



# DISPEC

Scientific exploitation of space Data for improved Ionospheric SPECification

## **Spatiotemporal Characterization of the Electron Content in the Ionosphere**

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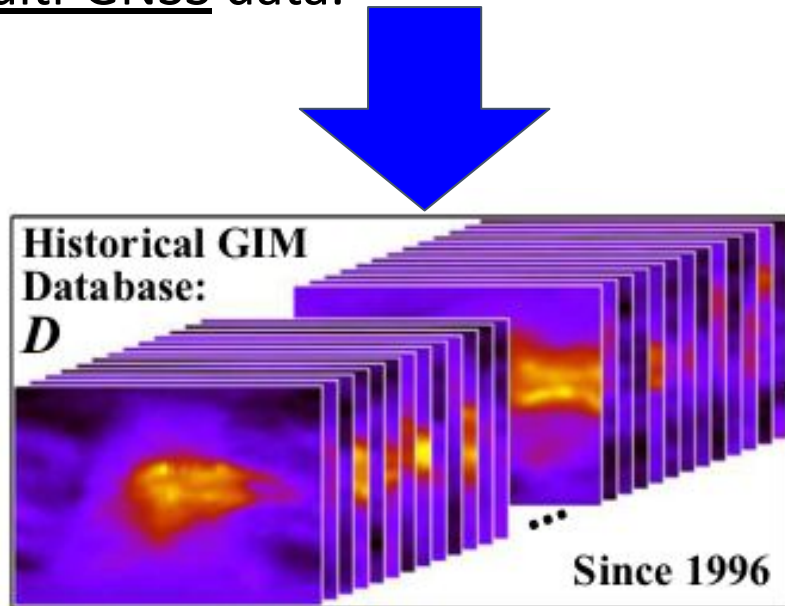
(1)UPC-IonSAT; (2)IEEC-UPC; (3)UPC-TALP ; (4) Henan University, (5)Yangtze Normal Univ.

**T-FORS Second Innovation Day, 4 December 2024**

# Dataset

- The UPC-IonSAT historical data set contains GIMs (Global Ionospheric Maps) computed every 15 mins since 1996.
- GIMs are 71 (lat) x 73 (lon) pixel-size images of the ionosphere.

Generation of data sets with TOMION software & multi-GNSS data.



- ❖ Long-Term Global 4D Ionospheric Time Series since 1996.
  - VTEC and VTEC gradient maps
  - Ne and Ne (v) gradient maps
  - DCB TS.
  - Global Electron Content TS
  - Iscale. Ionospheric Storm Index maps.

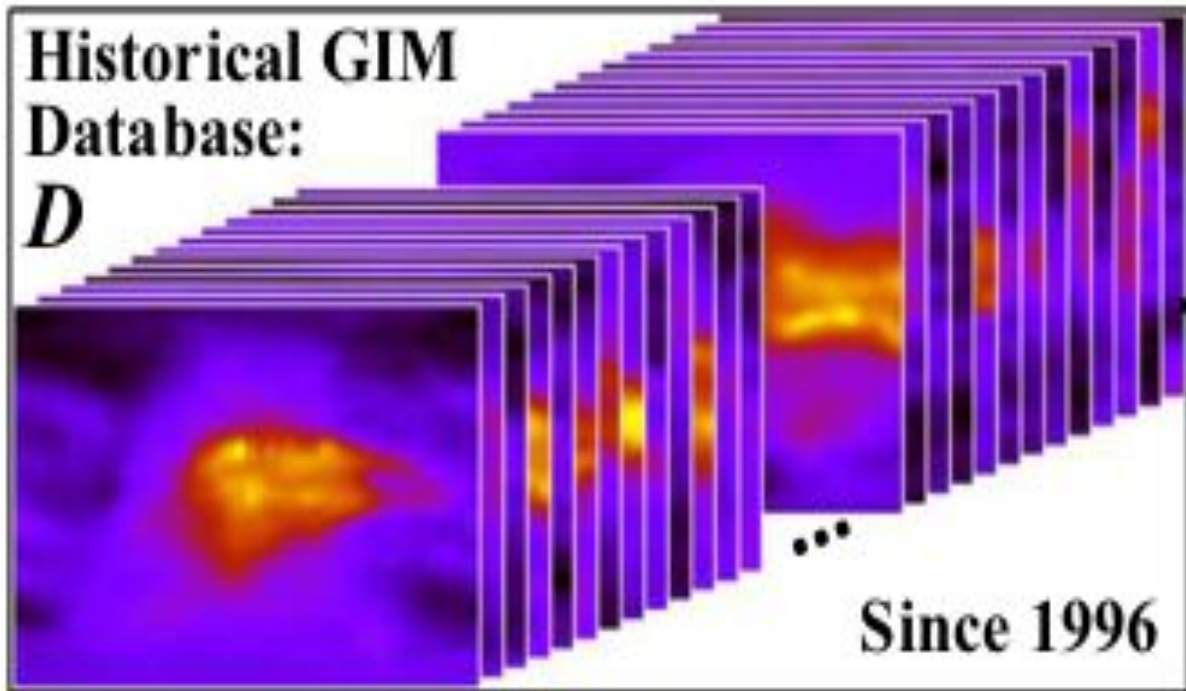


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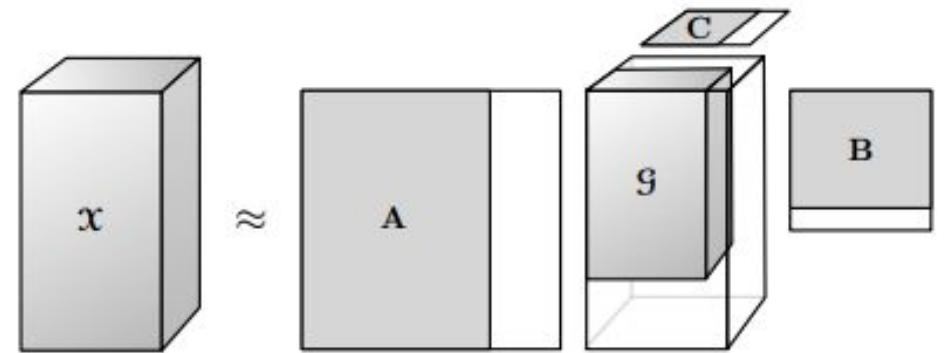
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# Higher Order SVD

- Time series of GIMs can be conceived as 3<sup>th</sup> order tensors.
- Singular Value Decomposition of 3<sup>th</sup> order tensors for long-term trends and spectral analysis.



Tucker decomposition or [Higher Order SVD](#)



- A, B, C: Lat, lon, time orthogonal basis.
- **Tensor products of two basis yield 2D maps.**

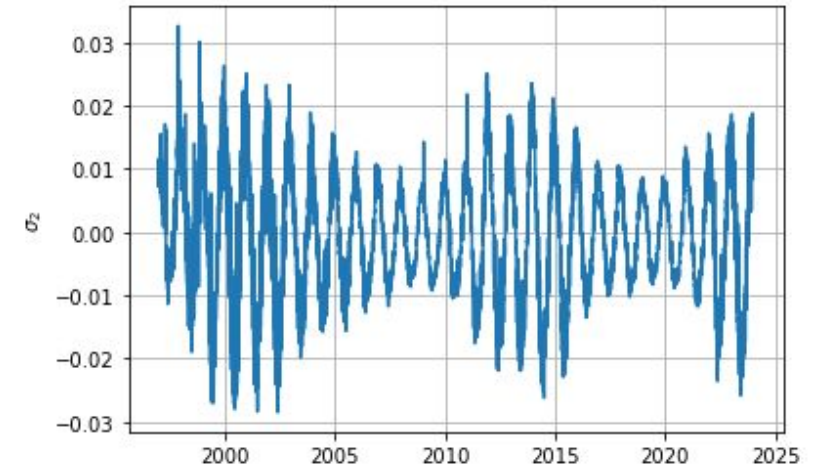
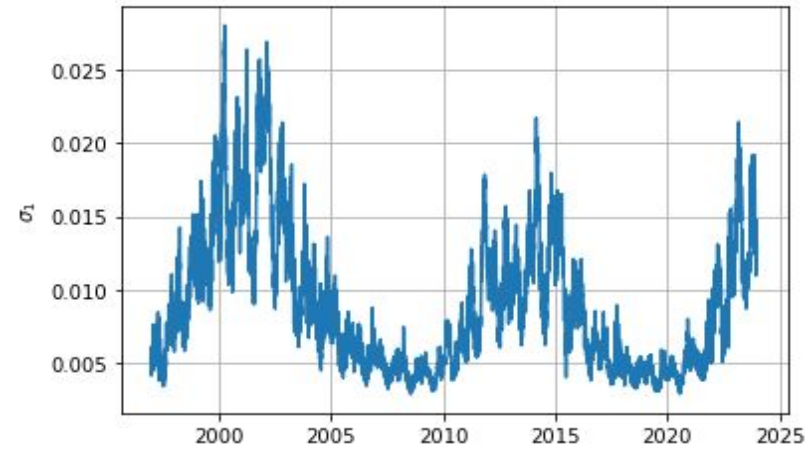


