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45TH SCIENTIFIC ASSEMBLY
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Correlation of Swarm in-situ electron density with geomagnetic indices and solar activity parameters at different frequency bands

UNIWERSYTET WARMIŃSKO-MAZURSKI W OLSZTYNIE

33507, C1.4-0007-24, room EC1-313 on Wednesday, July 17, 2024, 11:00-11:15

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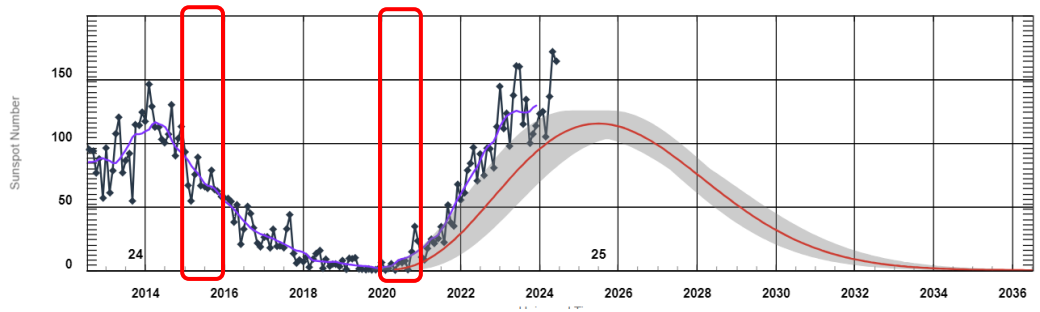
Starting points and objectives

- The objective: **sensitivity and wavelength of Ne variability** driven by geomagnetic and solar activity - required for search of other variabilities: e.g. lithospheric (LAIC).
- **Full solar cycle of Swarm** data has been collected – worth processing (here two years: 2015/2020)
- Two ronds of spectral analysis for Swarm Ne:
  - **time-space-frequency** analysis performed along the track
  - **time-frequency** analysis of time series sampled from Swarm passes daily over selected locations

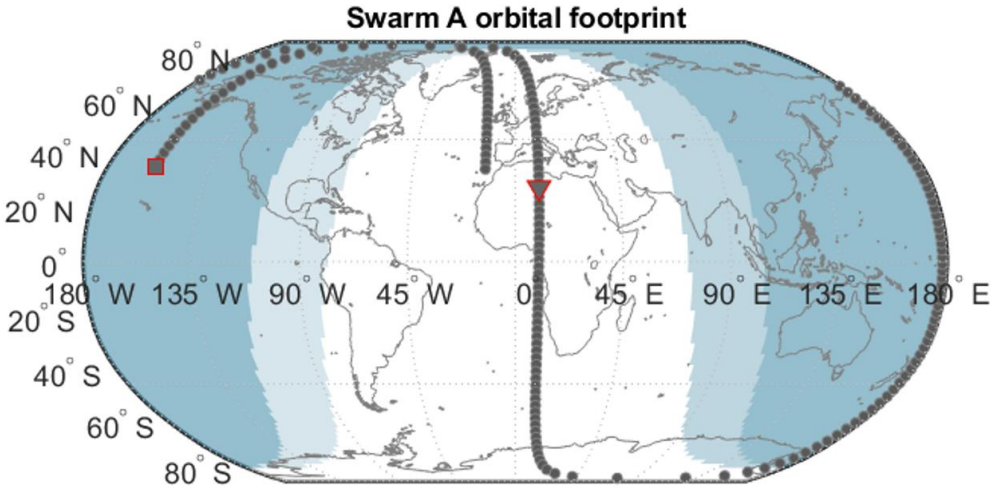
- Time series of **ancillary data (ap, Dst, F10.7, SN) are cross-analyzed** in second-type analysis
- We neglect amplitudes here (all become relative) and **focus on frequency and time**
- This round of short-term Fourier transform (STFT)/spectrograms is a **preiminary study**, the conclusions suggest directly what must be done more

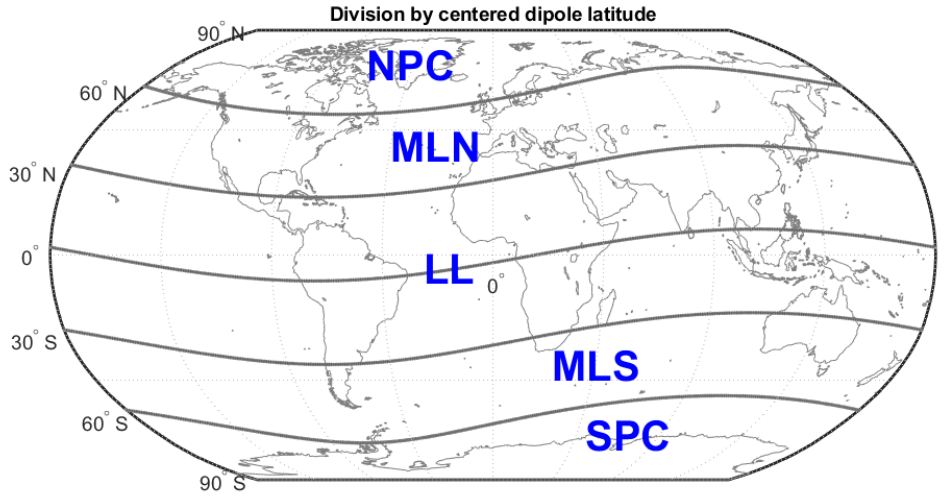
Swarm-C Data selection

- Swarm data are divided into daytime/nighttime samples with the use of terminator
- Swarm data are divided into 5 latitude sections with the use of dipole latitudes (sufficient for this first step - to be refined)
- Swarm C is only shown to shorten presentation
- Two yearly samples are selected from different solar activity periods: 2015 and 2020



