Studying solar wind properties using pattern recognition methods

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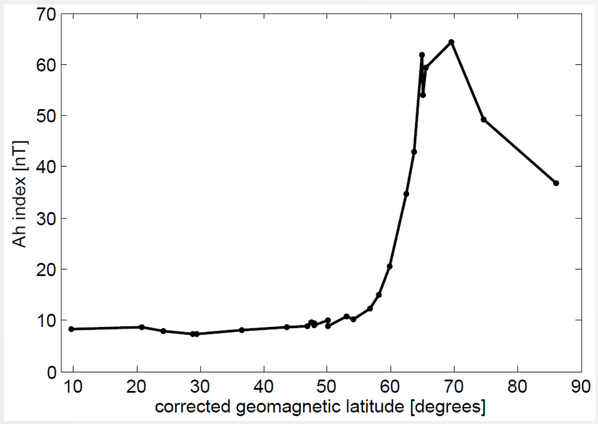
1. Local A_h and A_{hs} indices

- We use local A_h ***indices*** from 26 stations in the northern hemisphere.
- A_h indices are analogous to local A_k indices.
- 3-hourly value of the A_h index is defined as the range of the local horizontal magnetic field after removing the quiet day variation.
- *Ah* indices are calculated using hourly mean data at WDC Edinburgh www.wdc.bgs.ac.uk/.



Averages of the Ah indices in 1966-2009

Geomagnetic activity has a well known maximum at auroral latitudes.

In order to weight all stations (latitides) equally, we use standardized A_h indices

$$A_{hs} = \frac{A_h - \langle A_h \rangle}{\sigma}$$

where $\langle A_h \rangle$ and σ are the average and the standard deviation of the A_h indices. We use both standardized annual means and standardized 3-hour values of the A_h indices.

2. Principal component analysis

The yearly A_{hs} indices are collected into columns of 44x26 data matrix ***X***.

The singular value decomposition of the data matrix is

$$\boldsymbol{X = UDV^T}$$

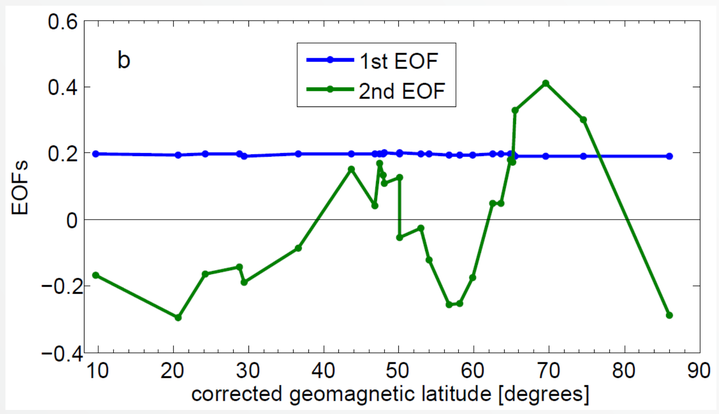
where columns of the matrix ***UD*** contain the **principal components (PCs)** and the columns of the matrix ***V*** the **empirical orthogonal functions (EOFs)**.

Two first PCs explain > **97%** of the variance of the A_{hs} indices.

The A_{hs} index of the *i*:th station can be presented as a linear combination of the two first PCs as

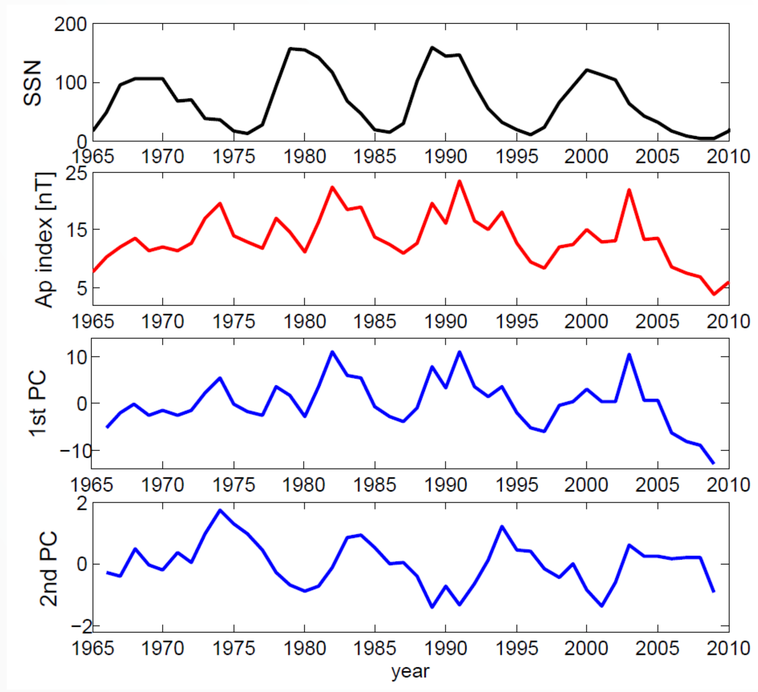
$$A_{hs}(i) \approx PC_1 \cdot EOF_1(i) + PC_2 \cdot EOF_2(i)$$

where $EOF_{1,2}(i)$ give station specific weights for the two PCs.



