MLT-dependent wave activity in the Earth's magnetosphere

ParAs master's thesis seminar

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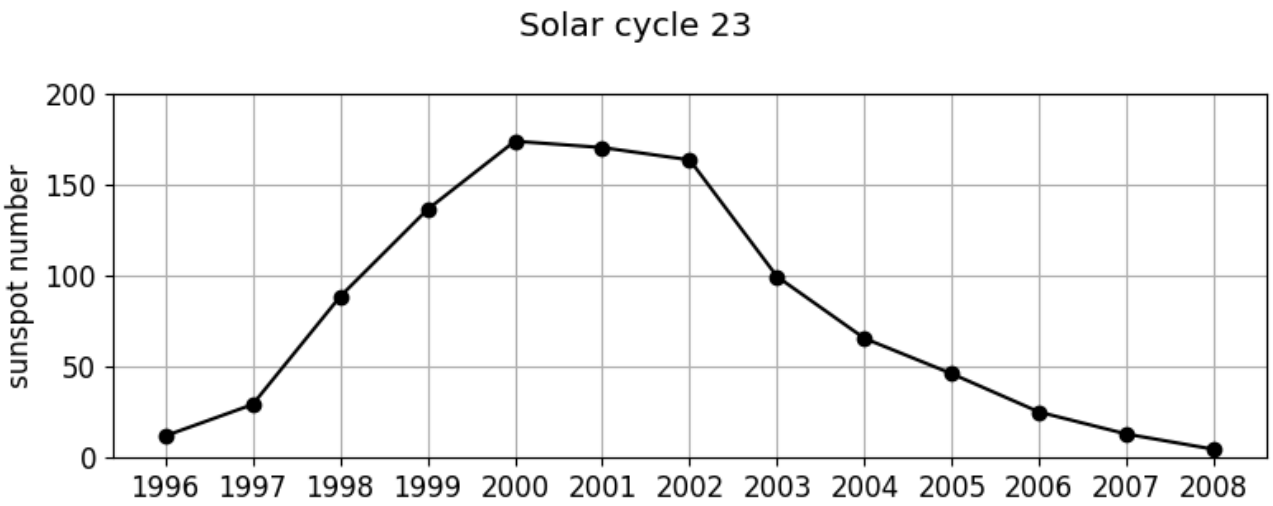
Outline

Earth's magnetosphere and the Sun

- Earth's inner dynamo generates a magnetosphere
- constant flow of solar wind interacts with the magnetosphere in various ways
- energetic particles, geomagnetic storms, radiation,...
  $\rightarrow$ space weather: phenomena in the near-Earth space that can affect life and infrastructure

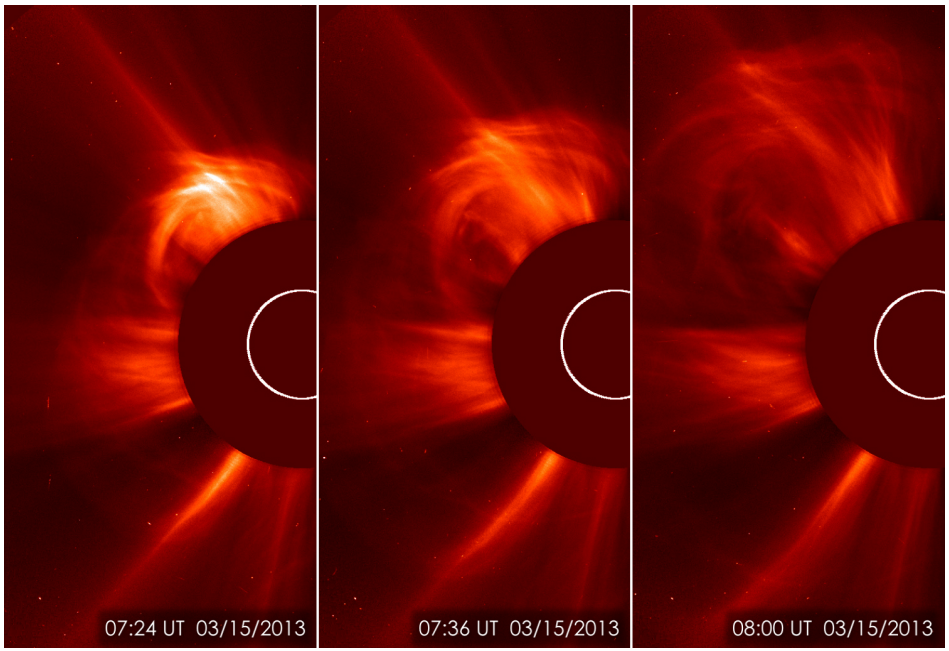
Solar cycles

- Sun has a 11 year activity cycle, often described by sunspot number
- amount of large-scale solar wind structures varies