https://www.swpc.noaa.gov/products/solar-cycle-progression

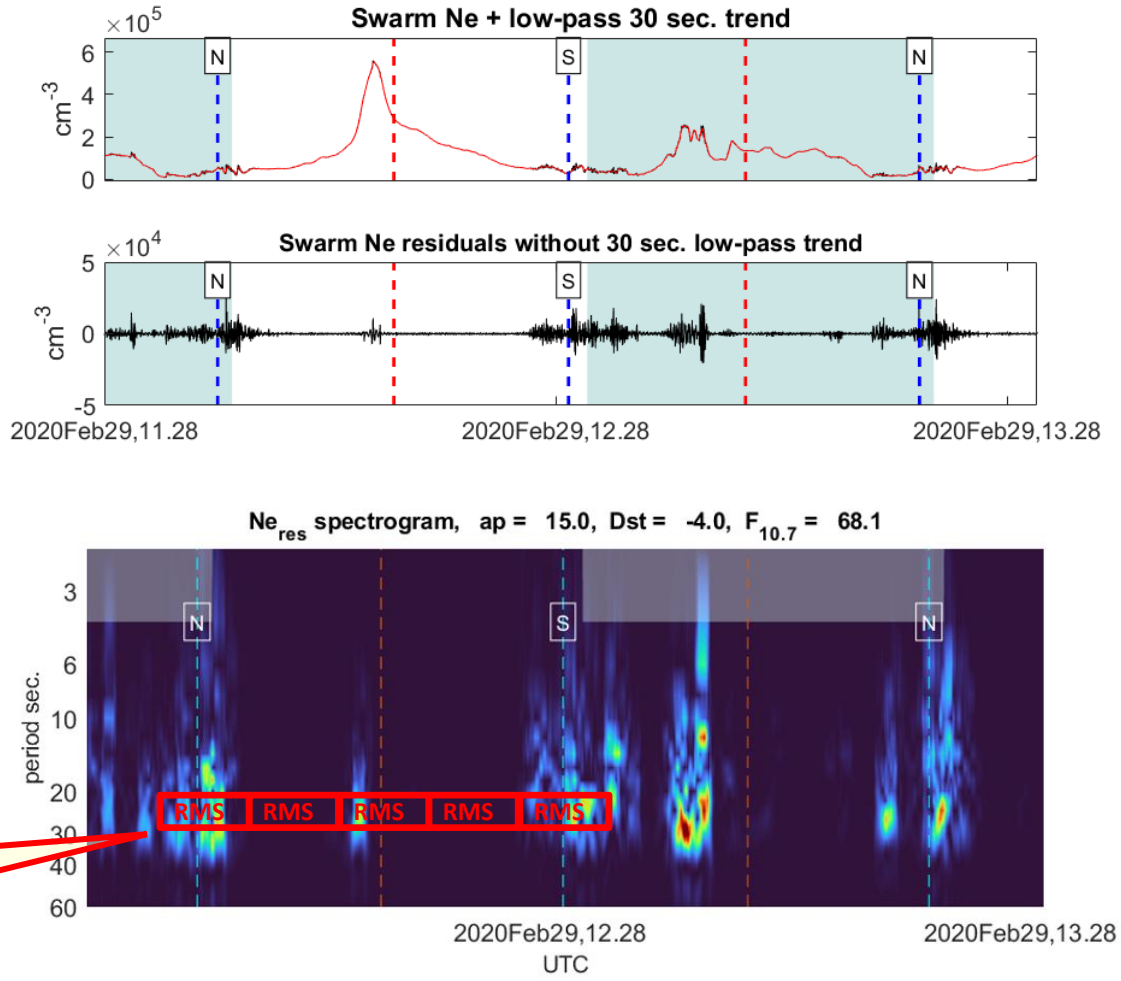




Swarm-C high-pass filtering and STFT, selection of frequency band

- Swarm along-track data are high-pass filtered (in this figure bound is 30 sec, but in PCC lower frequency residuals are used, up to 90 sec.)
- Spectrogram have been done, and data was sampled for second idea: STFT of yearly series
- RMS of power spectral density (PSD) calculated for Ne residuals is selected for creation of yearly series
- For sampling, a selected frequency band was used: (20-30 sec.), and a division into dipole-latitude sections

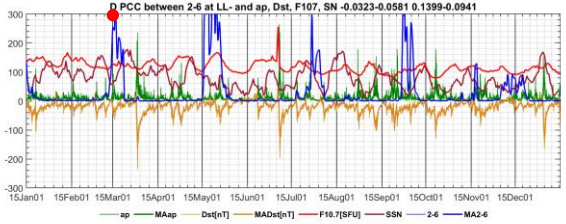
PSD is sampled from selected frequency band (here 20-30 sec) and also from selected latitude.

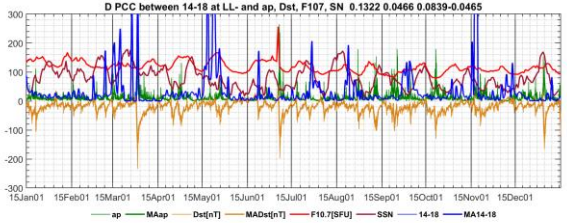


Pearson correlation coefficients for yearly series of RMS(PSD(Ne)) from selected along-track frequency

RMS from PSD of Swarm residuals represents state of Ne at its altitude (and selected latitude) at time of Swarm pass (once a day).

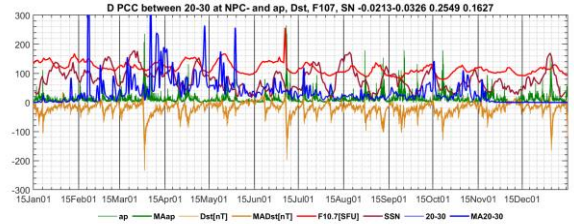
RMS

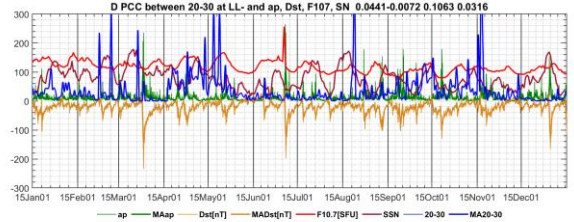


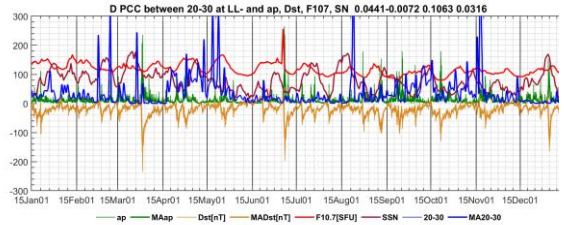


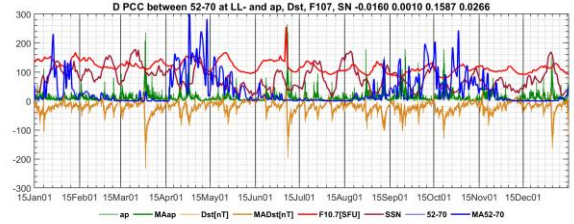
The ap, Dst, F10.7 and SN are also resampled at this interval (no other averaging applied)

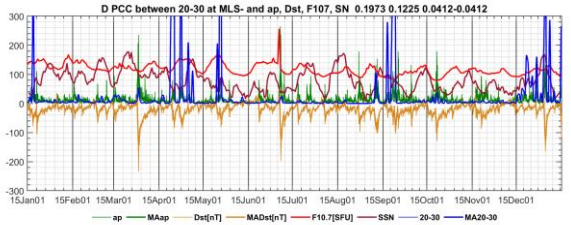
The apparent correlation is higher at the poles, which is observable even by naked eye

