Contribution of DORIS System to Global Ionospheric Scintillation Mapping

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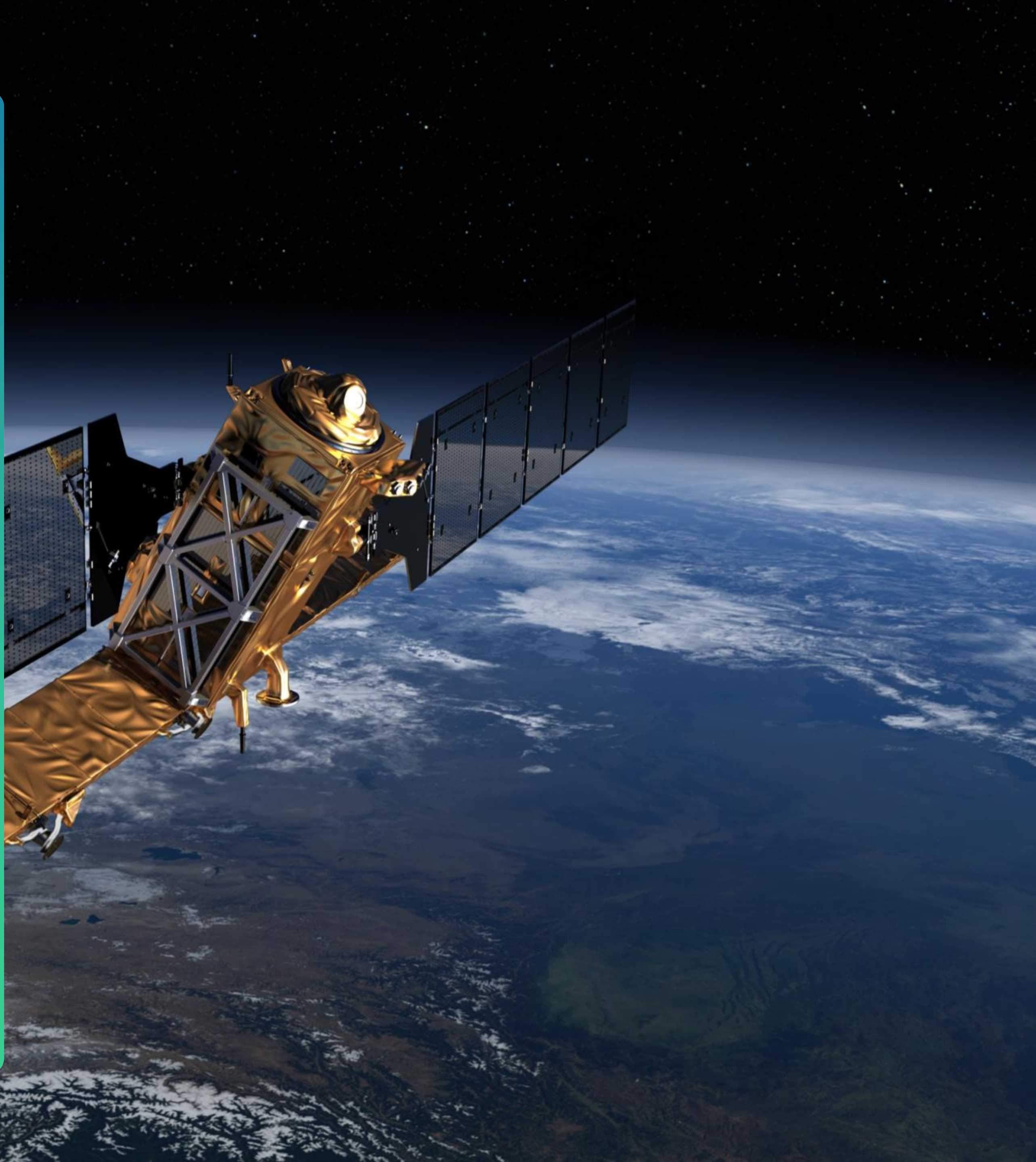

SUMMARY

1. Introduction
2. Long-term statistics
3. Short-term impact
   - *Quick overview of Mid-May 2024 geomagnetic event*
   - *DORIS data losses*
   - *Phase signal degradation*
   - *Power signal attenuation*

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1. Introduction

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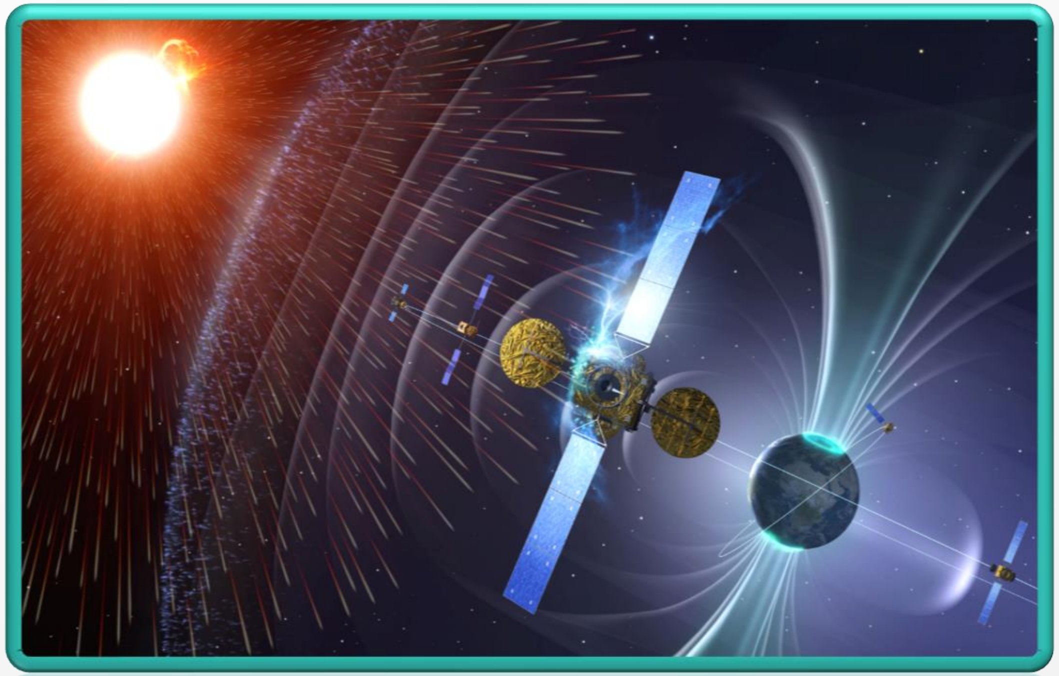
- Problematic? Ionospheric scintillations may severely degrade GNSS data in equatorial and high latitudes regions. Networks of ground-based GNSS receivers are used to derive maps of scintillation intensity, but it inevitably leads to sparse coverage.

- Purpose of the study? To add original data points based on the DORIS system to improve the scintillation coverage (DORIS 2GHz is near the L1 GNSS frequency at ~1.5 GHz).

- What's next? Explore if it is possible to define scintillation proxies based on DORIS data losses, phase signal degradation, or power signal attenuation, by a comparison to a scintillation data base from GNSS measurements.



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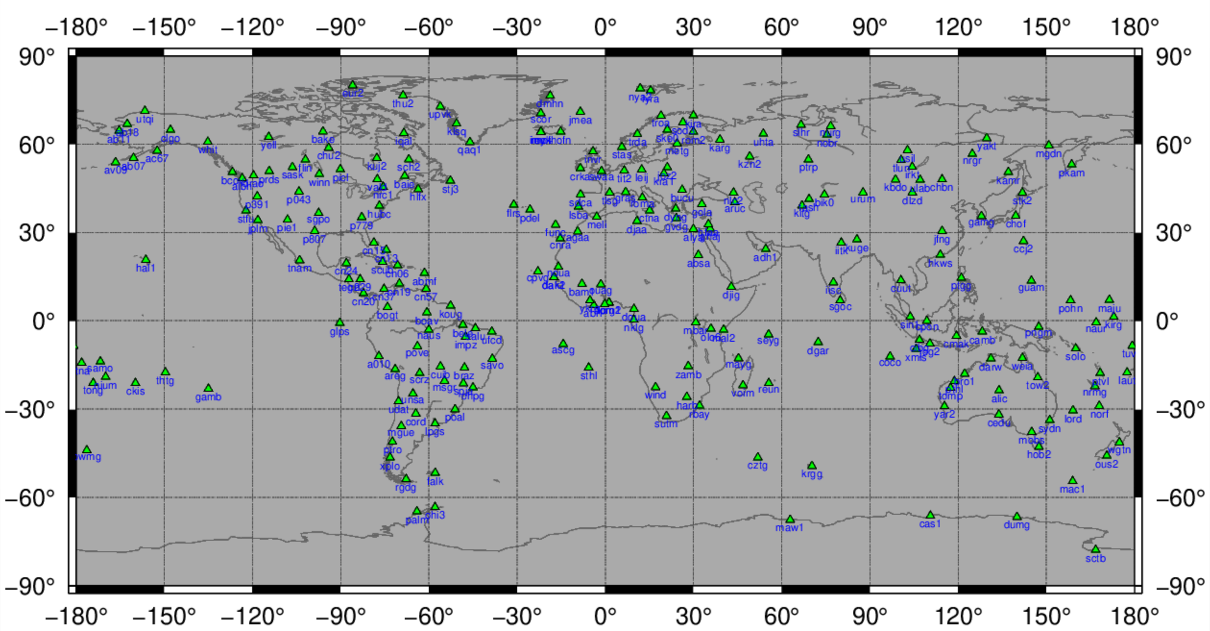
1. Introduction

→ Despite a lower data rate (0,1 Hz instead of 1 Hz for the GNSS) and a lower number of satellites, DORIS can add valuable information where there is no GNSS receivers.



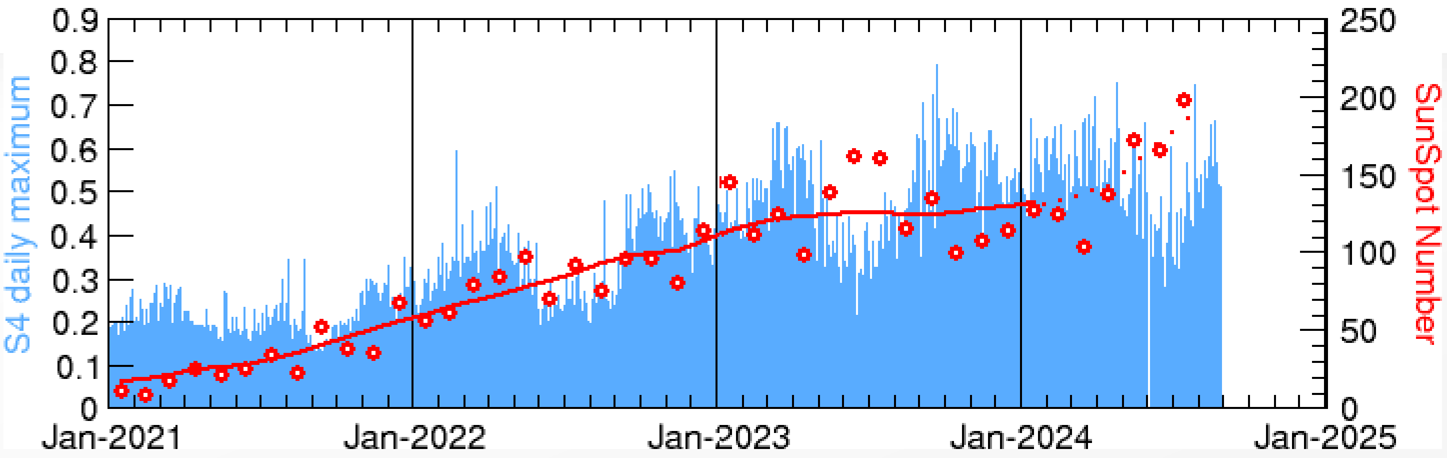
Selection of real-time or near-real-time (15’) GNSS stations

DORIS network (in September 2024) – Yellow rectangles show where DORIS could add valuable information

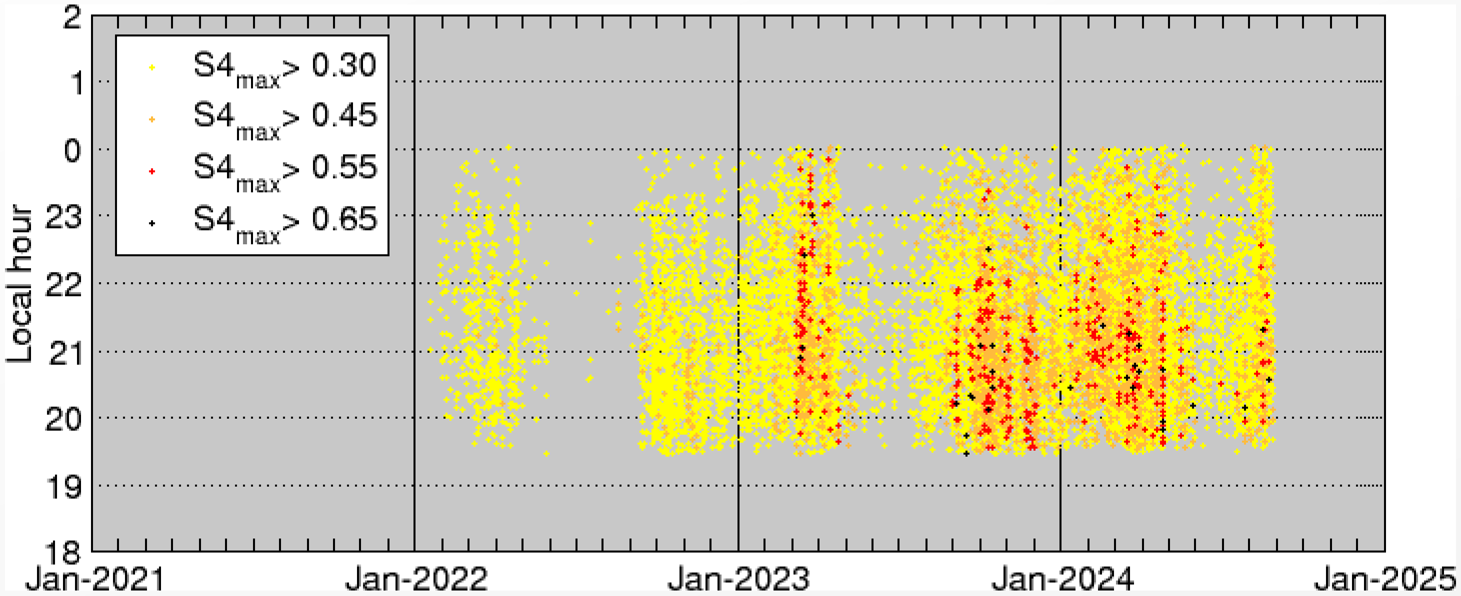
2. Long-term statistics

2. Long-term statistics

→ As the current solar cycle continues to progress (red line and dots), the level of amplitude scintillation observed worldwide by GNSS receivers (blue lines) also increases.