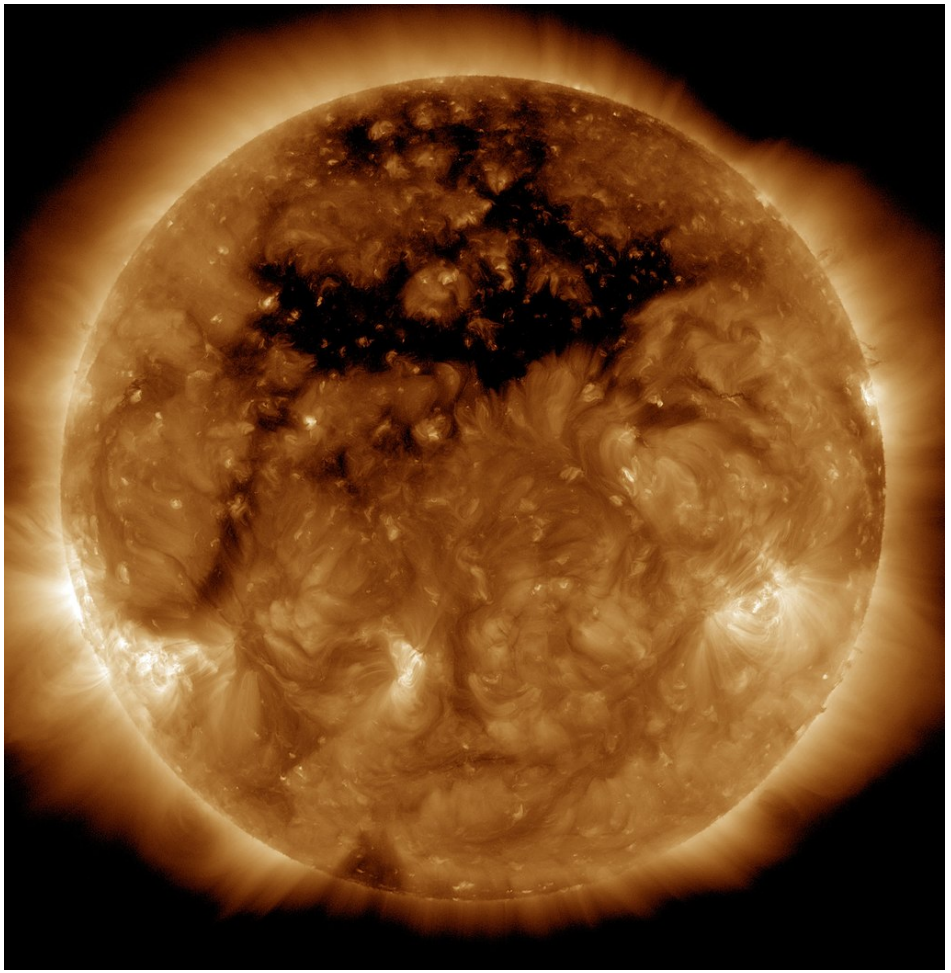
Interplanetary coronal mass ejections (ICMEs)

- powerful ejections of plasma from the Sun
- flux rope structure
- fast ICMEs create shocks, sheath region forms
- interaction with Earth's magnetosphere results in the strongest geomagnetic disturbances



High-speed streams

- fast, low-density solar wind, velocity 500-800 km/s
- originated from coronal holes
- compresses slow wind $\rightarrow$ stream interaction region
- can cause reoccurring magnetospheric disturbances



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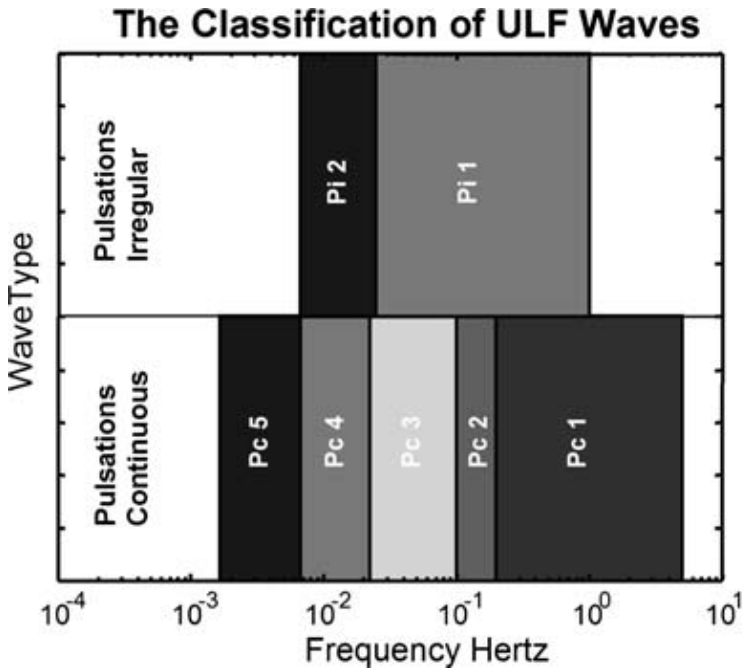
ULF waves

