Swarm Electron Temperature analysis over four years: statistical occurrence of “extreme events” as a function of latitude, local time and orbits

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Motivation:

- This study is done in the framework of the **INTENS** (characterisation of **I**o**N**ospheric **T**urbul**EN**ce level by **S**warm constellation) project, funded by ESA through the «*EO Science for Society Permanently Open Call 2017-2021*». Main purpose of the project is the investigation of the nature of fluctuations and their scaling features in the magnetic field and plasma parameters (electron density and temperature) during different geomagnetic disturbance conditions to unveil the role played by MHD turbulence on ionospheric environment in creating multi-scale plasma structures and plasma inhomogeneities.

- The project makes use of four years of Swarm A and B magnetic field and plasma data (**04/2014 – 03/2018**), and needs datasets, as far as possible, continuous and «physically reliable» (i.e. time series not affected by instrumental biases/disturbances which can introduce «spurious» fluctuations in the analysis).

- Almost no problems with magnetic field and electron density, but what about **electron temperature**?

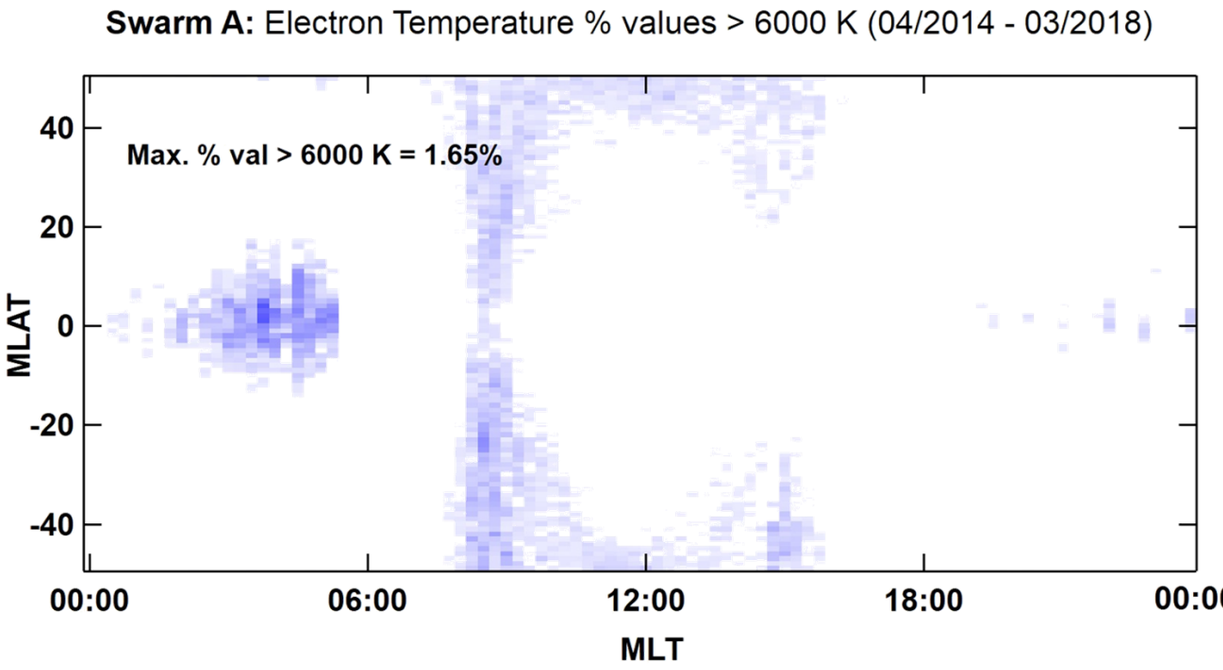
- Swarm electron temperature, measured by the Langmuir Probes (part of the Electric Field Instrument- EFI), has known problems:

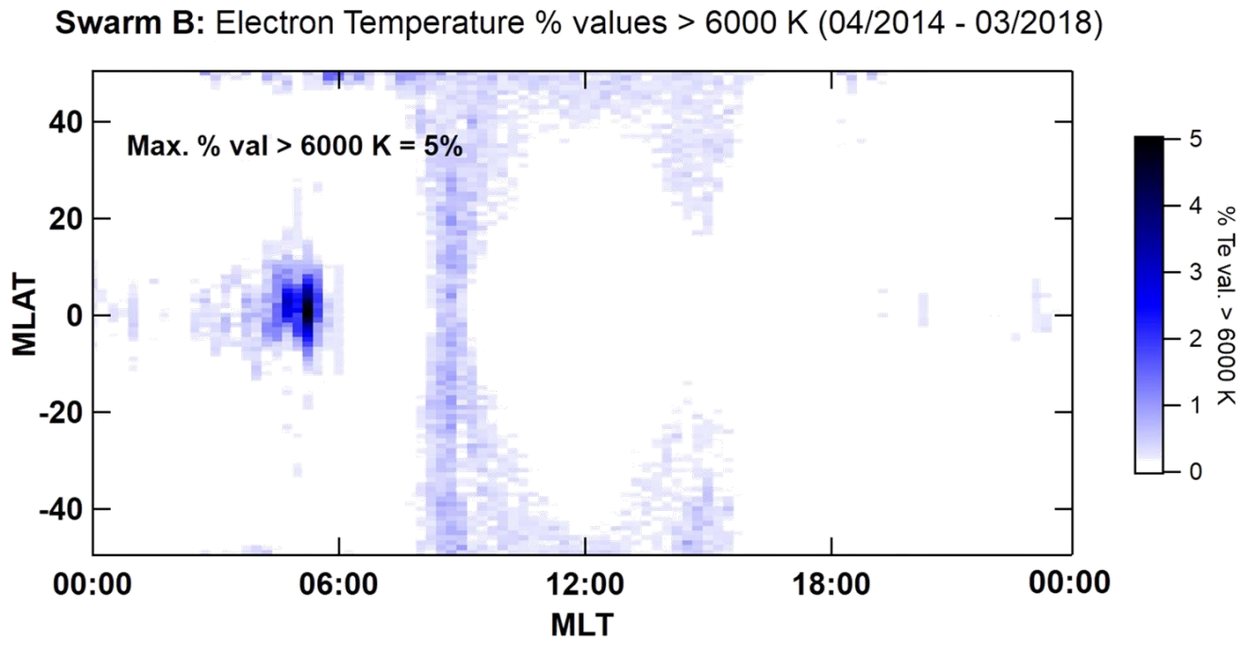
    1) High number of **gaps/invalid values**: in LP data, quality flags exist for each variable of interest (Ne, Te and S/C potential). In particular, for «Flags_Te», we have discarded all the records with values different than 10 or 20 (nominal cases), as recommended in the «Swarm Level 1b Product Definition» document (https://earth.esa.int/documents/10174/1514862/Swarm_L1b_Product_Definition). Invalid values are filled with «Not-a-number» (NaN) values in the **INTENS** dataset and sum up to other real gaps (luckily not too many) occurring when LP are off or functioning in offset mode.

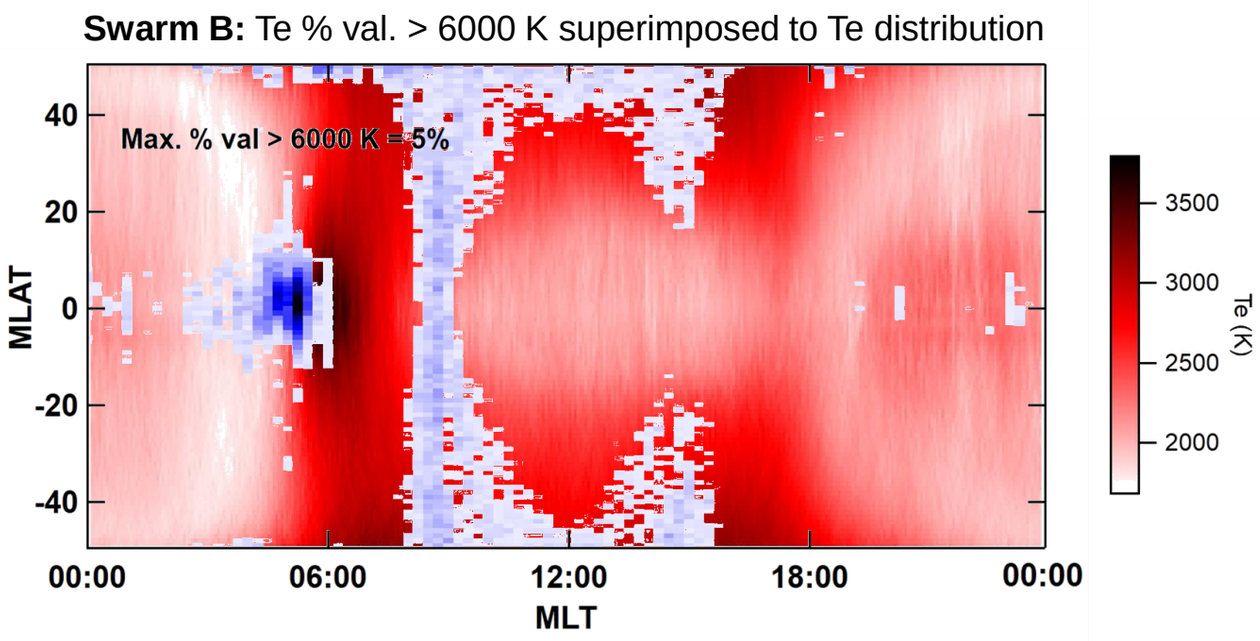
    2) So called «**spikes**» or «**outliers**»: very high values of Te (> 6000 K up to 40000 K and more), not flagged in data, that could often appear as fluctuating structures. Are they physical or «instrumental»?

- We will show here only the statistical distributions of spikes/outliers, which we group under the name of **«extreme events»**.

