DISPEC

Scientific exploitation of space Data for improved Ionospheric

SPECification

SDA4: Proxies for geophysical phenomena and long term trends

DISPEC 2nd Networking Meeting, 11/02/2025

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SD4. Context

- The historical data sets of VTEC, VTEC gradient, and Iscale GIMs; Ne, dNe/dz grids; and DCB and GEC time series provide a tool for the characterization of long-term spatio-temporal patterns in the ionosphere.

- Abrupt high-energy phenomena such as, earthquakes, tsunamis, volcanic eruptions, may appear as outliers within such long-term patterns.

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SD4. Methodology

- Analysis of long term spatiotemporal features.
  - ➢HOSVD
- Detection and characterization of geophysical phenomena.
  - ➢Abrupt changes in long-term patterns.

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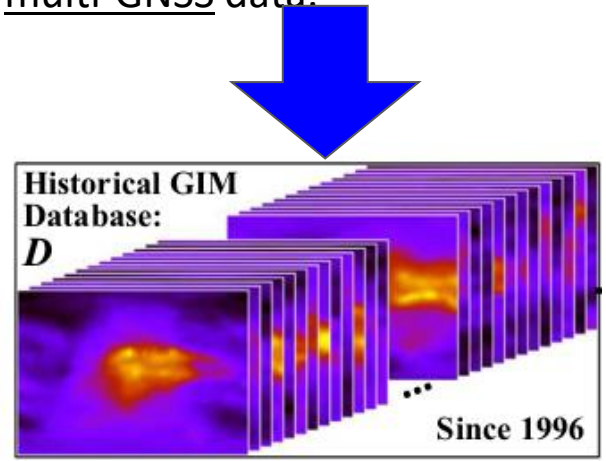
SD4. Historical Data Sets

- 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.



❖ Historical Data Sets (since 1996).

- ➢ VTEC and VTEC gradient maps
- ➢ Ne and Ne (v) gradient maps
- ➢ DCB Time Series.
- ➢ Global Electron Content TS
- ➢ Iscale. Ionospheric Storm Index maps.

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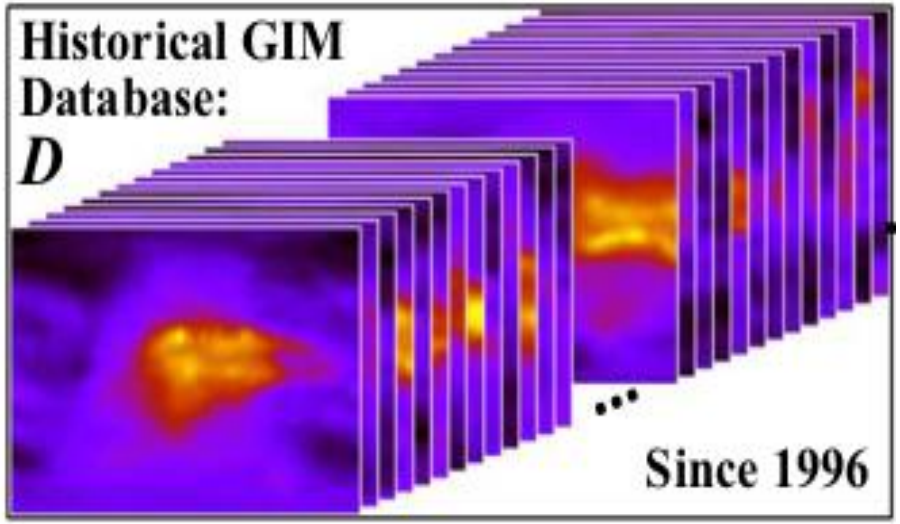
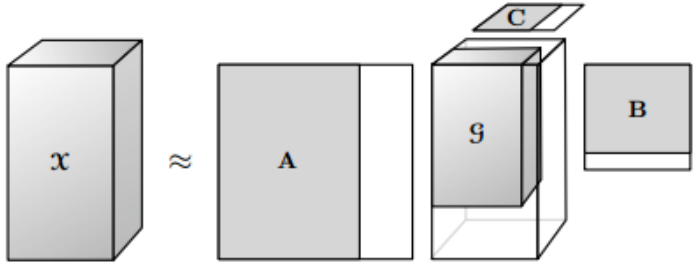
SD4. Spatio-temporal analysis

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



Tucker decomposition or
Higher Order SVD



- **A**, **B**, **C**: Lat, lon, time orthogonal basis.
- **G** core tensor indicates the interaction between basis.
- **Tensor products of two basis yield 2D maps.**