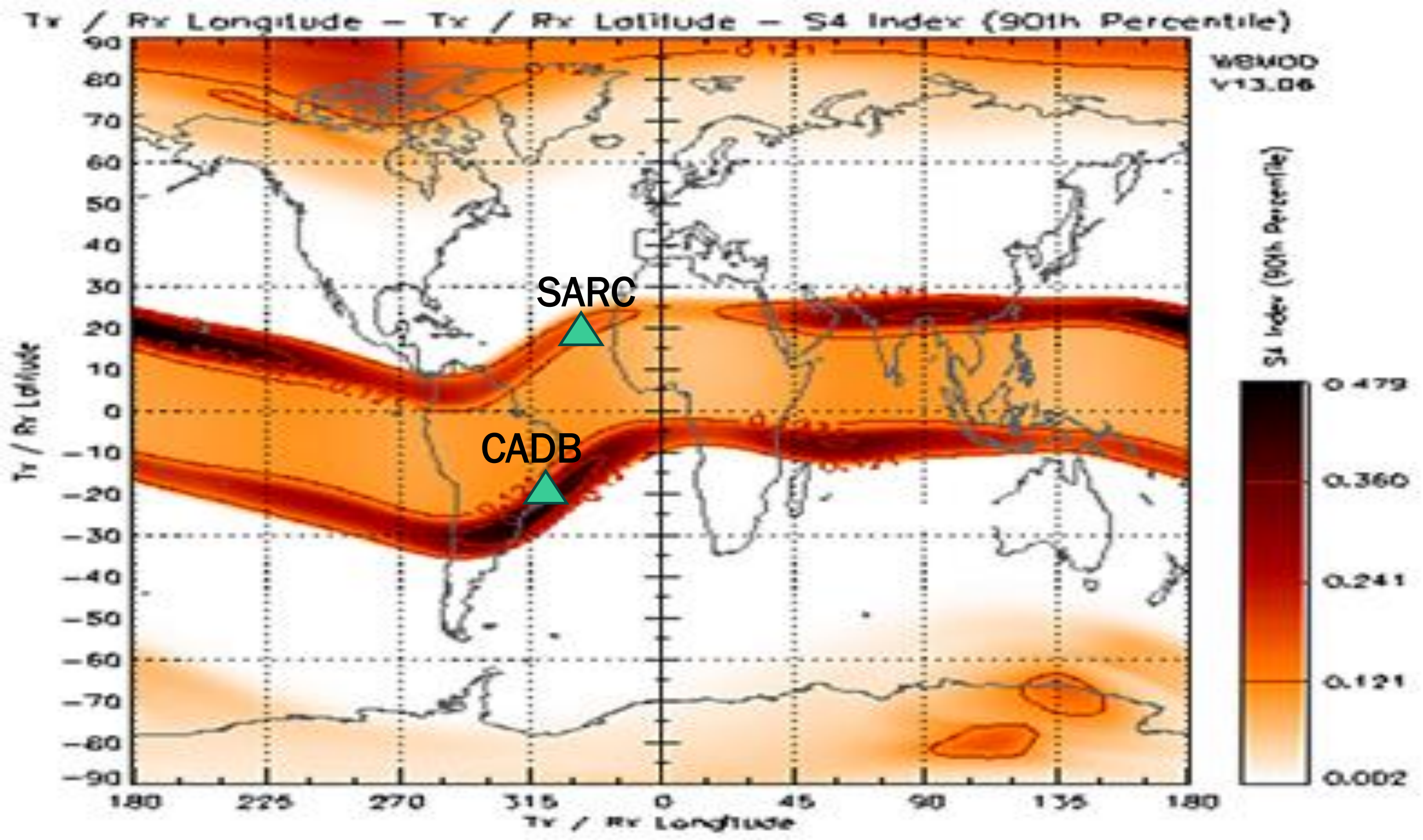
Sunspot number & Amplitude scintillation maximum over a 3-year period



Local hour of the S4 daily maximum (worldwide)

→ Regarding the daily maximum, the following observations can be made: amplitude scintillations (S4) tend to peak during the equinoxes and occurs during the night, starting at the sunset.

2. Long-term statistics



WBMOD Scintillation climatological model (NorthWest Research Associates, Inc).

→ DORIS 2 GHz frequency is not so far from the GNSS L1 frequency (1.5 GHz), therefore DORIS signal may also be affected by scintillations.

→ Analysis of statistics from Precise Orbit Determination (POD) of two DORIS satellites with DORIS beacons data :

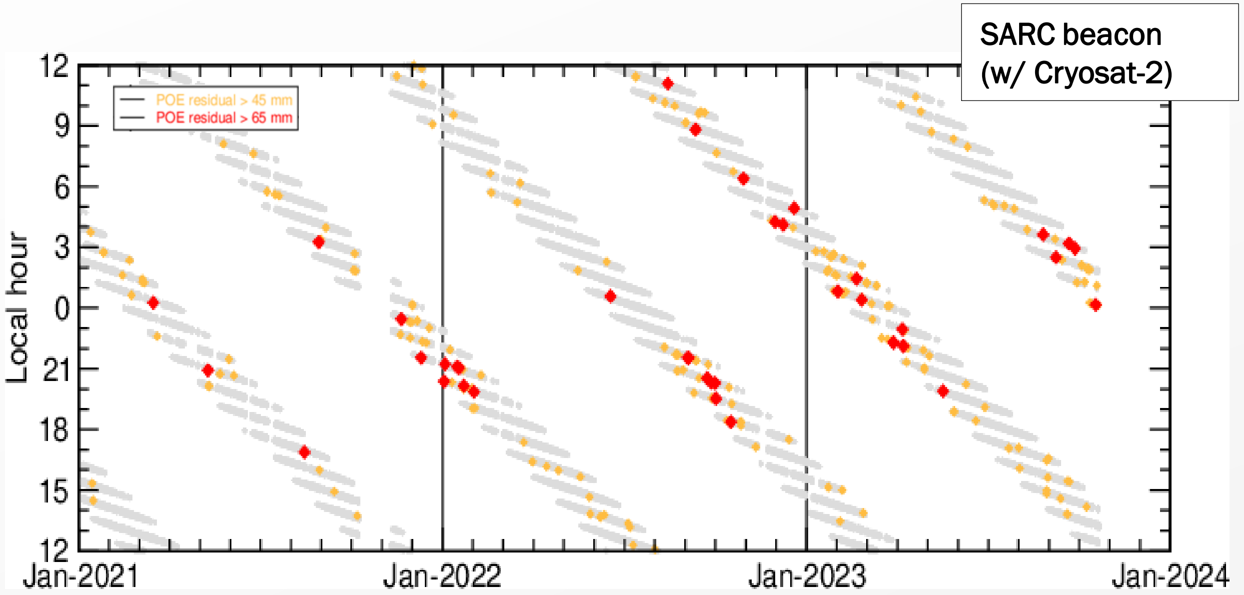
- Cryosat-2 with the Sal (**SARC**) beacon data
- Saral with the Cachoeira-Paulista (**CADB**) beacon data

2. Long-term statistics

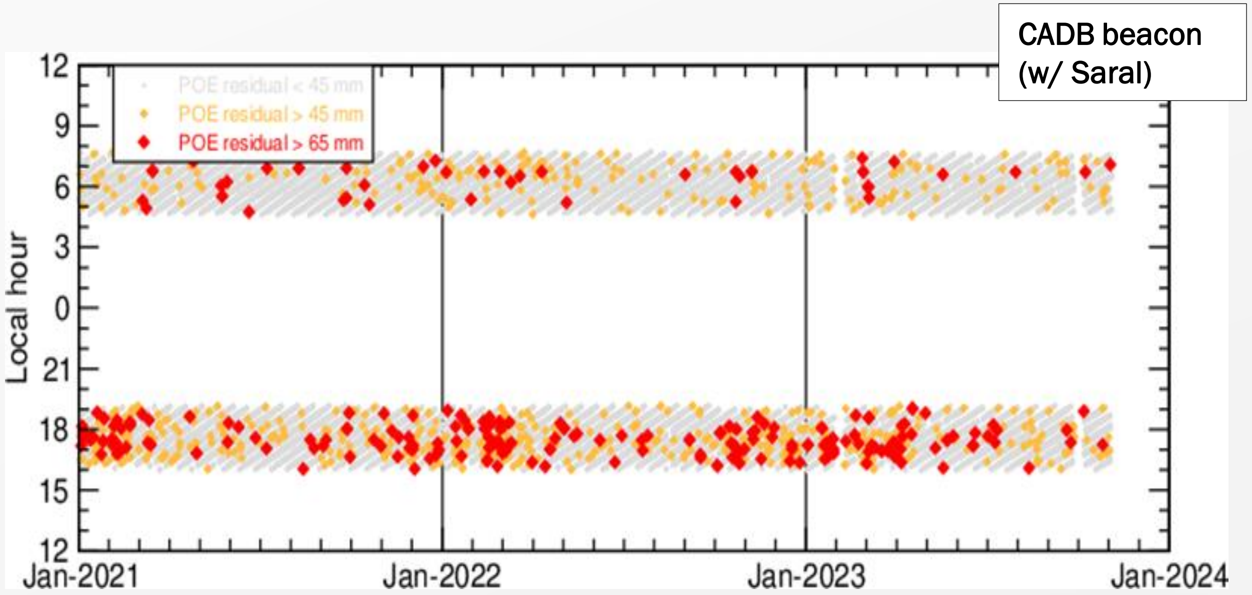
→ For the **SARC** beacon, measurements show that there are higher POE residuals (> 45 mm and > 65 mm) during the night, between 21h and 3h at local hour.

→ For the **CADB** beacon, measurements show that there are higher POE residuals (> 45 mm and > 65 mm) starting at sundown, and mostly between 17h and 20h at local hour.

→ For both beacons, the number of red and orange dots tends to increase as the solar cycle progresses.