- The first EOF is almost the same for all stations, i.e., the 1st PC represents the average of the 26 A_{hs} indices.
- The 2nd EOF depicts **auroral** and **midlatitude maxima** and a **subauroral minimum**.

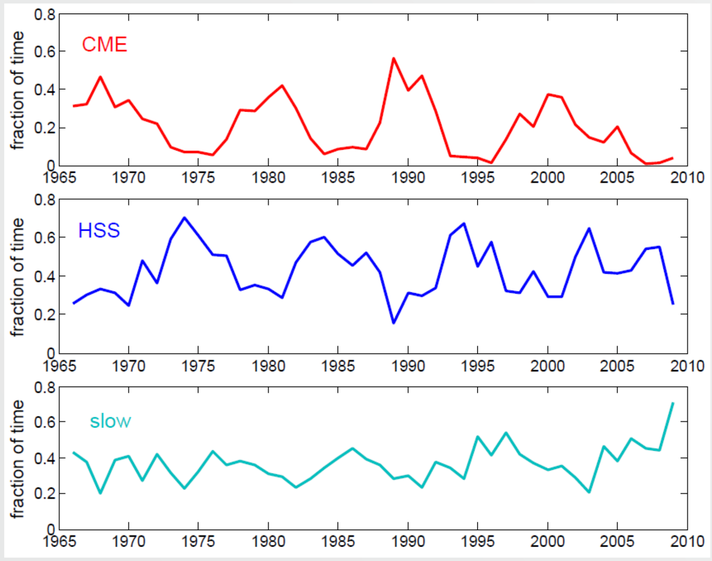
3. Two first principal components



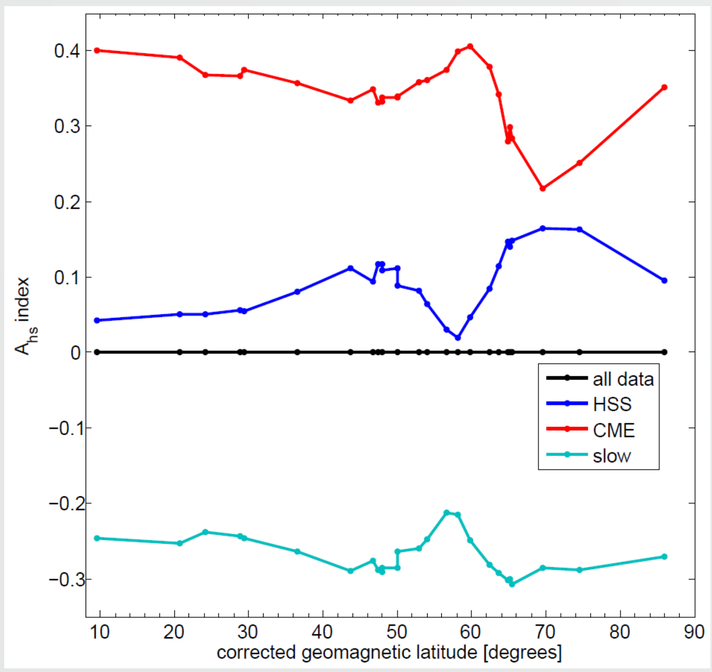
Sunspot number, Ap index and the two first PCs.

- The 1st PC is almost perfectly correlated with the Ap index representing the global geomagnetic activity.
- The 2nd PC shows a solar cycle variation with maxima during the declining phase of the solar cycle.

4. A_{hs} indices during different solar wind types



The annual fractions of time of CME-related solar wind, high speed streams (HSSs) and slow solar wind according to *Richardson et. al* (2012).