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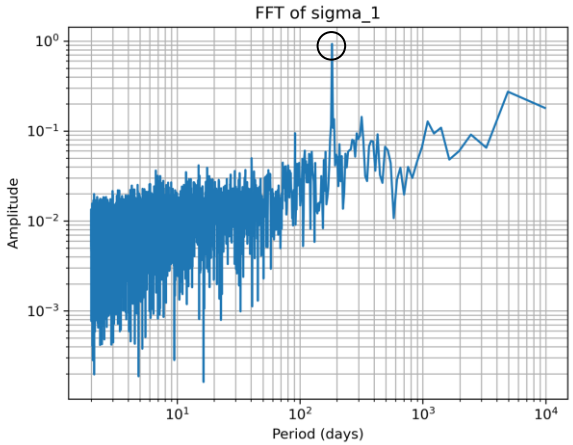
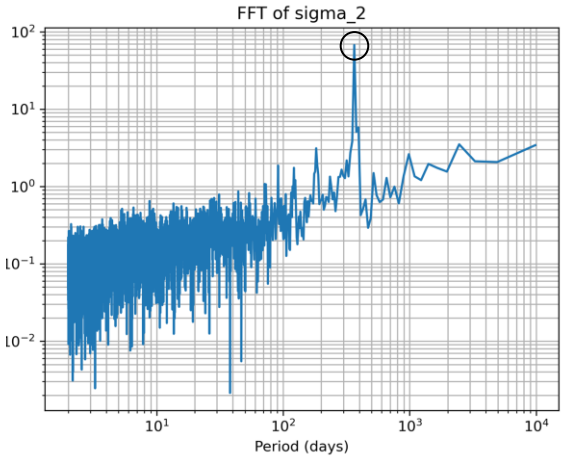
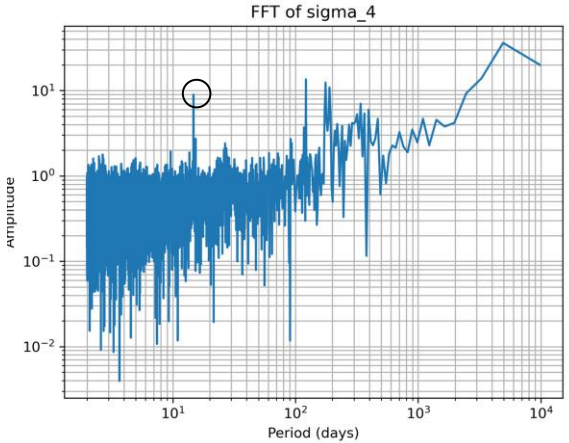
SD4. Spatio-temporal analysis

1997-2023
Norm Gims

FFT of orthogonal base of “time” vectors.







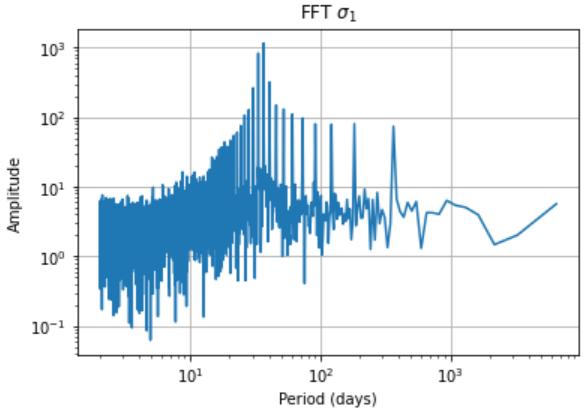
- Semiannual and annual peaks in the largest two modes
- The fourth mode presents a semimonthly peak.
- Semimonthly lunar tide modulation in foF2 has been previously reported, e.g. Tang et al. (2021).

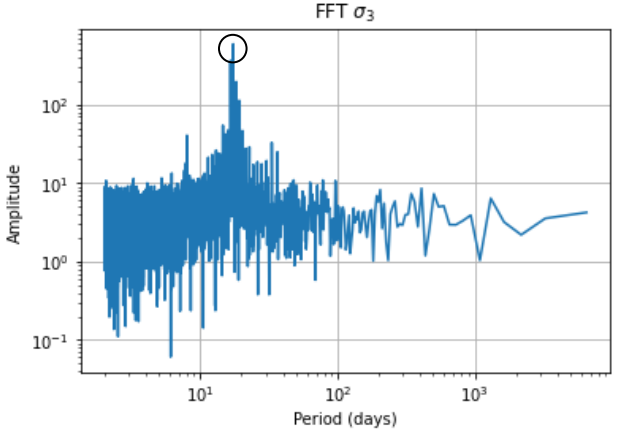
Tang Q, Zhou C, Li ZS, Liu Y, Chen GY. Semi-Monthly Lunar Tide Oscillation of foF2 in Equatorial Ionization Anomaly (EIA) Crests During 2014–2015 SSW. Journal of Geophysical Research: Space Physics. 2021 Feb;126(2):e2020JA028708.