Low-mid latitude distribution (+/- 50° MLAT) of Te values > 6000 K



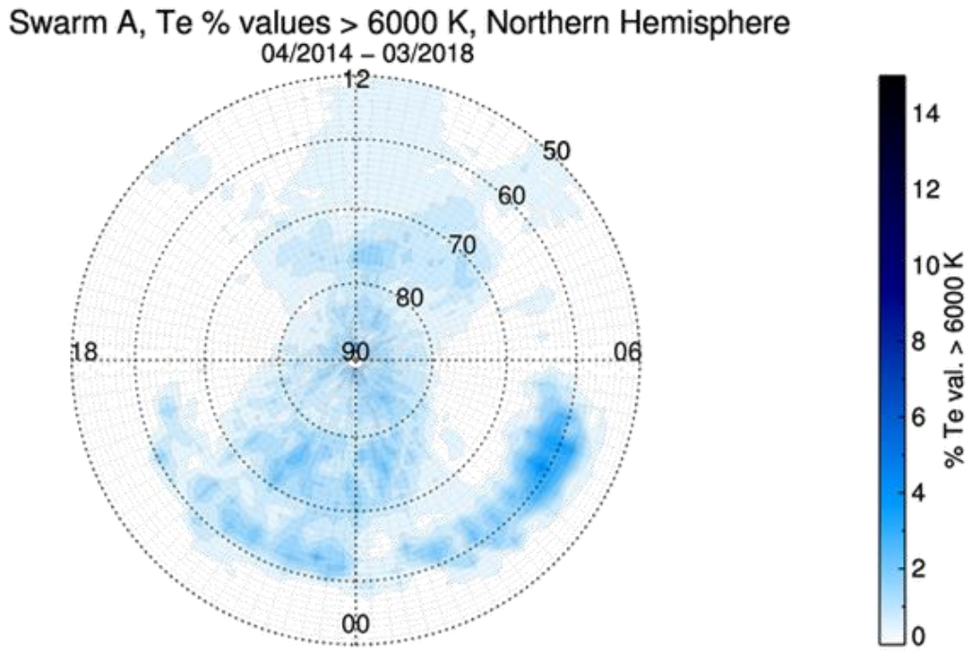


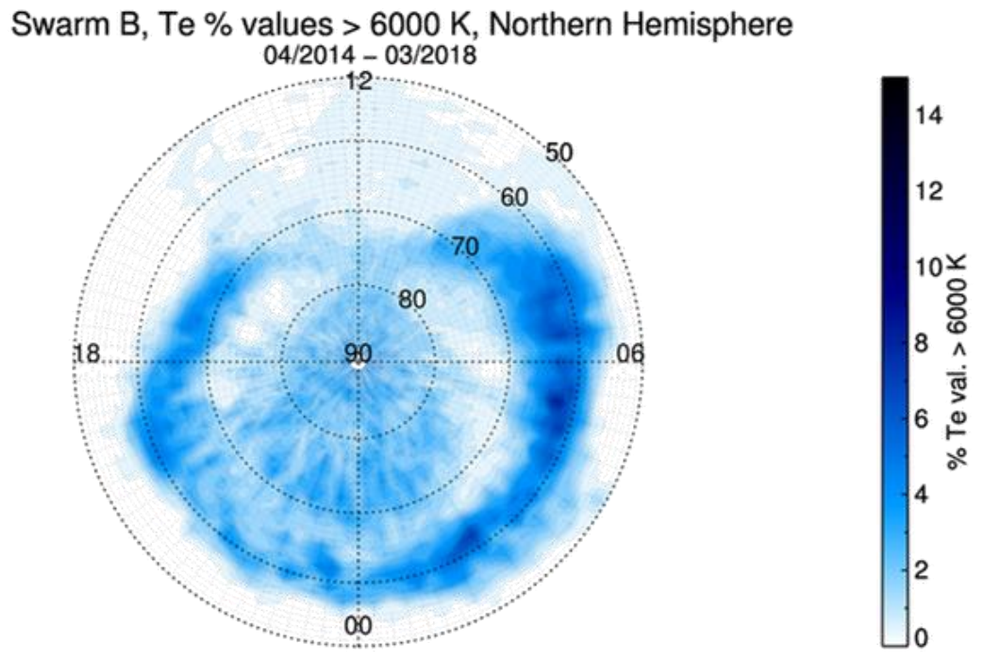


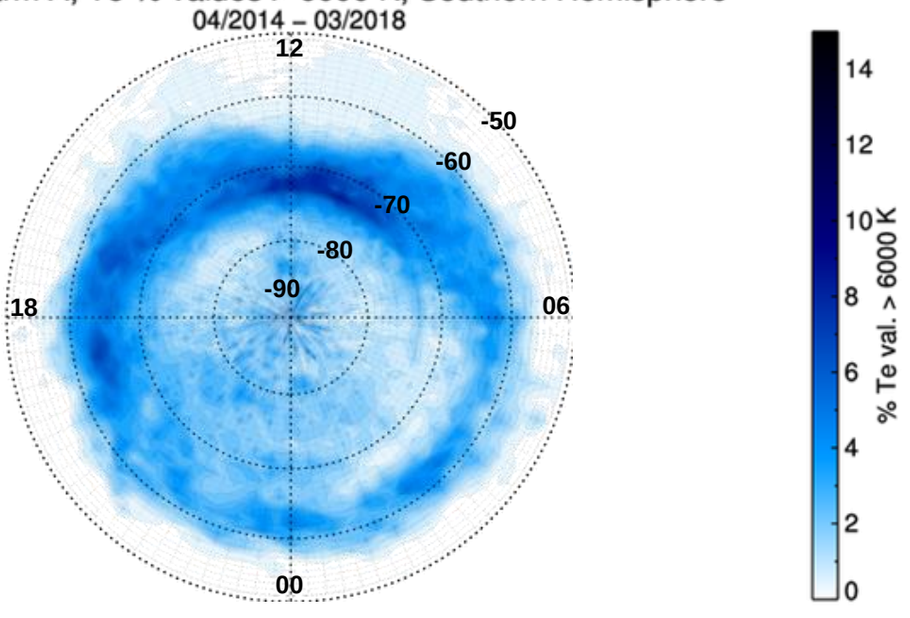
- Once gaps/inv. values are removed, not much outliers remain in the Te mid-low latitude distributions. **Swarm B** observes almost twice outliers, on average, wrt **Swarm A**, with peaks 3 times higher in the early morning sector.

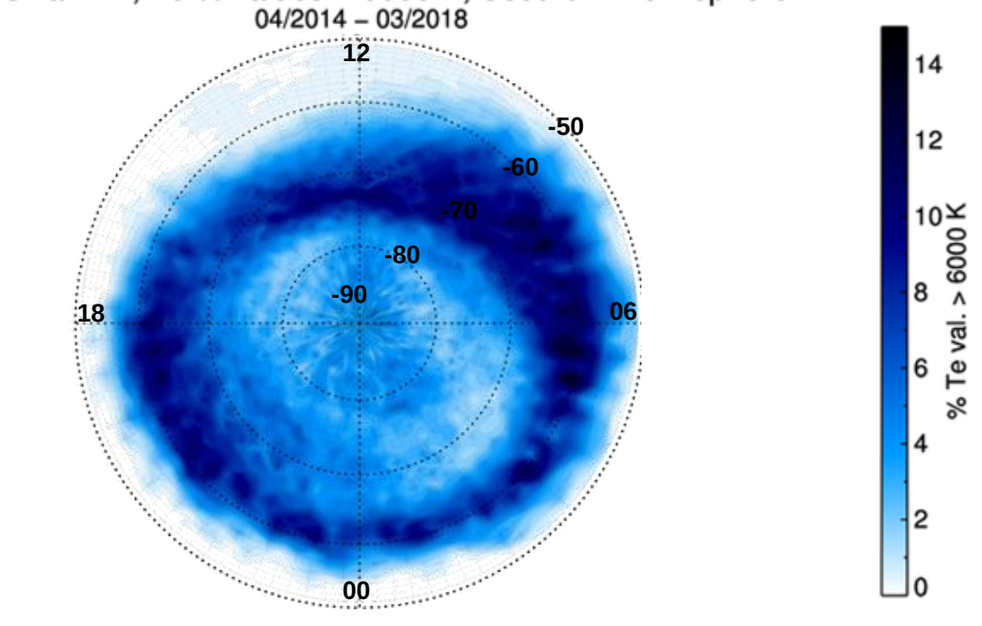
- There seems to be a connection between the outliers distributions and the Te overall distributions. In particular, outliers seem to cluster in regions around the temperature peaks. It is interesting to note the outlier spot between 4-5 MLT at the equator, close to the sunrise overshoot.

