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Reconstruction of energetic electron precipitation for the last 130 years

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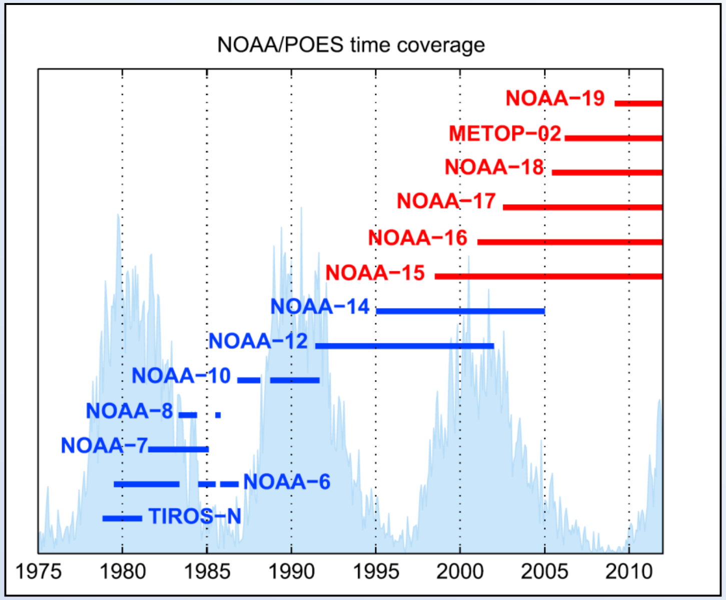
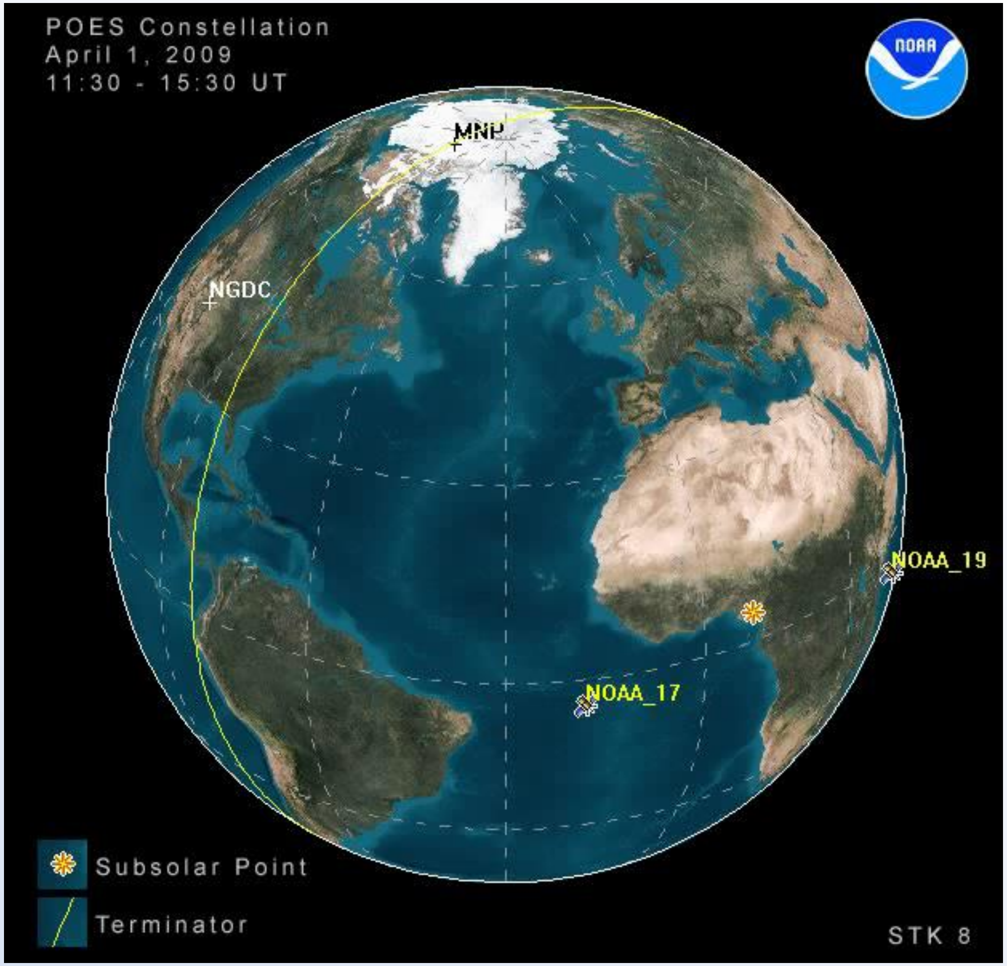
NOAA/POES particle measurements