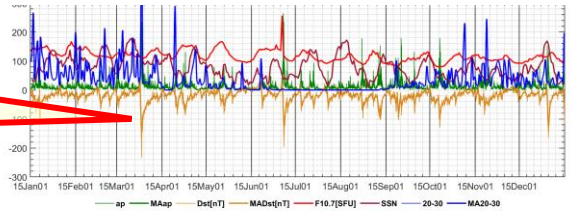








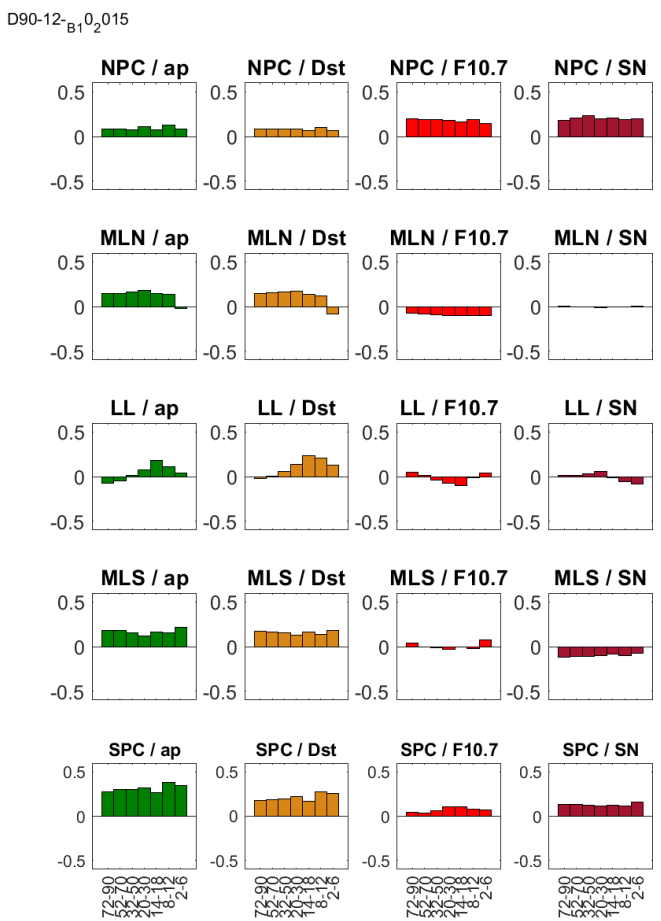


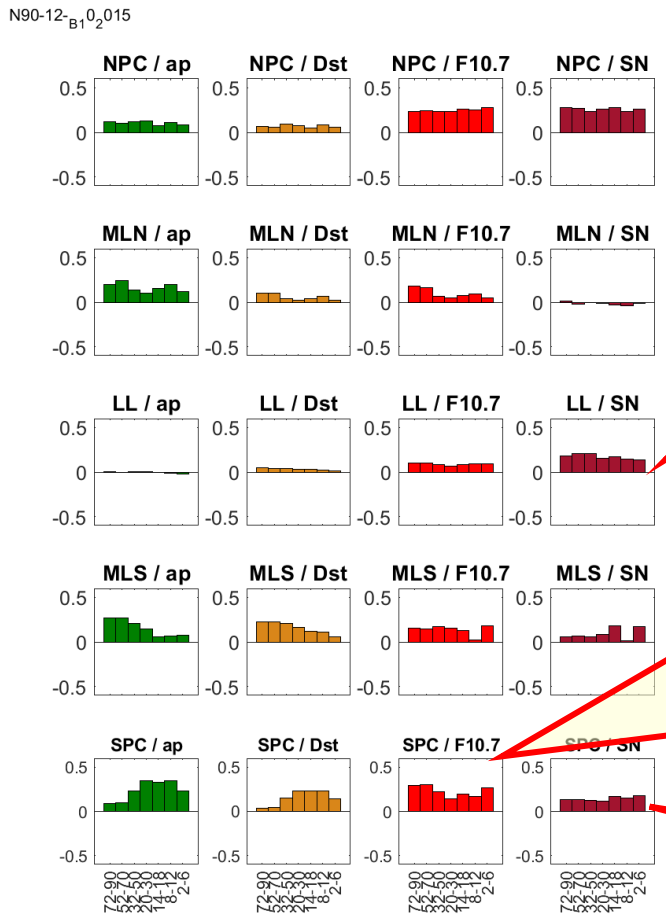


Pearson correlation coefficients 2015

PCC is calculated for pairs of yearly time series of RMS(PSD(Ne)) with geomagnetic index or solar activity parameter.

The series represent 1-day resolution, so PCC refers to a quite short-wave correlation.





Along track wave period (sec.)

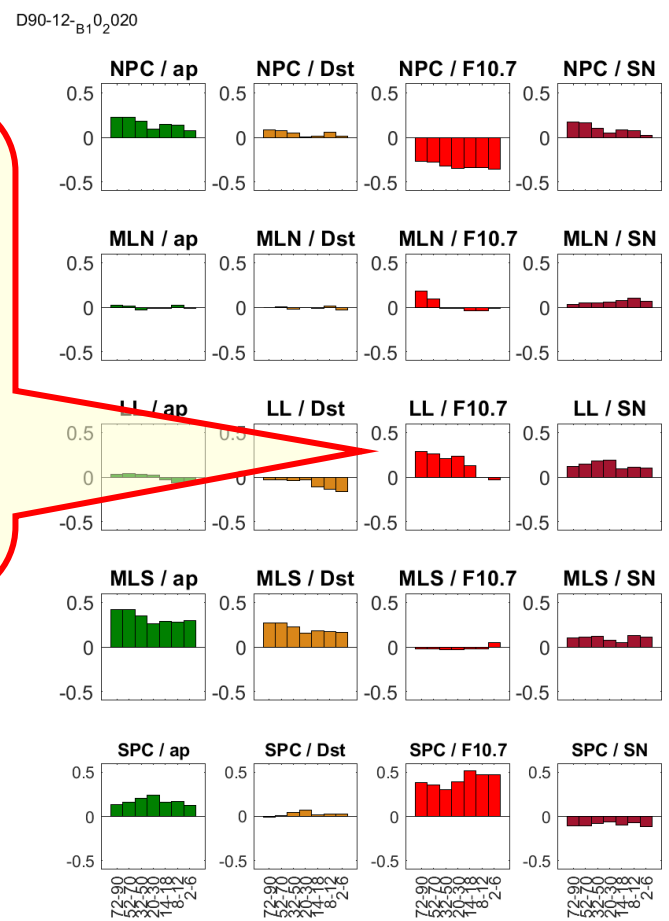
The lowest correlation is at the equator

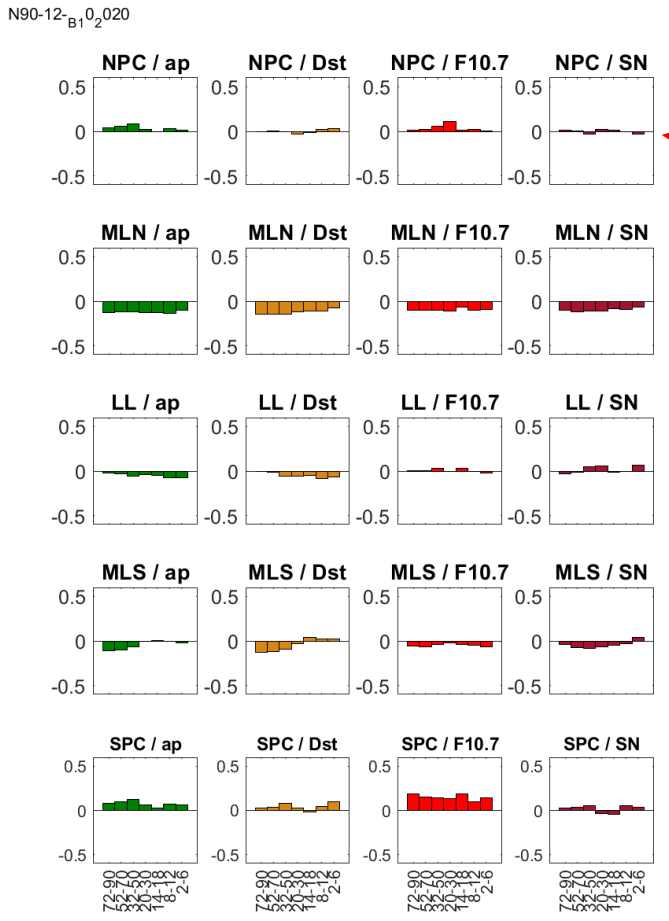
Some differences with respect to along-track frequency of irregularities is observed, but it is hard to say which frequency (along-track) are specific with respect to which phenomena at this stage

The highest correlation is observed at south pole

Pearson correlation coefficients 2020

The correletion doesn't decrease in the daytime (the amplitudes decrease only) at solar minimum.
In some cases it is even higher.