High latitude distribution (> |50|° MLAT) of Te values > 6000 K



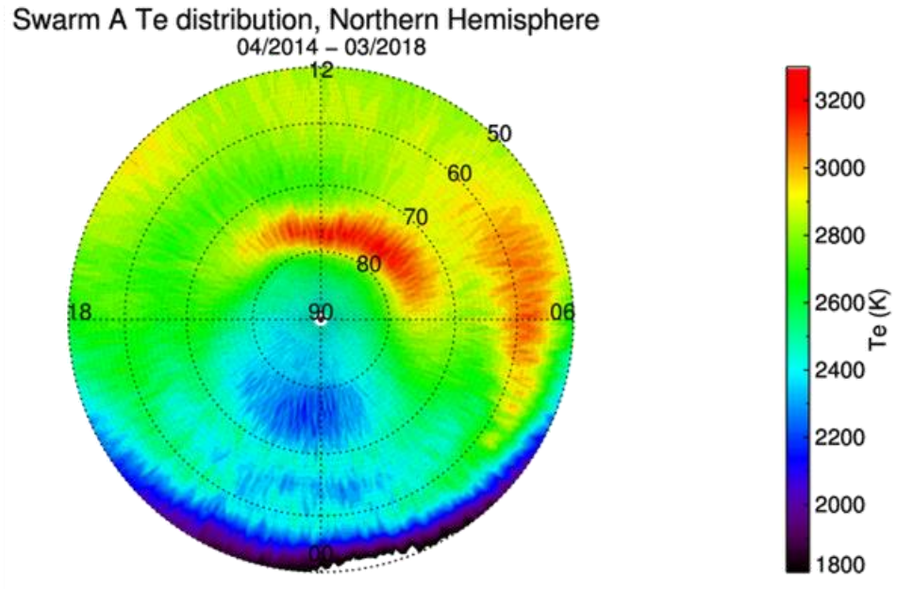


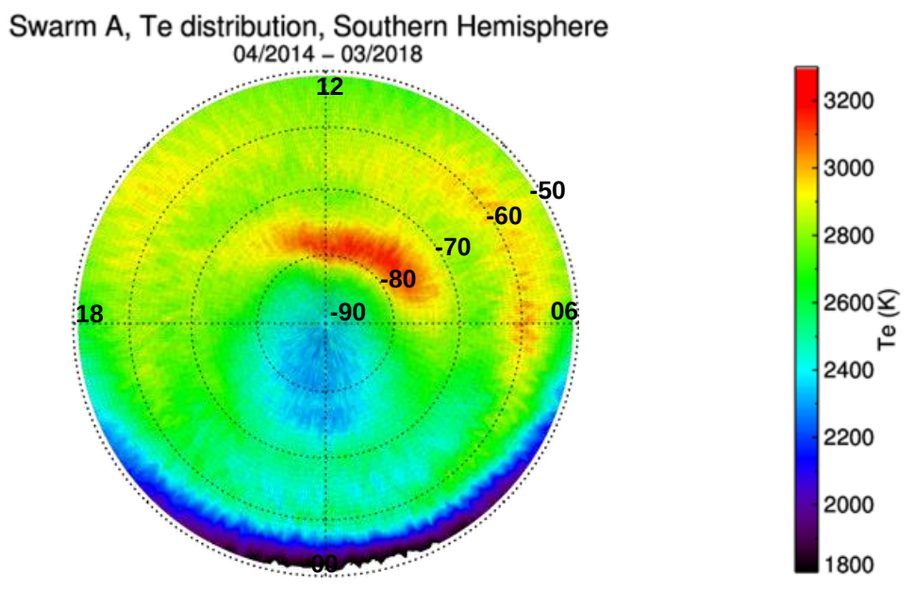


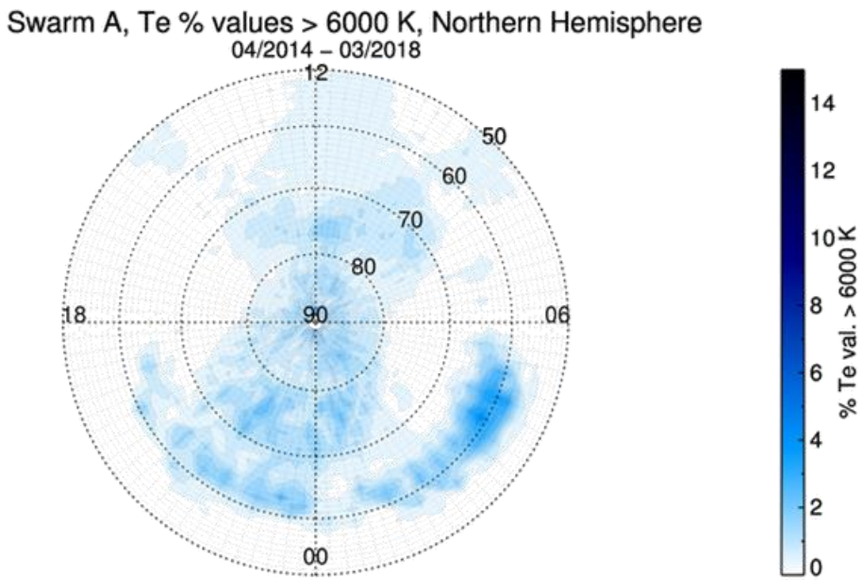


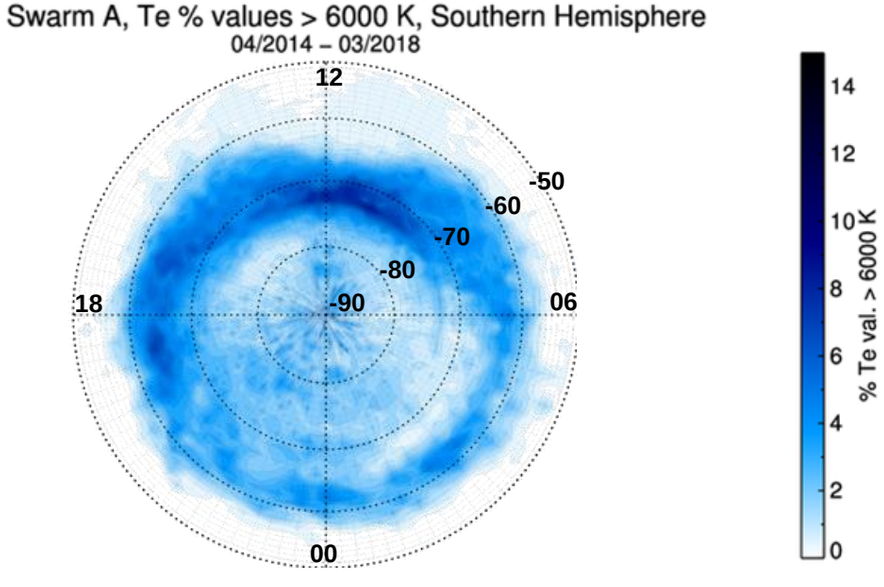
- Northern and Southern hemispheres behave rather differently: at **North**, the ouliers distributions peak in the nightside auroral oval, while at **South,** they peak in the dayside cusps.

- The numbers of outliers are, on average, much less in the Northern than in the Southern hemispere (by a factor of about 2-3), and overall Swarm B registers more outliers than Swarm A. At Swarm B height, the Northern hemisphere outliers distribution extends also towards the dayside.





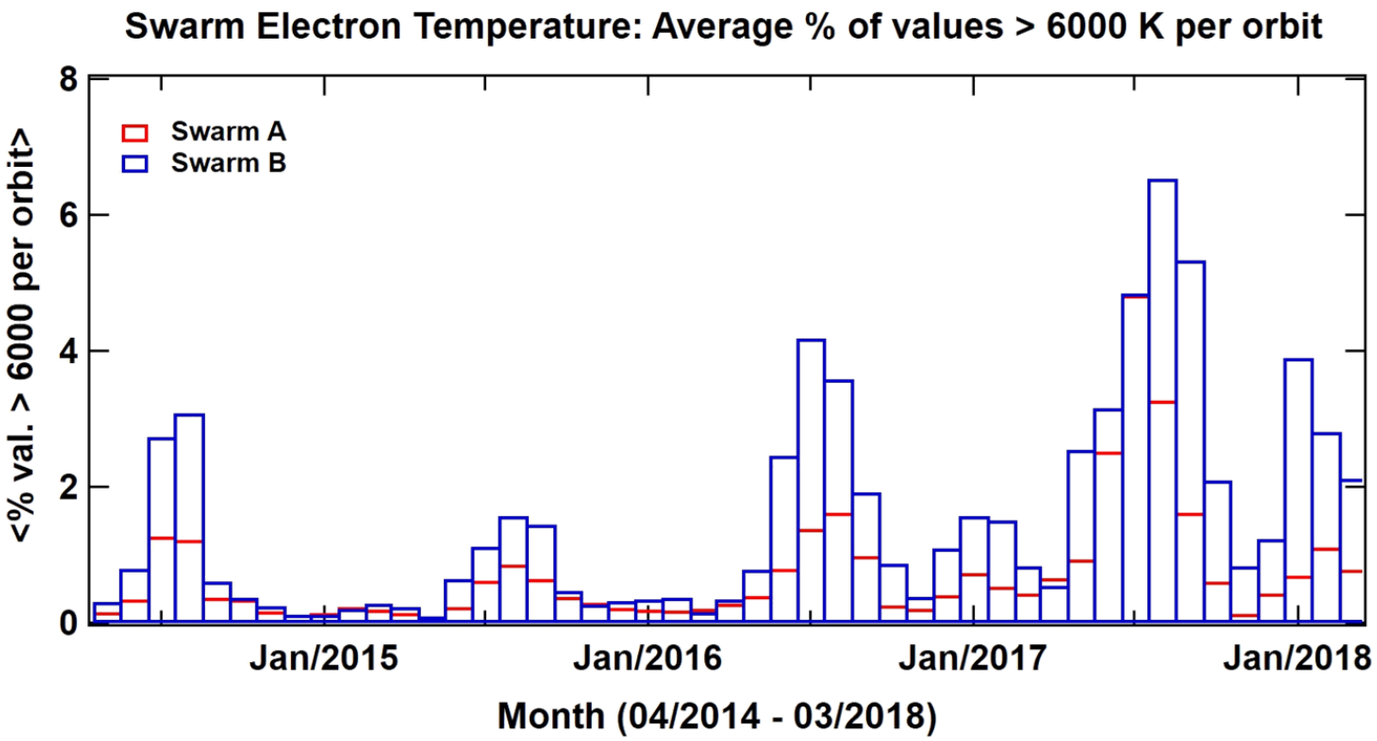


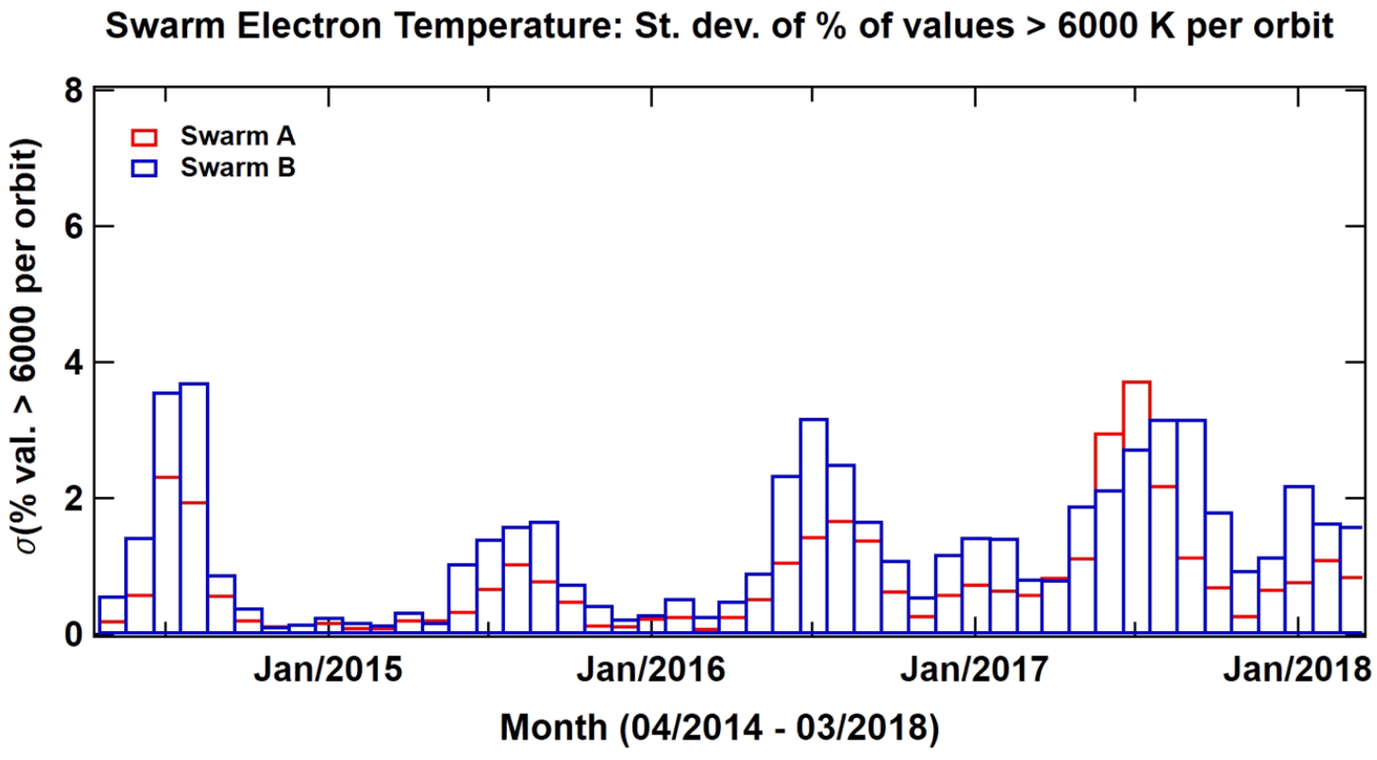


- In the **Northern hemisphere** (example for Swarm A) there is no clear correlation between the distribution of the outliers and the distribution of Te itself.