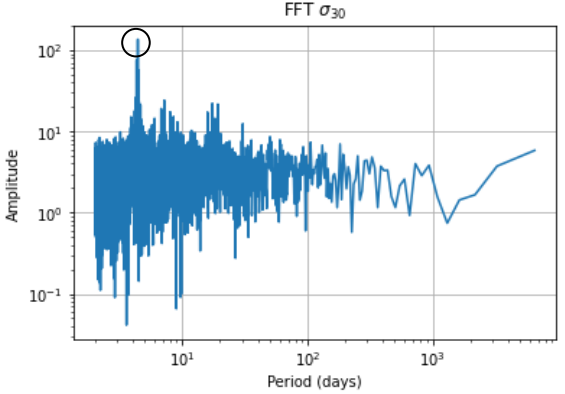
SD4. Spatio-temporal analysis

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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SD4. Spatio-temporal analysis

1. Both VTEC and VTEC gradient GIMs present time and spatial structures.
2. Both VTEC and gradient VTEC present:
   - 11-years, biannual, annual and semiannual periods.
   - Subannuals periods are important for the largest 2 SV in lon grad VTEC.
   - Both data sets present semi-monthly lunar tidal periodicity at high-order SVs (third and above).

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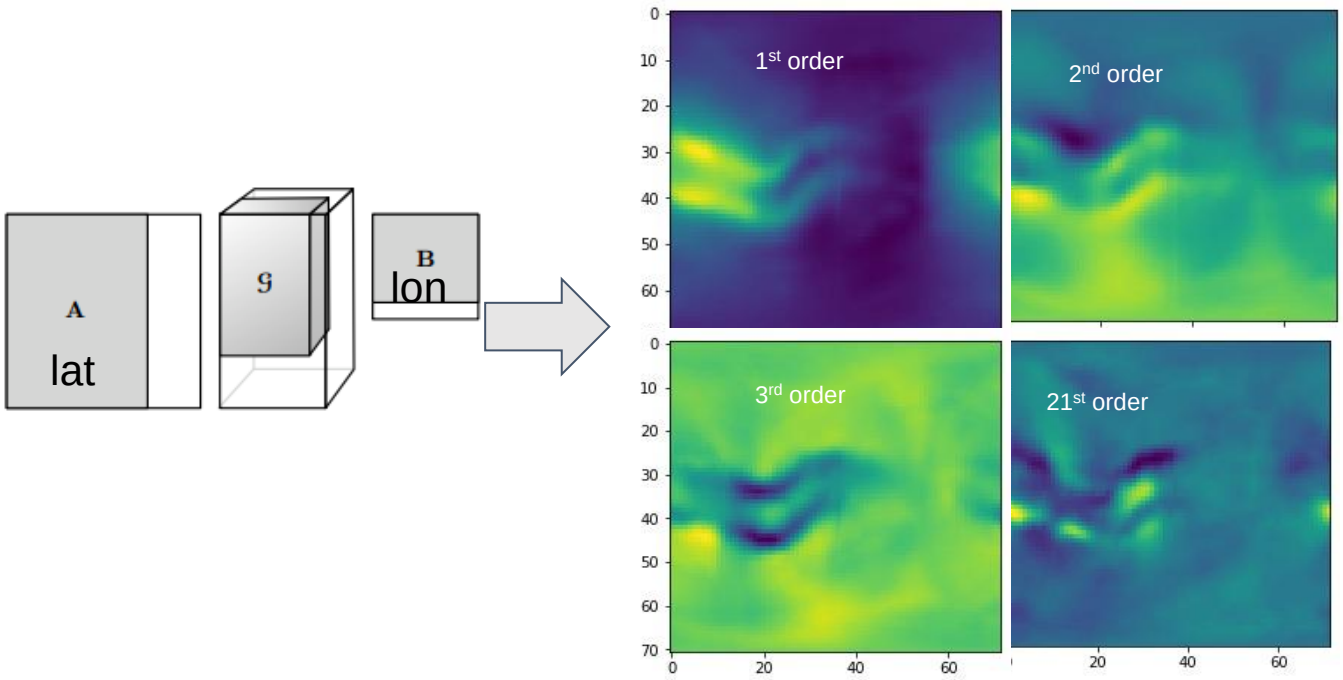
SD4. Spatio-temporal analysis

- HOSVD provides a tool to analyse spatiotemporal structures.



