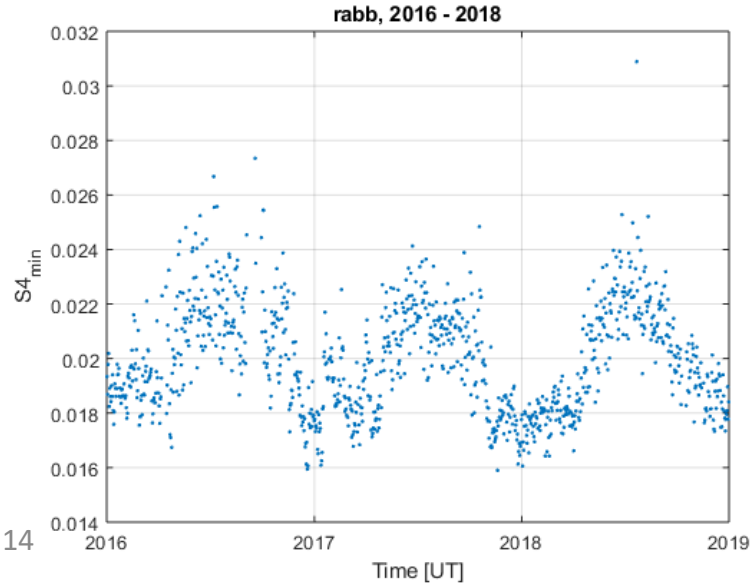


t_{out}

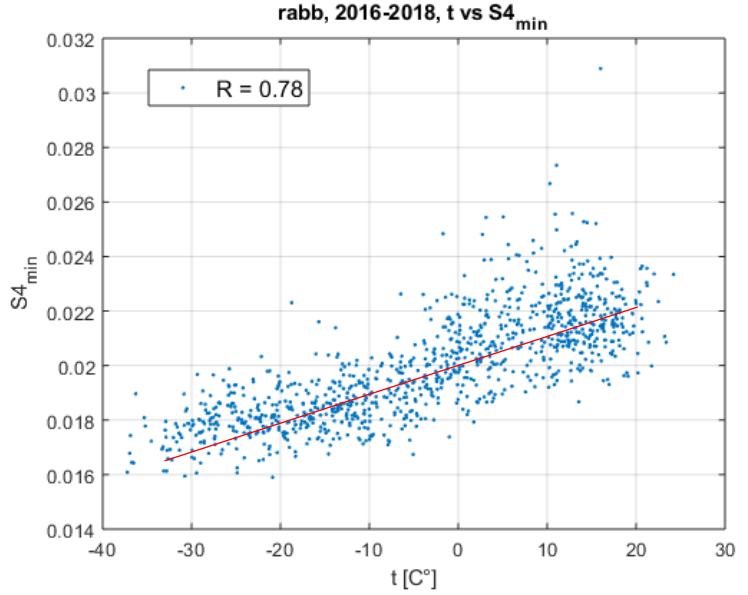


R



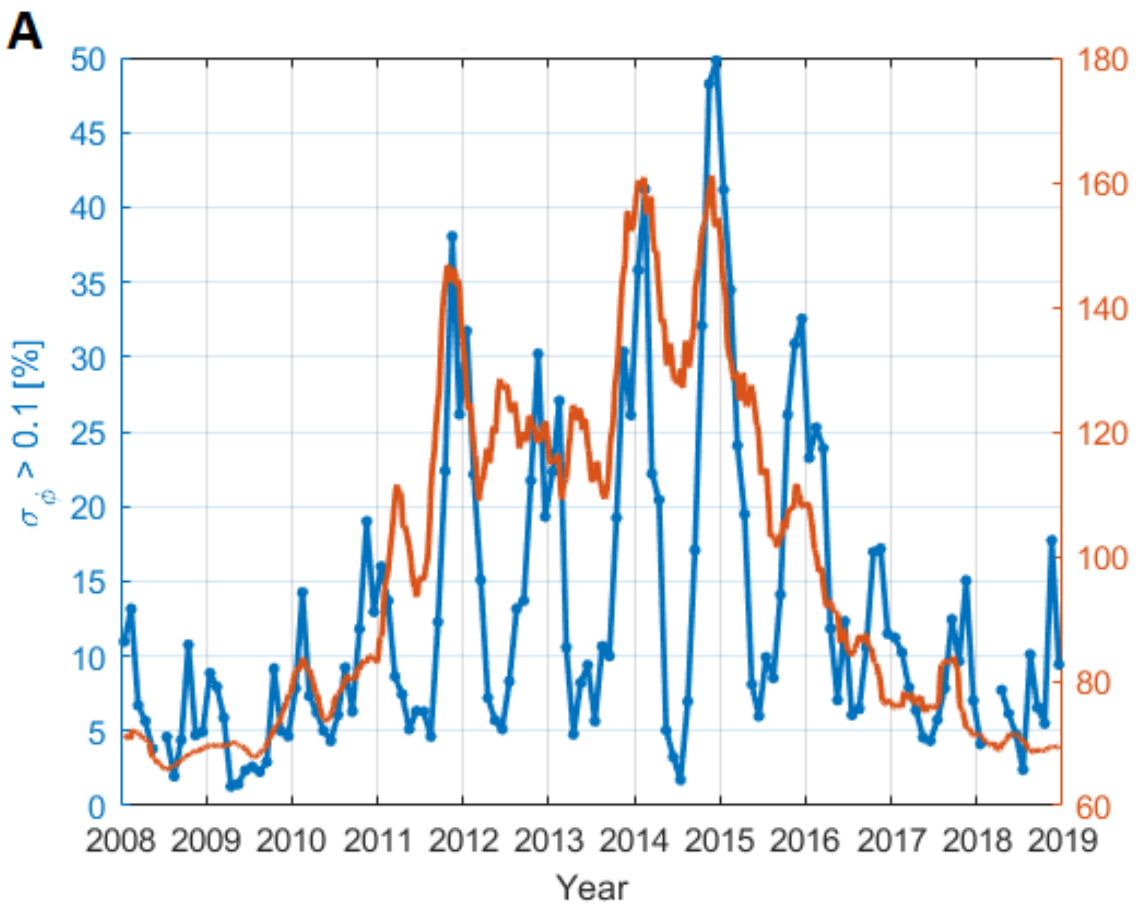


- Annual S_4 fluctuations are strongly correlated with ambient temperature
- The correlation is higher with the minimum level of S_4 (noise level)
- The fluctuation must be taken into account when using the data