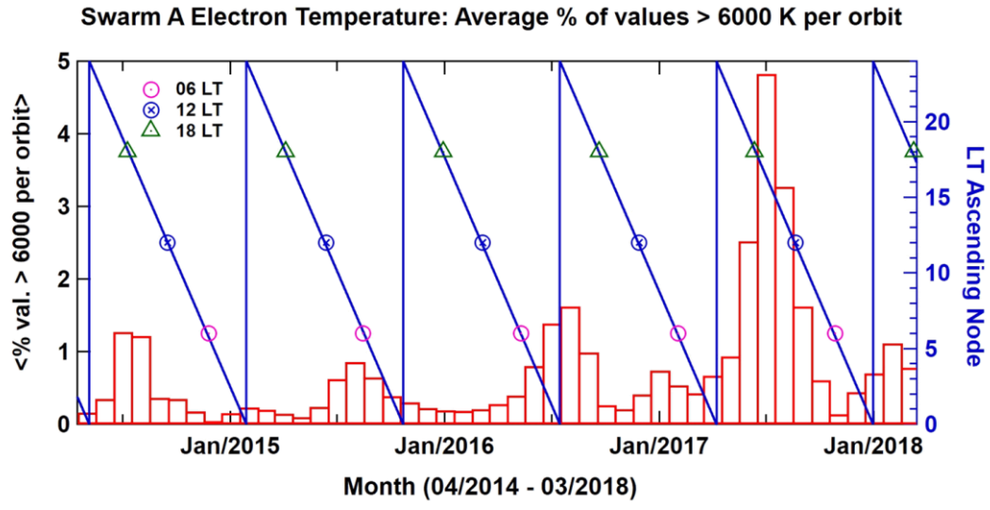
- In the **Southern hemisphere** one observes that the regions where the outliers are concentrated are mostly the same regions where Te itself is higher. In particular, the ouliers occurrence peak is located in a thin belt just equatorward of Te maximum intensity belt (70°-72° S).

«Extreme events» vs orbits (1)

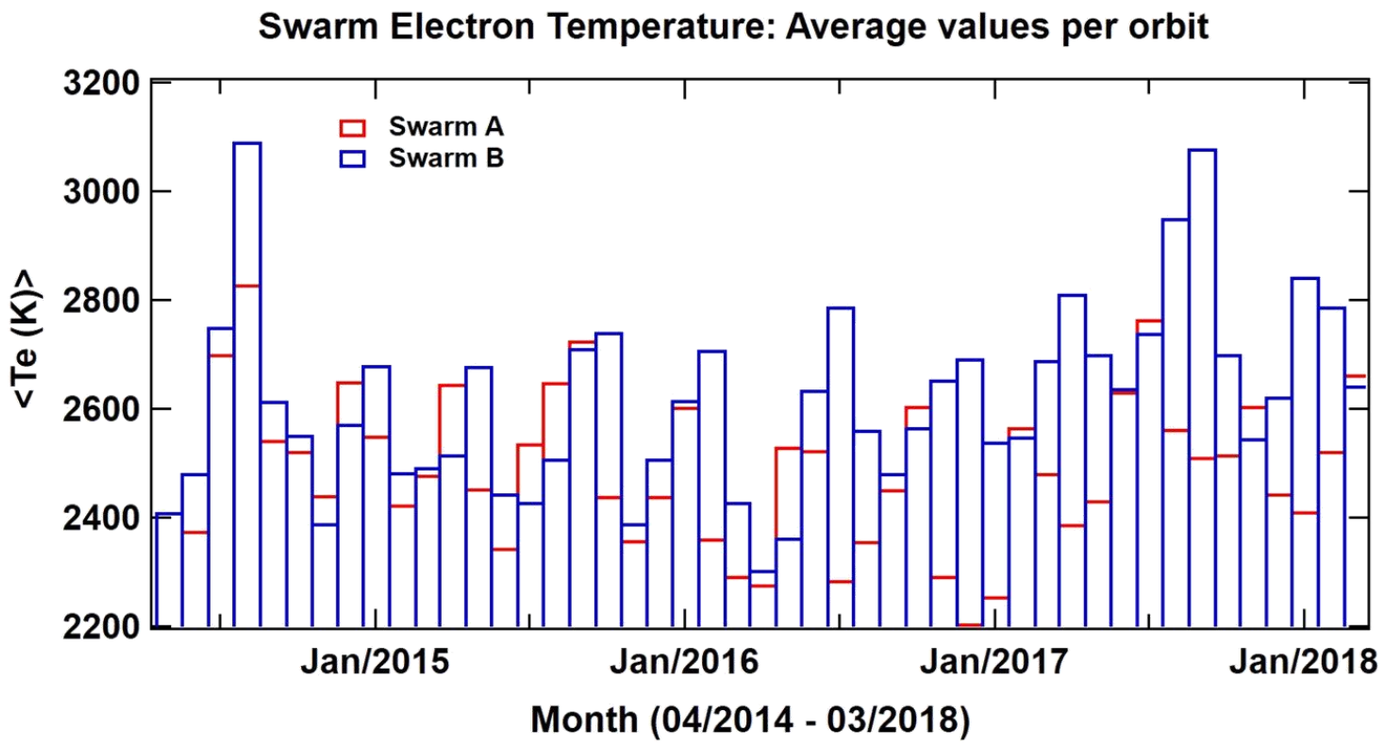


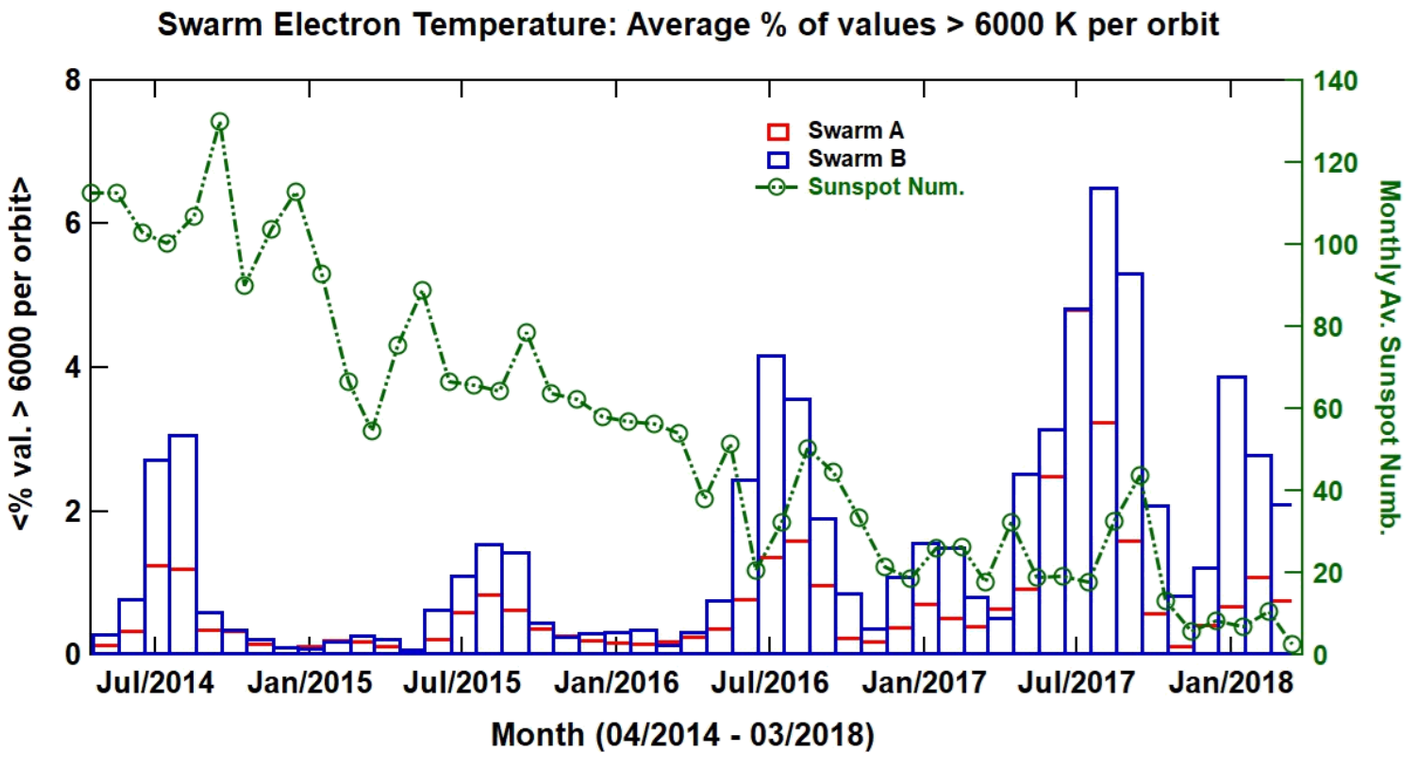


- The orbital occurrences of Te values > 6000 K are on average always less than 400 occurrences per orbit (~7%).
- The variability is very high, being the standard deviations of the distributions more or less comparable with the average itself.
- Interestingly, the number of values > 6000 K seems to follow a seasonal cycle, being lower in winter and higher in summer. Overall, such number baseline increases, in all seasons, after 2016 (solar minimum?).
- This kind of «breathing» of the outliers seems not to follow the orbital cycle (see below the case of Swarm A)



«Extreme events» vs orbits (2)



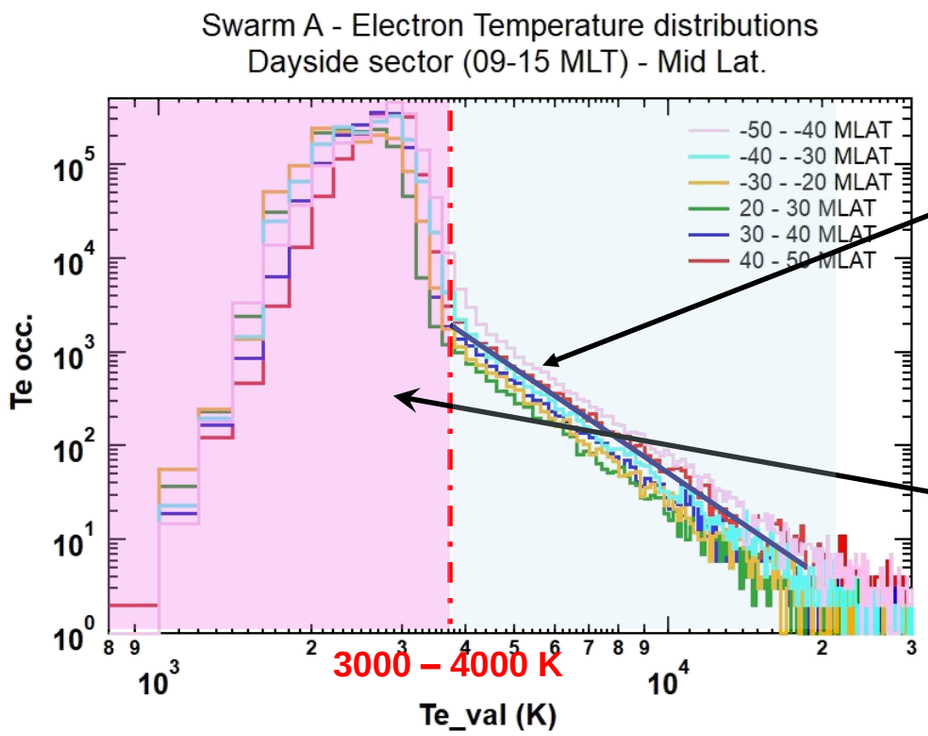


- The seasonal behaviour of the outliers distributions within the orbit seems not to be related to the any periodicity of the average «good» temperature values per orbit.