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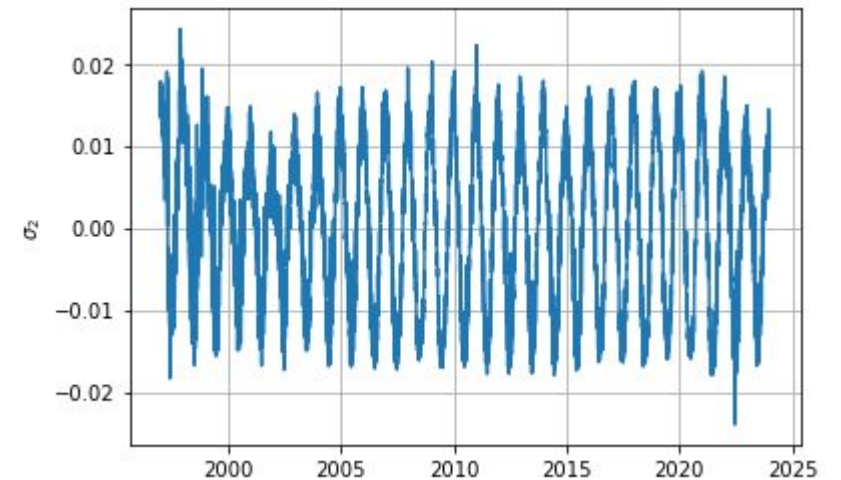
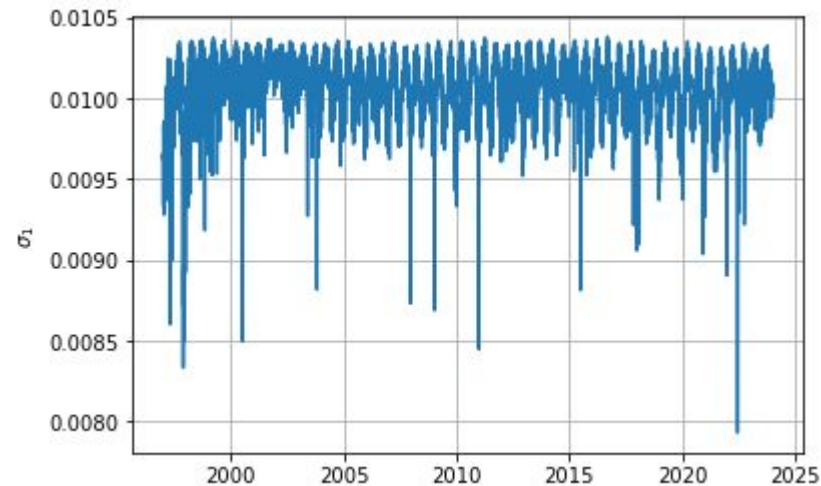
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# VTEC chronovectors

Chronovectors of  
GIMs



Chronovectors of  
normalized GIMs



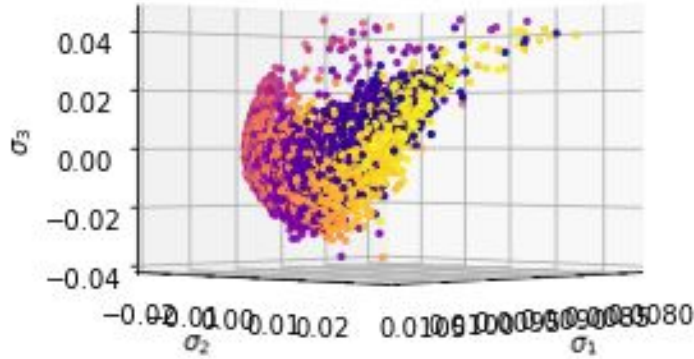
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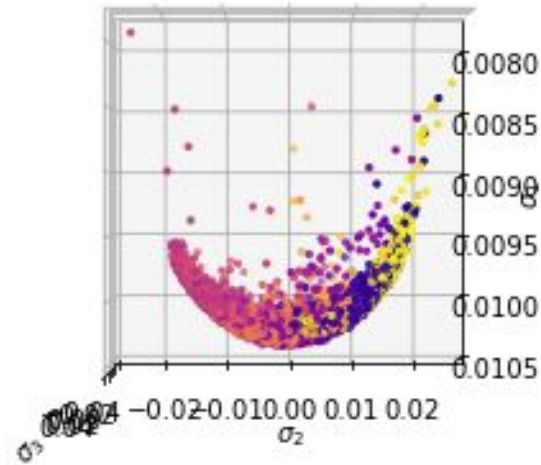
# VTEC Spatial Structures