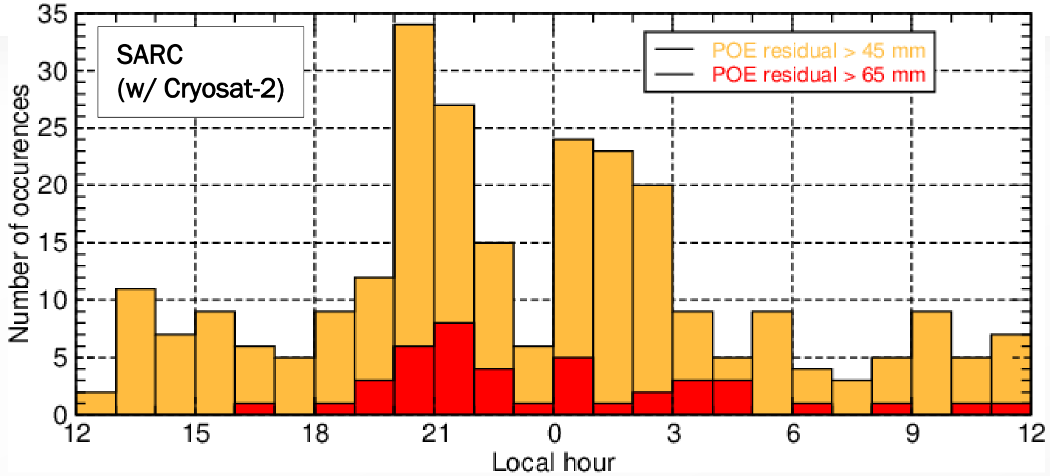


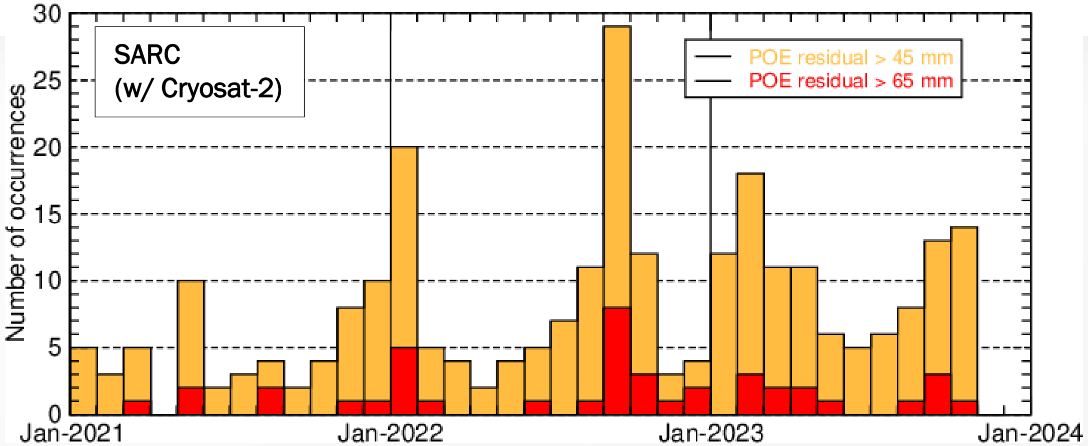
Plot of the measurements on a time vs local hour for the ***SARC*** *beacon*

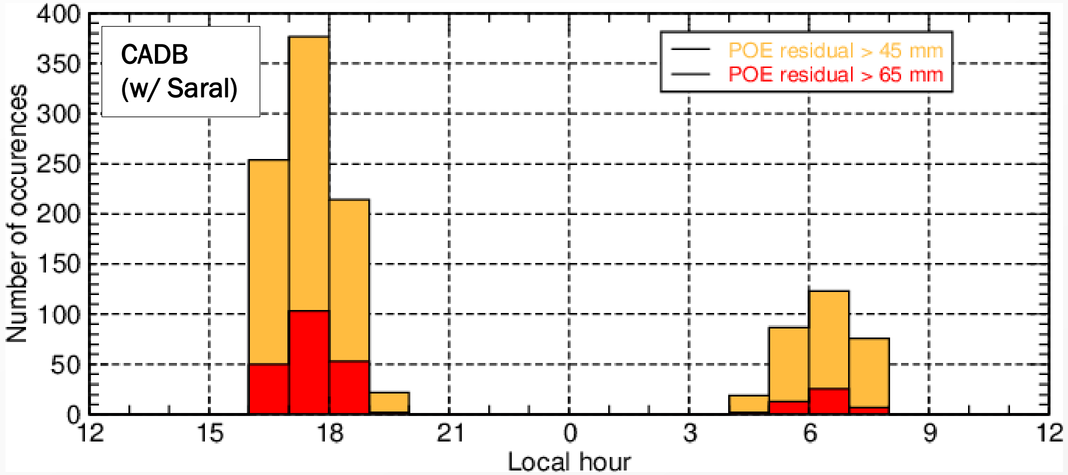


Plot of the measurements on a time vs local hour for the ***CADB*** *beacon*

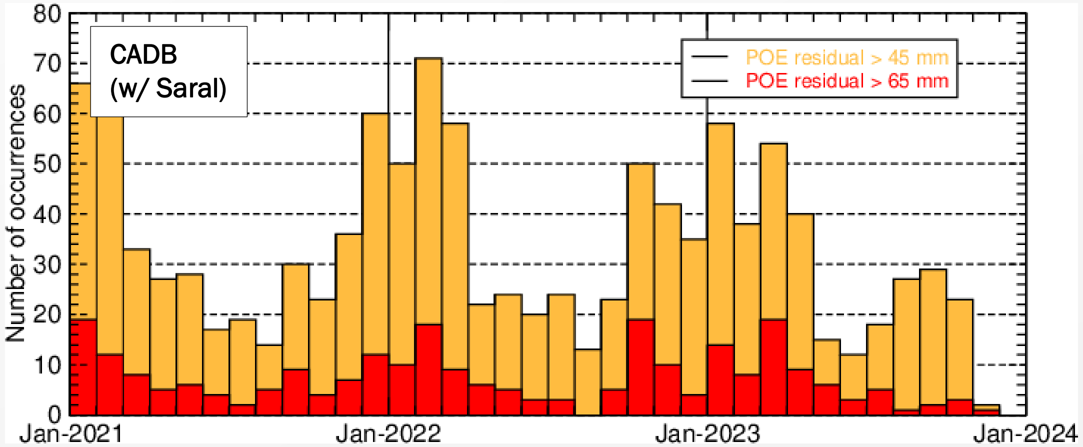
2. Long-term statistics







Derived statistics of the occurrence of high values VS local hour



Derived statistics of the occurrence of high values VS time

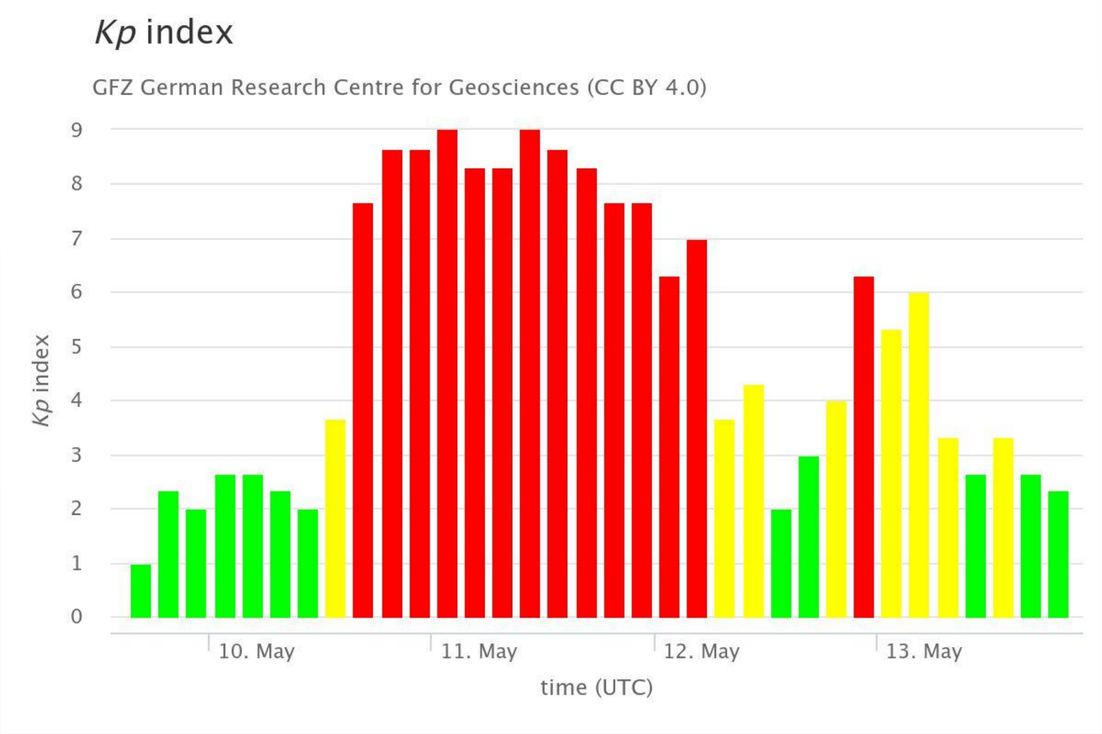
→ These derived statistics figures clearly show a correlation with scintillation level : high residuals are becoming higher with the solar cycle, during equinoxes and after sunset.

3. Short-term statistics

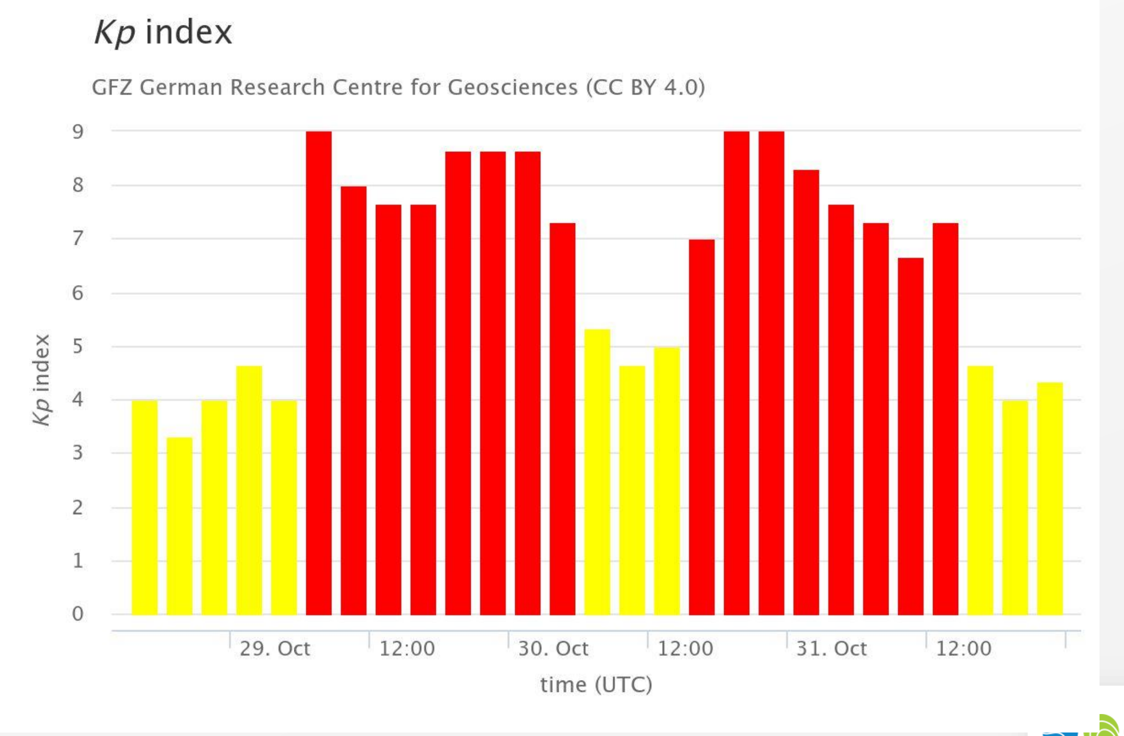
3. Short-term statistics : *Quick overview of the mid-May event*

→ The mid-May 2024 event is a strong geomagnetic storm that occurred from **May 10th, 2024 to May 12th, 2024**. This geomagnetic event was due to a series of solar storms involving solar flares and coronal mass ejections.

→ Strongest geomagnetic storm since the 2003 Halloween solar storms, peaking around October 28th - 29th, 2003 (during this event, the largest solar flare has been recorded by the GOES system, a X45 one).



Kp indices recorded during the mid-May 2024 event



Kp indices recorded during the 2003 Halloween event

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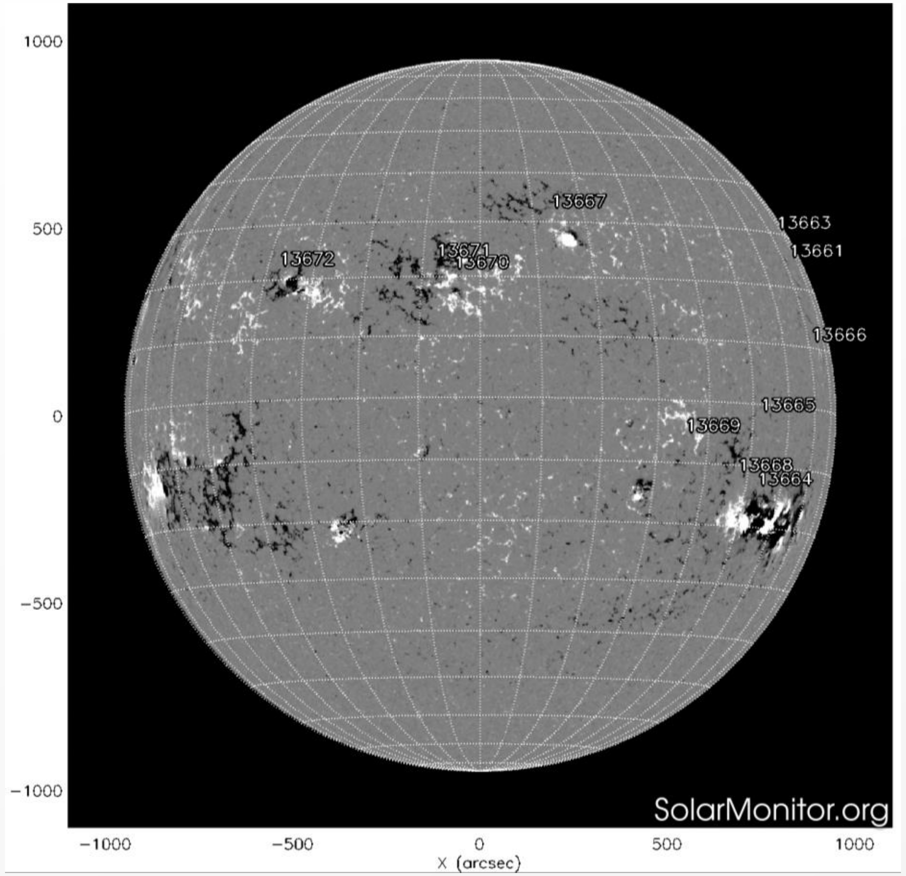
3. Short-term statistics : *Quick overview of the mid-May event*

→ From May 10th, 2024 to May 12th, 2024 were produced : ***12 C-class flares*, 24 M-class flares and 4 X-class flares** (strongest one being a X5.8), mostly erupting from the same active region **AR #13664**.