- In the end, the suspicion is that the outliers belong to a different distribution of events with respect to the main Te distribution, with features and properties that seem strongly related to the environement in which the S/C travel.

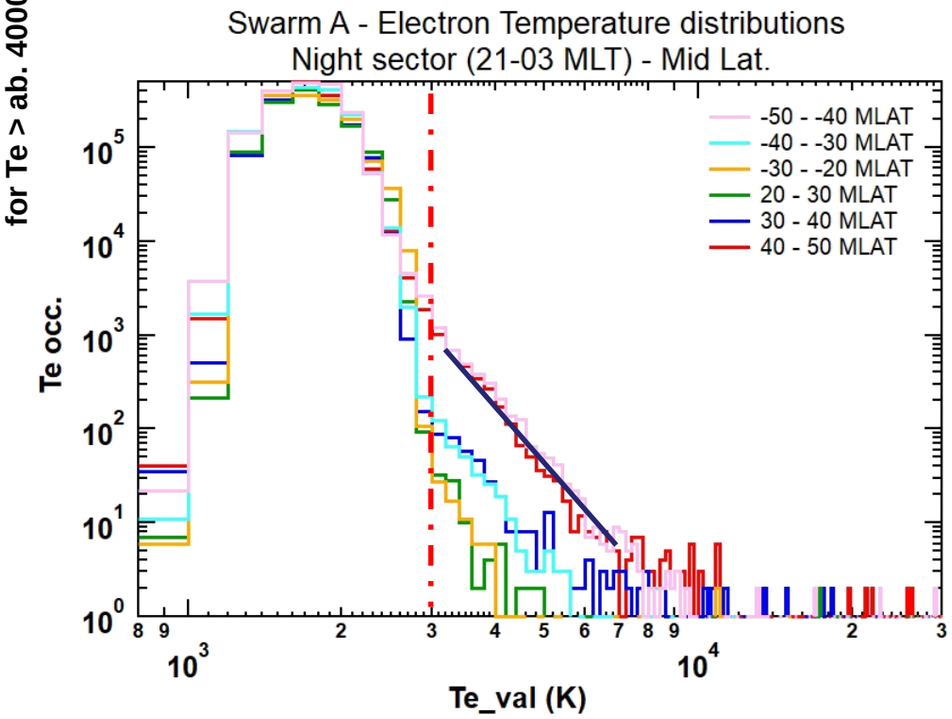
- In order to investigate this, we computed the distributions of Te values as functions of latitude and LT.

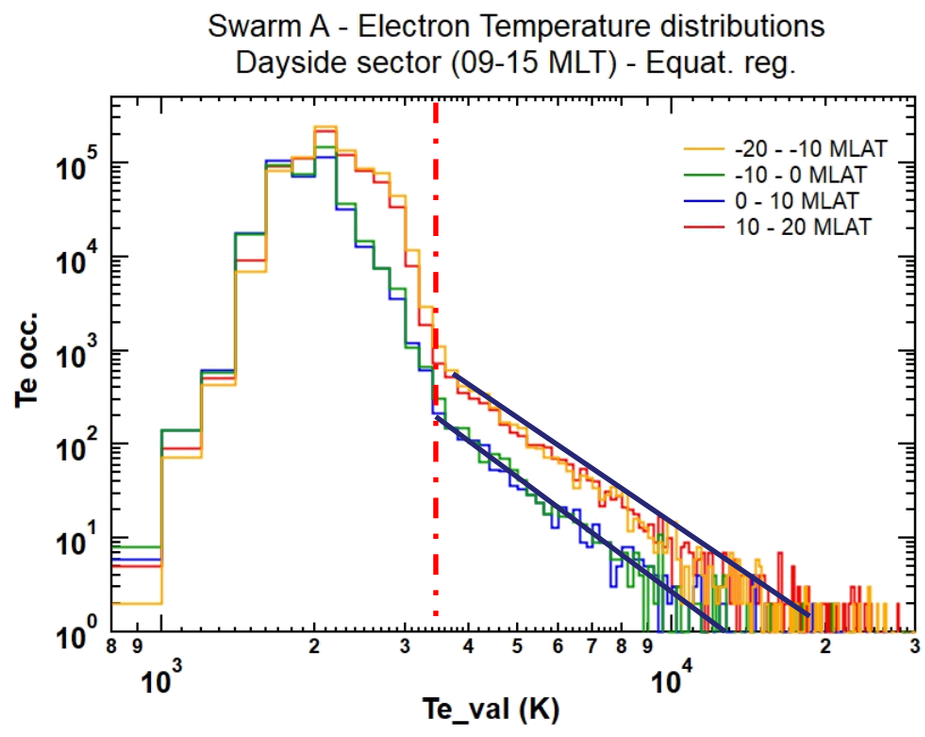
Log-log hystograms of Te: Mid-Low Latitudes

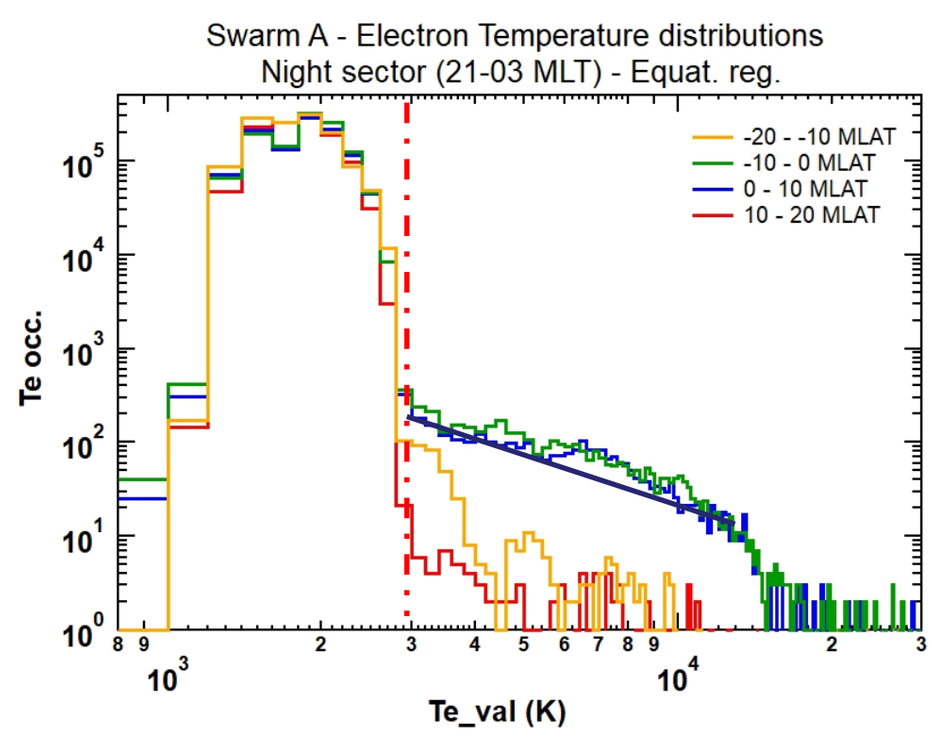


«Core» distribution (single or double log-normal, Weibull/Frechét…)