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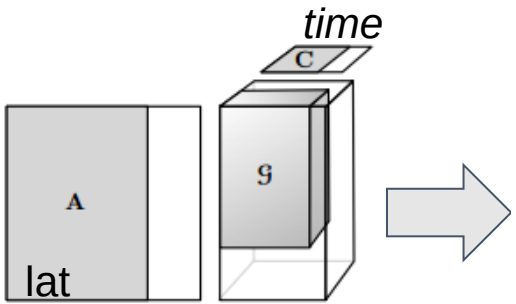
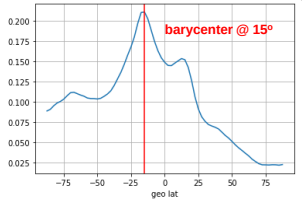
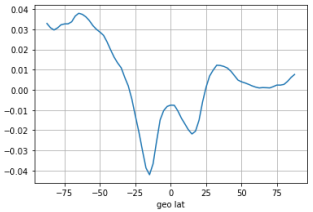
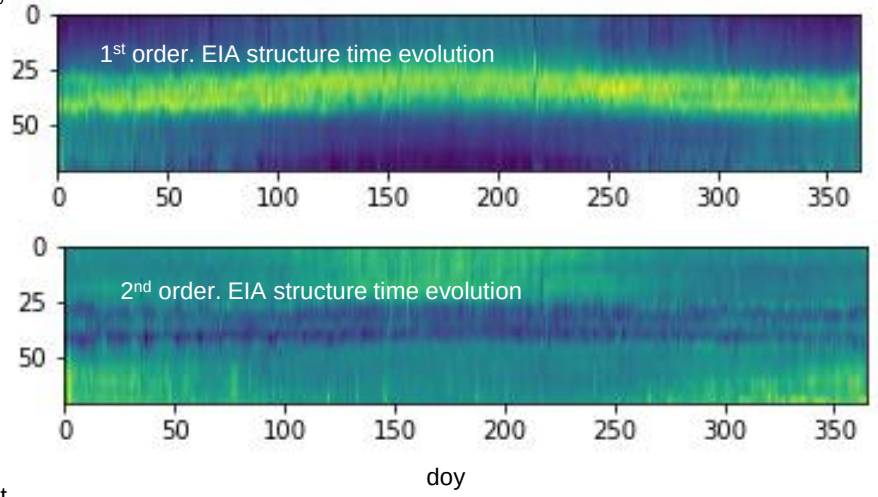


1st order. EIA structure @ t_0.





2nd order. EIA structure @ t_0.



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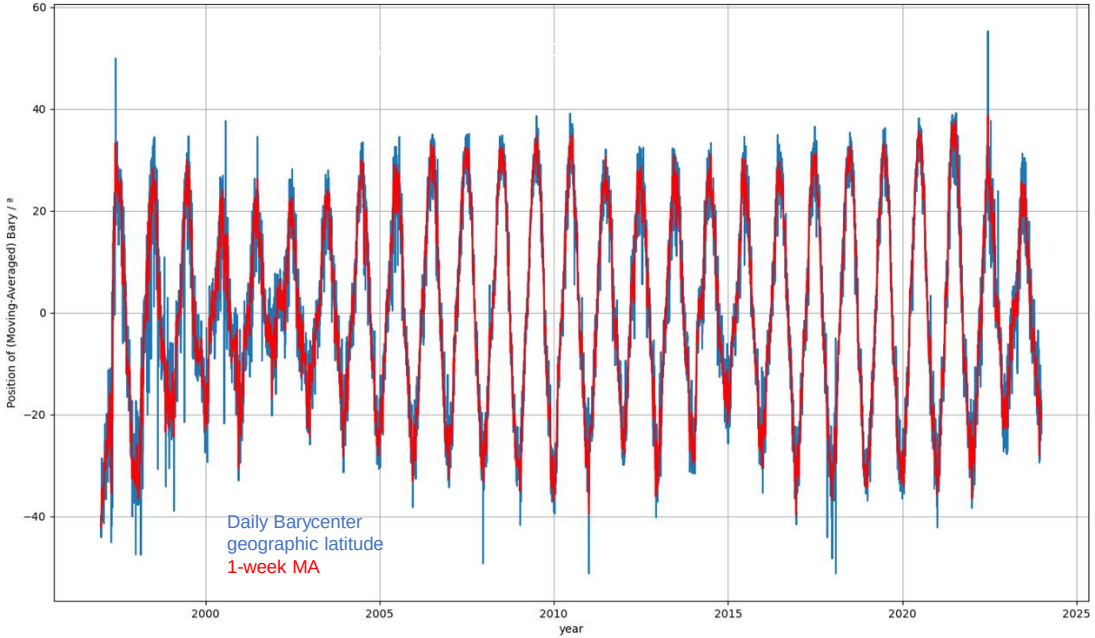
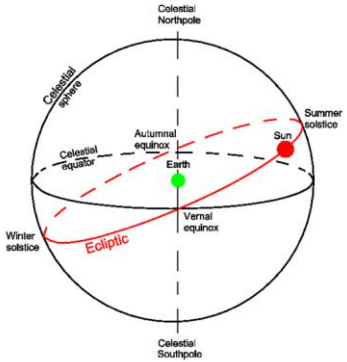
SD4. Spatio-temporal analysis

- 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 23.43º.