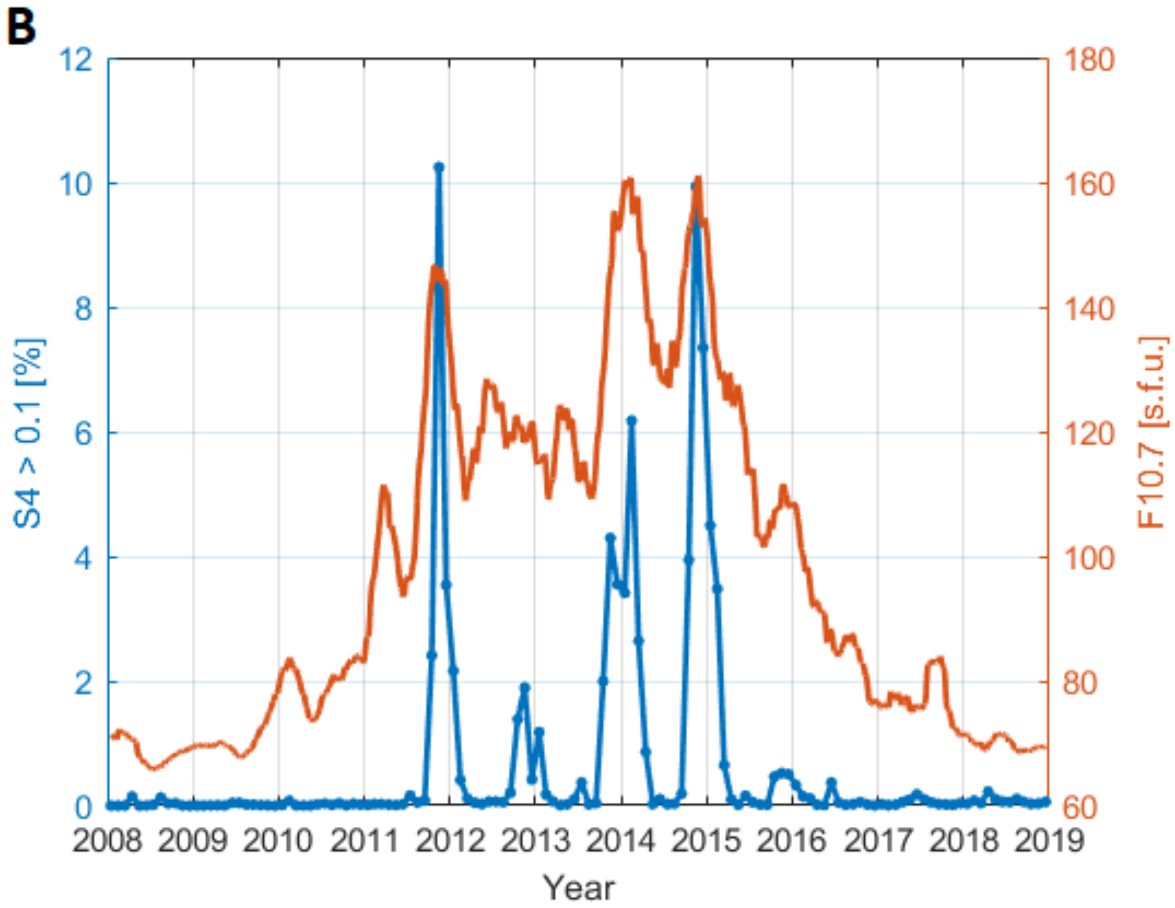


Solar cycle dependence

σ_φ

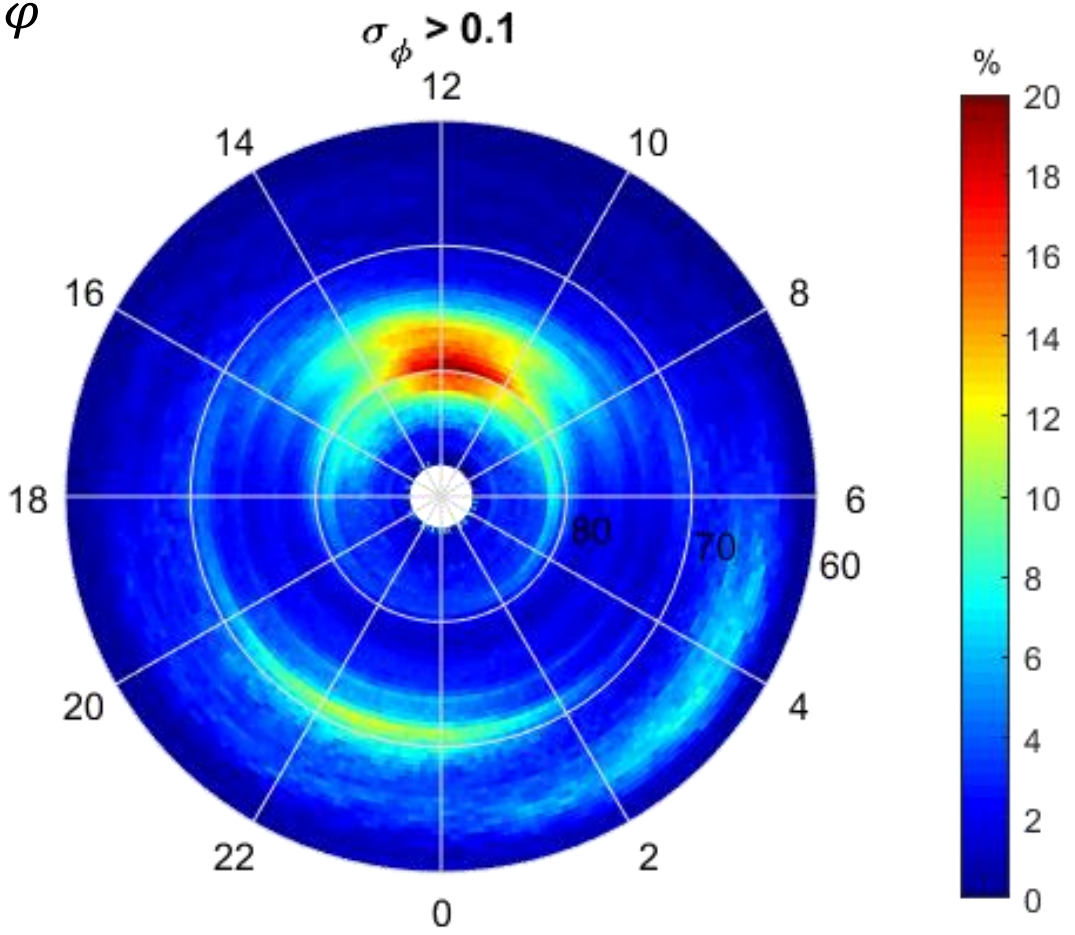


S_4