## Normalized Gims

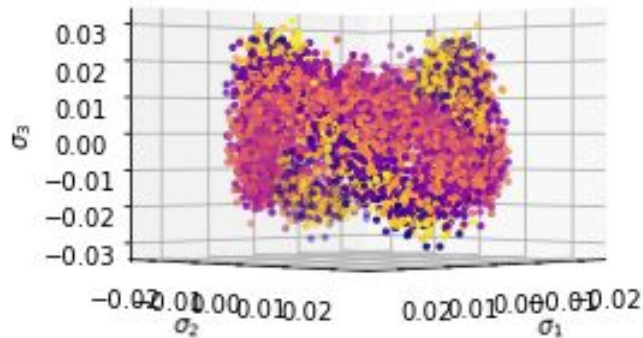
1997-2023



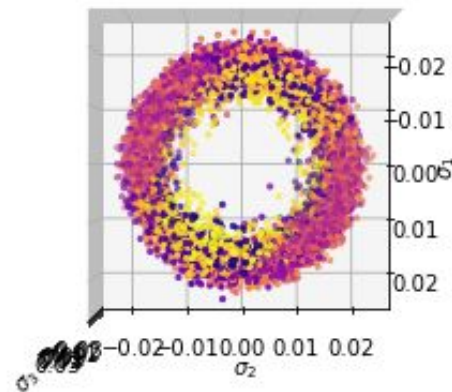
1997-2023



1997-2014



1997-2014

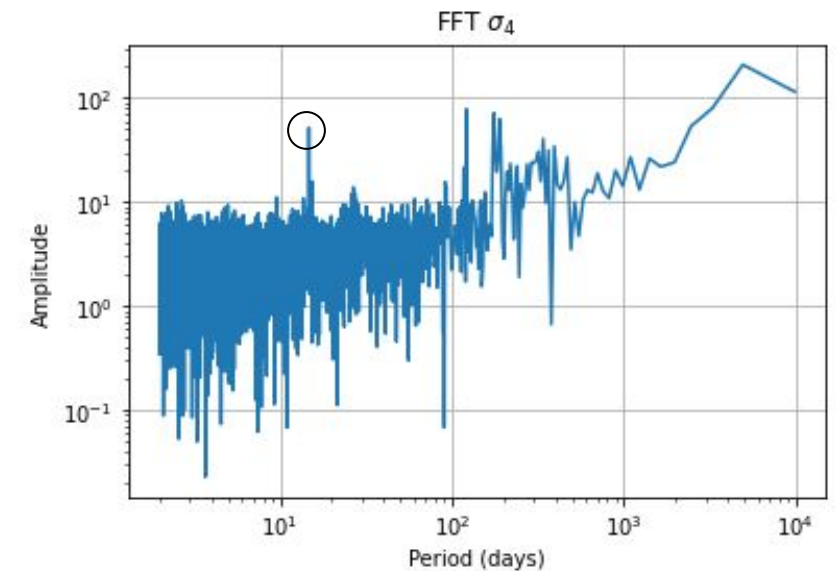
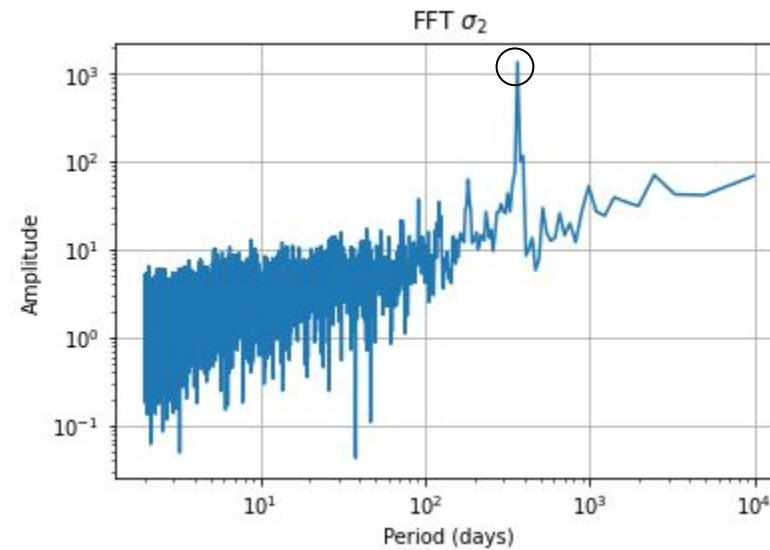
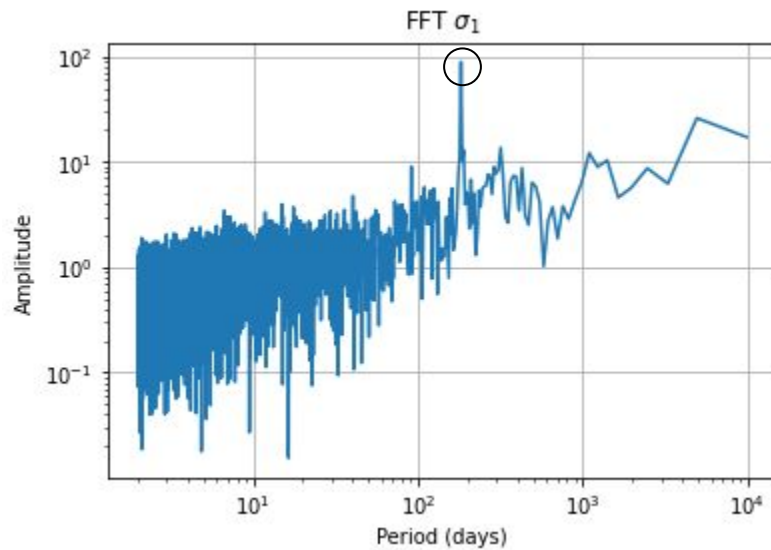


- **Top:** First 3 chronovectors of VTEC do not form closed orbits.
- **Bottom:** First 3 chronovectors of VTEC gradients form closed orbits.
- Potential development of forecast algorithms with longer time-windows for VTEC gradients.
- Color indicates season: **winter**, **spring**, **summer**, **autumn**.

# VTEC FFT chronovectors

1997-2023  
Norm Gims

FFT of orthogonal base of “time” vectors.

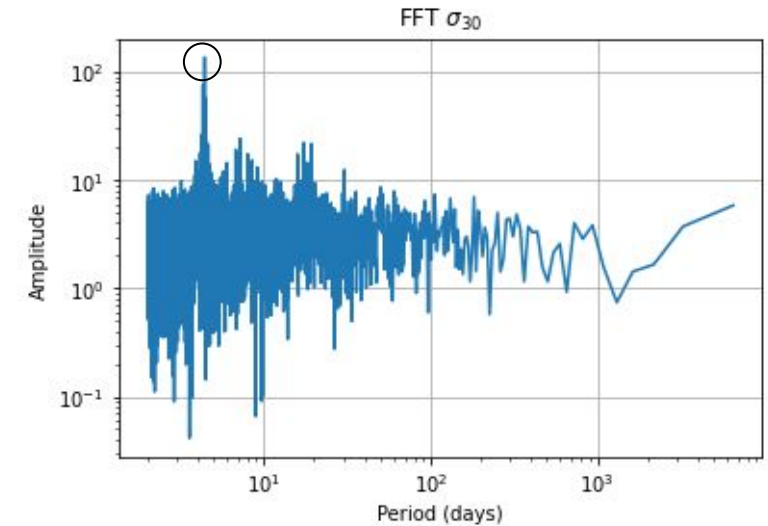
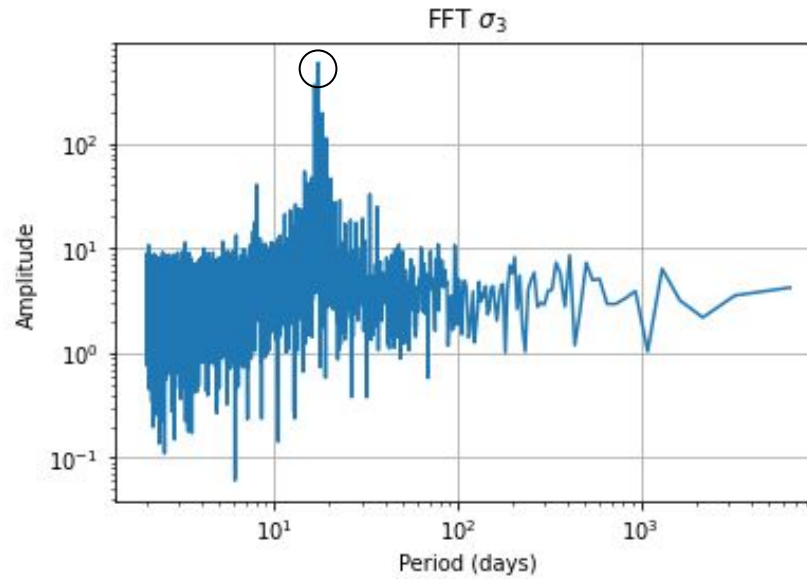
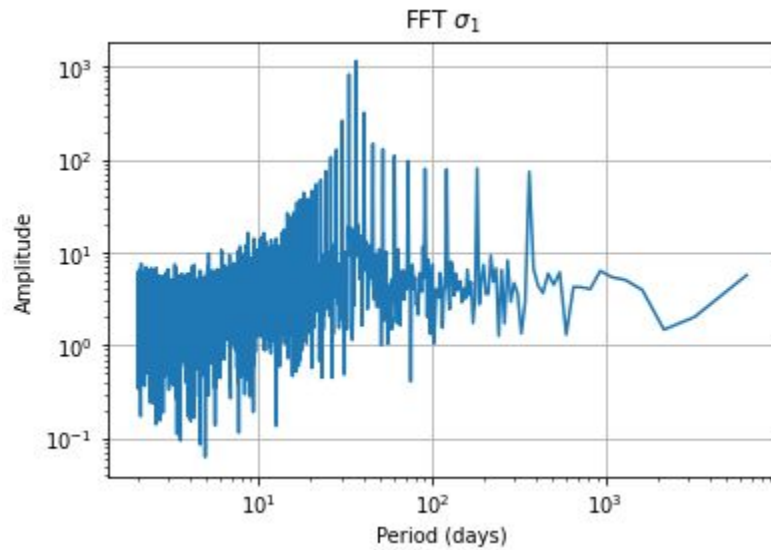


- Semiannual and annual peaks in the largest two modes
- The fourth mode presents a semimonthly peak.
- Semimonthly lunar tide modulation in foF2 has been previously reported, e.g. Tang et al. (2021).

# VTEC Ion gradient FFT chronovectors

1997-2014  
Norm Gims

FFT of orthogonal base of “time” vectors.



- Multimodal peaks in the largest two modes (the second is not shown).
- The third mode presents a semimonthly peak.
- Smaller modes present 4-5 days peaks.