Solar disc on May 11th, 2024

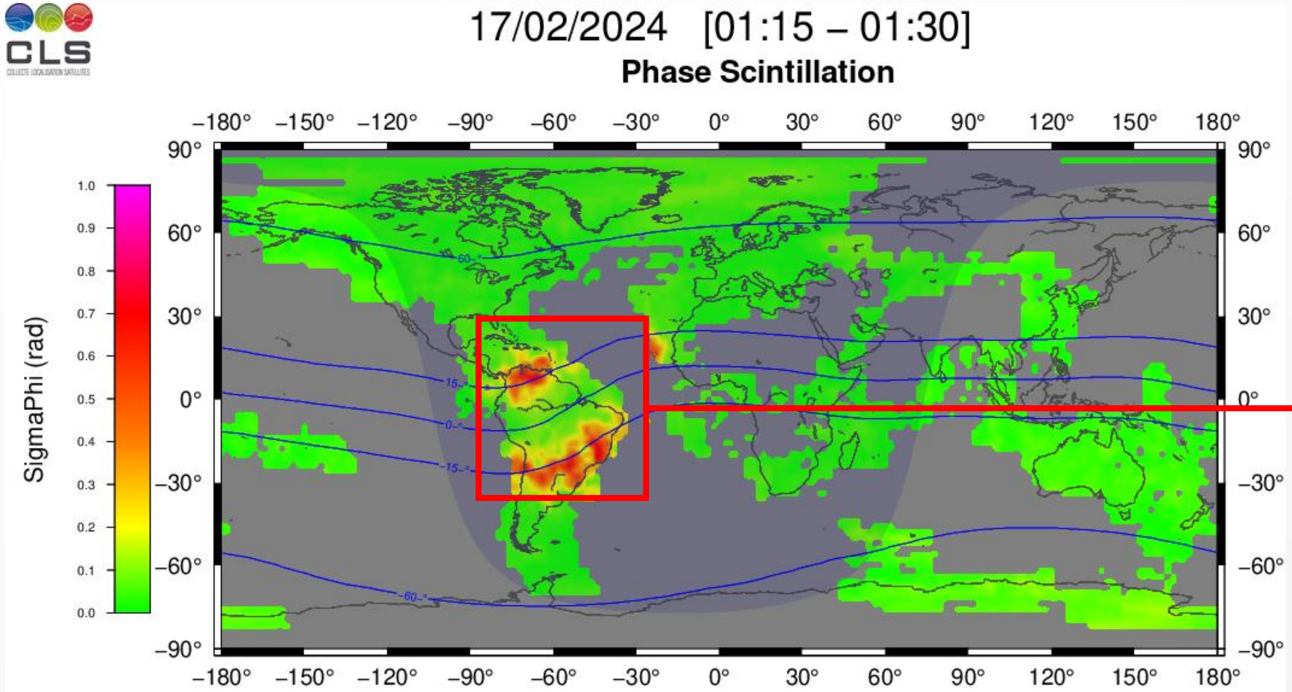
Today's/Yesterday's NOAA Active Regions						
NOAA Number	*Latest Position*	*Hale Class*	*McIntosh Class*	*Sunspot Area [millionths]*	*Number of Spots*	*Recent Flares*
13663	N27W91 (845",429")	βγ/βγ	Fkc/Fkc	0300/0300	10/10	-
13664	S17W62 (803",-255")	βγδ/βγδ	Fkc/Fkc	2400/1090	58/81	C7.8(21:52) C9.4(20:59) M1.2(20:32) M1.8(13:45) X1.5(11:15) M1.6(10:53) M3.1(10:03) M1.4(04:28) / M3.8(20:59) M1.9(19:56) M1.1(19:35) M2.0(18:57) M1.8(18:38) M1.1(18:26) C9.1(18:15) C7.3(15:41)
13666	N08W91 (939",131")	α/α	Hsx/Hsx	0050/0050	01/01	-
13667	N28W18 (259",488")	α/α	Hsx/Hsx	0140/0130	01/01	-
13670	N17W00 (0",325")	α/α	Hax/Hsx	0050/0040	06/01	-
13671	N19E03 (-47",356")	α/α	Hsx/Hax	0030/0040	01/01	-
13672	N18E31 (-466",334")	β/β	Cai/Cro	0140/0030	09/05	-
13661	N22W91 (879",354")	/	/	/	/	-
13665	S05W59 (812",-57")	/	/	/	/	-
13668	S15W55 (753",-218")	/	/	/	/	M8.9(14:46) X5.8(01:10) / -
13669	S09W41 (617",-111")	/	/	/	/	-

Description of the ARs visible on the solar disc on May 11th, 2024

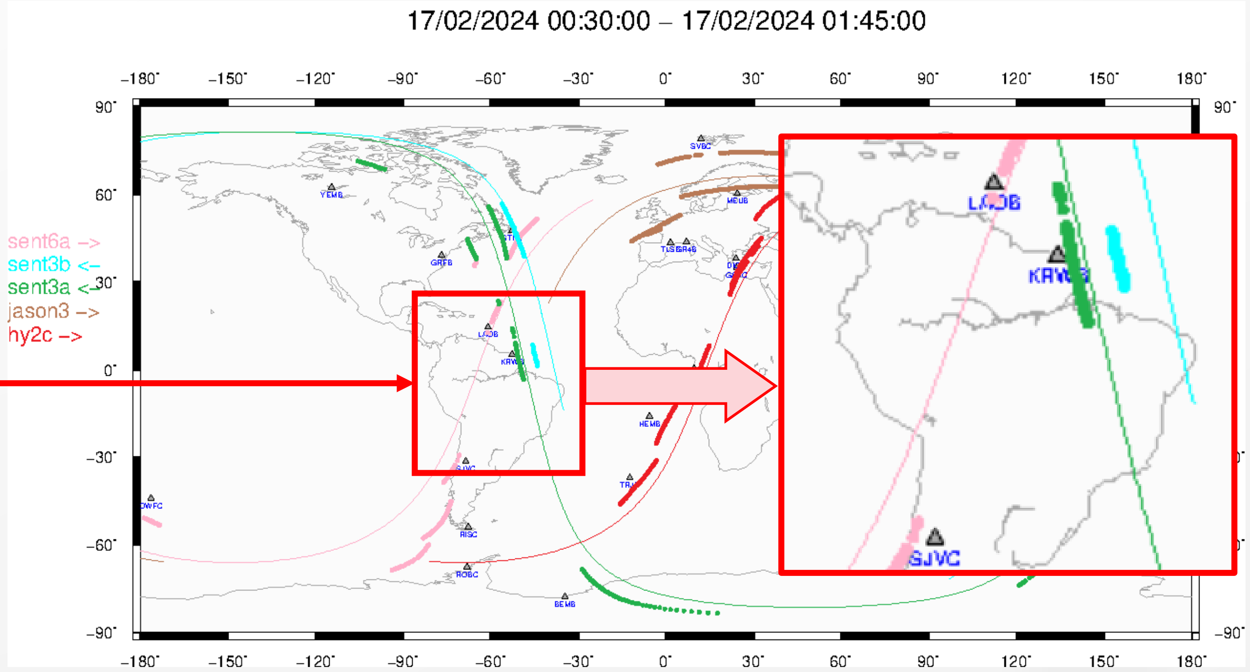
3. Short-term statistics : *DORIS data losses*

→ Studied scintillation event : **February 17th, 2024** – σ_{Φ} = *0,85 rad*

→ During the phase scintillation event occurring at Equatorial latitudes, beacons located in the zone of maximum scintillation show some data losses (slightly discontinuous measurement trace).



Phase scintillation map (17/02/2024) based on a GNSS network

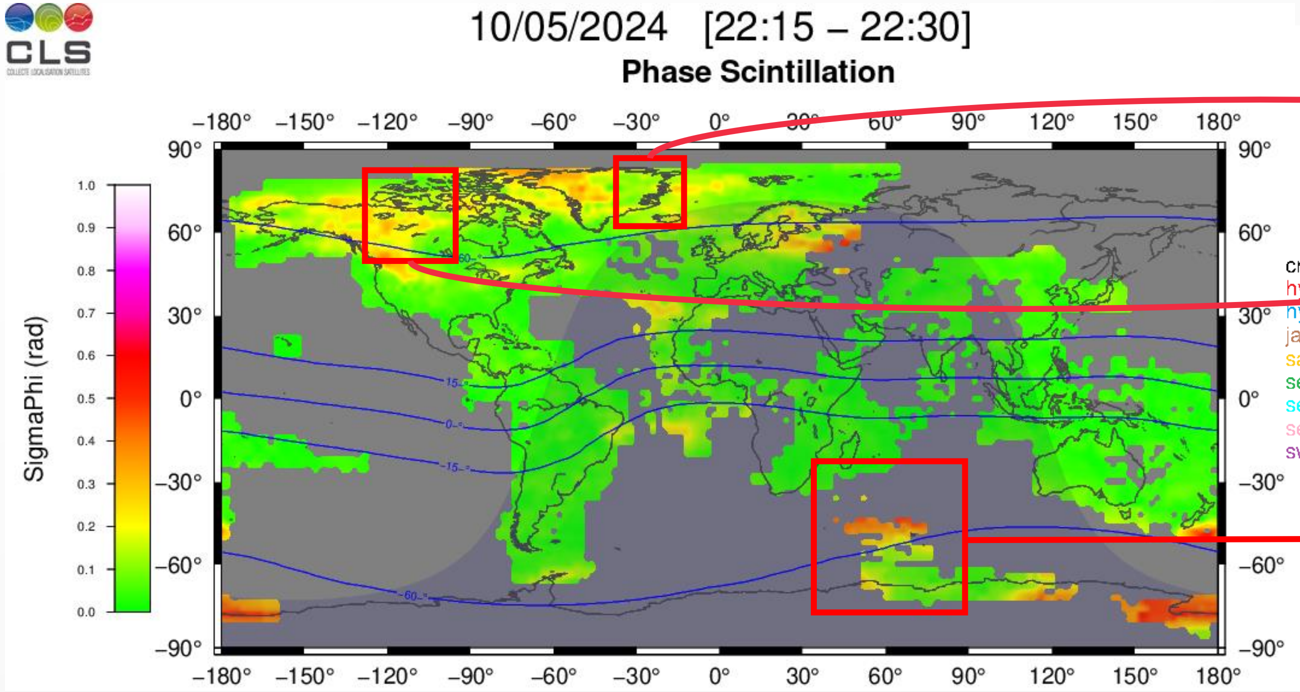


Ground track of DORIS satellites (17/02/2024)

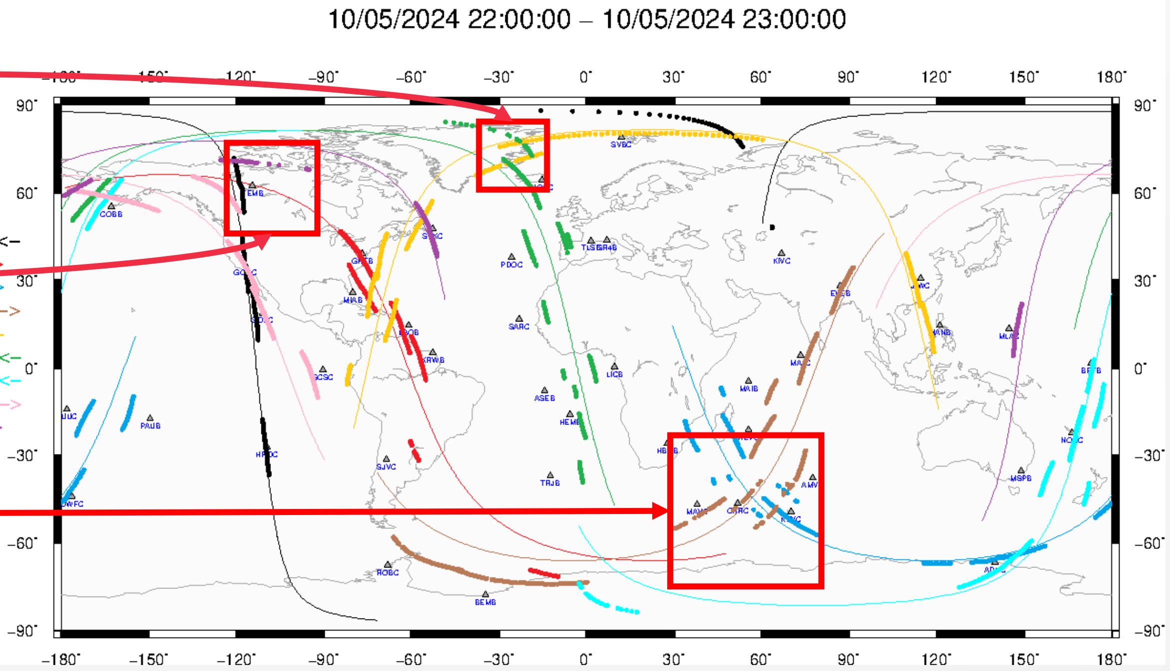
3. Short-term statistics : *DORIS data losses*

→ Studied scintillation event : **May 10th, 2024** – σ_{Φ} = *0,75 rad* at Northern latitudes and σ_{Φ} = *0,59 rad* at Southern latitudes. On this day, strong geomagnetic storm impacting all latitudes.