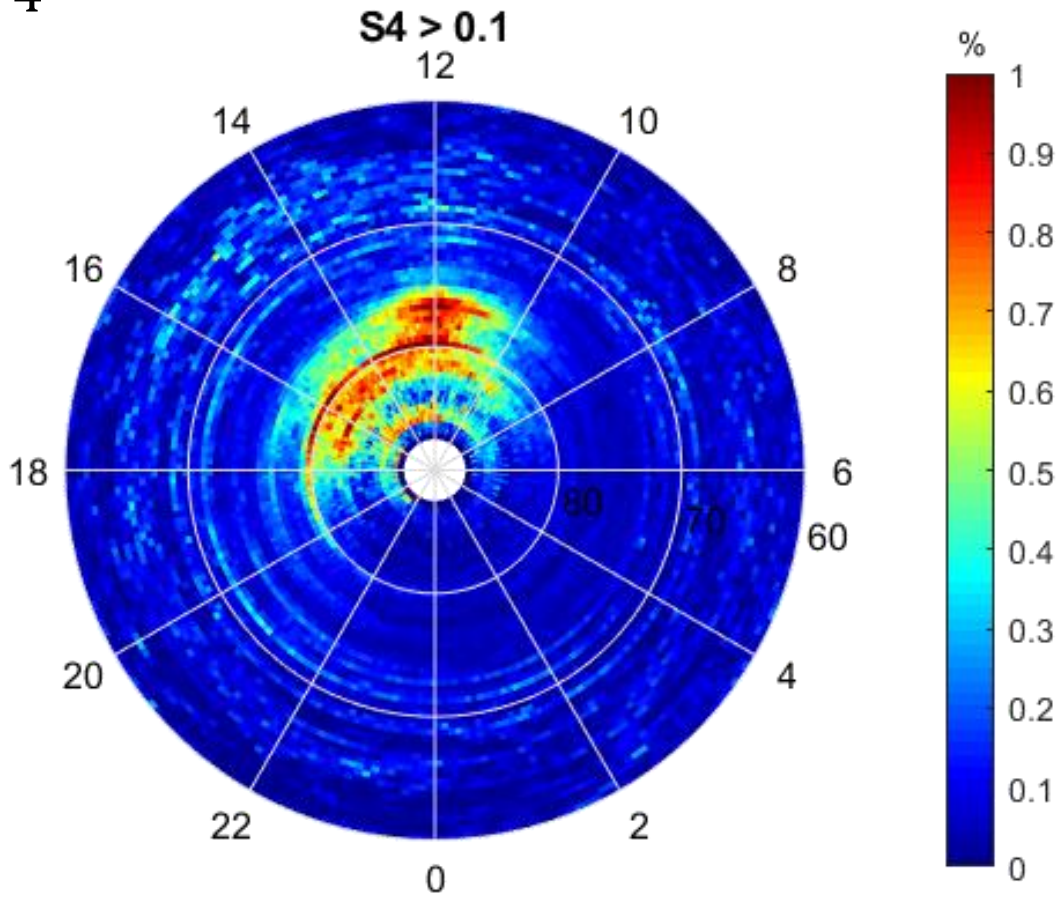


Magnetic time and latitude distribution

σ_φ

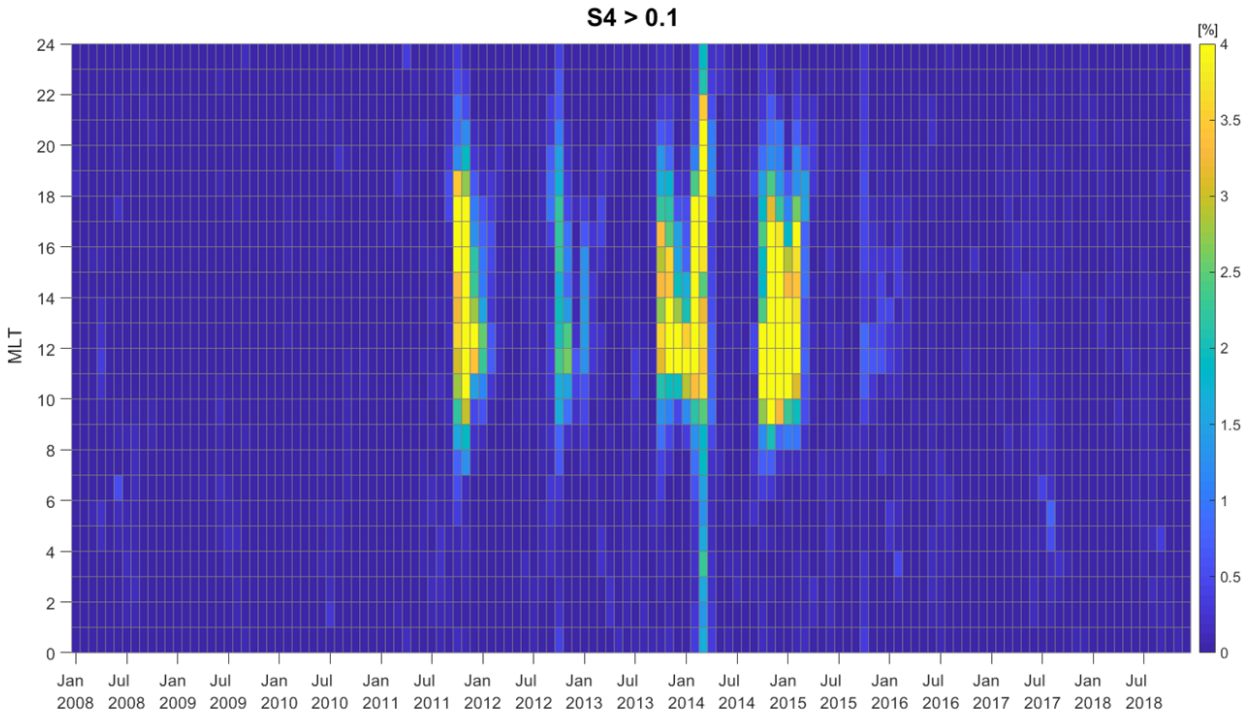