- ultra low frequency (ULF) pulsations in the Earth's magnetic field
- often categorized to continuous (Pc) and irregular (Pi) waves that are divided based on frequency (Pc1-5 and Pi1-3)
- focus on Pc5 waves



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Irregular Pulsations

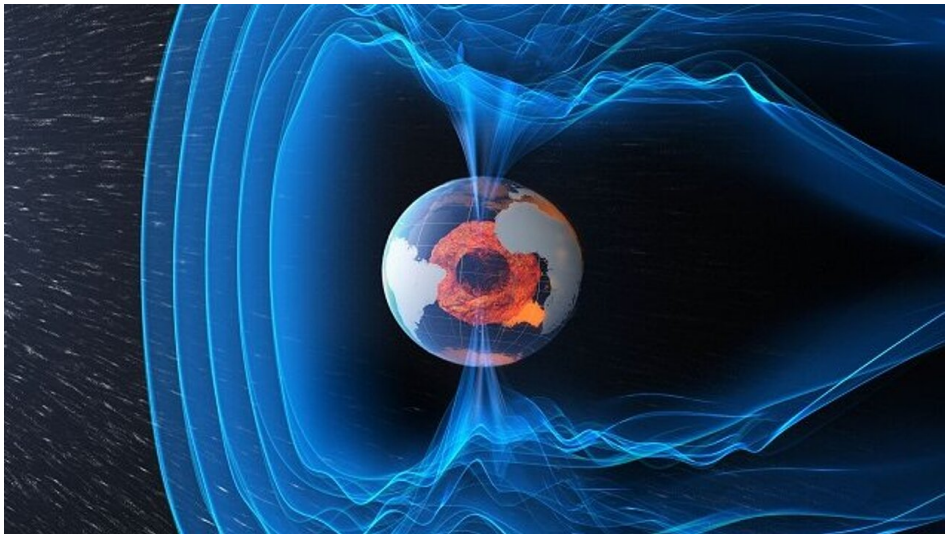
Class	Low edge Period (s)	High edge Period (s)
Pi 2	150	45
Pi 1	45	1

Continuous Pulsations

Class	Low edge Period (s)	High edge Period (s)
Pc 5	600	150
Pc 4	150	45
Pc 3	45	10
Pc 2	10	5
Pc 1	5	0.2

Why ULF waves?

- Earth has two radiation belts
- high energy electrons cause damage to satellite electronics
- Pc5 wave activity associated with high relativistic electron flux: the waves have suitable frequencies for accelerating electrons



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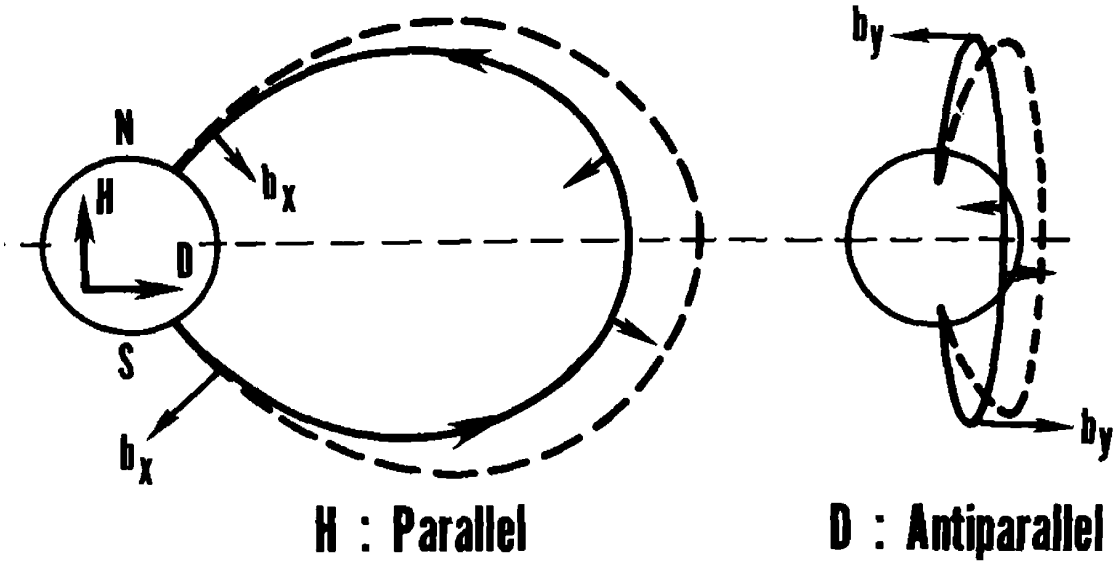
ULF waves