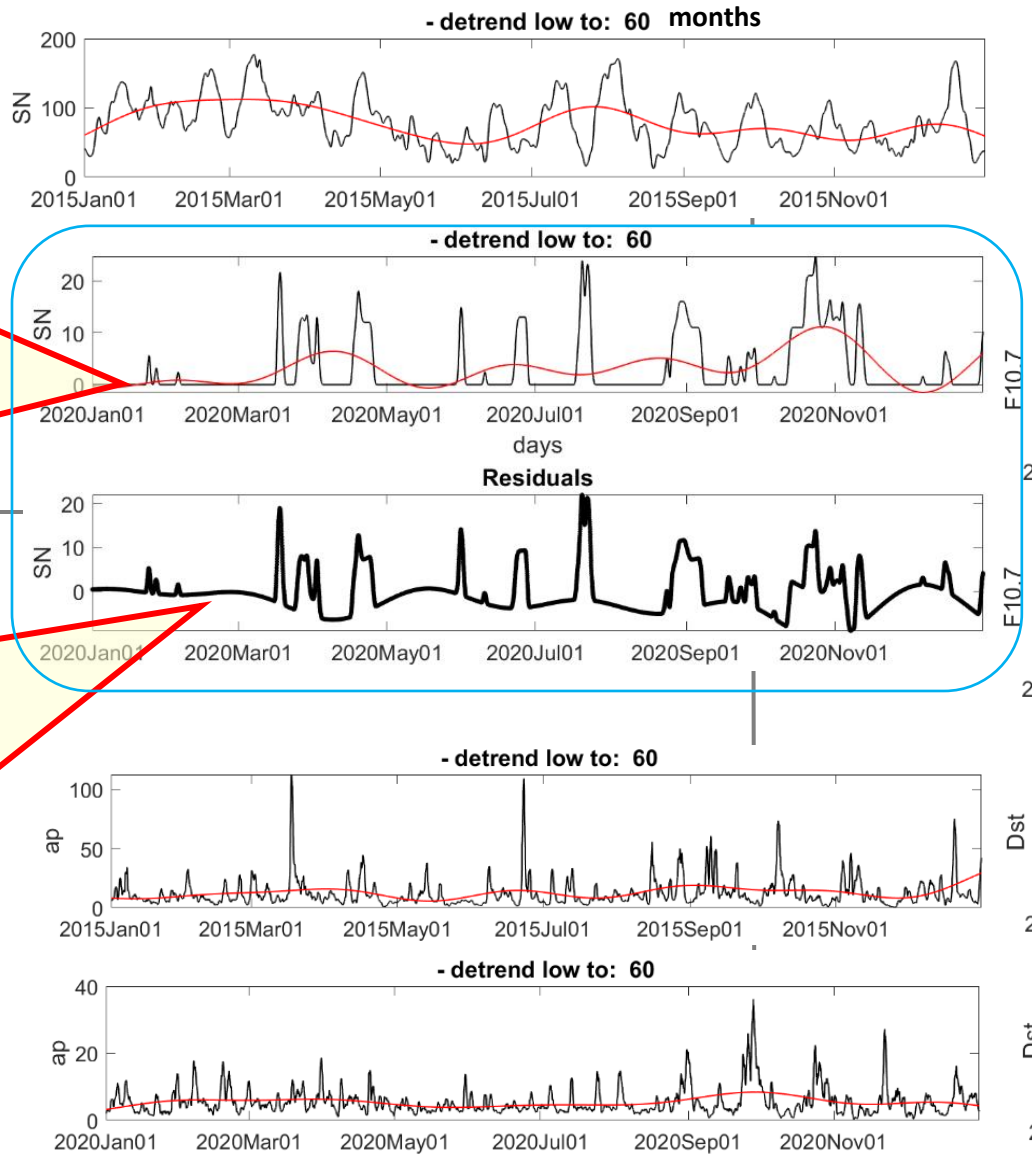
In the nighttime the correlation is lower. However still the highest at southern pole.

Along track wave period (sec.)

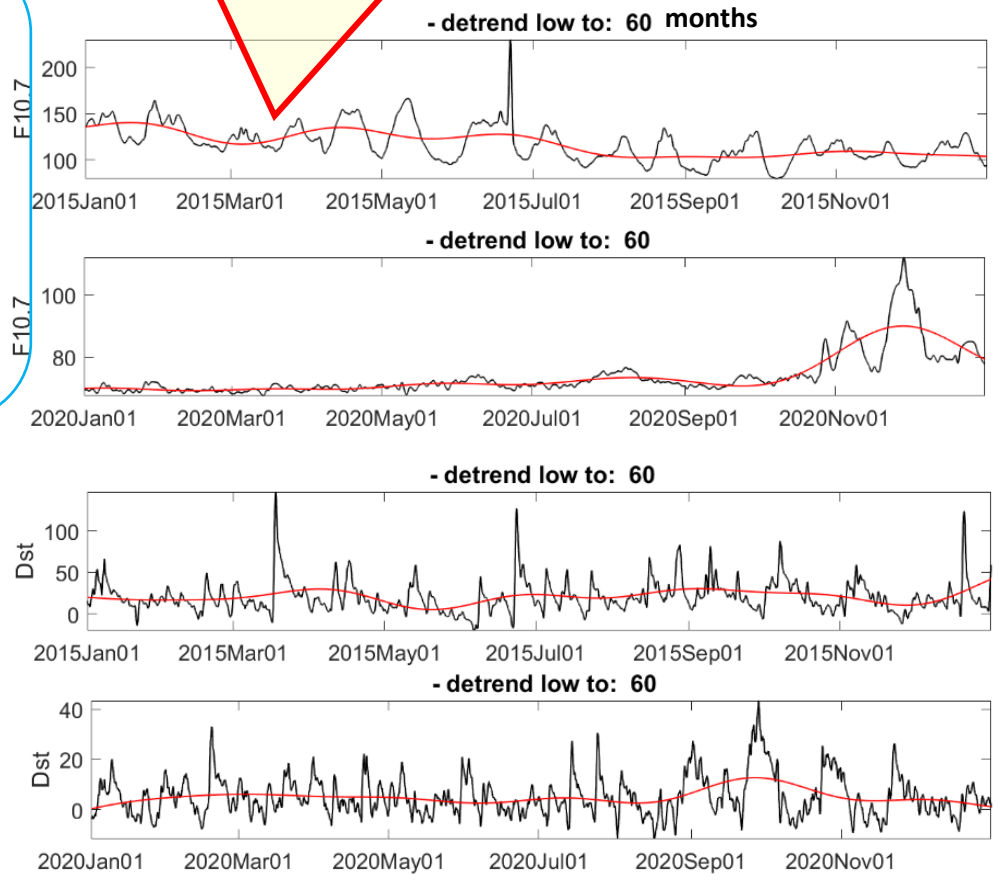
High-pass filtering issues – ap, Dst, F10.7, SN

Zero SN at solar mnimum raises a question if expected value is zero, or longer wavelengths of the phenomena are „undersampled”.

However, this makes no bigger problem in analysis. The artificial signal is of known frequency, has known amplitude and can be substituded by zeros if necessary.