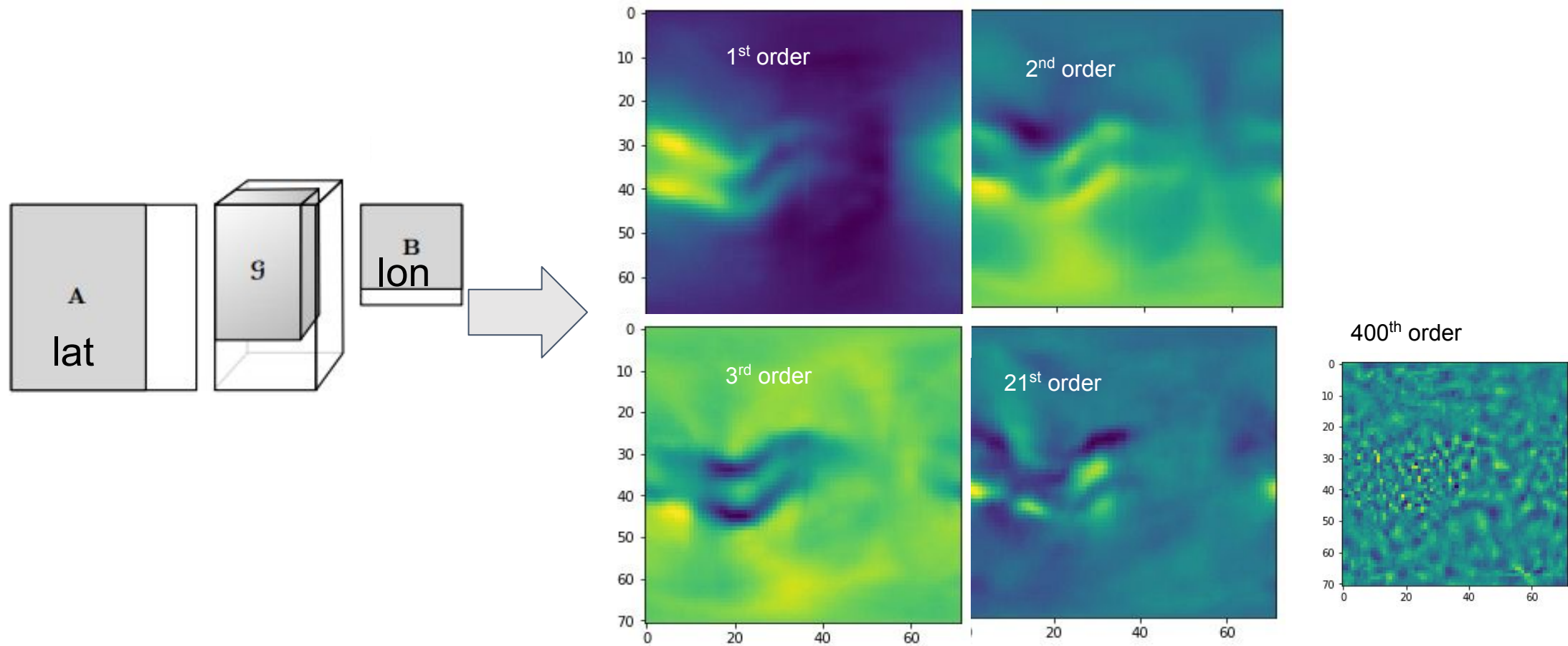


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# Geophysical structures. Spatial basis

- HOSVD provides a tool to analyse spatiotemporal structures.



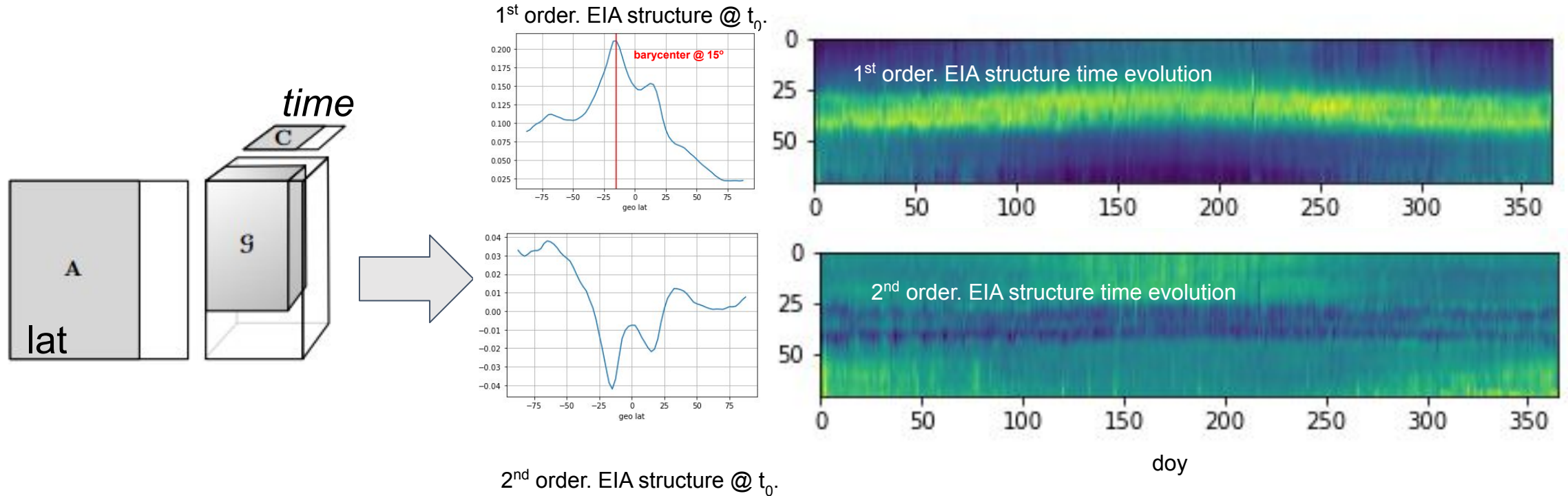
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# Geophysical structures. Lat-time basis

- HOSVD provides a tool to analyse spatiotemporal structures.

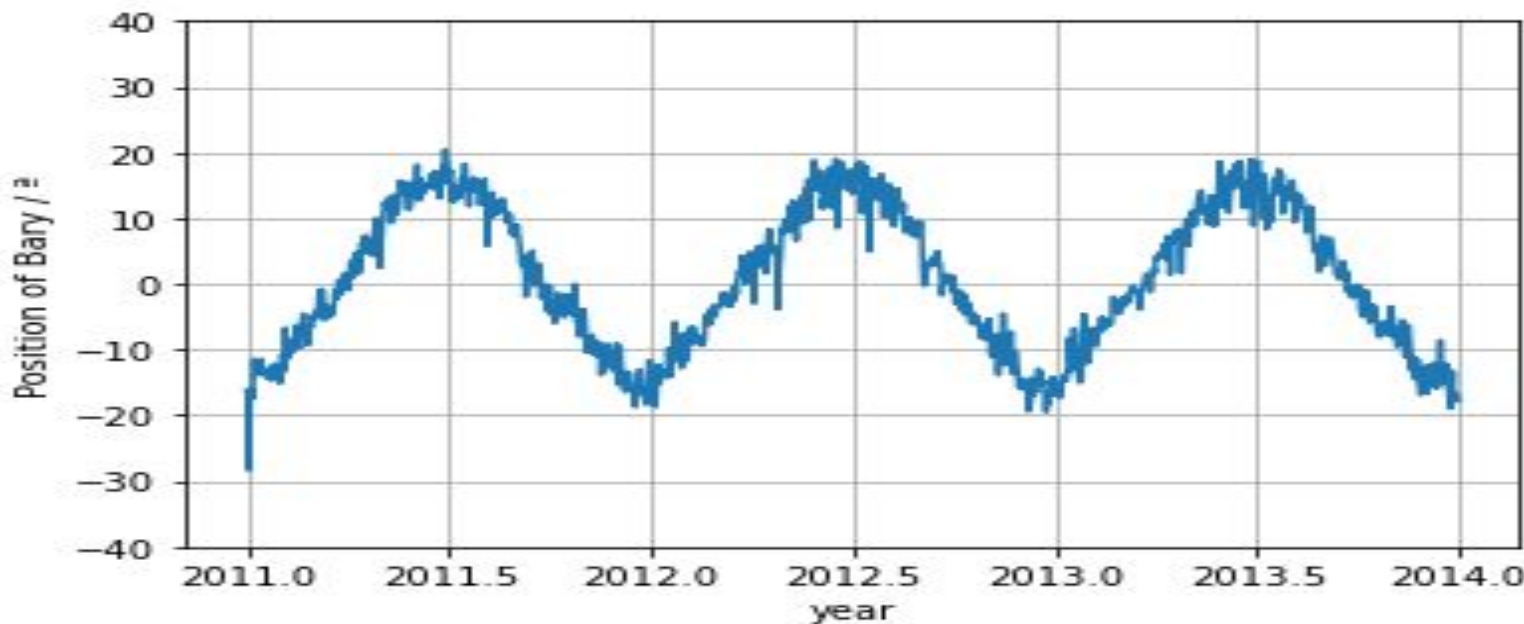
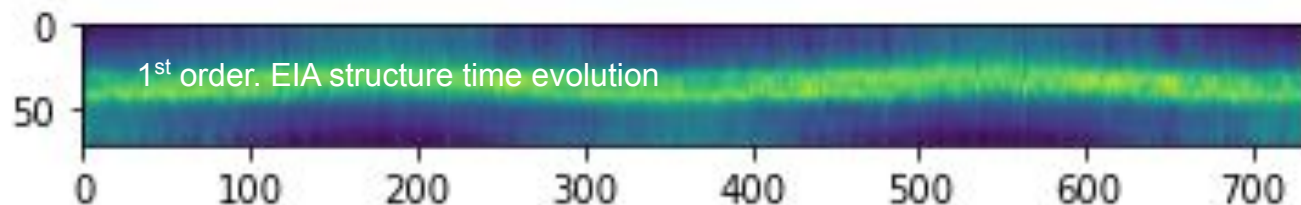