- various generation mechanisms, e.g. Kelvin-Helmholtz instability on the magnetopause → correlation with solar wind velocity
- divided to poloidal, toroidal and compressional waves
- toroidal waves most commonly observed on ground



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ULF waves

- wave activity known to depend on magnetic local time (MLT)
- wave activity known to strengthen during ICMEs and HSSs

Question 1

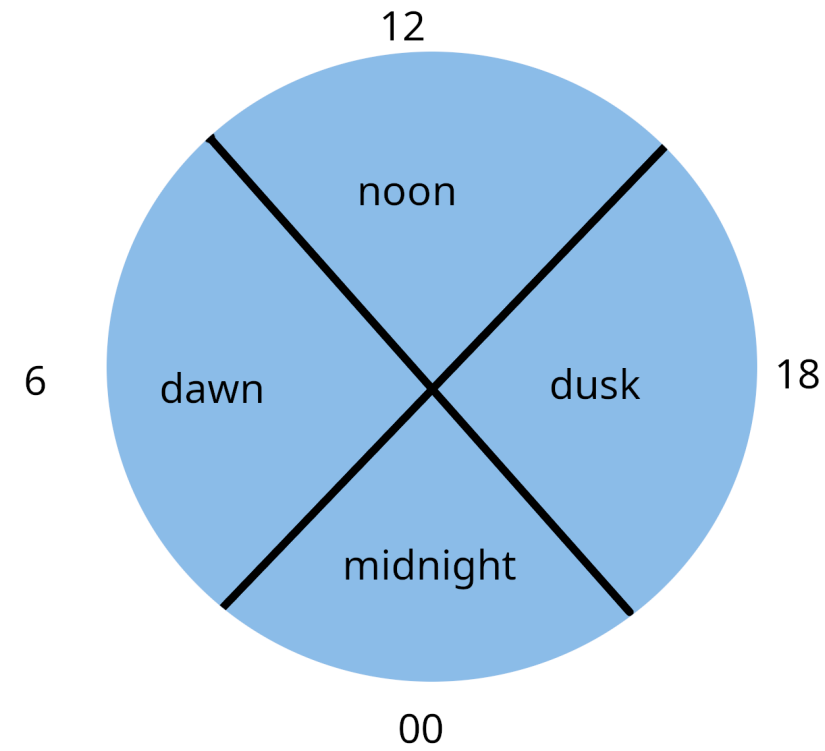
How does the Pc5 activity depend on MLT and large-scale solar wind structures?

Question 2

How does the Pc5 activity vary during individual geomagnetic storms?