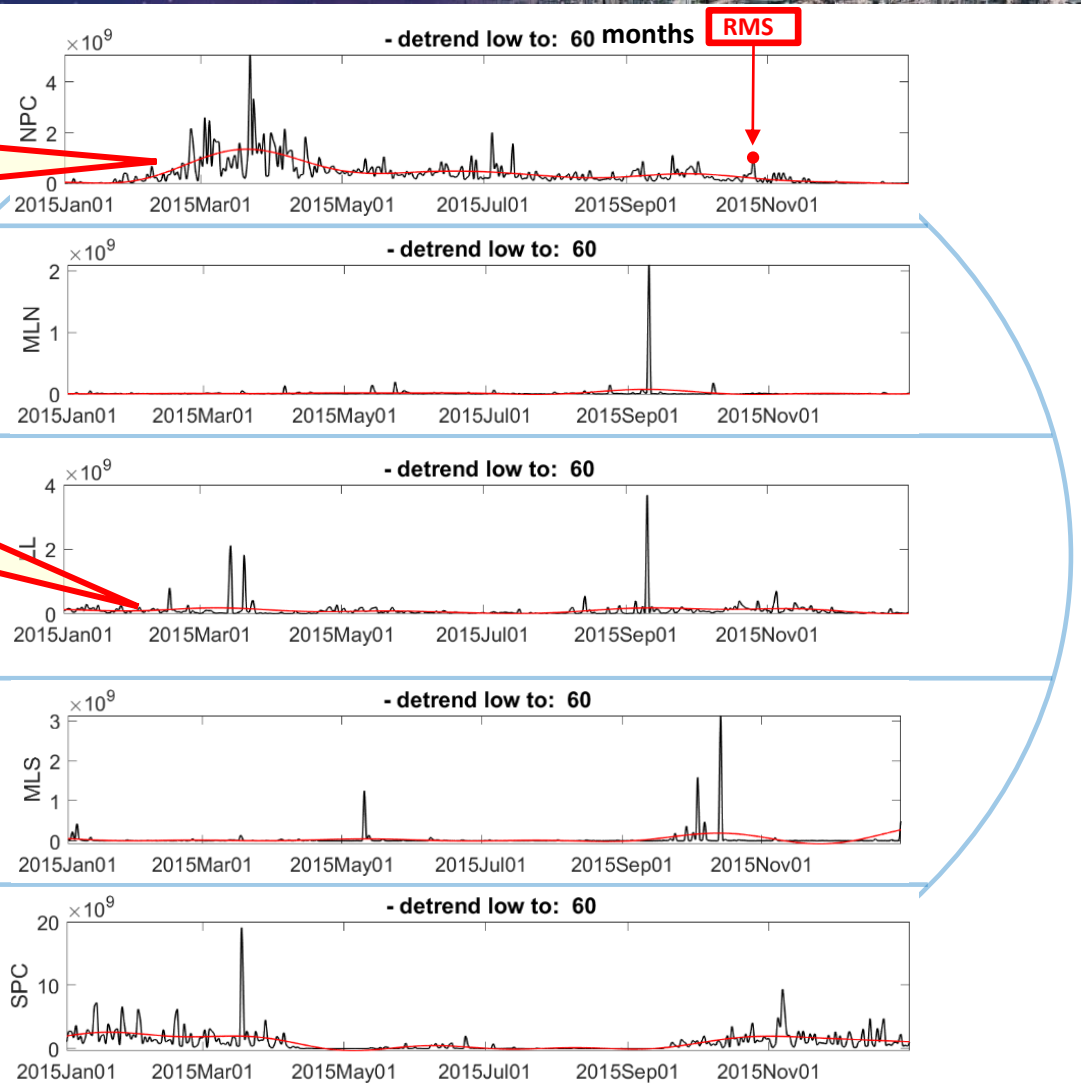
High-pass filtering at 2-month wave period preserves expected around monthly (27-day?) period



High-pass filtering issues – Swarm RMS(PSD(Ne))

„UNdersampling)" problem is not present in Swarm RMS(PSD(Ne)) at the poles, where solar wind affects Ne much.

… but is present again, where the solar and geomagnetic impact is lower. From the upper figure (NPC), and from the groups of peaks we know, that lower frequences exist here, but are small in scale with respect to the highest disturbances.



This issue will be solved, but the reasons of that are complex:

- The ionospheric layers change their altitude (the ionization differs), so maybe in situ data are not the best for analysis over time
- The orbital tracks from consecutive days have only similar latitudes and times (diferences reach hours), etc…
- But, on the other hand, topside TEC is measured in different directions and includes more composed signals

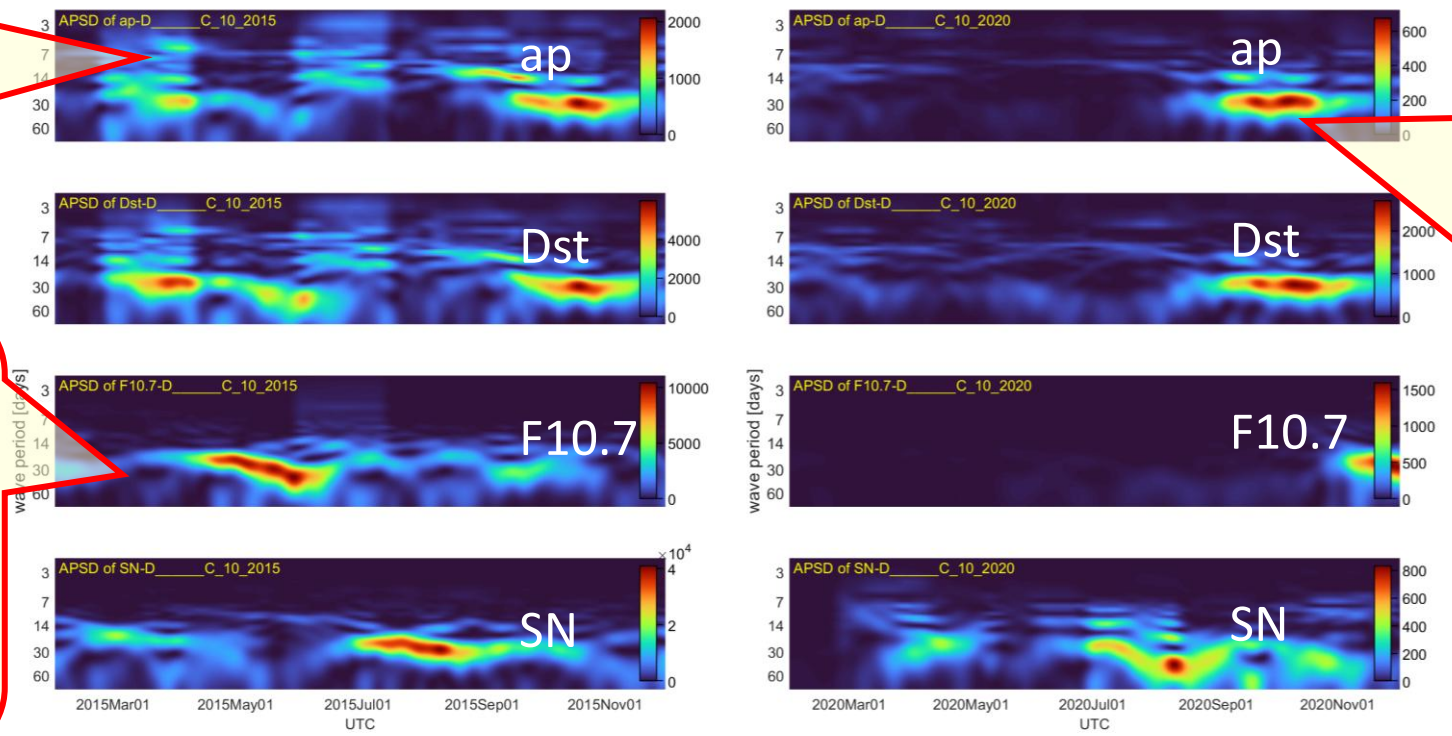
Autospectrograms in 2015 and 2020 – ap, Dst, F10.7, SN

The spectrograms have different scales, because we decided to focus on frequency and time, ignoring amplitudes for a moment. However, all scales are giver on the right.

The other important issue: The length of STFT window is 2-months – to allow analyzing shorter and longer wave periods together. The perisistence time of short wave-like oscillations is in fact much shorter than that observed from 2-m window

Variations of geomagnetic indices occupy shorter wave periods (< 14 day).