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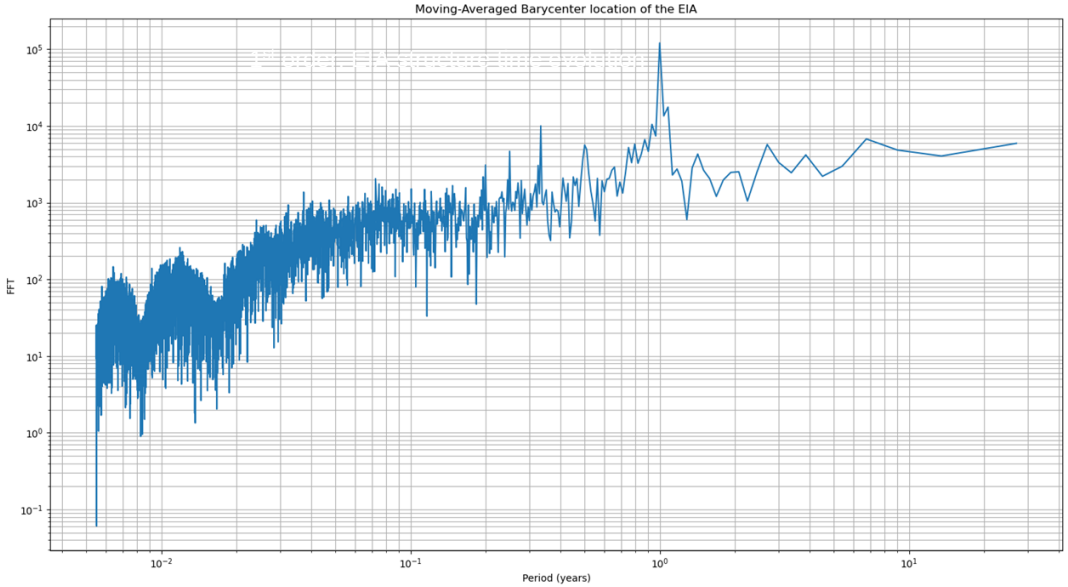

- Largest mode is the annual modulation.
- 2nd and 3rd modes are seasonal and half-year periods.

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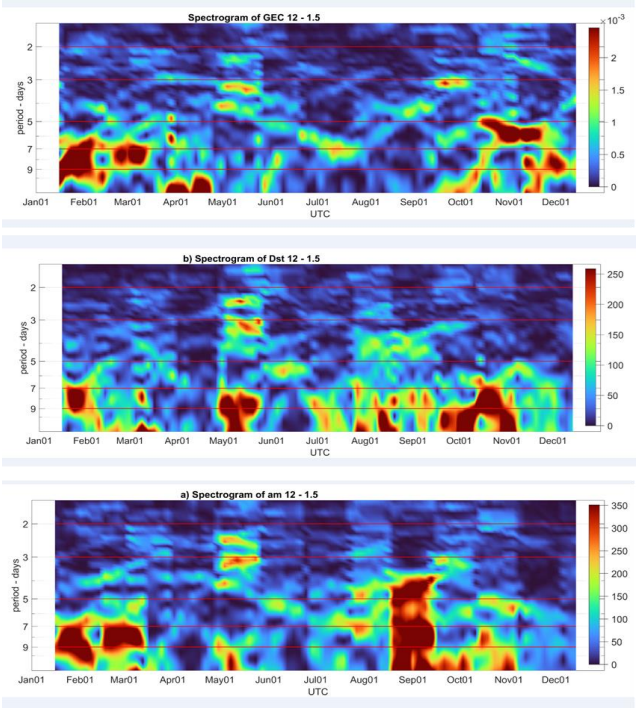
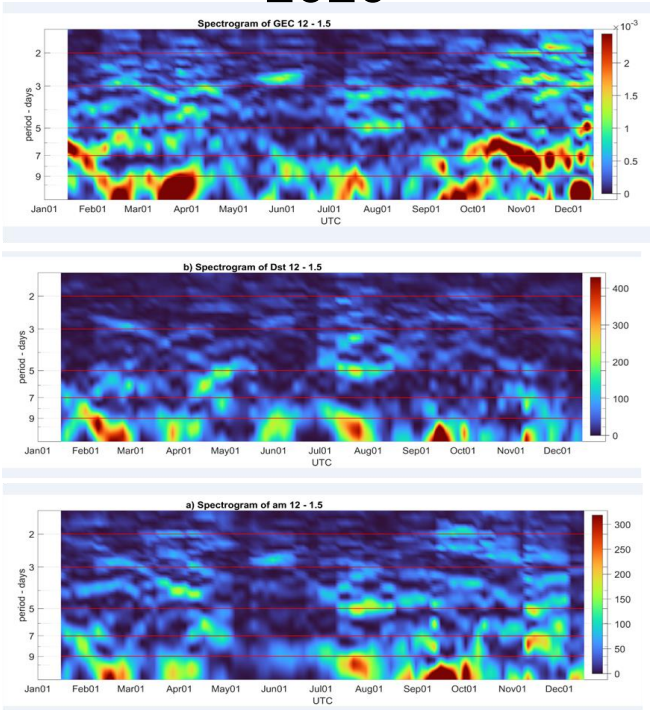
SD4. GEC time-frequency analysis