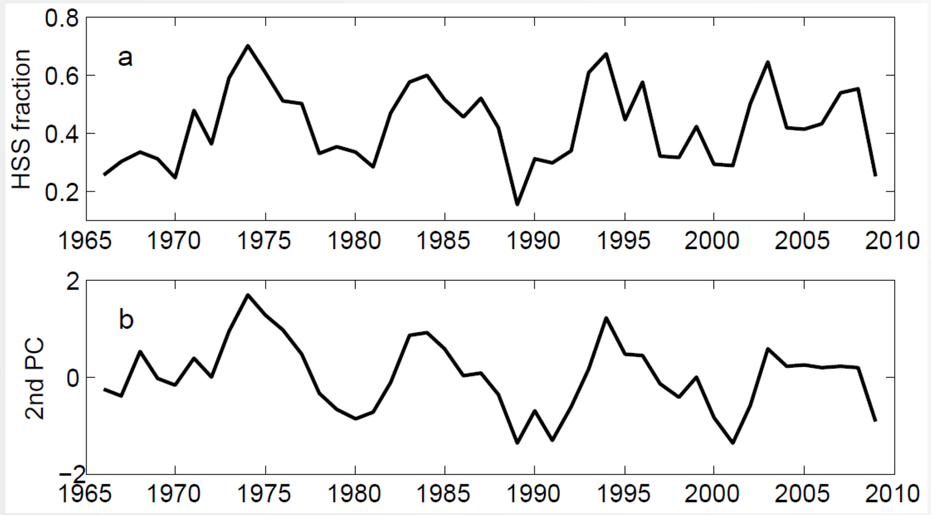


Averages of the 3-hourly A_{hs} indices during the three solar wind types.

- Note that the distribution of the A_{hs} indices during HSSs is strikingly similar with the 2nd EOF.
- The distribution during CMEs is almost the mirror image of the distribution during HSSs.

⇒ The 2nd PC is related to different relative contributions of HSSs and CMEs to A_{hs} indices?

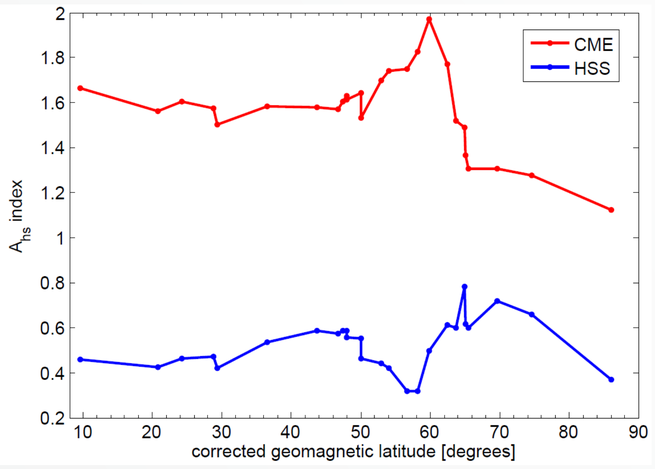
5. The 2nd PC and high speed streams



The annual fraction of time of HSSs and the 2nd PC.

- The correlation coefficient between the two is 0.83.
- On the other hand, there is an anticorrelation between the 2nd PC and the CME fraction (cc = -0.79).

6. A_{hs} indices during substorms



Averages of the A_{hs} indices during CME and HSS driven substorms identified by the SuperMAG magnetometer network in 1980-2009.

- While the effects of HSS substorms maximize at auroral latitudes the effects of CME substorms maximize at subauroral latitudes.

This explains the auroral maximum and the subauroral minimum in the 2nd EOF.

7. Summary

- **Local geomagnetic indices can be used to extract the relative annual fraction of high speed streams in solar wind .**
- **Latitudinal distribution of geomagnetic activity and its temporal evolution can be described by the two leading EOFs and PCs.**
- **The 1st PC describes globally averaged geomagnetic activity and is highly correlated with the Ap index and other indices of global geomagnetic activity.**
- **The 2nd PC is best explained by the time fraction of HSSs in solar wind.**
- **The 2nd EOF corresponds to the average distribution of standardized Ah indices during HSSs.**
- **Relative effect of CMEs in local geomagnetic activity is largest at subauroral latitudes.**

References

Holappa, L., K. Mursula, T. Asikainen and I.G. Richardson, Annual fractions of high speed streams from principal component analysis of local geomagnetic activity, *J. Geophys. Res.*, 119, 2014.

Holappa, L., K. Mursula, T. Asikainen, A new method to estimate annual solar wind parameters and contributions of different stream structures to geomagnetic activity, *J. Geophys. Res.*, submitted.

Mursula, K. and Martini, D.: A new verifiable measure of centennial geomagnetic activity: Modifying the K index method for hourly data, *Geophys. Res. Lett.*, 342, L22107, 2007.

Richardson, I. G. and Cane, H. V.: Near-earth solar wind flows and related geomagnetic activity during more than four solar cycles (1963-2011), *J. Space Weather Space Clim.*, 2, A02, 2012.