The solar activity parameters are dominated by ~30-day (possibly ~27-day Sun rotation) periodicity, which is also not uniform over the year



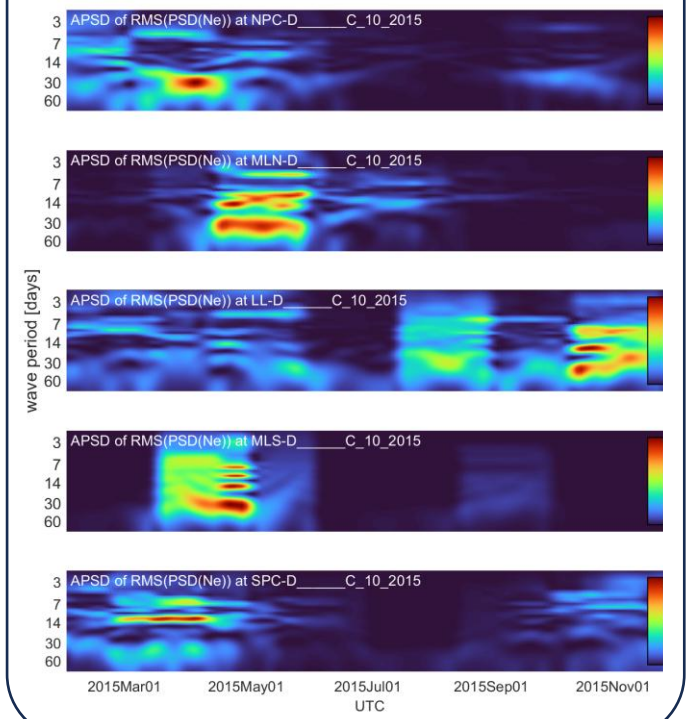
At solar minimum the variations differ. In comparison to solar max.

The seasonal effects are suspected.

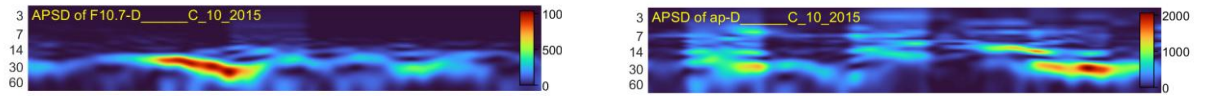
Solar activity – longer wave periods.

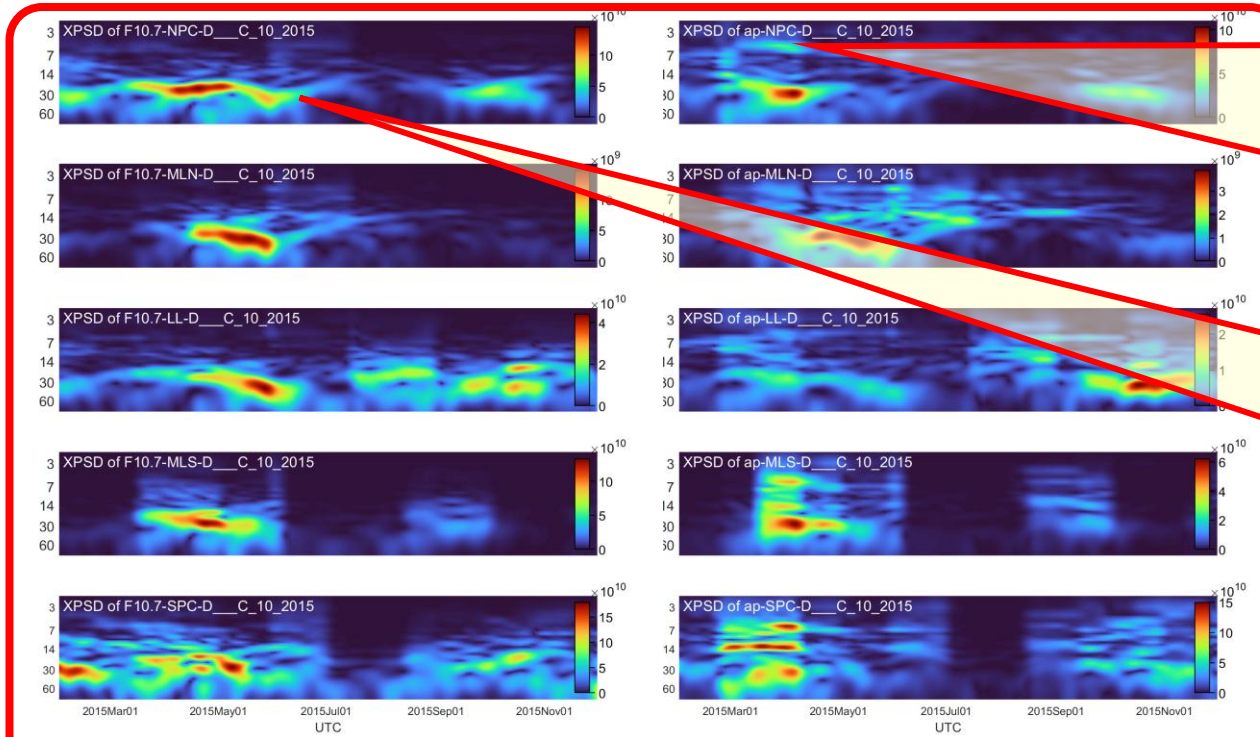
Cross-spectrograms in 2015 – daytime Swarm

PSD (auto-spectra) of Swarm C in time-frequency Day-2015



PSD (auto-spectra) of F10.7 and ap-index





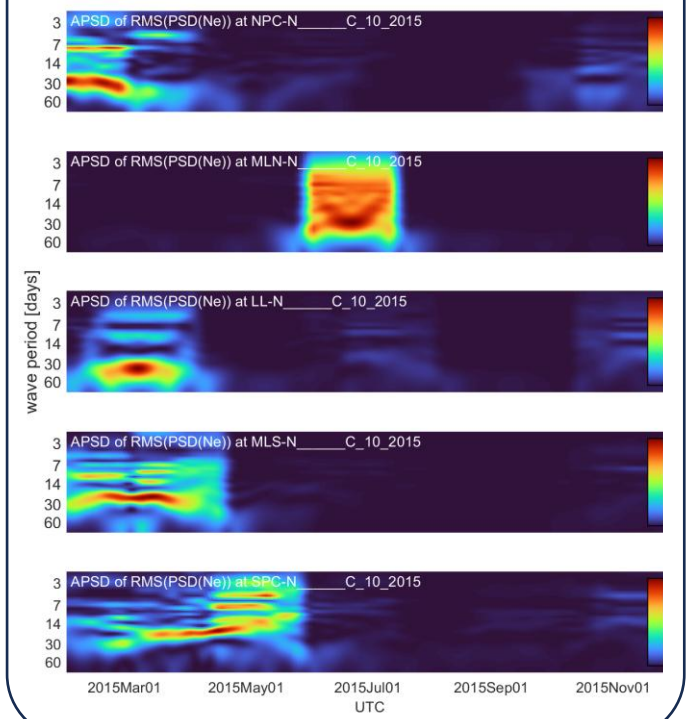
CSD (cross-spectra) with Swarm Ne (RMS(PSD(Ne))

Swarm-geomagnetic csoss-correlations at short wave periods. Spectrograms must be repeated at these frequencies with shorter windows.