- Time correlation between GEC and proxies of space-weather state.

2019



2020



SD4. GEC time-frequency analysis

- VTEC, Dst and solar wind (proton density - PD) are high-pass filtered at 40 days (but wave periods >12 days are not shown to keep clarity when using a single window size)
- Presented frequency band is between **12 days and 1.4 day**
- **Window size is 30 days here**
- Wide available signal band must be limited at single step, due to windowing issues
- Other frequency bands and years will beprepared later, for GEC within-day are impossible, but longer are interesting like: annual, semi-annual, those >12 days, those around 27-day etc.
- Size of the window can/must be adjusted to analysed narrow bands, or variable can be applied, like in case of wavelets
- data mus be checked, also for geomagnetic parameters

SD4. Spatio-temporal analysis

- Review of scientific publications on spatio-temporal analysis of the ionosphere.
  - EIA spectrum
  - Solar and troposphere driven periods.
- Review of scientific publications on ionospheric detection of natural hazards.
  - Earthquakes, tsunamis, volcanic eruptions, severe tropospheric weather events.

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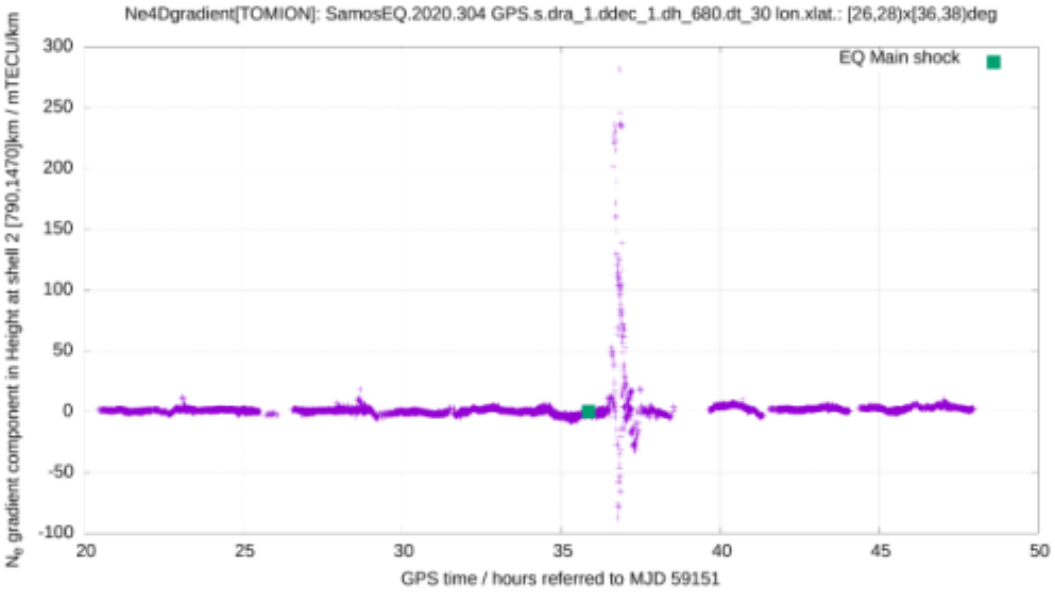
SD4. Proxies of geophysical phenomena

- Potential applications of Ne v-grad in order to detect geophysical phenomena, e.g. cyclones, earthquake, volcano eruptions.