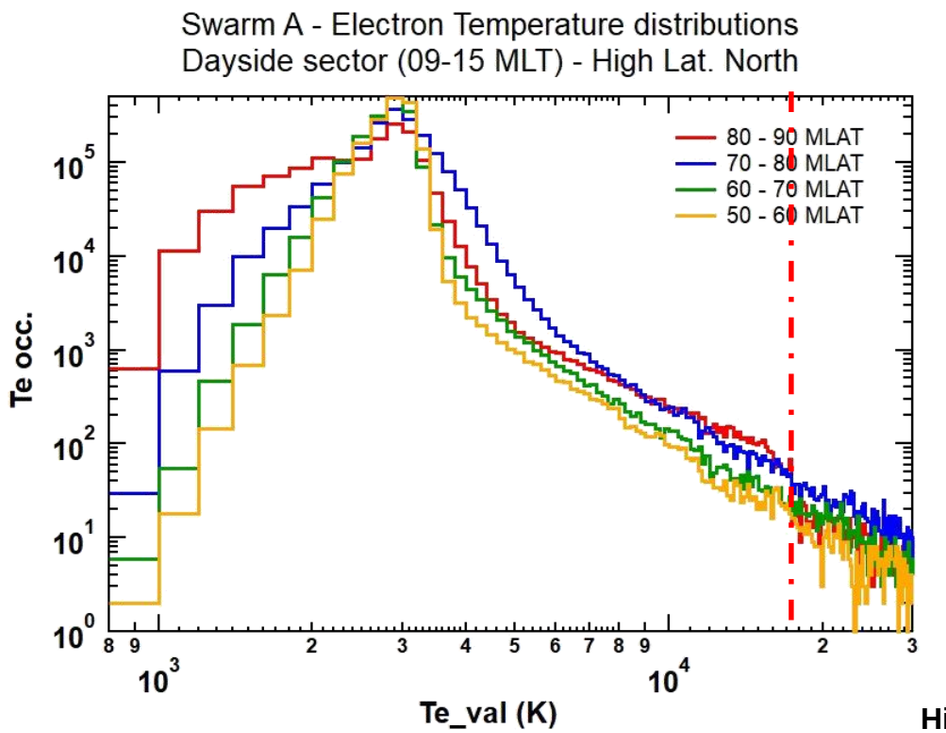
Power law behaviour for Te > ab. 4000 K

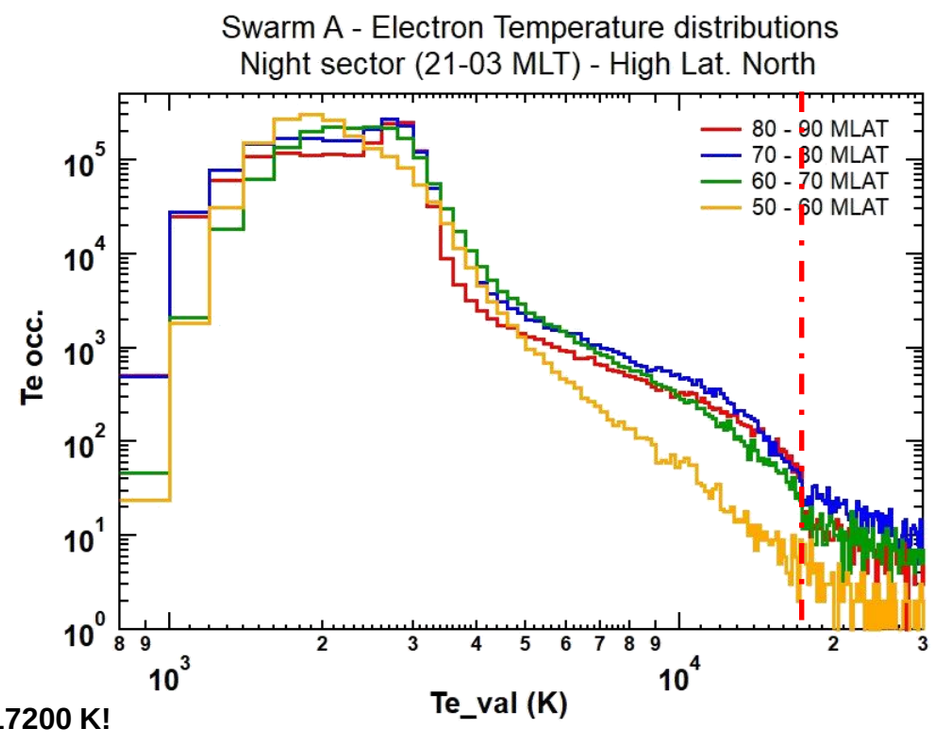




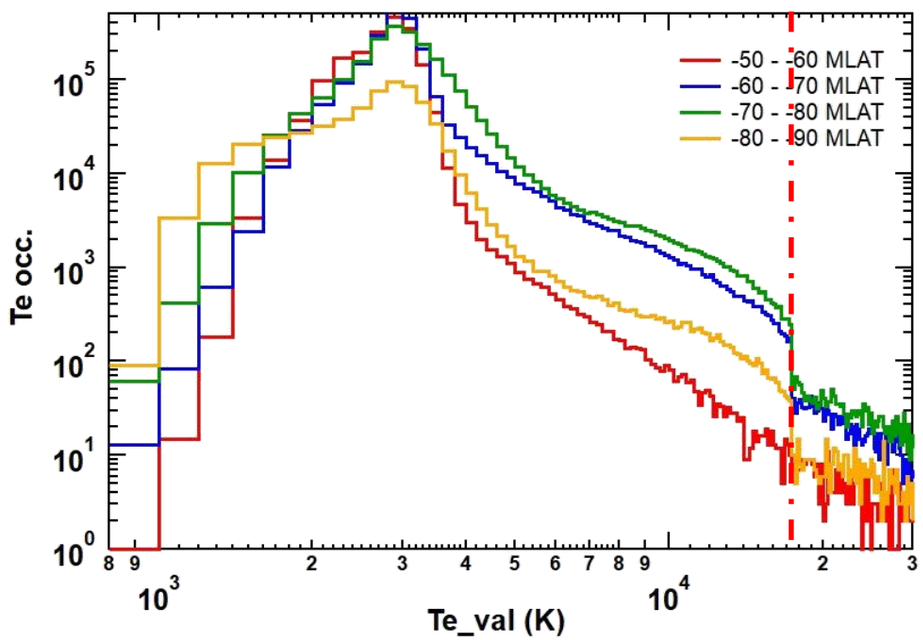


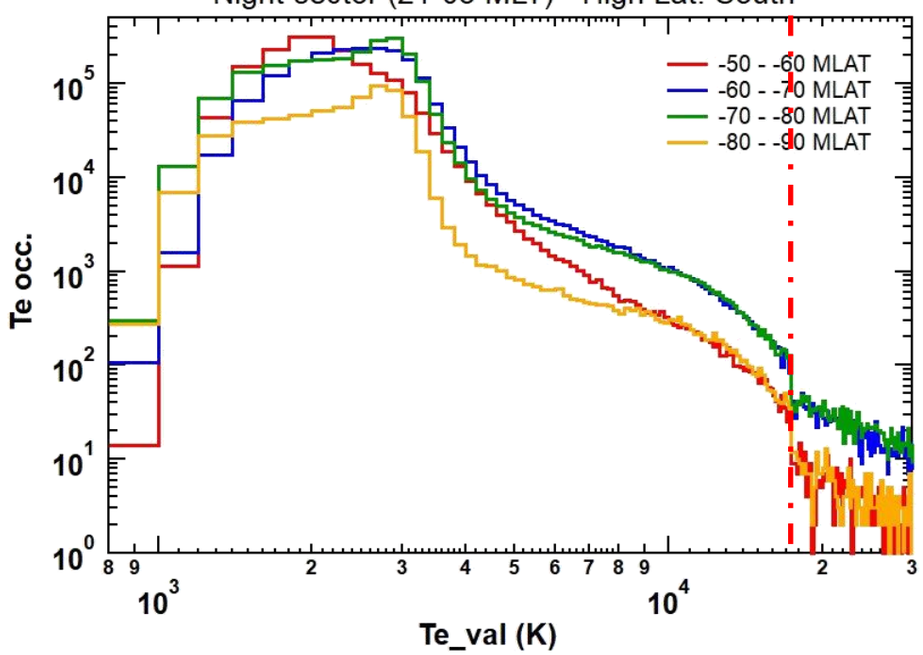
Log-log hystograms of Te: High Latitudes





High Lat. cut off at ab. 17200 K!
This seems a curious instrumental effect…





Summary and conclusions

- **«Extreme events»** of high electron temperature (> 6000 K) are not exactly ubiquitous, but tend to cluster in regions where the core of the electron temperature main distributions have local maxima.

- **General climatology:** More frequent at high latitudes (> |60|° MLAT), with occurrence peaks close to 20% of overall data, 2-3 times more intense in Southern Hemisphere than in the Northern one. Low occurrence at mid-low lat. (2-5 %). More frequent at higher altitude (Swarm B observe 2-3 times the occurrences of Swarm A).

- **Orbital/Seasonal climatology:** More frequent in Summer than in Winter, with a growing trend in the maxima from 2016 on (solar cycle dependence?).

- **Distributions** as a function of magnetic latitude and local time shows that «extreme events» are not random, but belong to a neatly separate population wrt the core of Te distribution: they follow power laws (cascade) whose exponents depends on Mlat and MLT. Moreover, there is a remarkable symmetry around magnetic equator for the extreme events populations, up to Mlat of about |60°| where the phenomenology radically changes.

- **An instrumental cut-off** seems to exist at about 17200 K, after which the counts fall from few tens to quasi-zero. This occurs particularly at high latitude and more clearly in the Southern hemisphere, but in some circumstances the cut-off is also observed around the equator.

Future perspectives

- The results found seem very promising and we want to continue the investigation of Te extreme events, in the framework of turbulence theories (distributions of thermal speed/energy and internal energy)

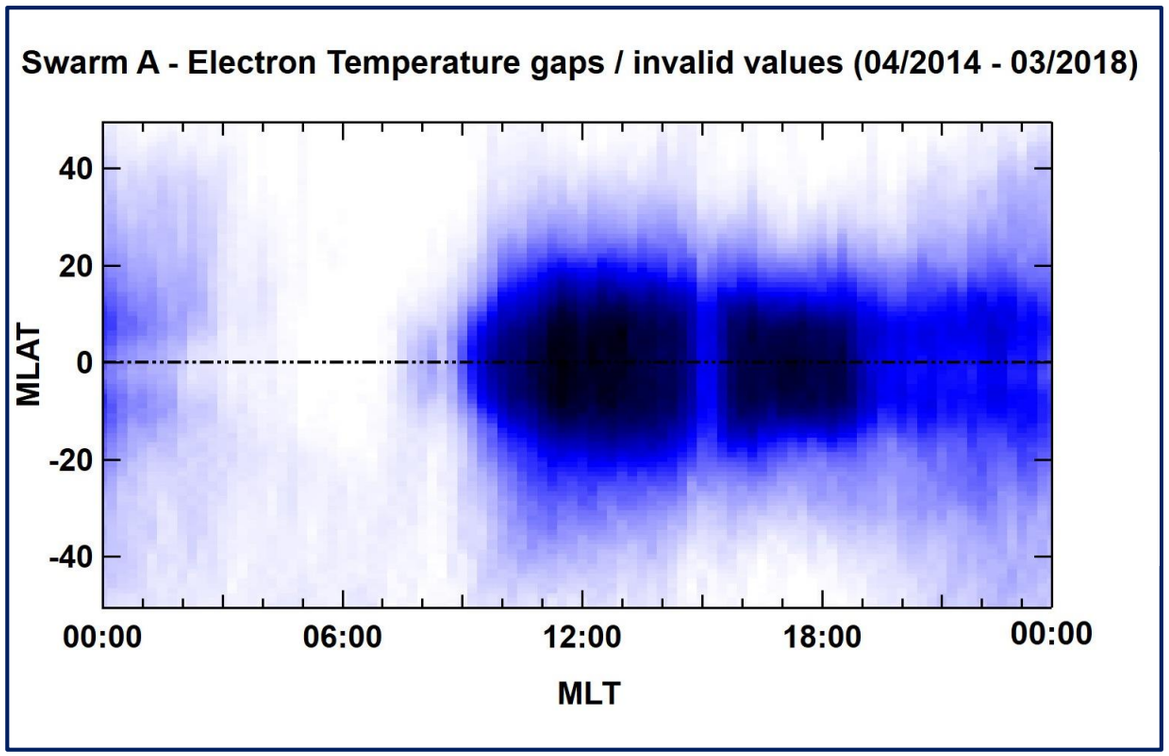
- Many observations suggest that detailed analyses should be done as a function of geographic latitude/local time and season, rather than magnetic coordinates and geomagnetic activity.