→ During the phase scintillation event, beacons located at high latitudes and in different zones of maximum scintillation (northern and southern latitudes) show data losses.



Phase scintillation map (10/05/2024) based on a GNSS network

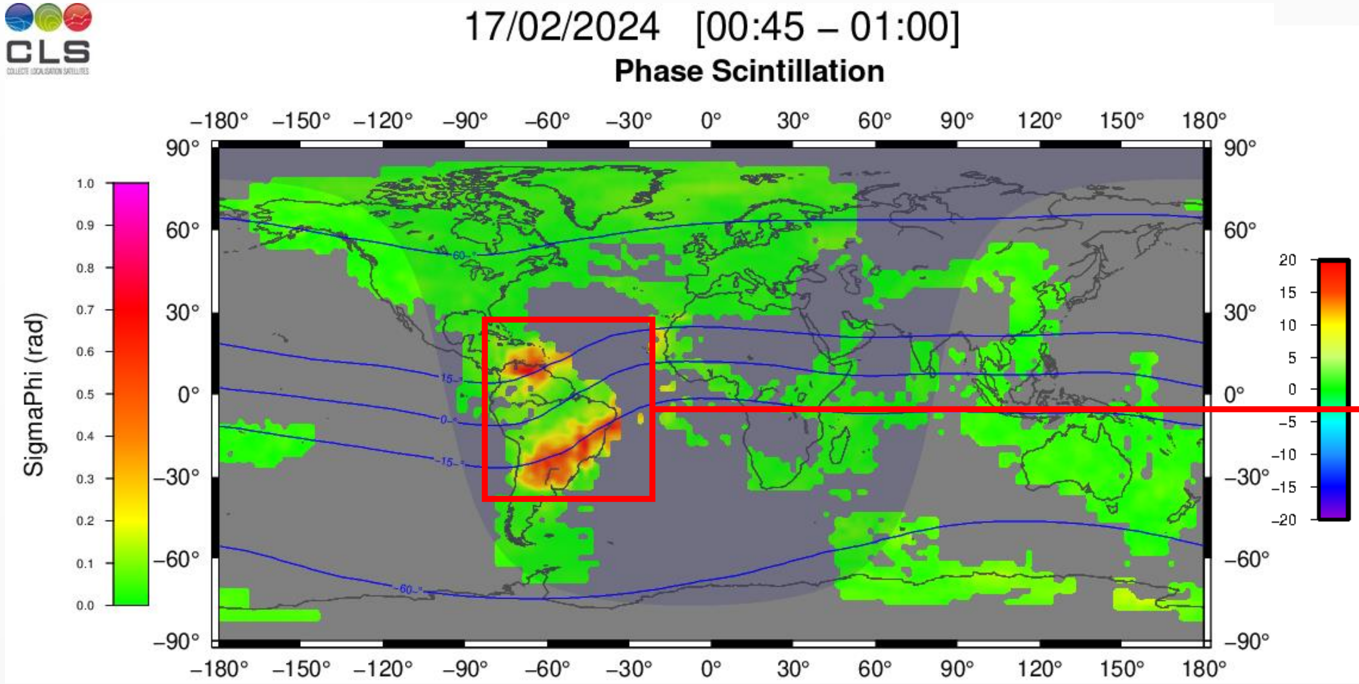


Ground track of DORIS satellites (10/05/2024)

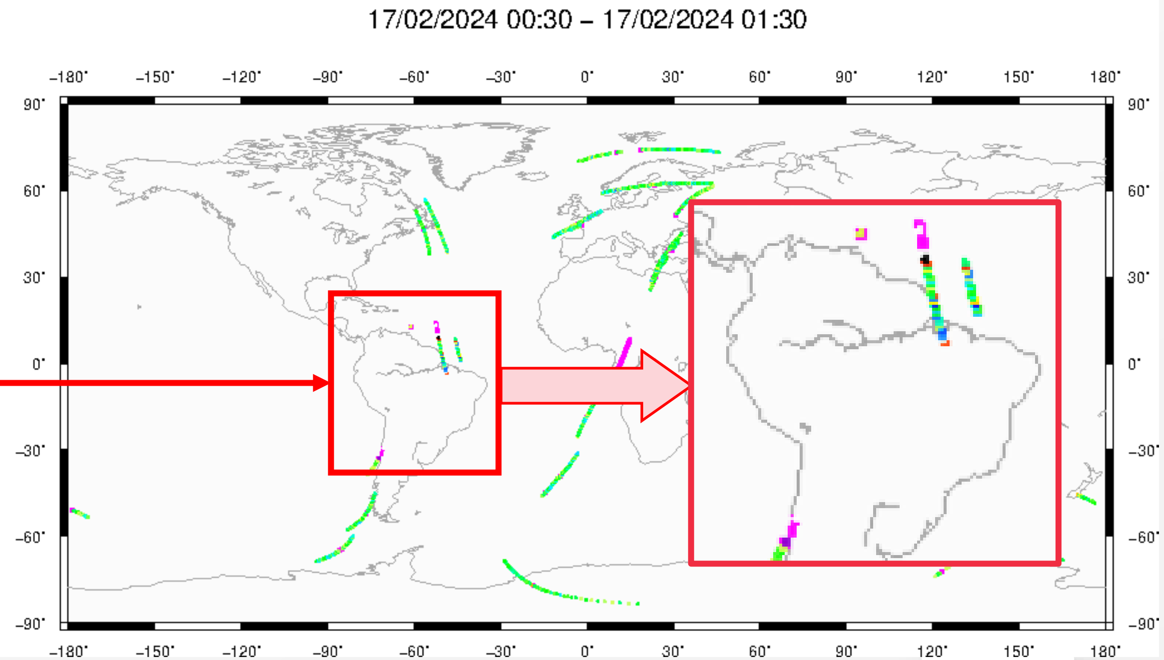
3. Short-term statistics : *phase signal degradation*

→ Studied scintillation event : **February 17th, 2024** – $\sigma_\Phi = 0{,}85\ rad$

→ Analysis of least-square residuals of the orbit fitting on DORIS data is a good way of monitoring scintillation events and to highlight phase signal degradation. By plotting on a map these least-square residuals as the satellite pass over the receiving DORIS beacons, we can observe that higher residuals are recorded during the peak, and thus eliminated (represented in pink).



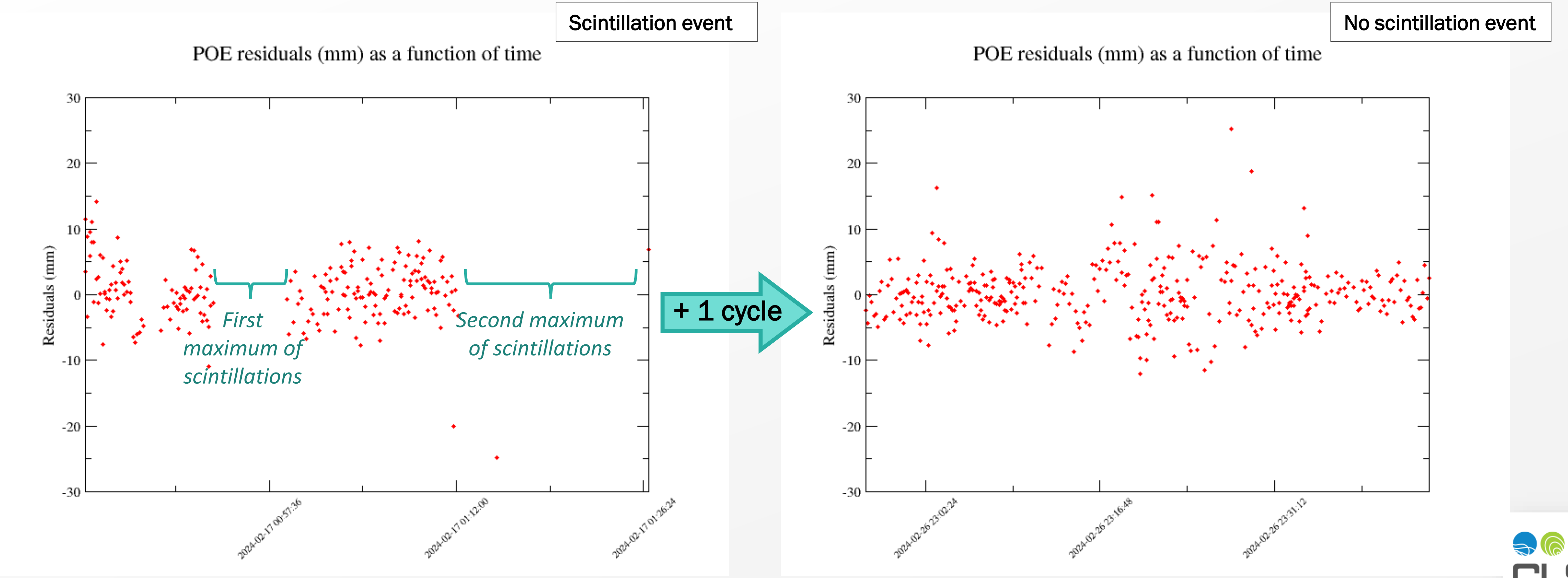
Phase scintillation map (17/02/2024) based on a GNSS network



Residuals map of DORIS satellites passes (17/02/2024)

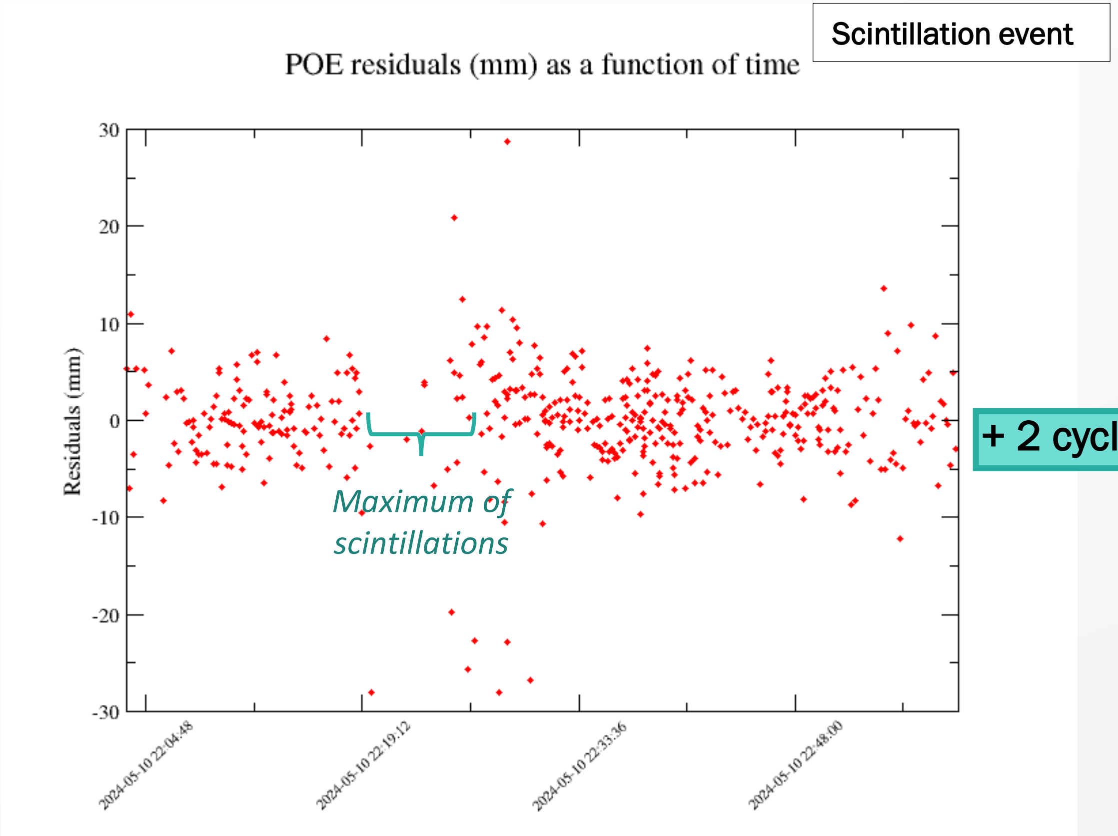
3. Short-term statistics : *phase signal degradation*

→ Analysis of the passage of Sentinel-6A through the scintillation zone during the event, compared to its passage during the subsequent cycle (without scintillation), reveals a complete data loss during a few minutes when the scintillations peak is reached. Moreover, during the scintillation period, the residuals have a larger dispersion.