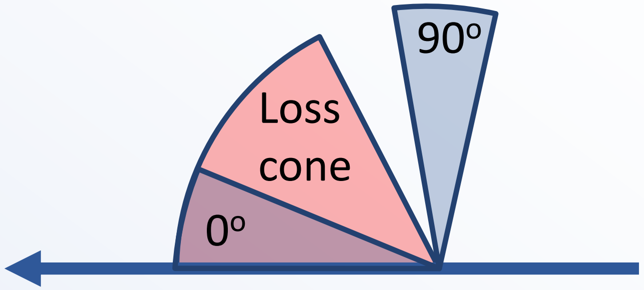
- The particle dataset has been plagued by significant problems related to the MEPED instrument and data quality.

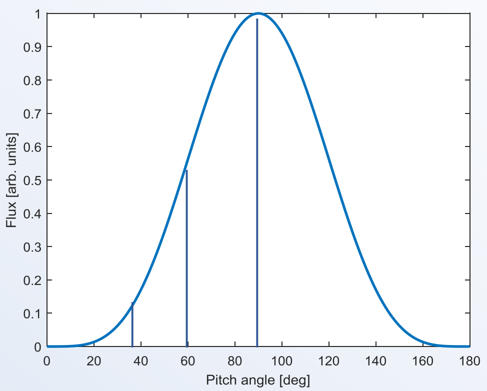
Corrections/Calibrations to NOAA/MEPED data

- Estimating the detector aging effects (radiation damage, noise effects) [Asikainen and Mursula, 2011; Asikainen et al. 2012]
- Cross-contamination (electron instrument also measures protons and vice versa) [Asikainen and Mursula, 2013]
- Non-ideal instrument effciencies (estimated by detector simulations) [Asikainen and Mursula, 2013]
- Effects of differences in instrument design in different satellites [Asikainen and Mursula, 2013]
- Recomputed satellite positions and dependent data (magnetic fields, L-values, MLT etc.)

NOAA/MEPED data used here

- Average of 0° (radial) and 90° (horizontal) telescope fluxes
  – Better represents the precipitating flux than the 0° telescope, which only measures a small portion of the total precipitation

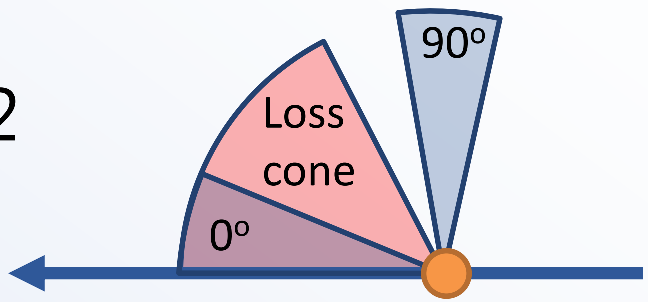




- Fluxes from dawn/dusk on Northern hemisphere L>2
- Electron fluxes at 3 different energy ranges
  – > 30 keV (ring current electrons)
  – > 100 keV (ring current electrons)
  – > 300 keV (radiation belt electrons)

NOAA/MEPED data used here

- 90^o telescope before 1998 (SEM-1 era) pointed in a different direction than after 1998 (SEM-2 era)