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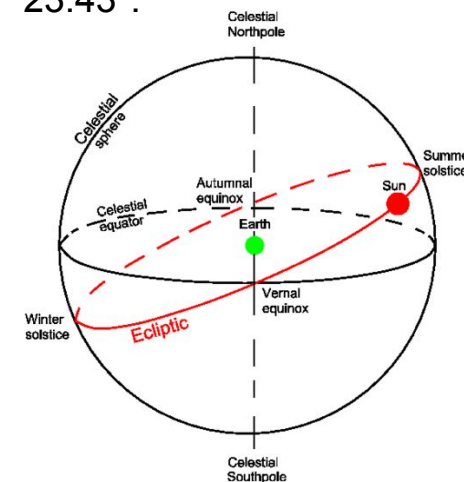
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# Geophysical structures. EIA oscillations

- HOSVD provides a tool to analyse spatiotemporal structures:
  - The EIA barycenter oscillates due to the angle with the ecliptic plane.



Angle between the celestial equator and ecliptic plane is  $23.43^\circ$ .

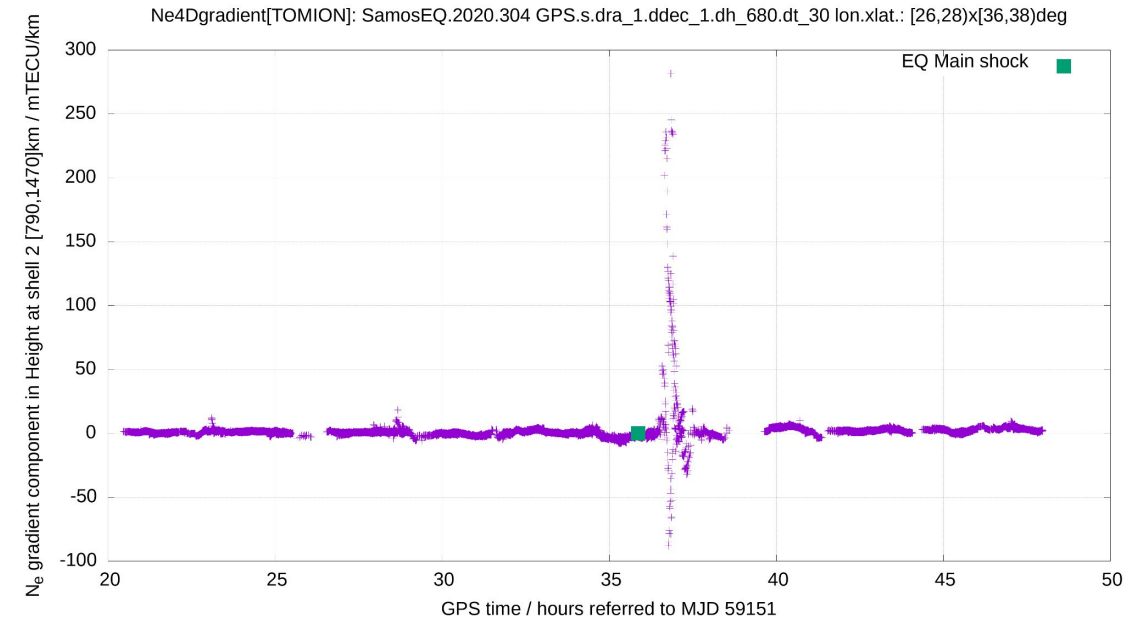
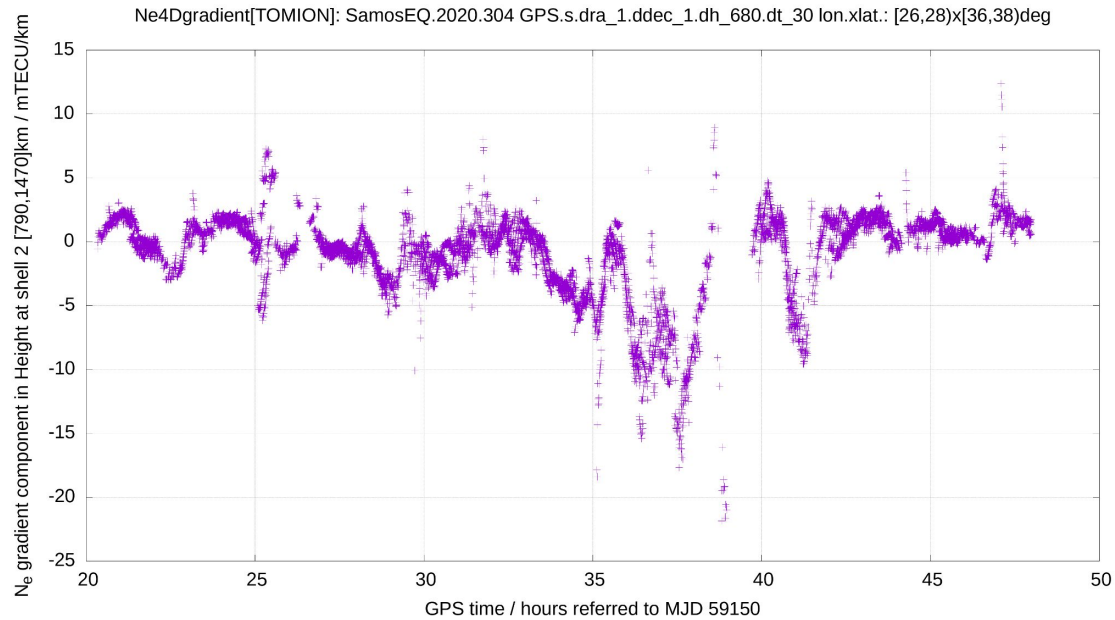


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# Geophysical structures. Samos Tsunami

- Dataset of Ne vertical gradients provides a tool to analyse spatiotemporal structures:
  - Tsunami generated by the 2020 Samos earthquake