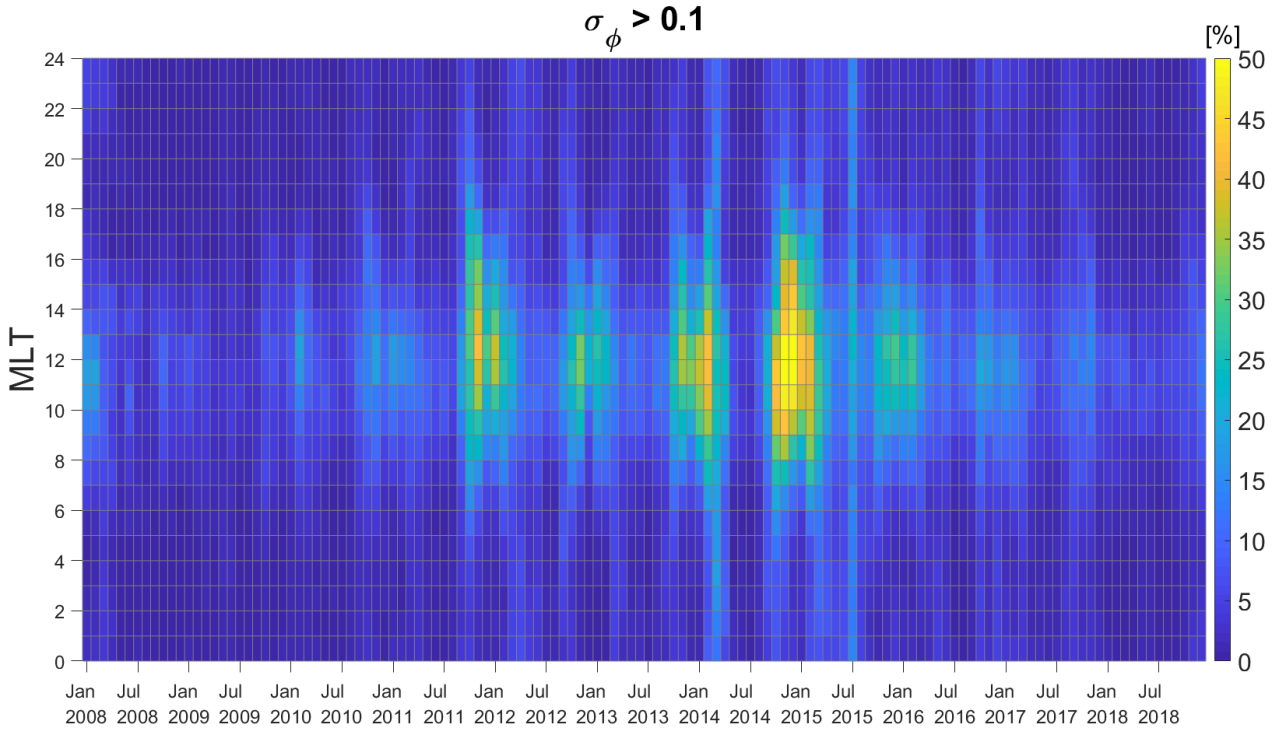
S_4



Meziane, K., Kashcheyev, A., Patra, S., Jayachandran, P. T., & Hamza, A. M. (2020). Solar cycle variations of GPS amplitude scintillation for the polar region. Space Weather, 18, e2019SW002434. https://doi.org/10.1029/2019SW002434