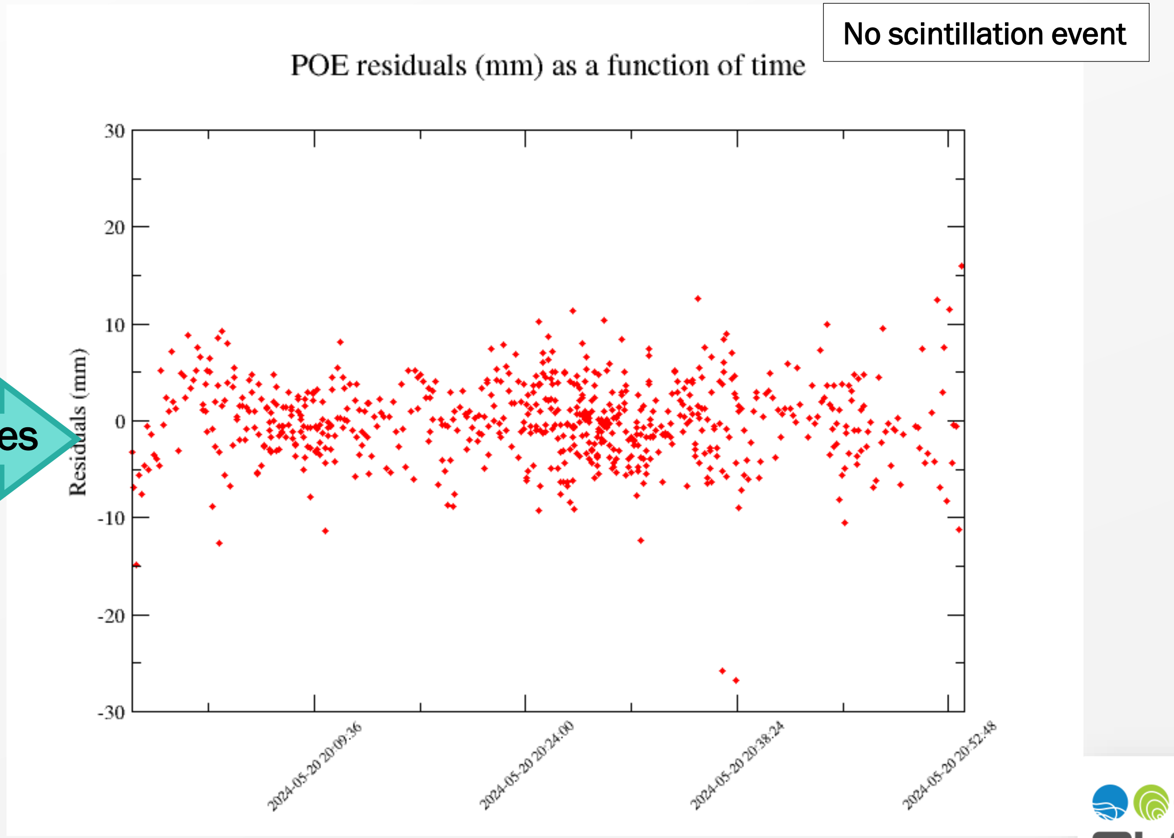


3. Short-term statistics : *phase signal degradation*

→ ***Example of the mid-May event :*** analysis of the Jason-3 pass through the scintillation zone during the event, compared to its pass during two subsequent cycles (without scintillation). Data loss is observed during a few minutes when the scintillations peak is reached, and the residuals also show a slightly larger dispersion.



+ 2 cycles



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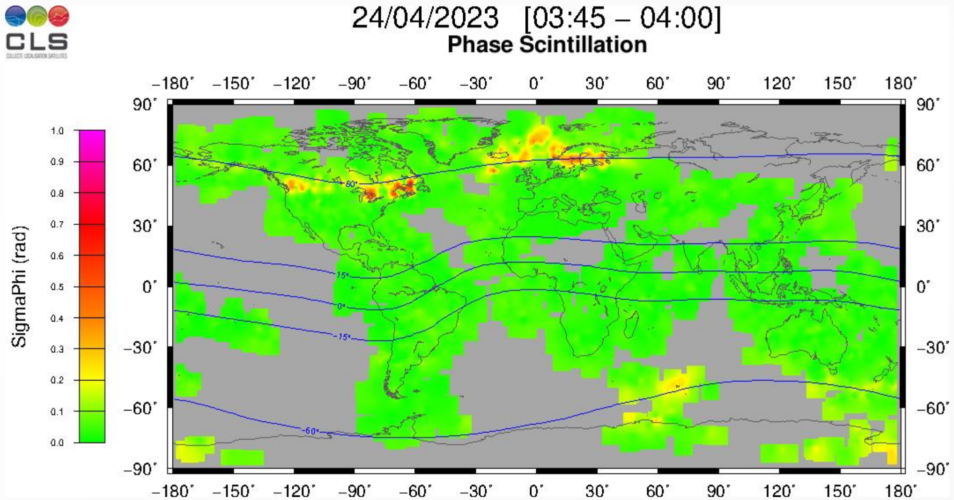
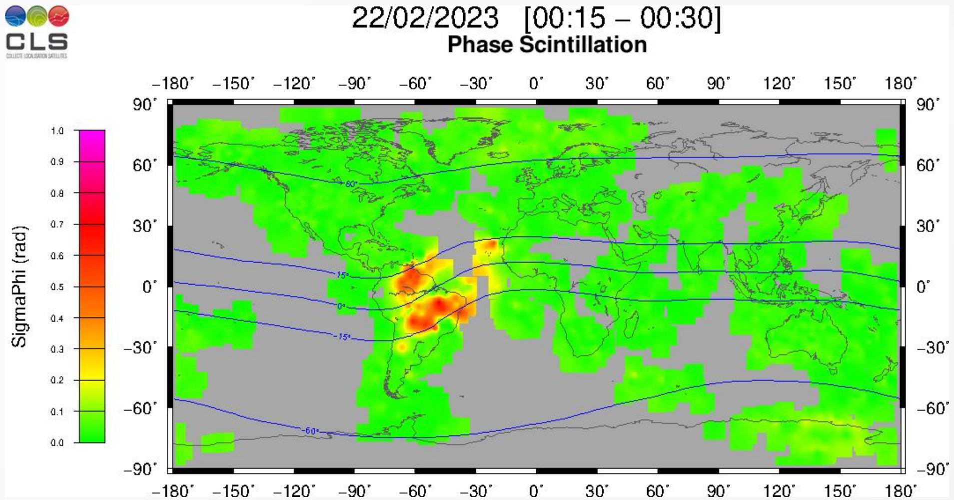
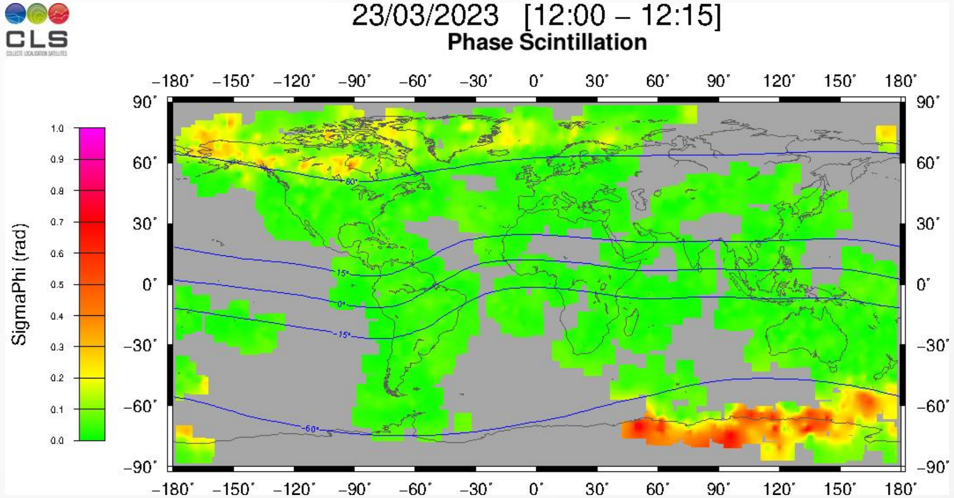
3. Short-term statistics : *power signal attenuation*



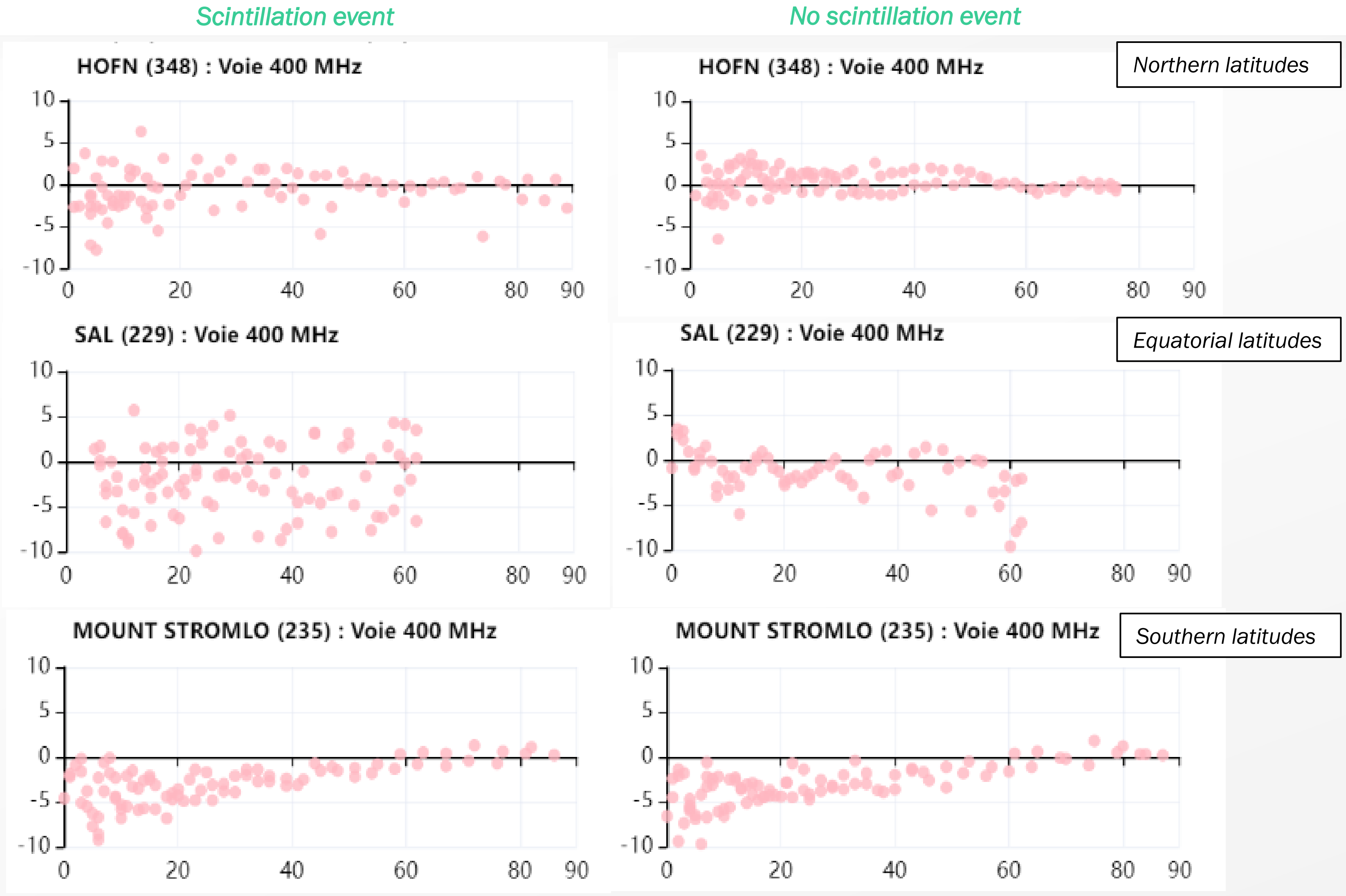




→Studied scintillation events : 3 different events occuring at Northern, Equatorial and Southern latitudes :

- Northern latitudes : **April 24th, 2023** - $\sigma_{\Phi} = 0{,}79$ *rad*
- Equatorial latitudes : **February 22sd, 2023** - $\sigma_{\Phi} = 0{,}73$ *rad*
- Southern latitudes : **March 23rd, 2023** - $\sigma_{\Phi} = 0{,}79$ *rad*

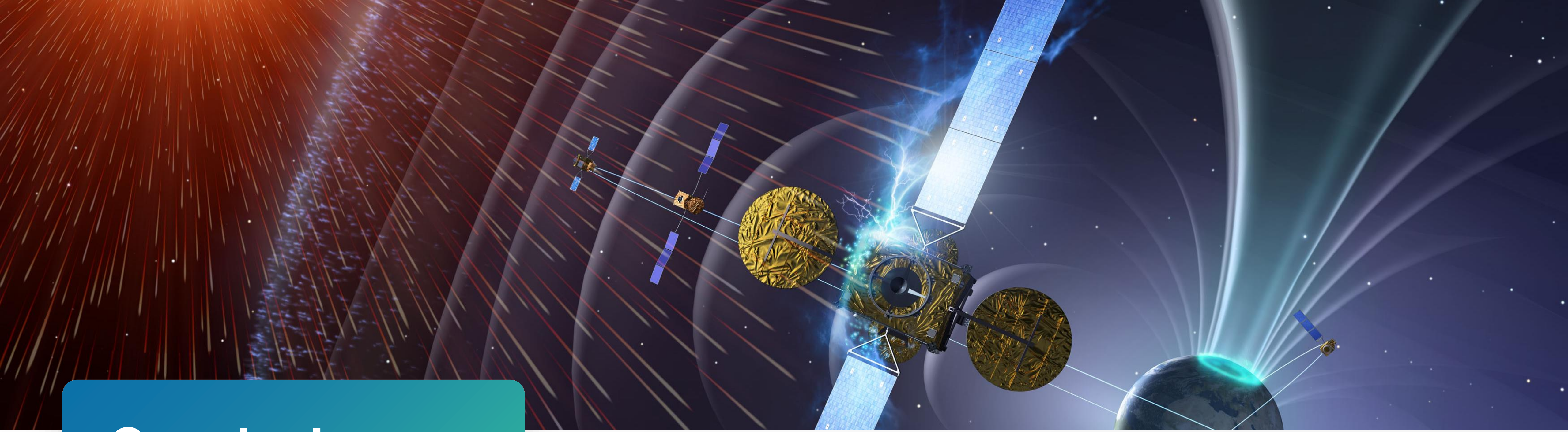
3. Short-term statistics : *power signal degradation*



Power attenuation of 3 DORIS beacons during a scintillation event or not

→ We are looking for potential power loss or greater fluctuation during strong scintillation events.