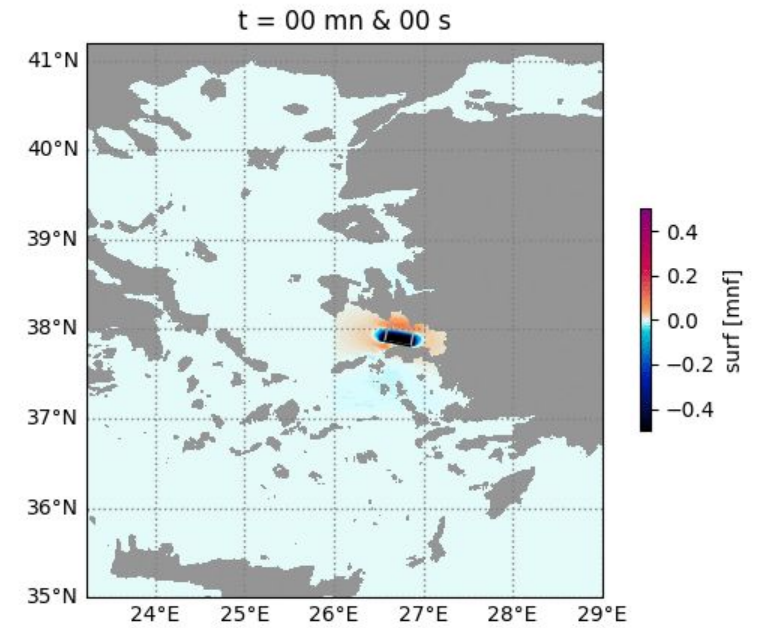
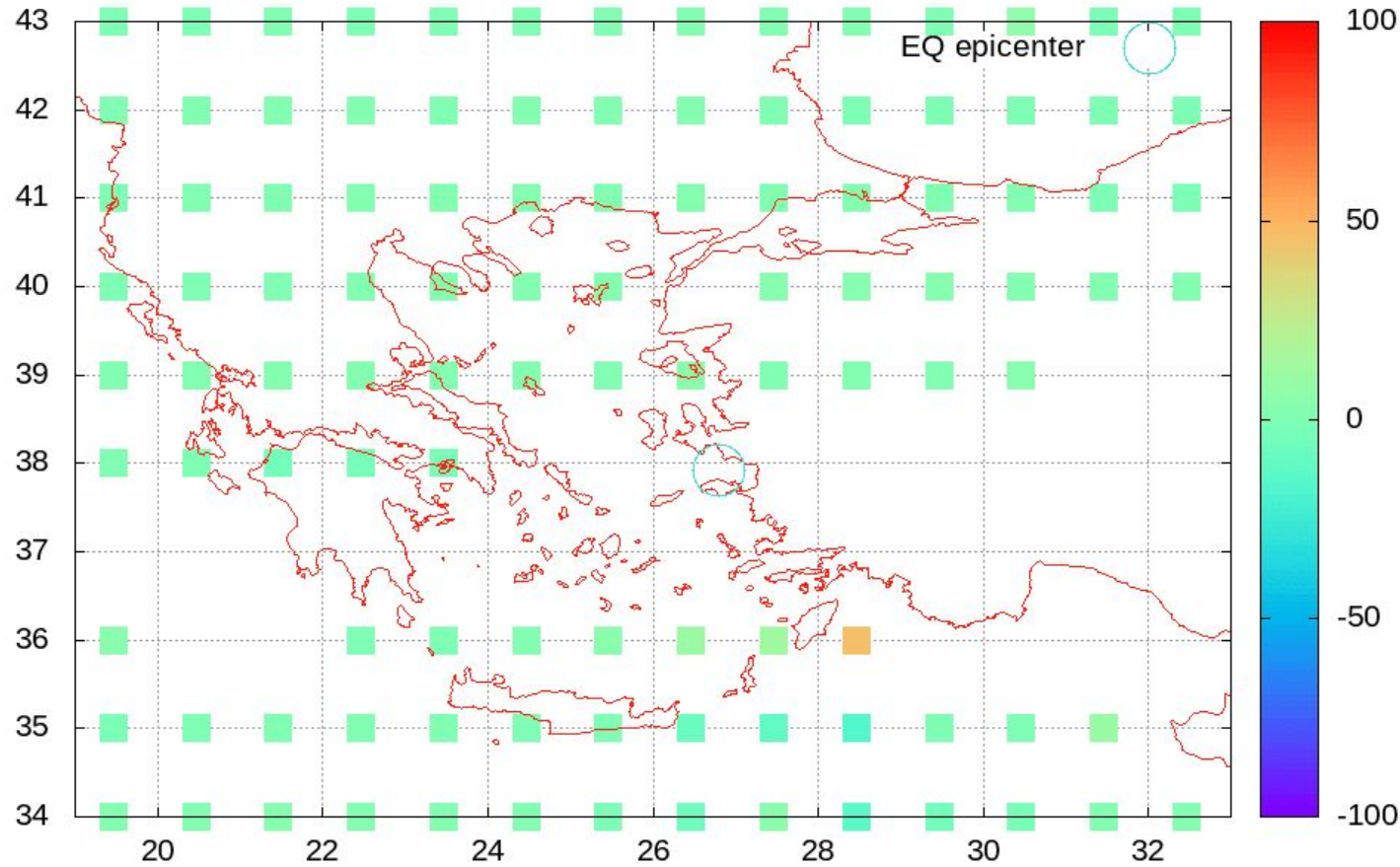


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# Geophysical structures. Samos Tsunami

Ne4Dgradient-dNedh-SamosEQ-tjdm59152.52291667 at height = 1130km (+ 41m 16s after EQ)

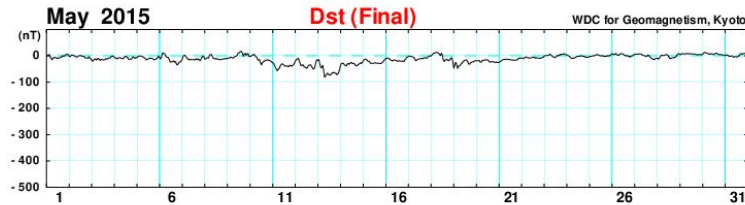


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# Iscale. Ionospheric Storm Scale Index

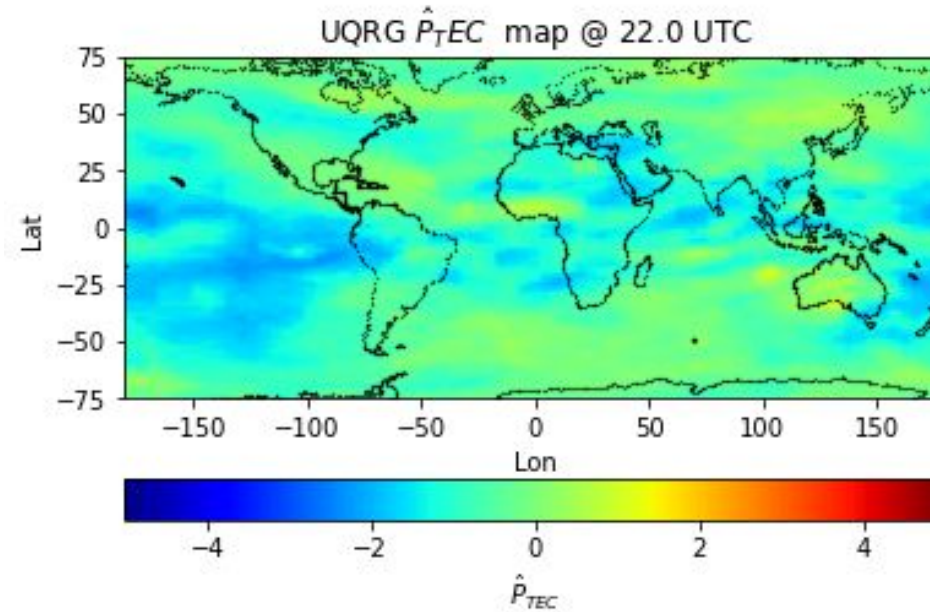
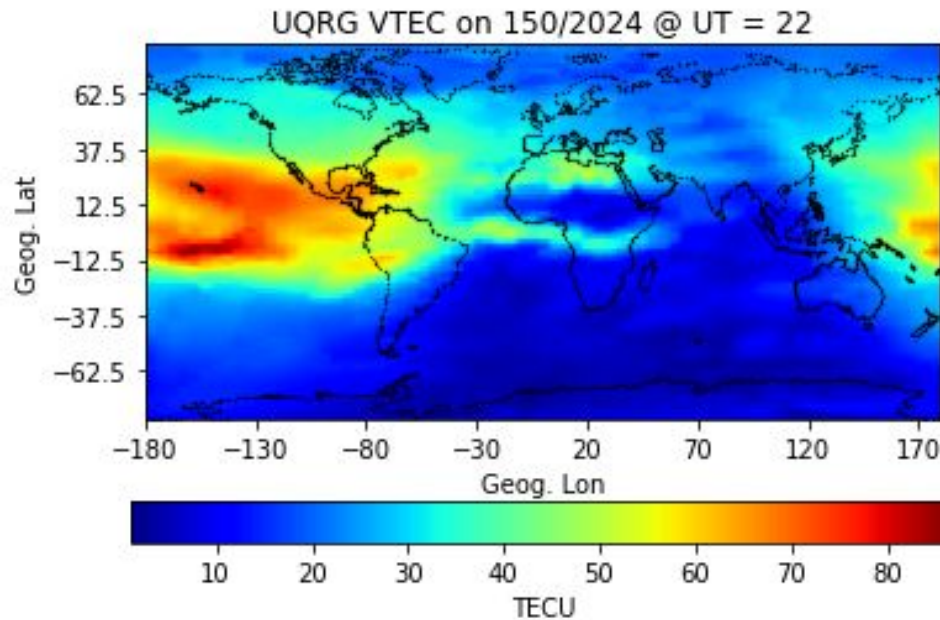
- **Iscale Index Maps.** GIMs can be used to characterize the state of the ionosphere.
- Example for quiet conditions. May 30<sup>th</sup> 2015