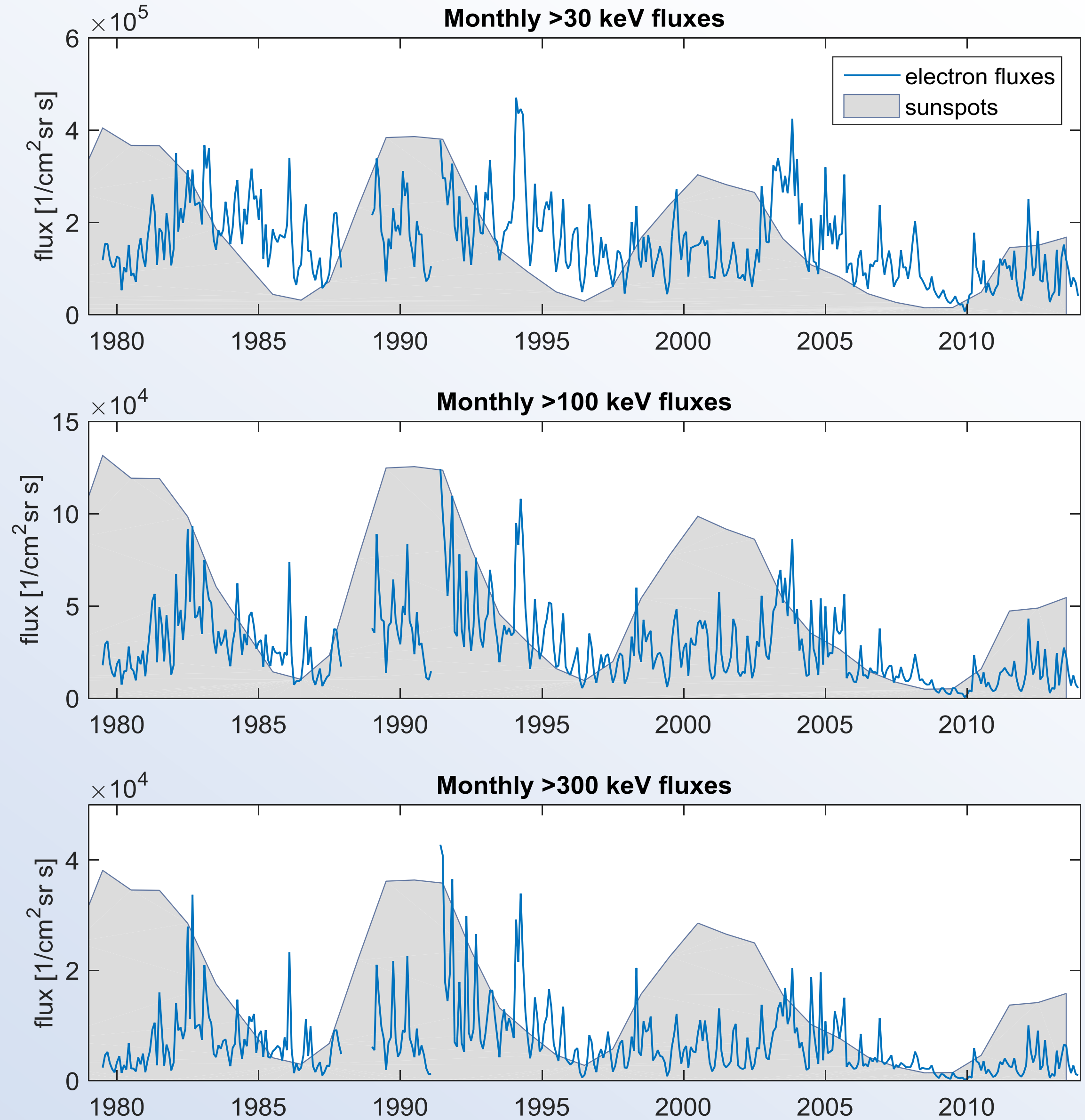


- ➔ Systematic difference in pre-1998 and post-1998

- This will be taken into account in the analysis