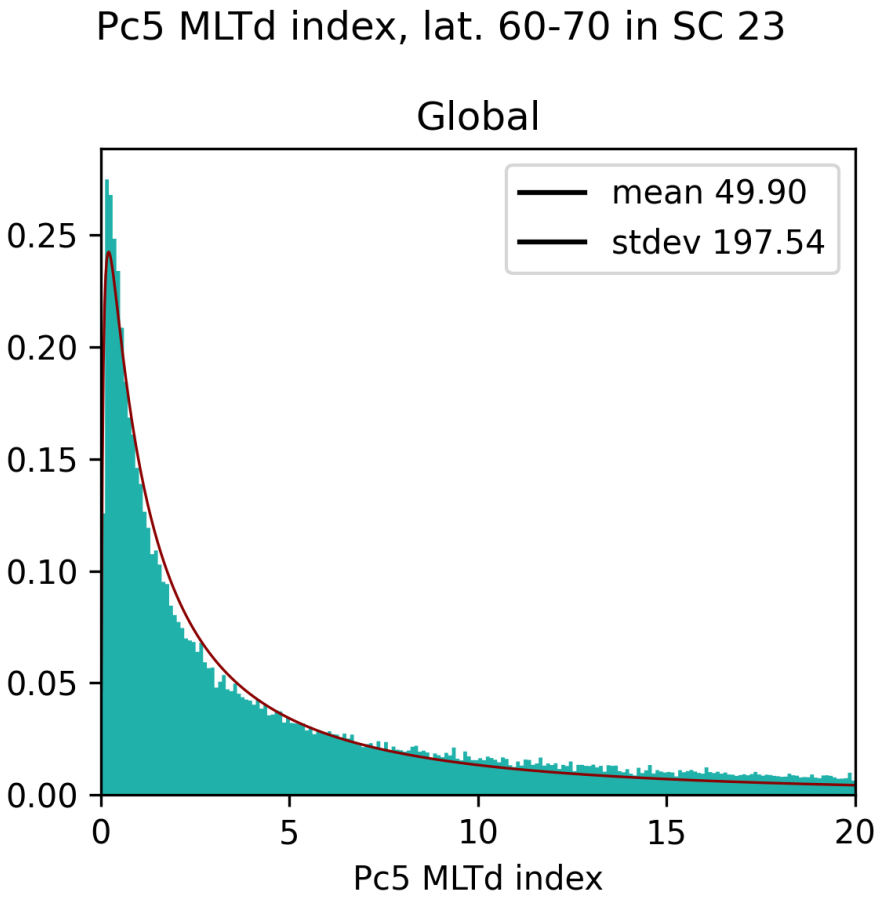
Pc5 MLTd index

- ground-based magnetometer measurements from SuperMAG
- wave activity index to quantify the amount of Pc5 frequency range activity
- using either horizontal (H) component or N/E components of the geomagnetic field
- separate indices for MLT quadrants:
  - dawn: 3-9 MLT
  - noon: 9-15 MLT
  - dusk: 15-21 MLT
  - midnight: 21-3 MLT