SD4. Proxies of geophysical phenomena

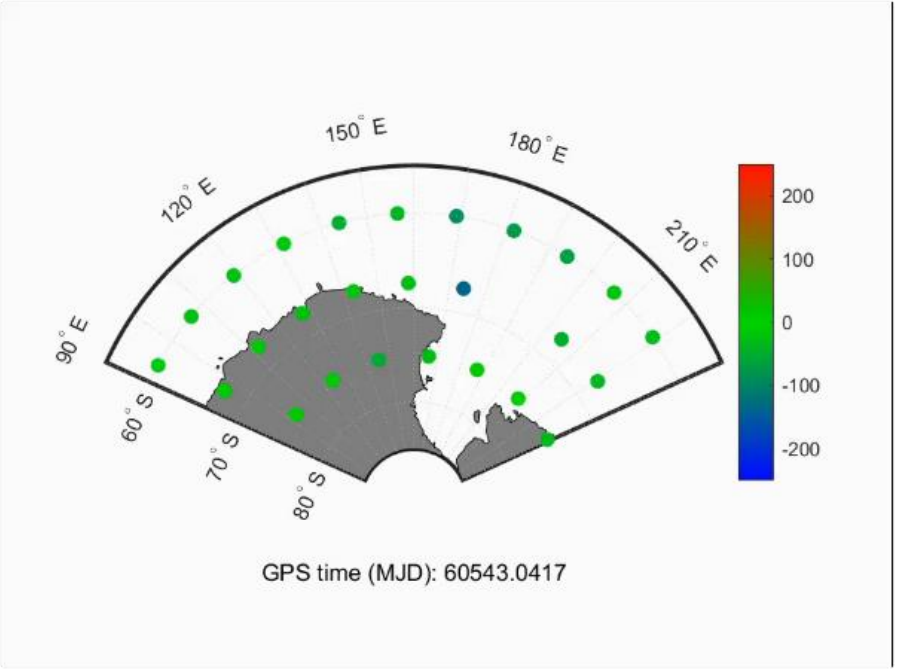
- UPC-IonSAT TOMION output is a two-layer grid with Ne estimates in voxels with GNSS measurements.
- Vertical Ne gradient can be computed directly for the Ne grids at each epoch.

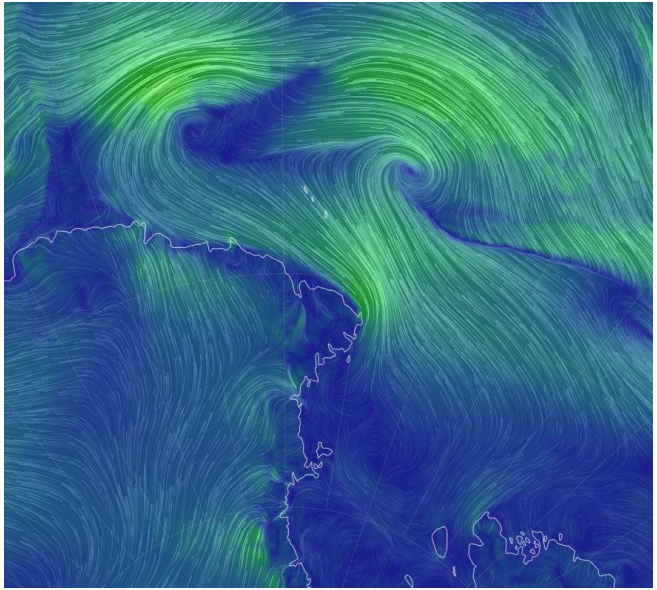


- Example of vertical component of the Ne gradient estimated from TOMION among the two-layers, with central heights at 450 km and 1130 km during the earthquake day (top) and during the previous day (bottom) in the bin 26°–28°N, 36°–38° E
- Figure from ALFONSI, Lucilla, et al. **Ionospheric response to the 2020 Samos earthquake and tsunami.** *Earth, Planets and Space*, 2024, vol. 76, no 1, p. 13.
- Potential tool, i.e. Scientific Data Application, for monitoring and detection of geophysical phenomena that affect the ionosphere.

SD4. Proxies of geophysical phenomena

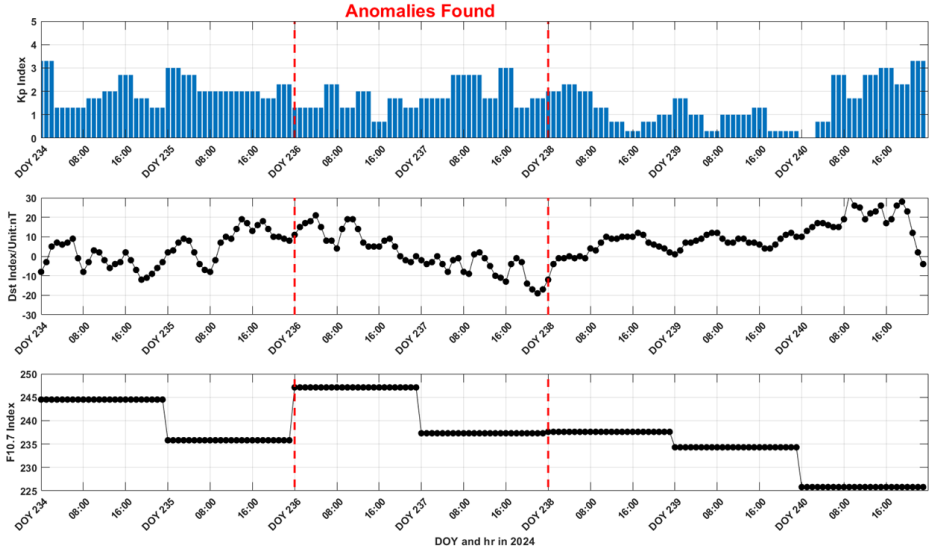
- Analysis of potential detection of ionospheric gravity waves (IGW) generated by cyclones.