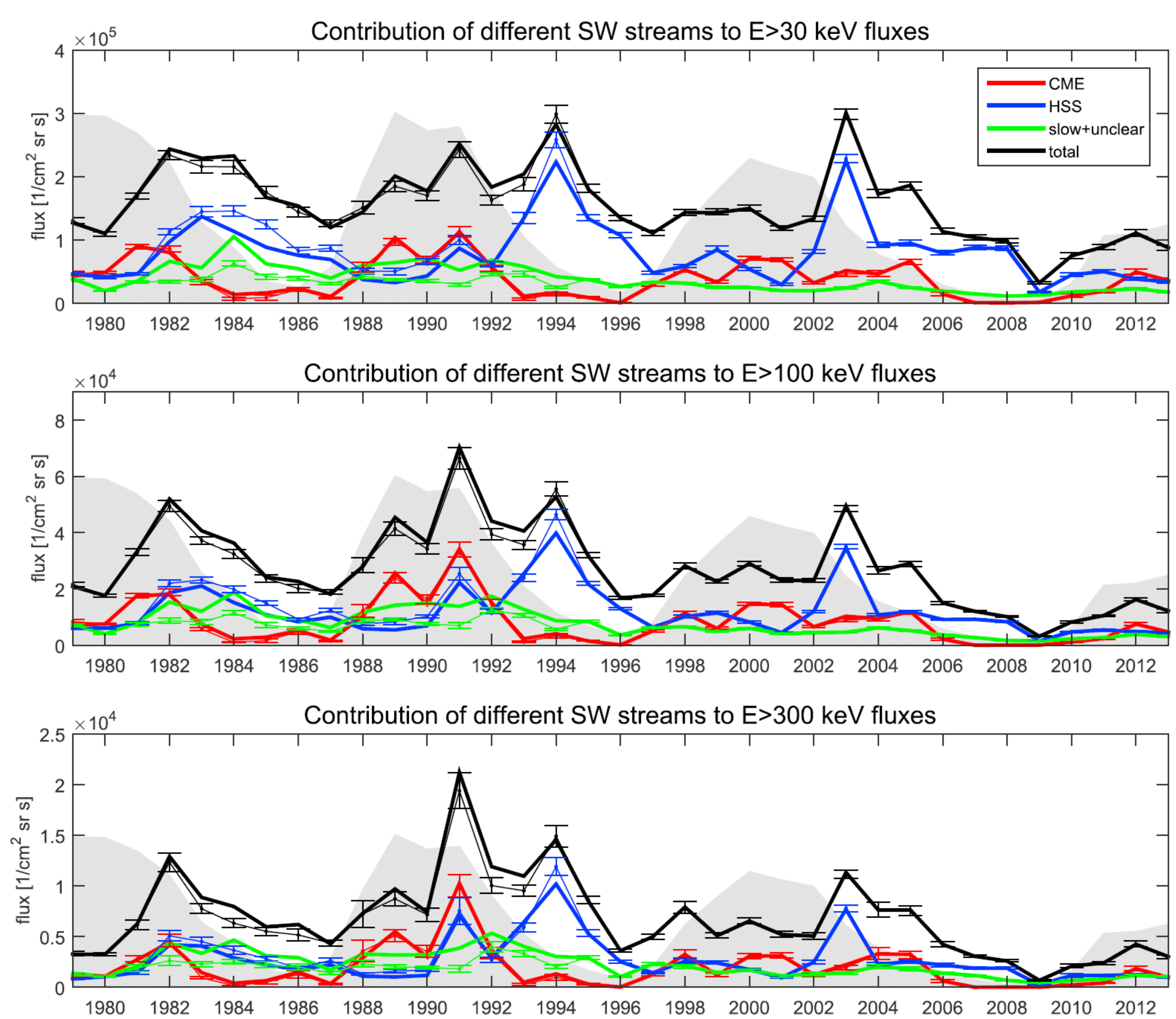
Overview of electron precipitation

- We have direct measurements over three solar cycles.
- Fluxes peak in the declining phase