→ For equatorial scintillation events, we can see a slightly greater dispersion and a slightly lower event average. These observations are less visible on high-latitude events.



Conclusions :

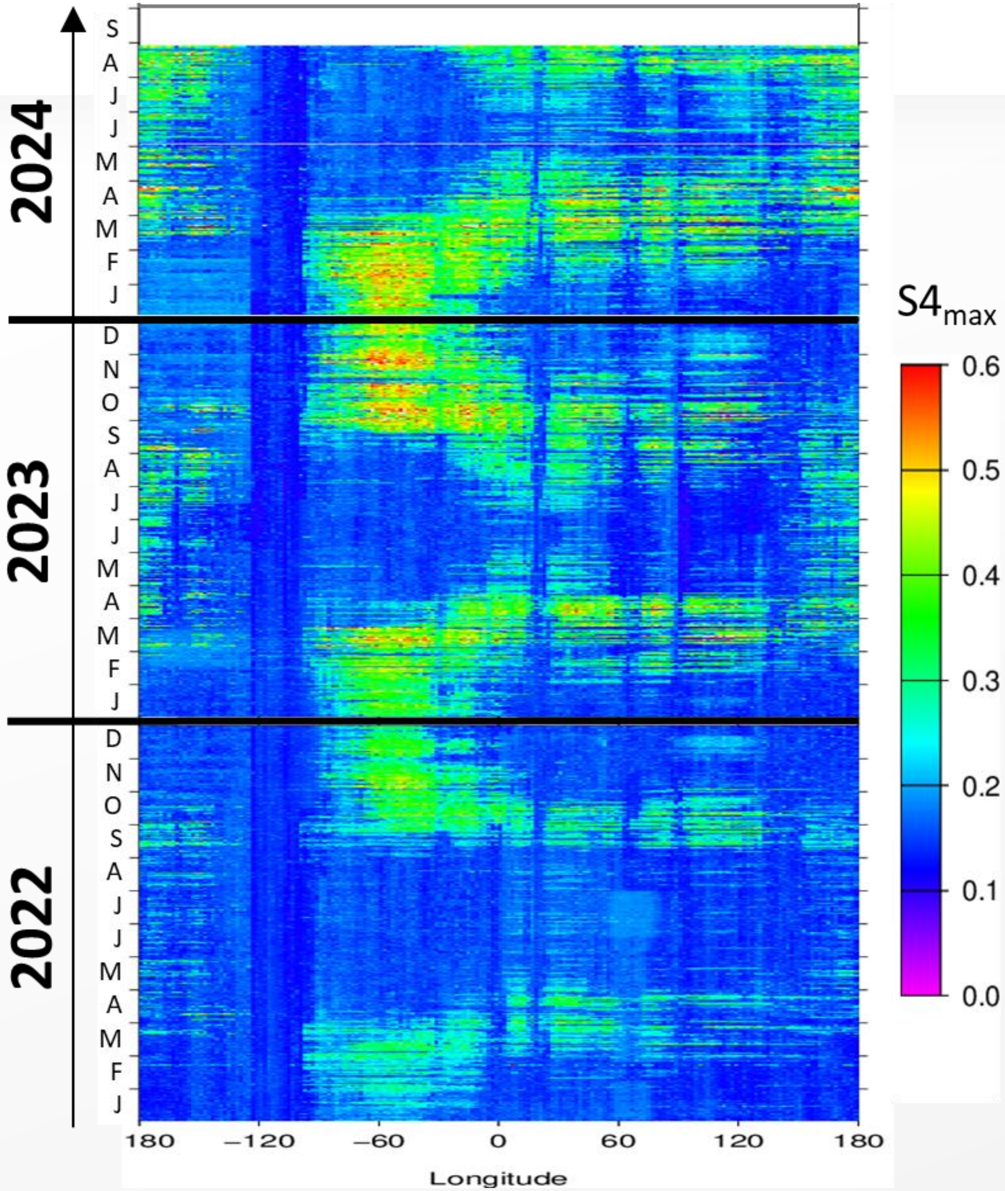
- Results on DORIS data losses and phase signal degradation suggest that DORIS could help complete the global scintillation maps. Results on the analysis of the power signal attenuation are harder to interpret.

- These observations are valid for strong scintillation events. However, for smaller events, the results are more mitigated. Perhaps the DORIS count interval (10 sec) may be too low for these smaller events ?

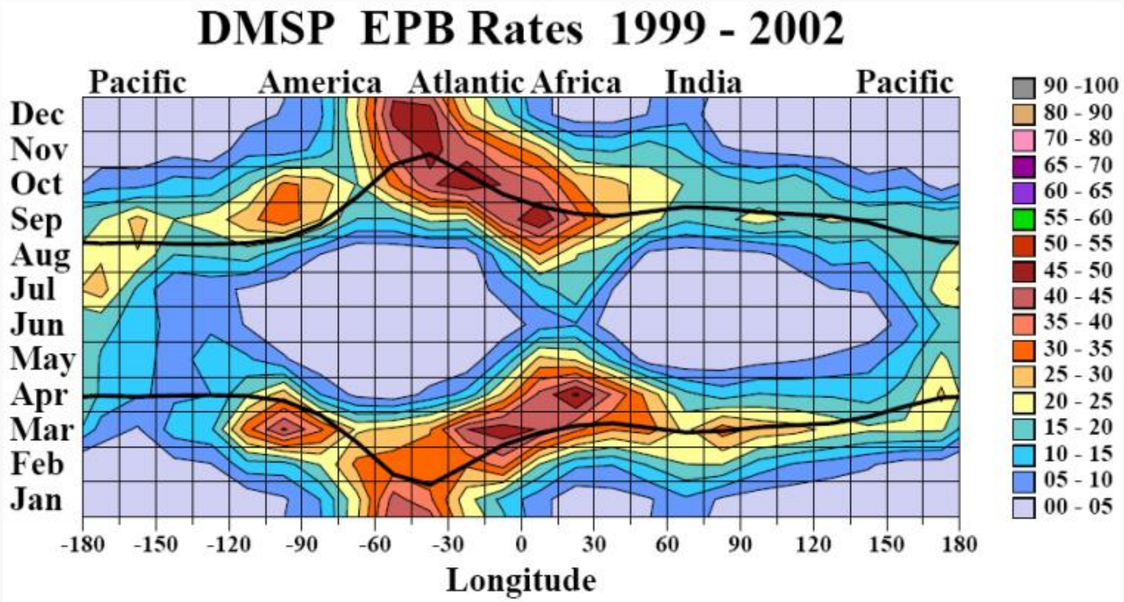
- In this study, we used the results of precise orbit determinations, and many phenomena (other than scintillation) have an impact on residuals. To go further on the analysis of scintillations on the orbit determination, the behavior of the ionospheric correction (i.e. related to the Total Electronic Content) during scintillation events should also be analyzed.

BONUS SLIDES

Equatorial S4 maximum **VS** longitude and time

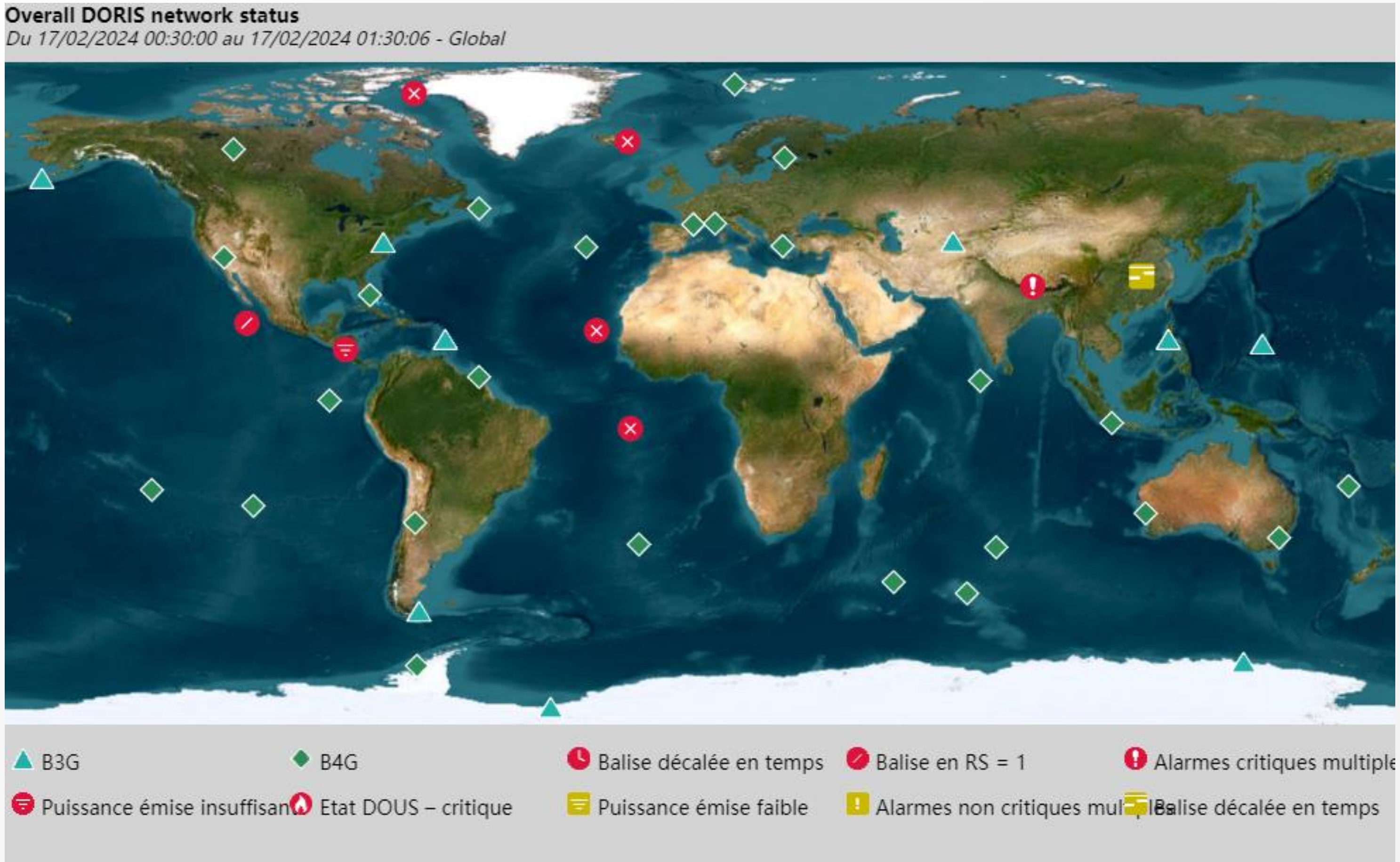


[14] L. C. Gentile, W. J. Burke, and F. J. Rich, "A global climatology for equatorial plasma bubbles in the topside ionosphere", Annales Geophysicae, 24, 163–172, 2006.