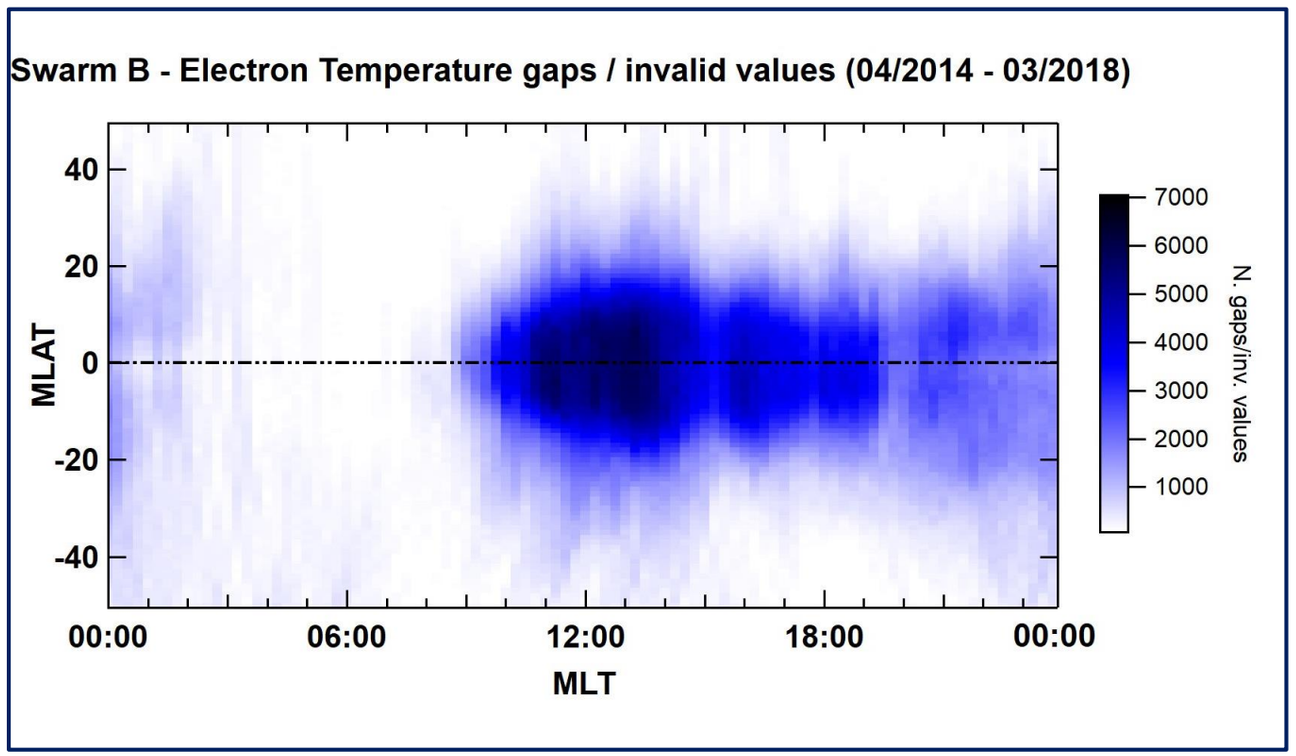
- Of course the analysis should be completed with more recent data, and for Swarm Charlie too…

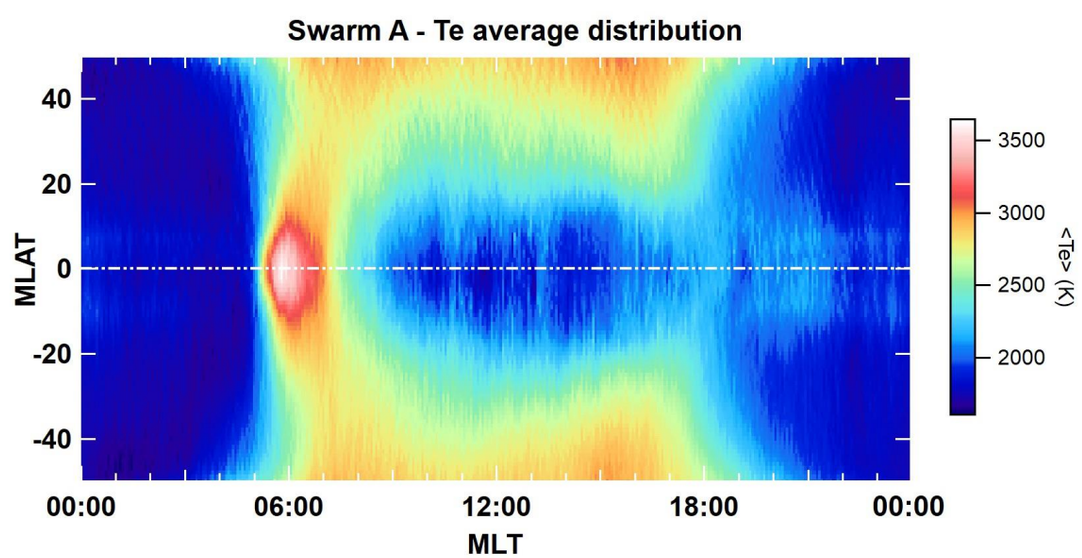
Additional

Gaps/invalid values statistics (1)

Low-mid latitude distribution (+/- 50° MLAT)







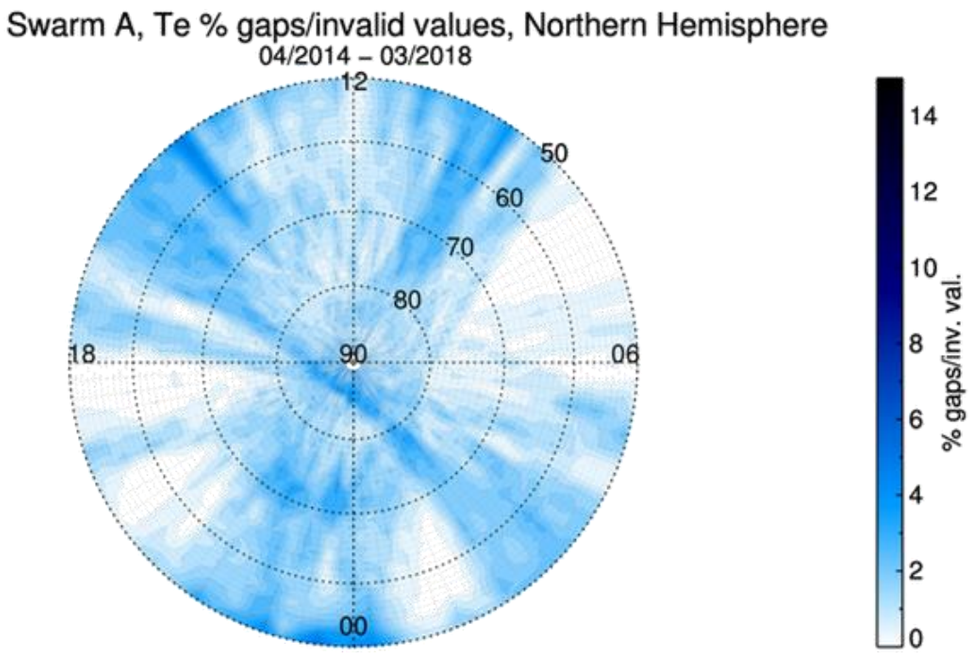
- **Swarm B** (up right) shows less gaps/invalid values than **Swarm A** (up left).

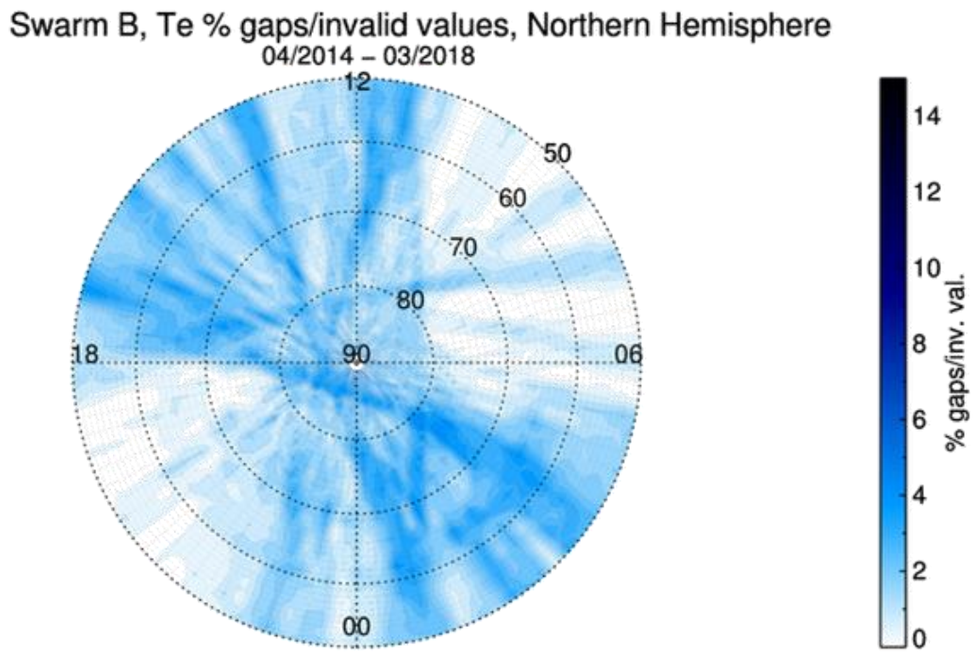
- The distributions of gaps/invalid values seems to be specular to the distributions of Te itself. See, for example, on the left, the Te average distribution for Swarm A, 04/2014 – 03/2018. Where Te is lower, we have on average a large number of gaps/inv. values, where Te is higher (above about 2000 K) the average number of gaps/inv. values is very low, falling close to zero in the early morning sector.