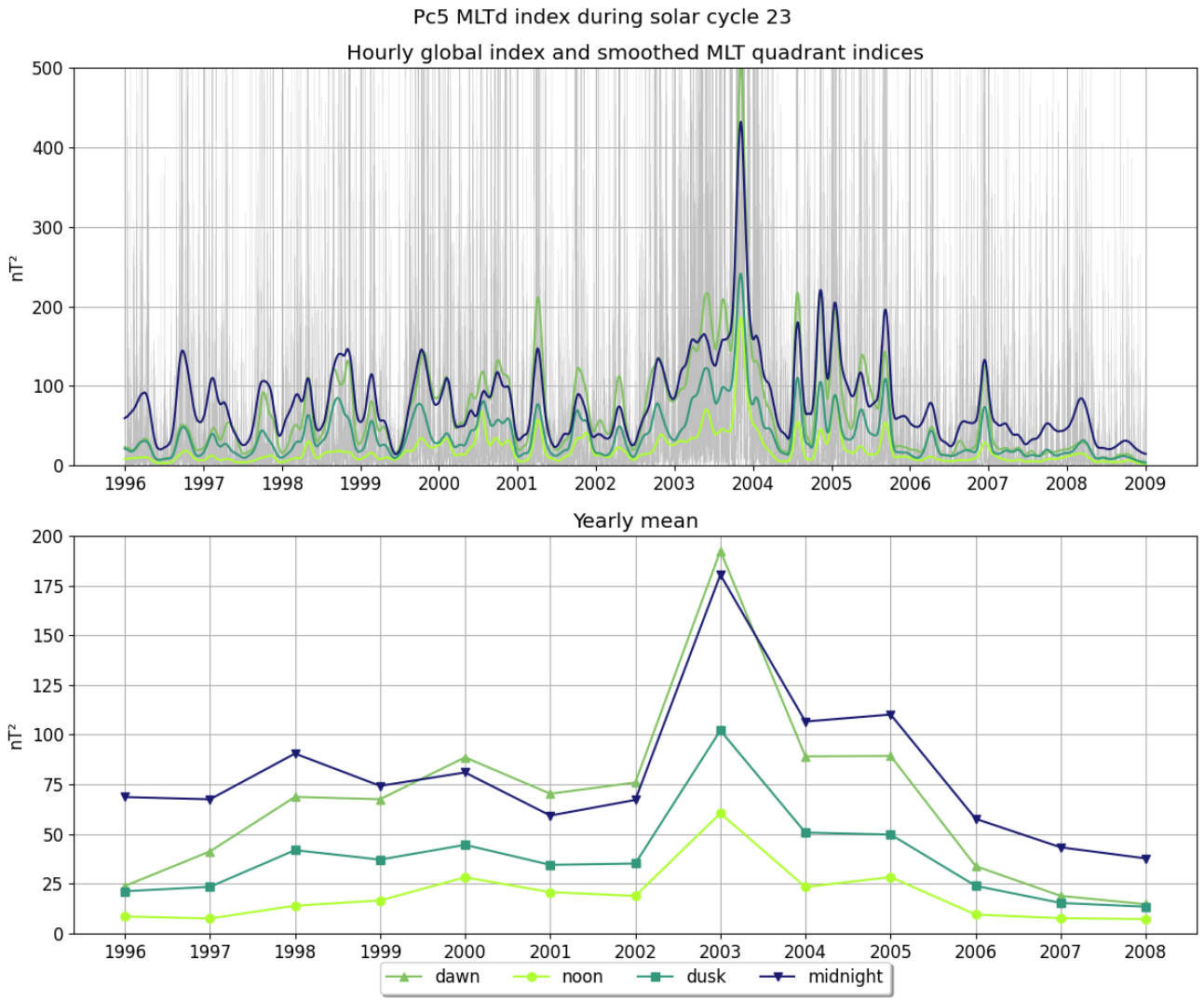
Distribution of the Pc5 index

- Normalized histogram of the global Pc5 index during solar cycle 23 (1996-2008)
- Resembles a log-normal distribution, but the peak is barely distinguished from zero and the tail has too much volume