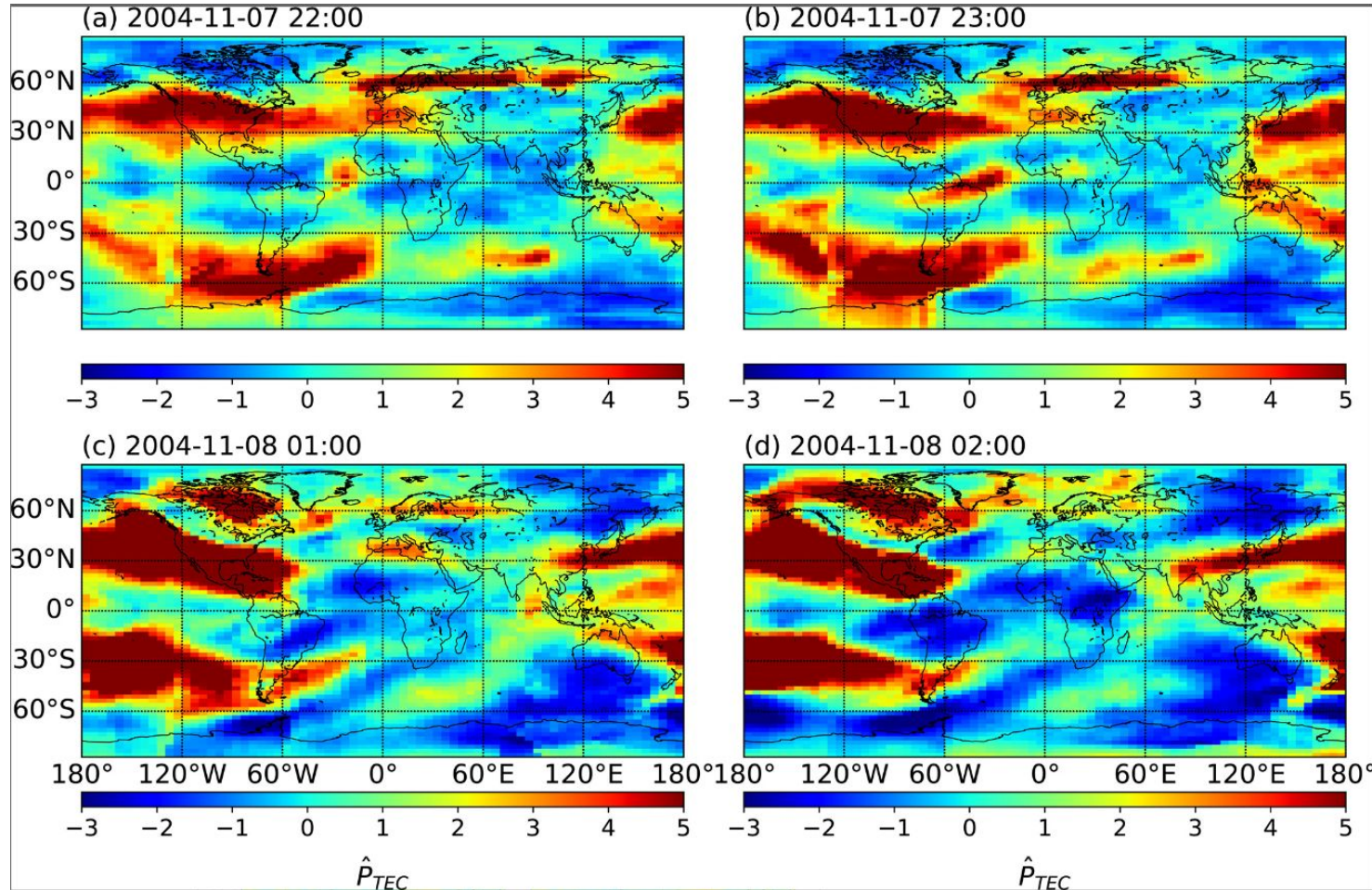
$$P_{TEC} = \frac{100 \times (G_{TEC} - R_{TEC})}{R_{TEC}}$$

$$\hat{P}_{TEC} = \frac{P_{TEC} - \mu}{\sigma}$$

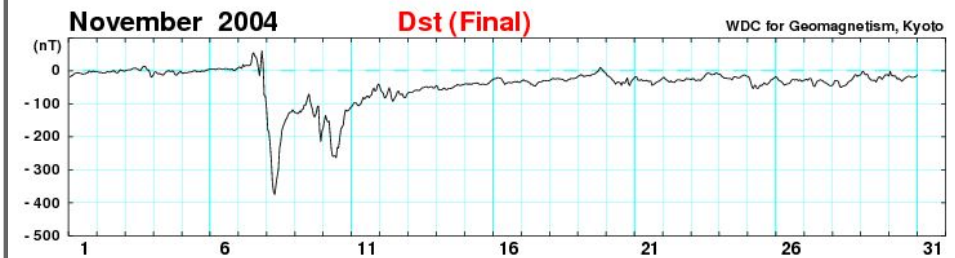
- $G_{TEC}$ : Hourly VTEC
- $R_{TEC}$ : Median of the  $G_{TEC}$  for the last 27 days @ the same local time and geographical location.



# Iscale. Ionospheric Storm Scale Index



- November 2004 G5 geomagnetic storm. Kp 9
- Displacement of the EIA lobes.



- From Liu, Q., Hernández-Pajares, M., Lyu, H., Nishioka, M., Yang, H., Monte-Moreno, E., Gulyaeva, T., Béniguel, Y., Wilken, V., Olivares-Pulido, G. and Orús-Pérez, R., 2021. Ionospheric storm scale index based on high time resolution UPC-IonSAT global ionospheric maps (IsUG). *Space Weather*, 19(11), p.e2021SW002853.

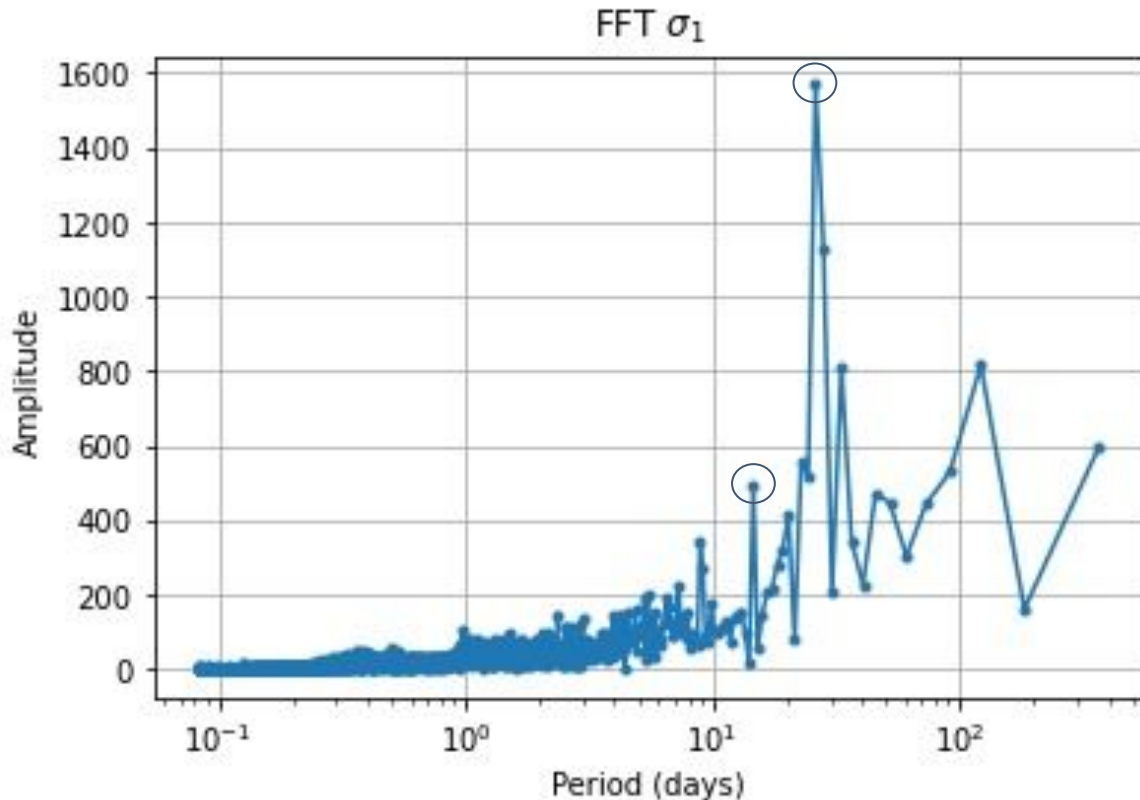


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# HOSVD. Iscale FFT chronovector

- Preliminary results. Hourly Iscale maps from 2015.