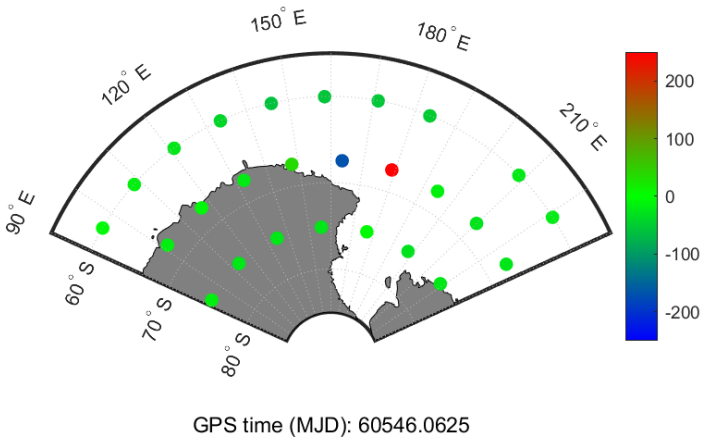




SD4. Proxies of geophysical phenomena

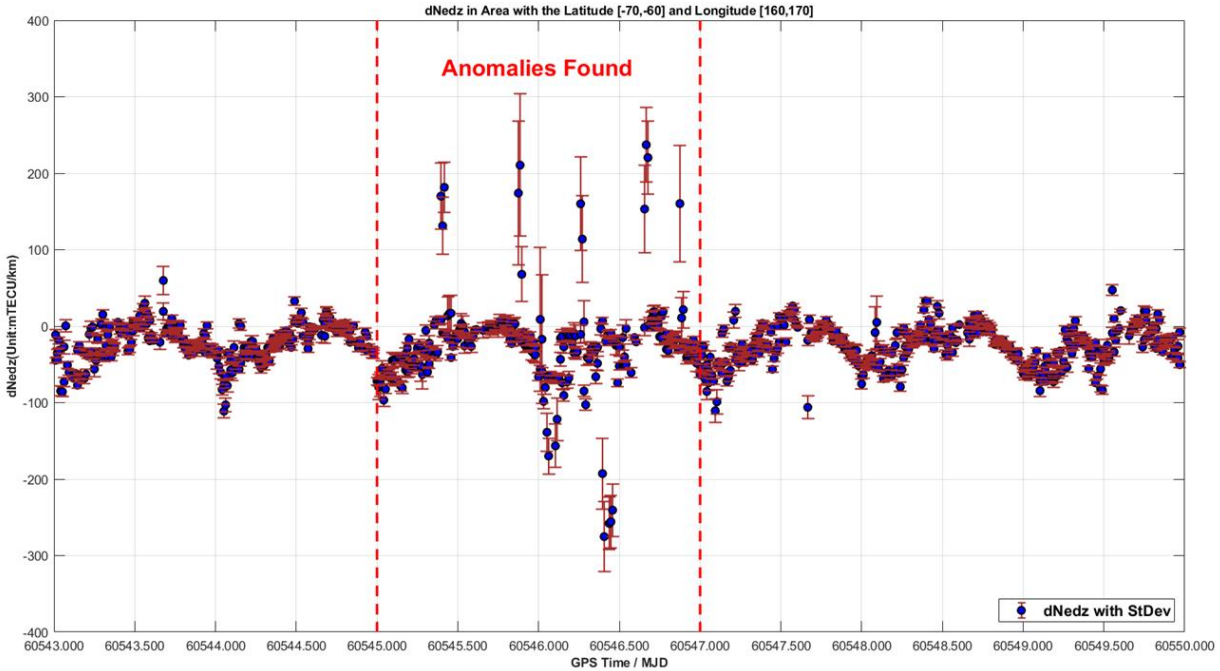
- Space weather conditions were quiet.





SD4. Proxies of geophysical phenomena

- Ne v-grad presents outliers coincident with the occurrence of cyclones.



Conclusions

- The computation of six historical data sets is finished.
- The data sets span over two-solar cycles, since 1996.
- HOSVD analysis over GIMs reveals rich content of spatio-temporal structures, i.e. fractal phenomena.
- The data sets provide tools for the detection and characterization of geophysical phenomena, e.g. space-weather, long-term atmospheric patterns, natural hazards, etc.

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Appendix

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