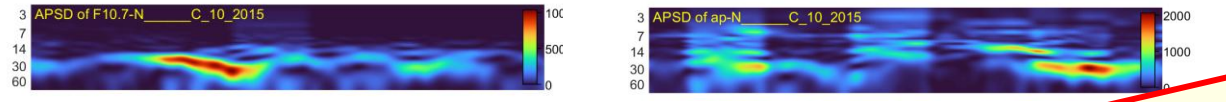
Solar parameters have strong correlations with Swarm Ne rather at longer wave periods > 14-day

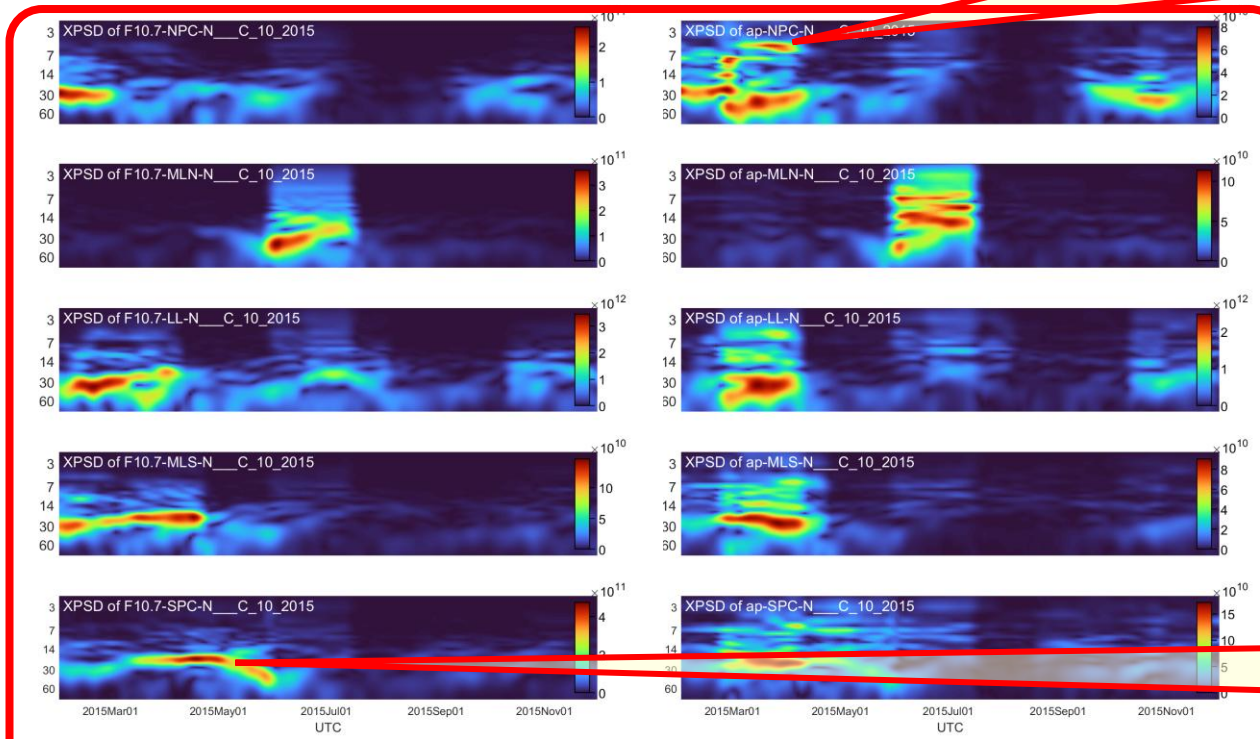
Cross-spectrograms in 2015 – nighttime Swarm

PSD (auto-spectra) of Swarm C in time-frequency Night-2015



PSD (auto-spectra) of F10.7 and ap-index





CSD (cross-spectra) with Swarm Ne (RMS(PSD(Ne))

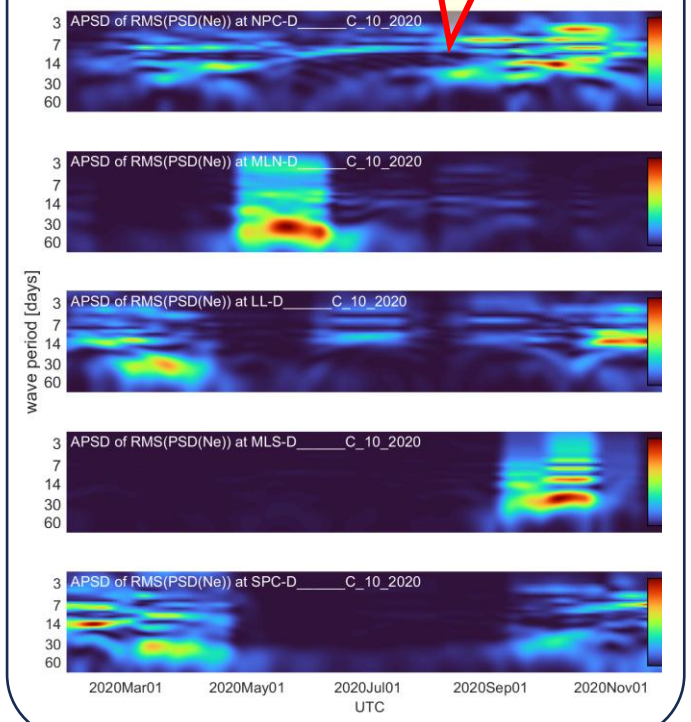
Nighttime Swarm data again correlated at shorter wave periods with geomagnetic indices

And at longer ones with solar activity parameters

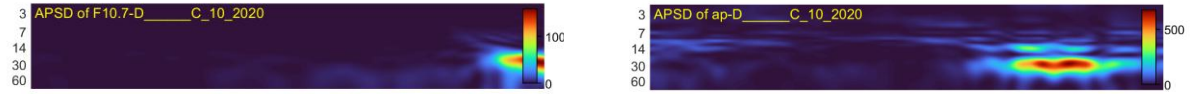
Cross-spectrograms in 2020 – daytime Swarm

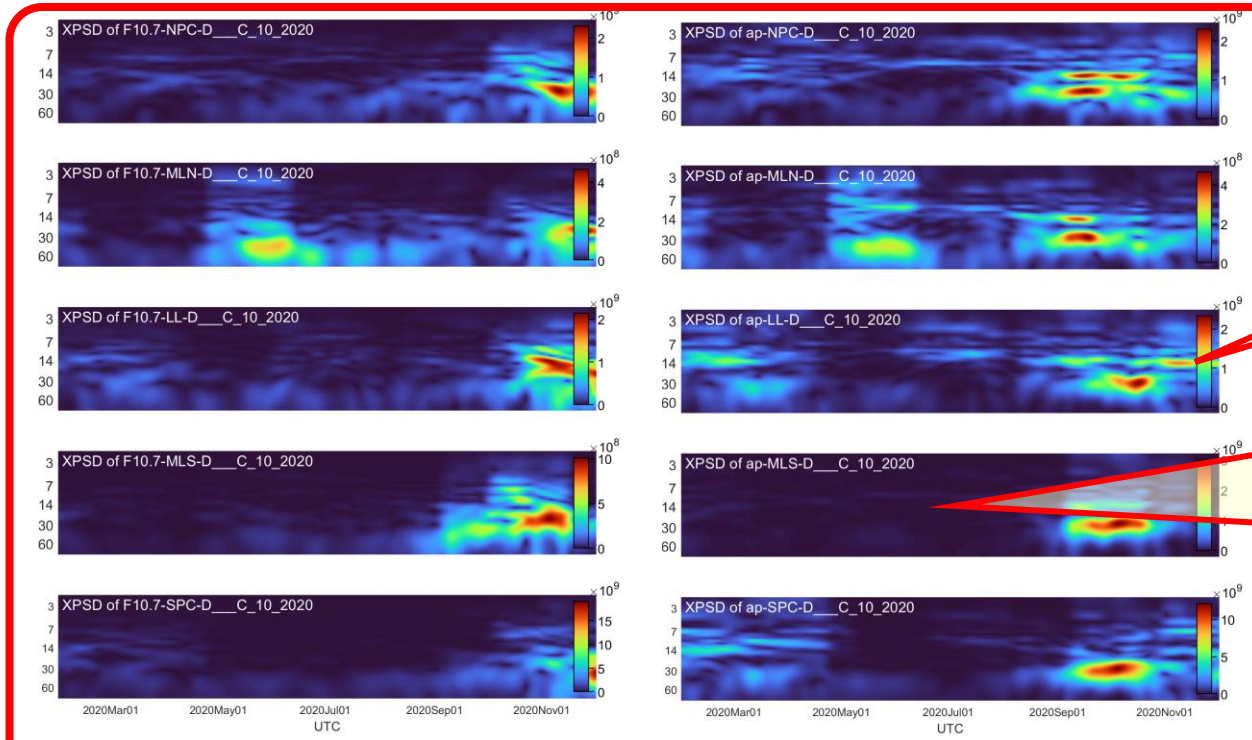
A 9-day wave-like oscillations were also shown in the literature for ap (Katsavrias et al. 2012)