Magnetic time and seasonal distribution





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Modelling efforts (PDF fit)

Phase fluctuations, σ_{φ}

- Normal distribution
- Generalized normal distribution
- Log-normal distribution
- Nakagami distribution
- a-μ distribution
- Lévy alpha-stable (or stable) distribution
- Landau-like distribution

Stable Distribution

$f_{\alpha,\beta,\gamma,\delta}(x)$ – a function of 4 parameters α, β, γ and δ.

$0 < \alpha \leq 2$,	index of the distribution
$-1 \leq \beta \leq 1$,	skewness
$\gamma > 0$,	scale
$-\infty \leq \delta \leq +\infty$,	shift

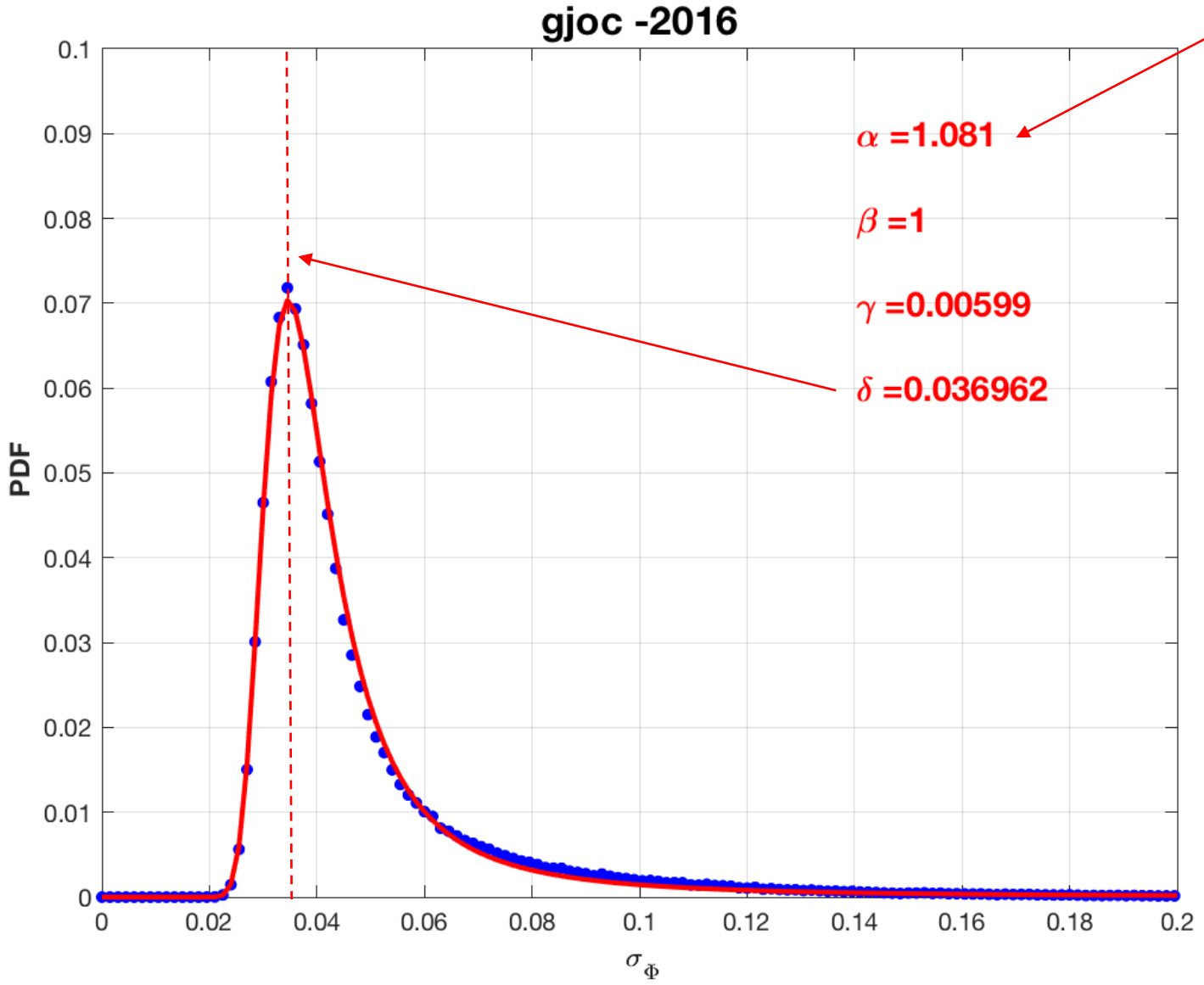
Landau Distribution

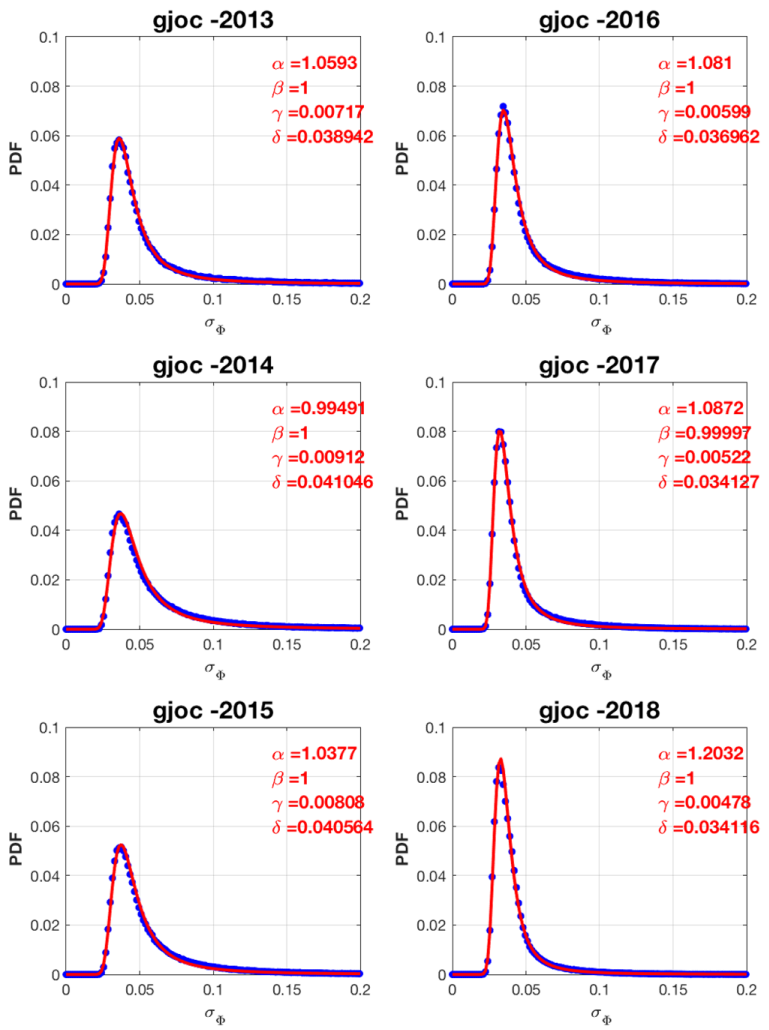
$\alpha=1$, $\beta=1$

Modelling efforts (PDF fit)