- FFT of the first-order chrono-vector.
- Highest peak @27 days
- Semimonthly peak.
- Other peaks to be identified.

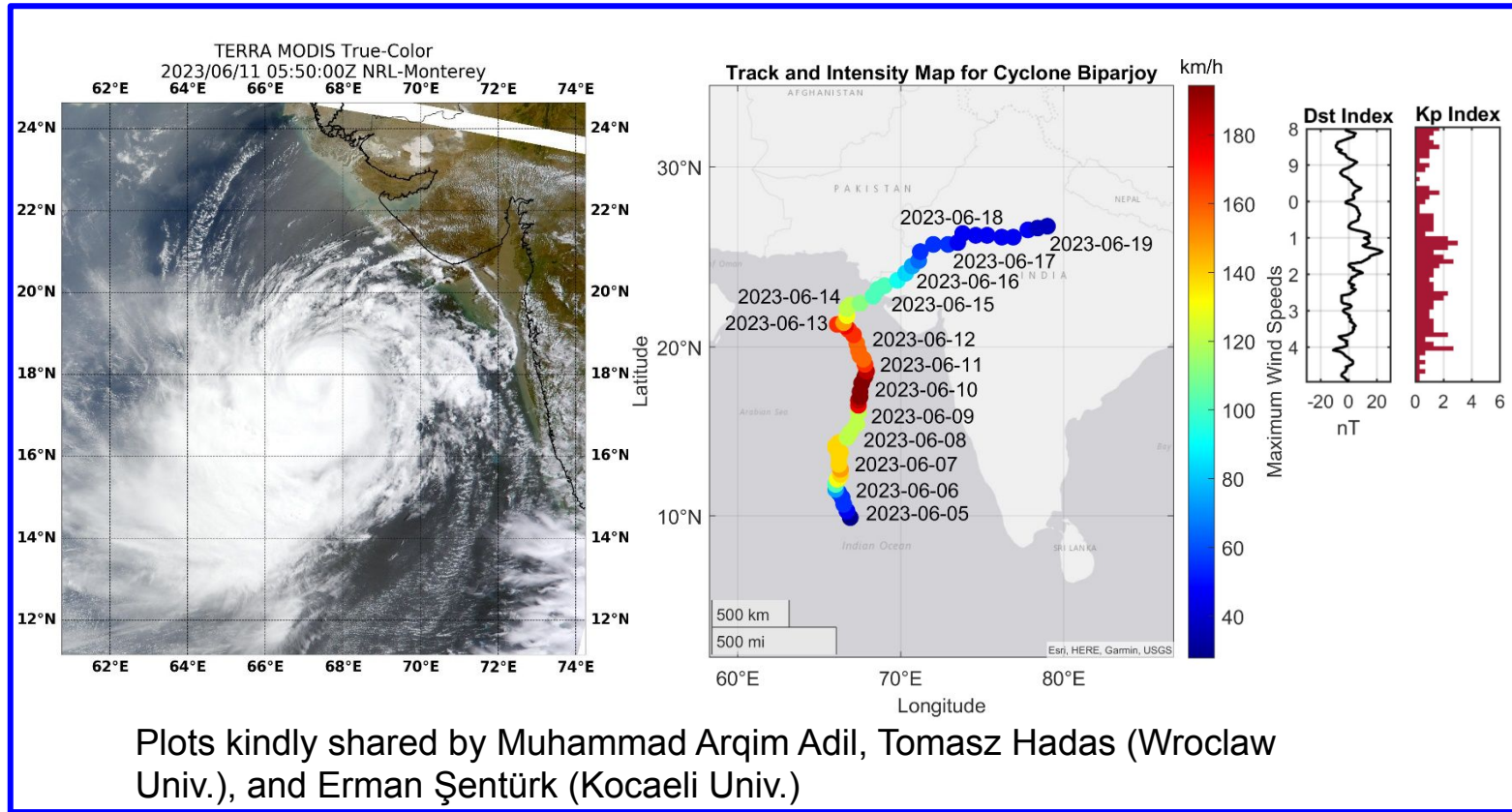


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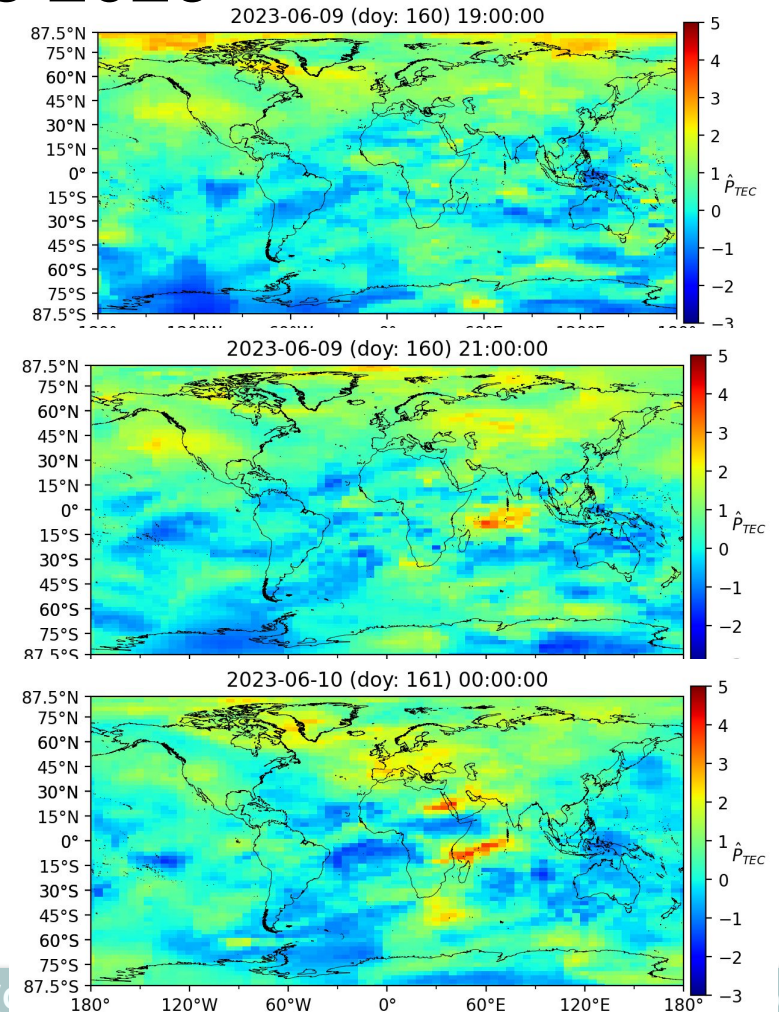
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# Geophysical structures. Cyclones

- Iscale maps provide a tool to analyse spatiotemporal structures:
  - geophysical events: Cyclone Biparjoy, June 2023



Plots kindly shared by Muhammad Arqim Adil, Tomasz Hadas (Wroclaw Univ.), and Erman Şentürk (Kocaeli Univ.)



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however



# Conclusions

- UPC-IonSAT two-solar-cycle data set of GIMS provides enough data to analyse and characterize spatiotemporal structures.
- HOSVD is a tool for spatiotemporal characterization of GIMs.
- HOSVD, as opposed to SVD, preserves spatiotemporal structures.
- HOSVD characterizes seasonal structures (annual, semiannual, semimonthly, ecliptic oscillation of the EIA).
- Geophysical phenomena that impact the ionosphere can be detected in the dataset and products, e.g. cyclones in Iscale maps, tsunamis in time series of Ne vertical gradients.



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# Thank you for your attention!

**WEB:** <https://dispec.eu>



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- [2] Liu, Q., Hernández-Pajares, M., Yang, H., Monte-Moreno, E., García-Rigo, A., Lyu, H., Olivares-Pulido, G. and Orús-Pérez, R., 2022. A New Way of Estimating the Spatial and Temporal Components of the Vertical Total Electron Content Gradient Based on UPC-IonSAT Global Ionosphere Maps. *Space Weather*, 20(2), p.e2021SW002926.
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