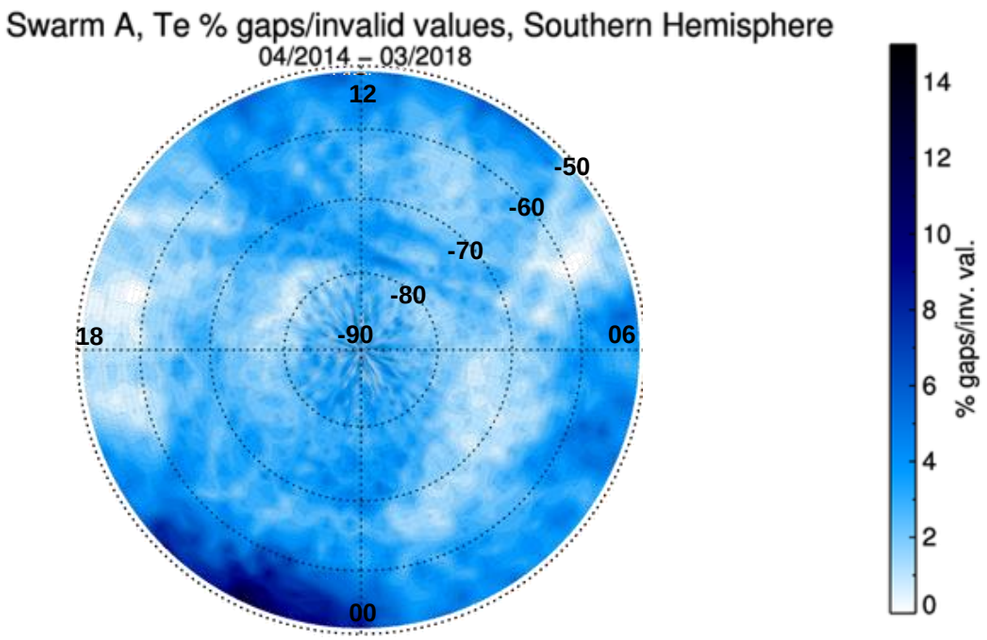
Additional

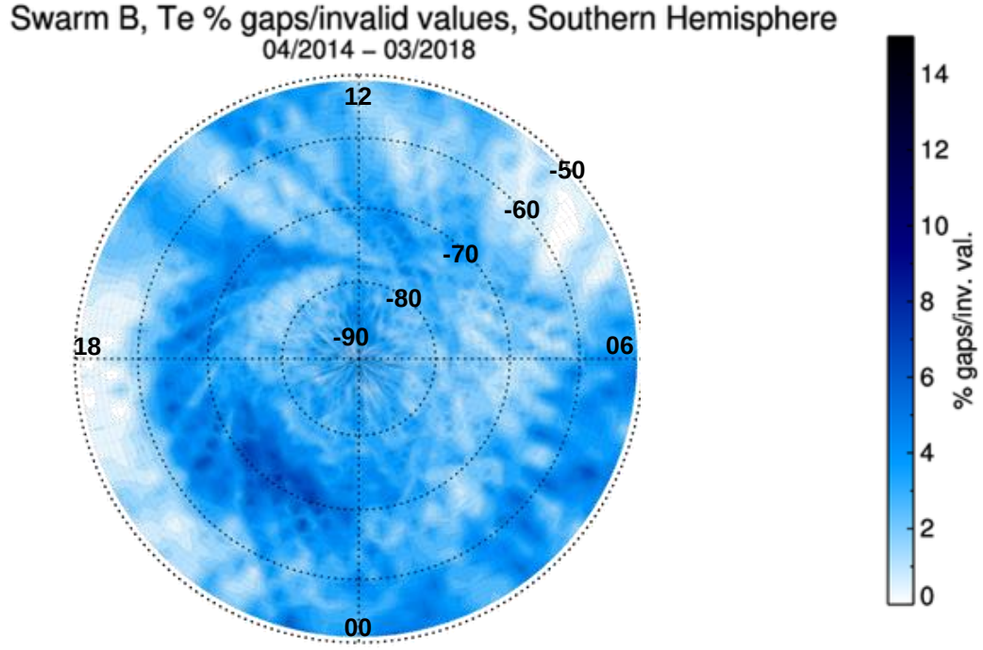
Gaps/invalid values statistics (2)

High latitude distribution (> |50|° MLAT)







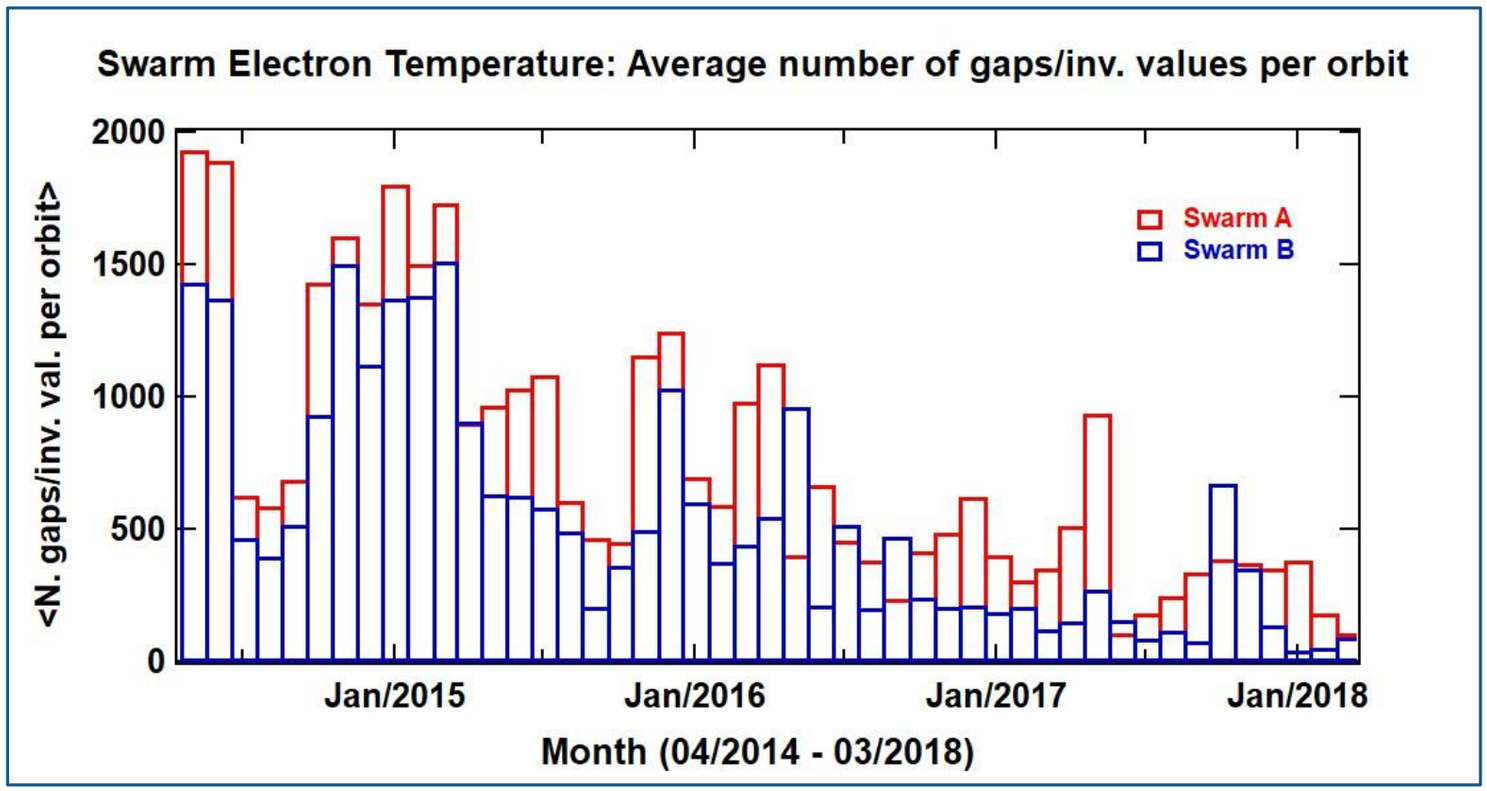


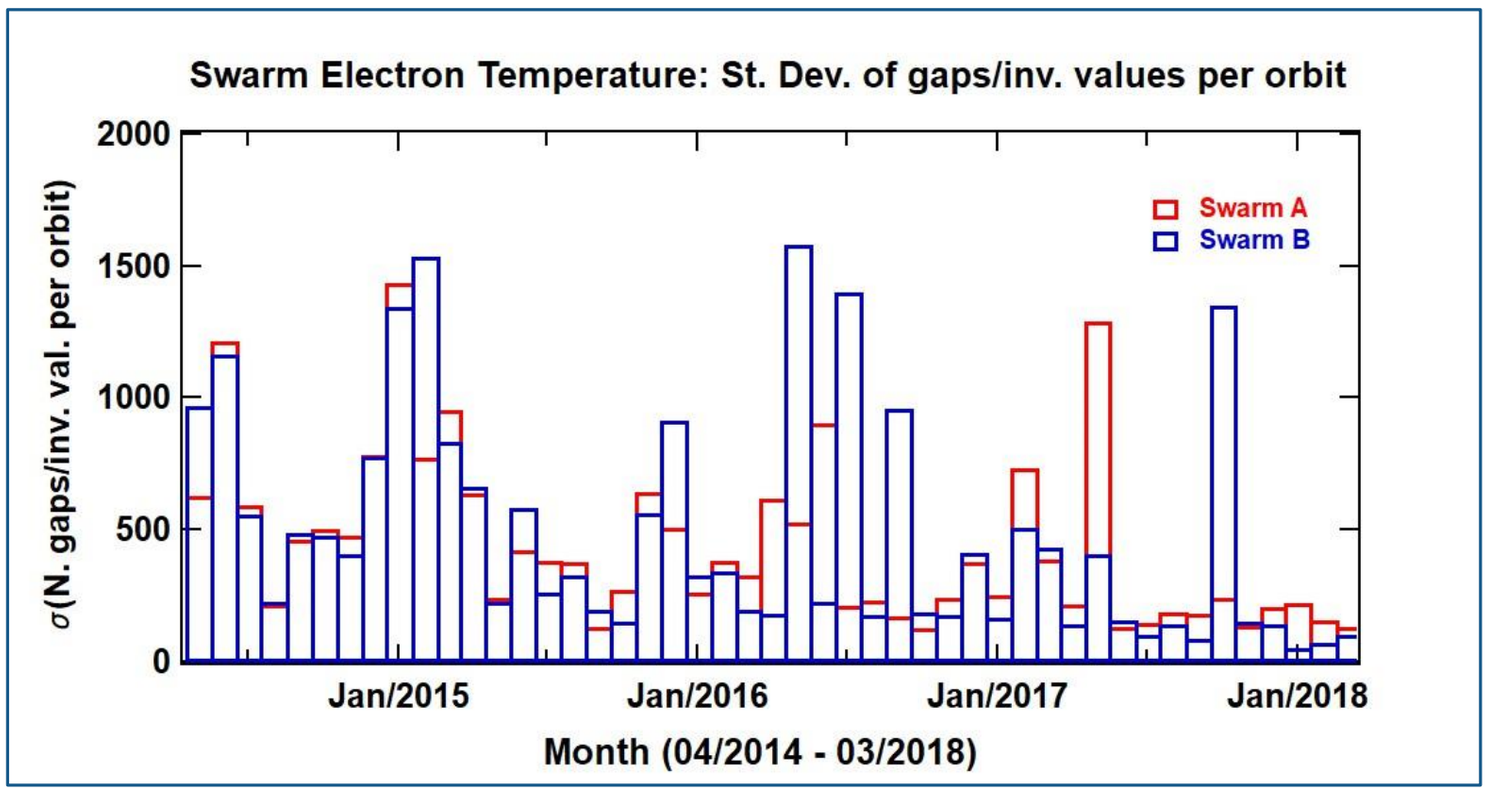
- In the North occurrences are lower than in the South (by about 15-20%), and, due to the orbital configuration and a «distortion» of S/C trajectories due to the use of magnetic coordinates in the South, at North it is more evident a different distribution of gaps/inv. values wrt local time.

- At high latitudes, one does not observe correlations or similarities of the gaps/invalid values distributions with the overall Te distributions (not shown here, but we will show them in the «outliers» section)

Additional

Gaps/invalid values statistics (3)





- The orbital distribution shows that the average gaps/invalid values per orbit is decreasing from the beginning of mission, especially for Swarm B.
- The variability is nonetheless very high, being the standard deviations of the distributions more or less comparable with the average itself.
- The number of gaps/inv. Values per orbit is in general rather high almost everywhere, and it is not possible to identify extended periods with few enough gaps in order to try a statistical study on Te.