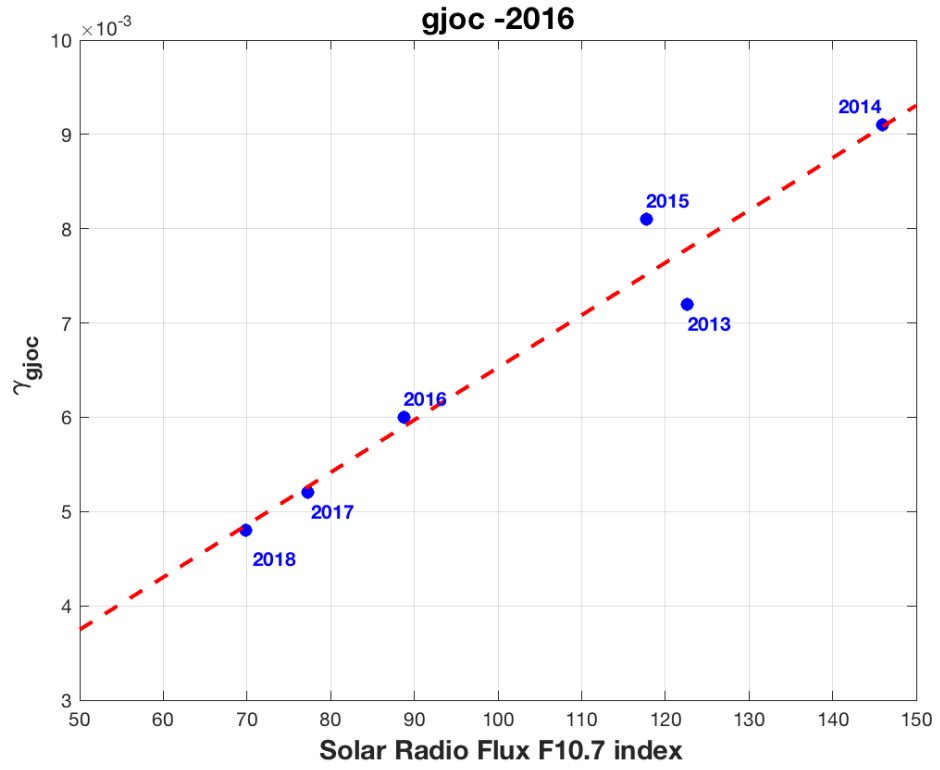
σ_φ

Landau-Like Distribution





Modelling efforts (PDF fit)



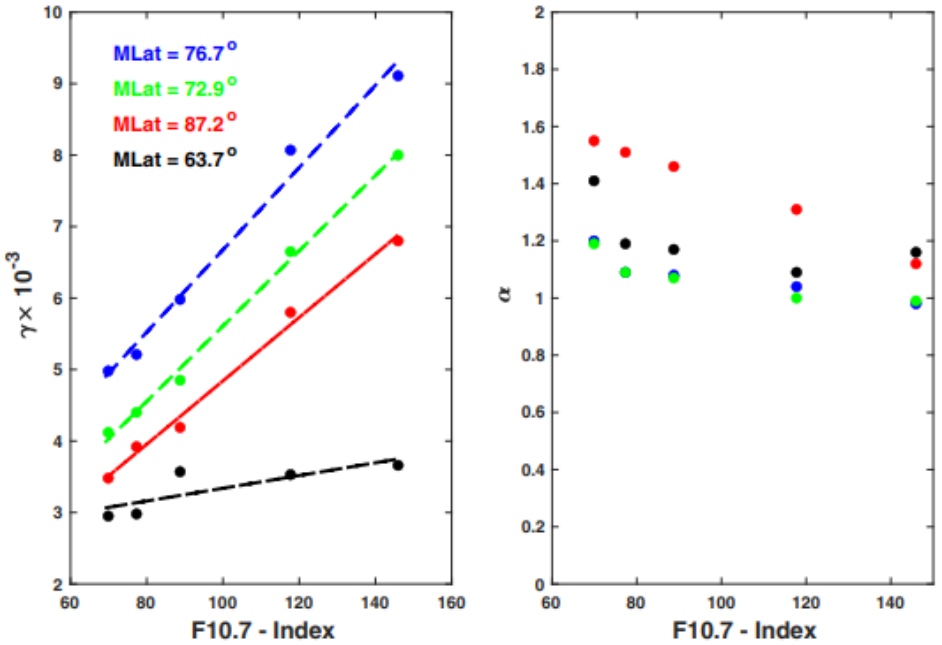


Fig. 4. Left (Right) panel shows the scale parameter γ (the distribution index α) obtained from the stable distribution fit versus the $F10.7$ solar radio flux for each year between 2014 and 2018 at *Gjoa Haven* (blue dots), *Eureka* (red dots), *Coral Harbour* (green dots) and *Fort McMurry* (black dots). Lines represent the best linear fit to the data. The magnetic latitude numerical values are indicated on the left panel. Each value of $F10.7$ index is obtained by averaging yearly.

- distribution index α does not vary significantly
- scale parameter γ has a good correlation with F10.7

K. Meziane, A. Kashcheyev, P. T. Jayachandran and A. M. Hamza, "On the latitude-dependence of the GPS phase variation index in the polar region," 2020 IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE), 2020, pp. 72-77, doi: 10.1109/WiSEE44079.2020.9262655

Conclusions

- GNSS data from 23 stations during the 24th solar cycle analyzed and cleaned
- Scintillation indices computed using raw phase and amplitude data
- Statistical analysis of the scintillation indices performed to look for well known periodic fluctuations
- Solar cycle, seasonal, time/location dependence identified
- Probability distribution function for the phase fluctuation index selected
- A climatological modelling approach (based on F10.7) suggested for phase fluctuations

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Thank you!