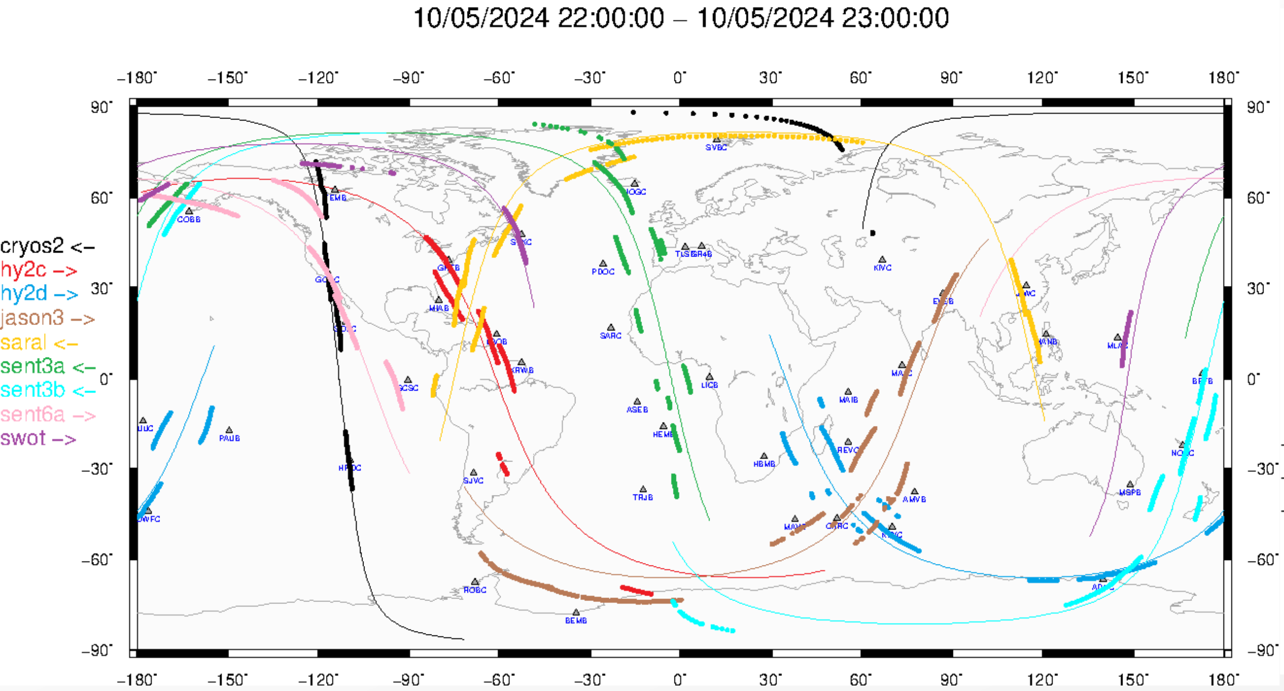


The S4 observations are in **good agreement** with the EPB rate observed by the DMSP satellites (Defense Meteorological Satellite Program) during SC23 maximum.

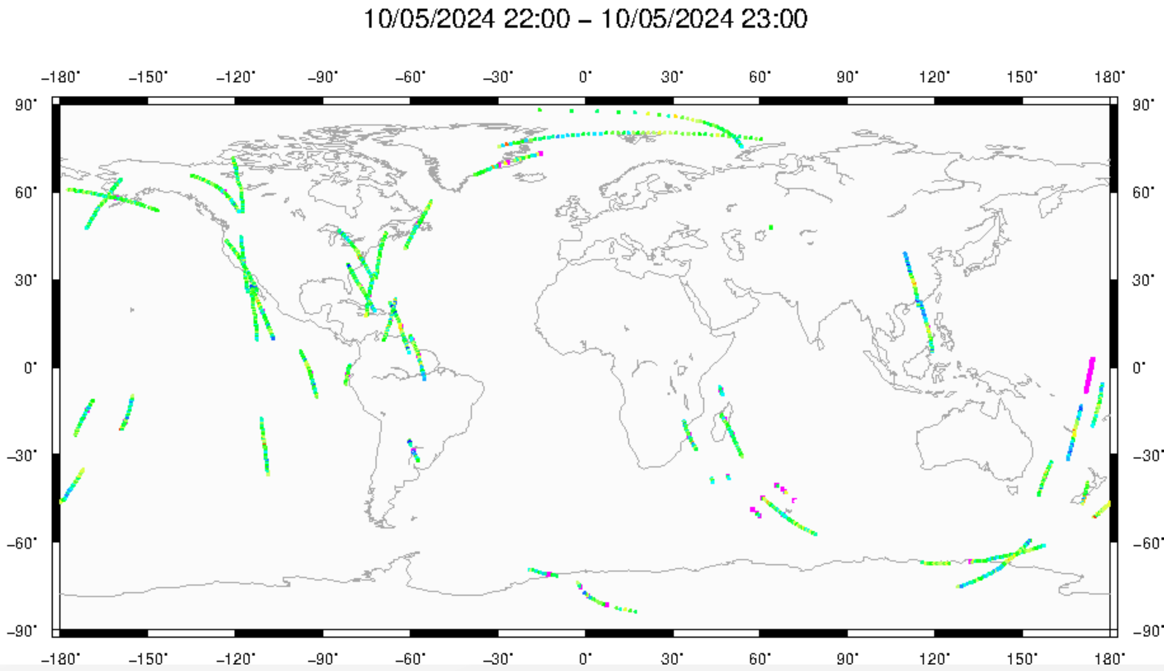
→Studied scintillation event : **February 17th, 2024** – σ_{Φ} = *0,85 rad.* Beacons that were not properly working when recording the event :



→ Least-square residuals of several satellites passing over DORIS beacons during the mid-May event. We can observe that higher residuals are recorded during the peak, and thus eliminated (represented in pink).

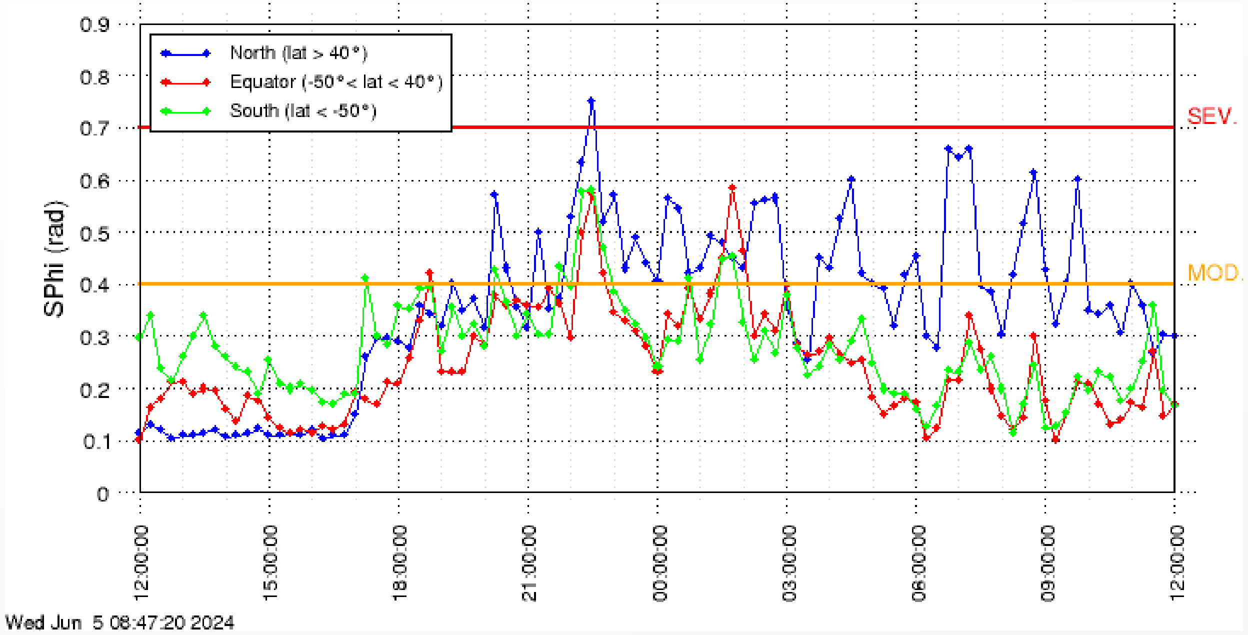


Ground track of DORIS satellites (10/05/2024)

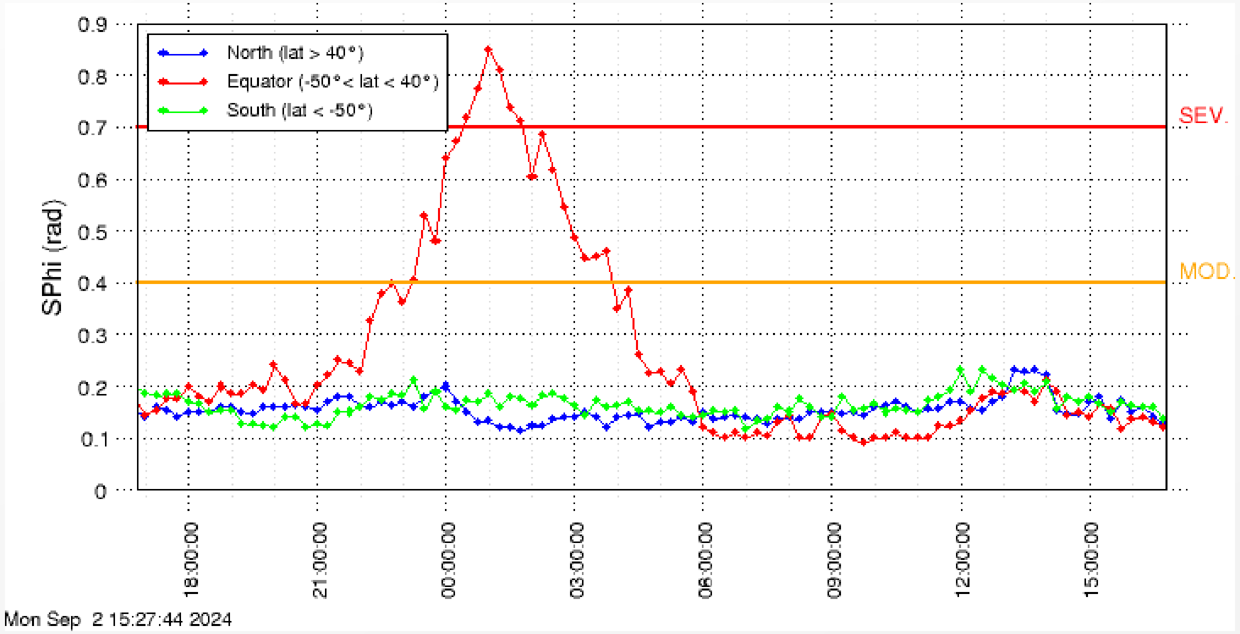


Residuals map of DORIS satellites passes (10/05/2024)

→ Plot of the maximum of phase scintillations (σ_{Φ}) during the mid-May event (on the left) et during the February 17th, 2024 event (on the right).

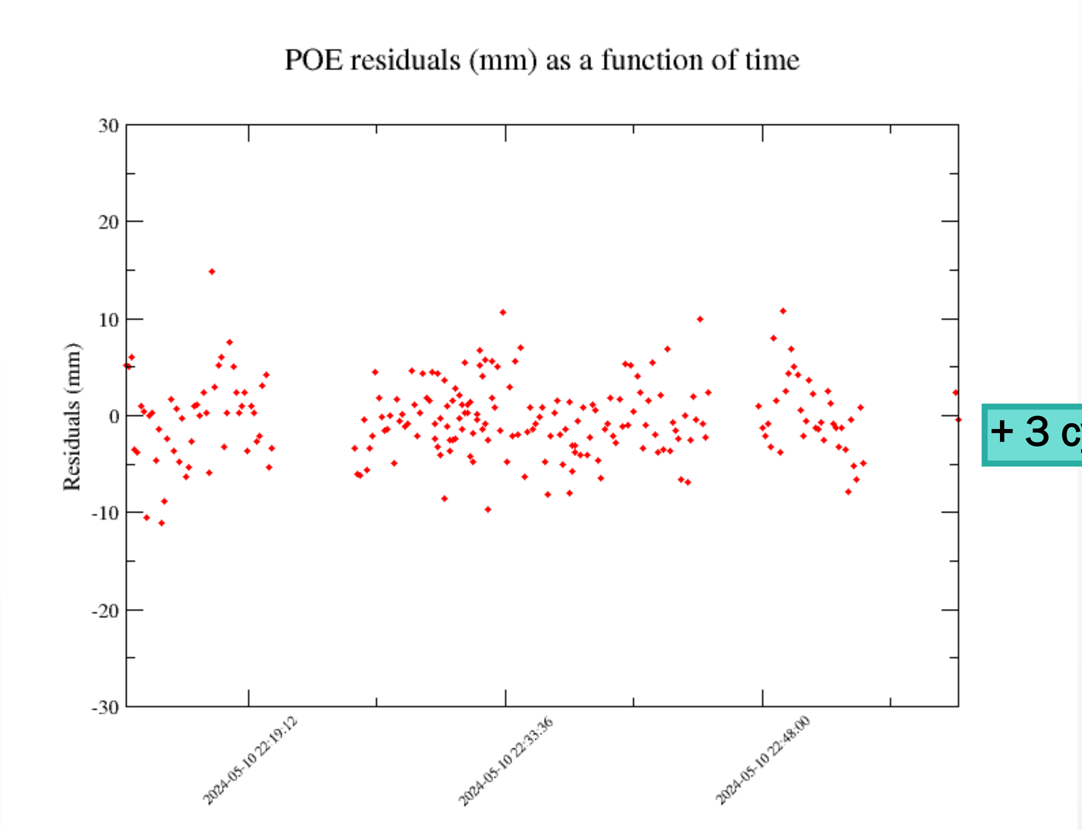


σ_{Φ} variations during the mid-May event



σ_{Φ} variations during the February 17th , 2024

→ Analysis of least-square residuals during the passage of Cryosat-2 through the scintillation zone during the mid-May event, compared to is passage during the third subsequent cycle (without scintillation).



+ 3 cycles