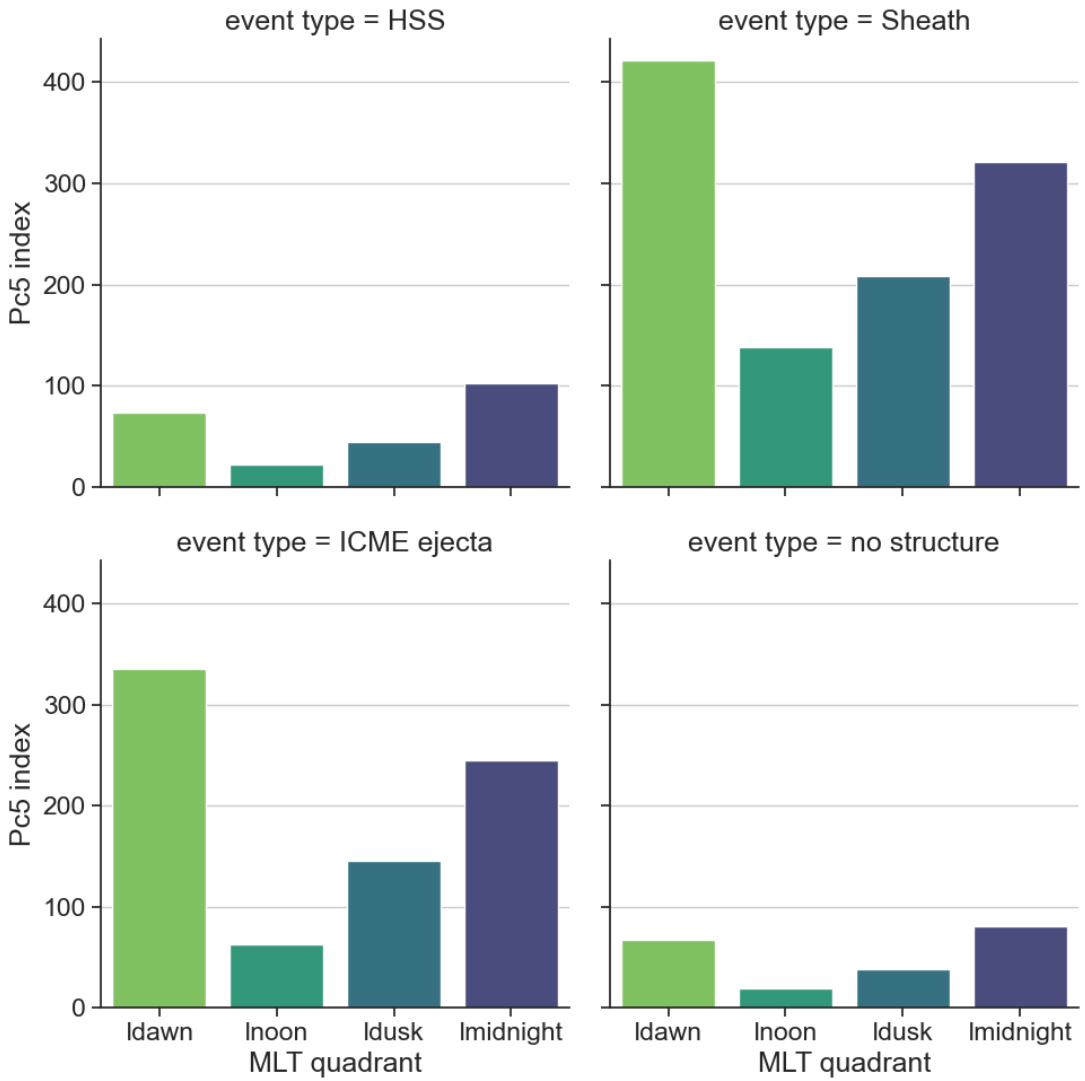
Pc5 activity during the solar cycle

- clear solar cycle dependence
- MLT differences vary



Pc5 activity during solar wind structures

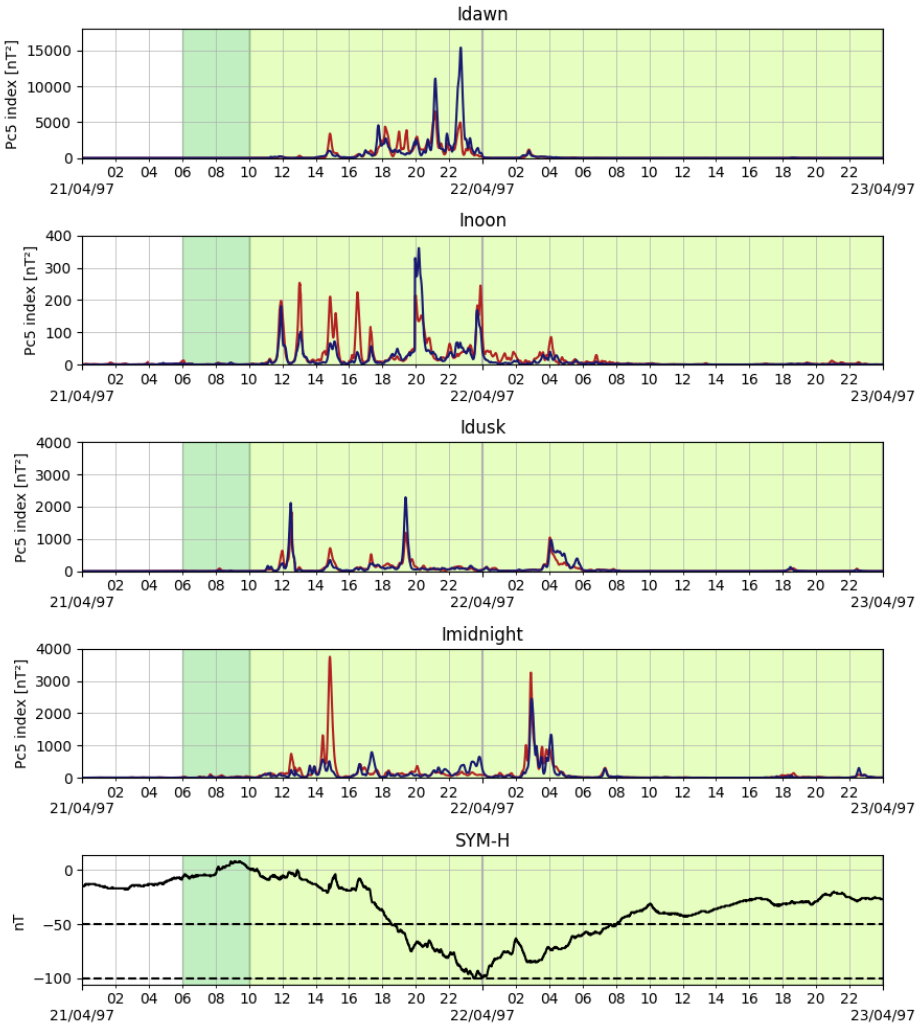
- sorted to HSS, ICME sheath region, ICME ejecta and no structure
- ICME related activity high
- MLT differences are large, dawn is strongest in ICMEs
- event length affects a lot: sheaths are short, HSSs are long