PSD (auto-spectra) of Swarm C in time-frequency Day-2020



PSD (auto-spectra) of F10.7 and ap-index





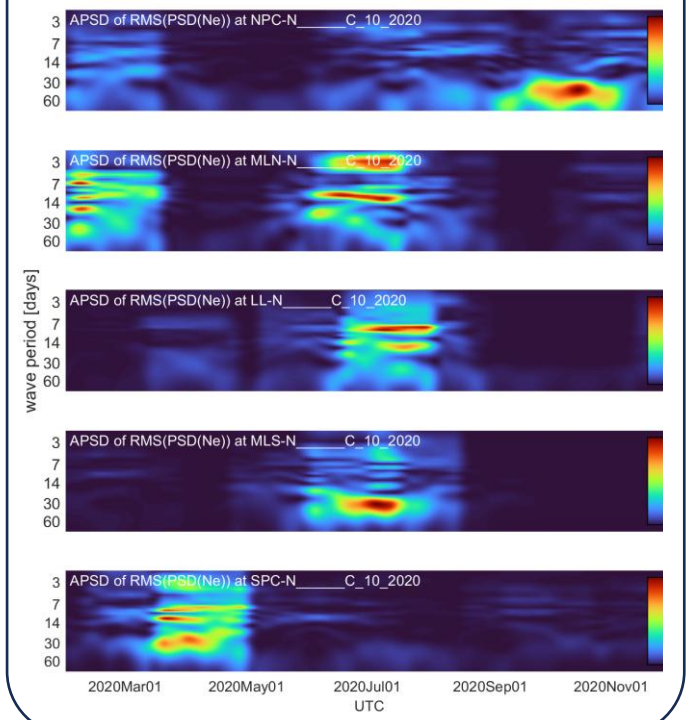
CSD (cross-spectra) with Swarm Ne (RMS(PSD(Ne))

A 14-day wave-like oscillations

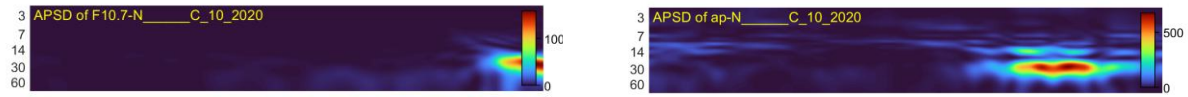
Also change of the scale will be useful, establishing of confidence level (but this needs a priori error!)

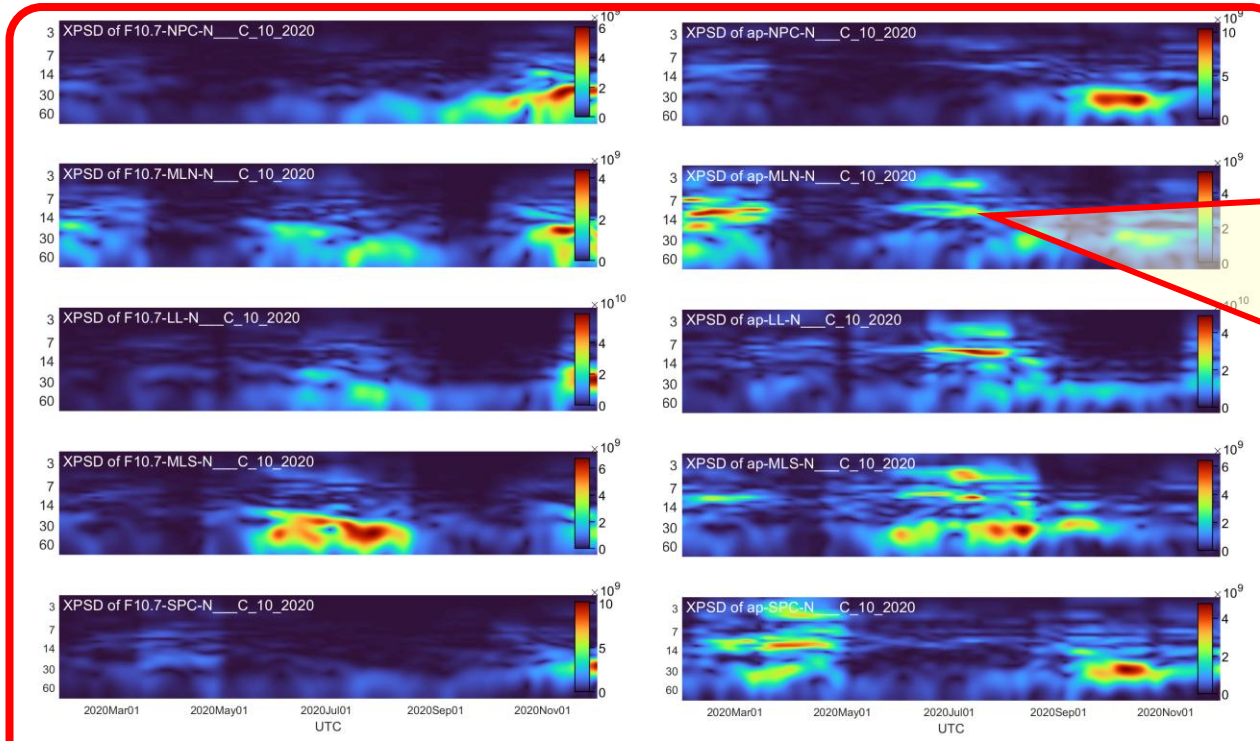
Cross-spectrograms in 2020 – nighttime Swarm

PSD (auto-spectra) of Swarm C in time-frequency Night-2020



PSD (auto-spectra) of F10.7 and ap-index





CSD (cross-spectra) with Swarm Ne (RMS(PSD(Ne))

The signals are complex in frequency domain, and vary in time.

Therefore their „background" is important for search of LAIC.

Conclusions

- Found periodicities of Swarm Ne, solar activity and geomagnetic indices are **consistent with globally determined periodicities** in previous studies
- **Variation of periodic components is worth investigation** (seasonal effects observable, differences between geomagnetic/solar)
- Swarm **Ne exhibits variations at longer and shorter** wave periods.
  Longer ones show cross-correlation with solar activity parameters,
  whereas shorter ones (say <14 days) have more cross-correlation with geomagnetic indices.
- These **short wave periods must be reanalysed** in details with shorter windows in narrower spectral band
- **Frequency/time domain facilitates recognition** of influence of different factors affecting the ionosphere.
- There are some drawbacks in Ne data:
  not the same time on the second day, variations of ionospheric layer altitude,and other …

Acknowledgements

The EQ series are downloaded from the Search Earthquake Catalog of United States Geological Survey (available at: **https://earthquake.usgs.gov/earthquakes/search/**).
The Solar Radio Flux data are downloaded from the website of International Reference Ionosphere (IRI) of Committee on Space Research (COSPAR) (**http://irimodel.org/**).
The results presented in this paper rely on geomagnetic indices calculated and made available by ISGI Collaborating Institutes from data collected at magnetic observatories. We thank the involved national institutes, the INTERMAGNET network and ISGI (**isgi.unistra.fr**).

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