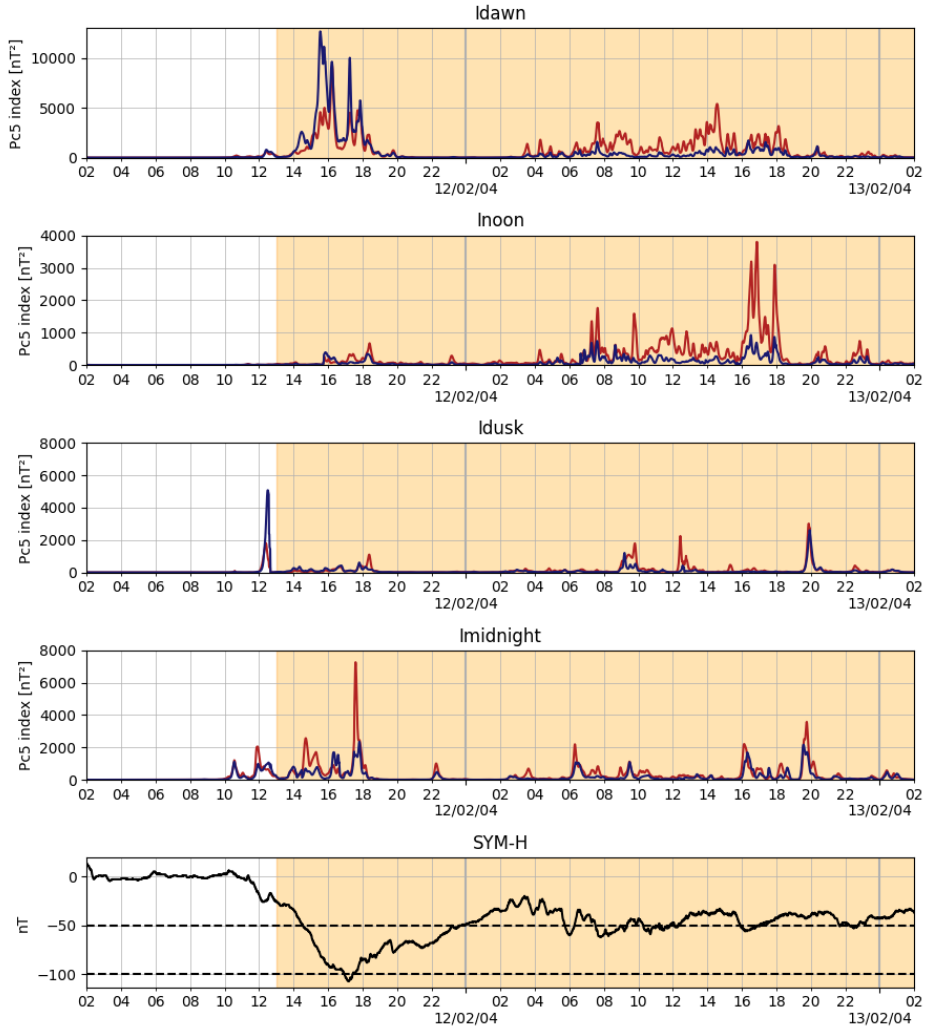


Event comparisons

- Comparing two pairs of geomagnetic storms, selected based on similar Dst profiles.
- Comparing N- and E-component wave indices in different MLT quadrants
- Solar wind parameters from OMNI data for reference

ICME 21.4.1997 and HSS 11.2.2004





ICME 21.4.1997 and HSS 11.2.2004

Why are they different?

- Not sure!
- Differences in solar wind velocity and density
  $\rightarrow$ different processes driving the wave activity?

Conclusions

- not yet finished
- MLT differences similar to many previous studies on the topic
- addition of a narrowband wave index?

Summary

- ULF waves are an important part of the magnetosphere dynamics and are influenced by the solar wind
- Pc5 activity depends heavily on magnetic local time
- wave activity varies a lot during geomagnetic storms

Thank you!

Questions?

Incomplete list of references

[1] Mark Engebretson et al. "The dependence of high-latitude Pc5 wave power on solar wind velocity and on the phase of high-speed solar wind streams". In: 103.A11 (Nov. 1998), pp. 26271–26384. DOI: 10.1029/97JA03143.

[2] D. M. Pahud et al. "Ground-based Pc5 ULF wave power: Solar wind speed and MLT dependence". In: *Journal of Atmospheric and Solar-Terrestrial Physics* 71.10-11 (July 2009), pp. 1082–1092. DOI: 10.1016/j.jastp.2008.12.004.

[3] Theodore E. Sarris et al. "Distribution of ULF Wave Power in Magnetic Latitude and Local Time Using THEMIS and Arase Measurements". In: *Journal of Geophysical Research (Space Physics)* 127.10, e2022JA030469 (Oct. 2022), e2022JA030469. DOI: 10.1029/2022JA030469.