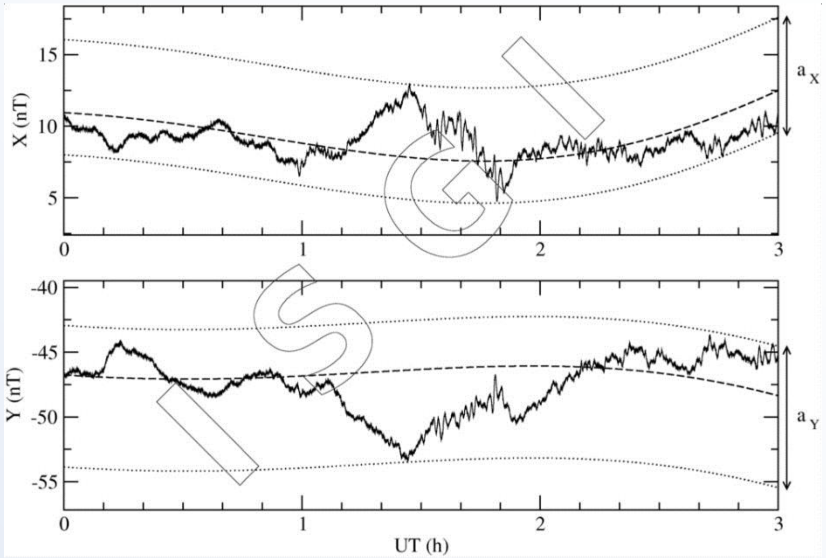
Overview of electron precipitation

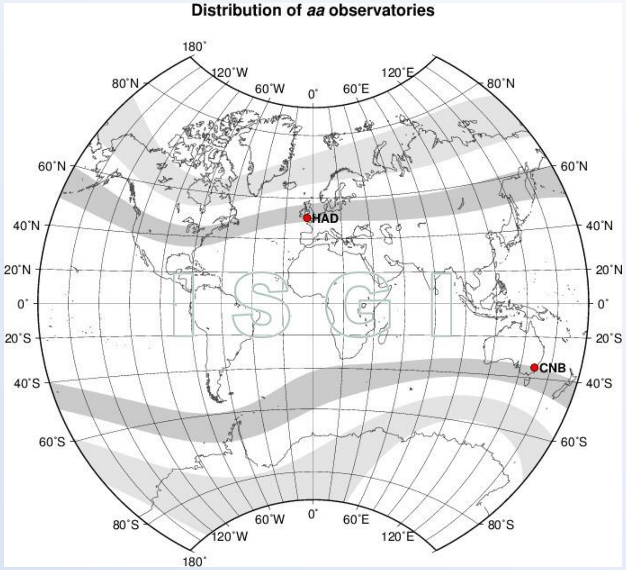
- Recent results show that high-speed streams are the most significant driver of electron precipptation
- Asikainen and Ruopsa (2016), JGR



Geomagnetic indices: aa index

- aa index is derived from K-indices of two antipodal stations:
  - Hartland, UK (previously Greenwich and Abinger)
  - Melbourne, Toolangi, Canberra (Australia)



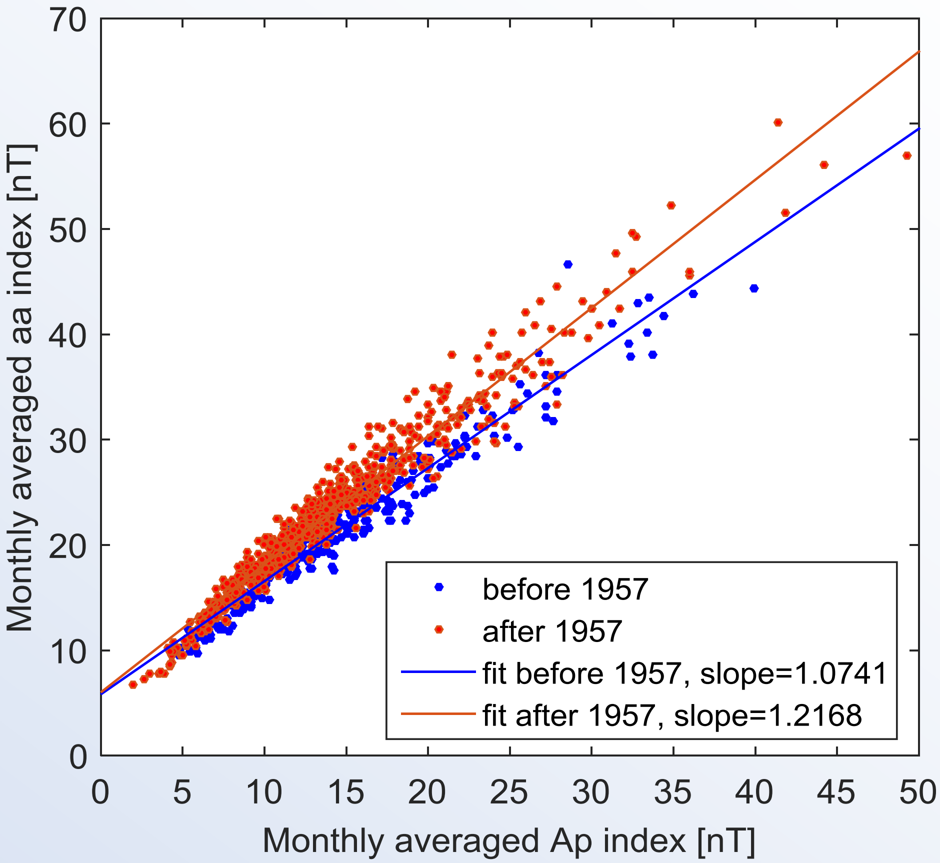


- Describes range of geomagnetic variation in 3h time intervals
- ➔ Responds to short-term variations like substorms
- aa index is available from 1868 to present

Geomagnetic indices: aa index

- Geomagnetic aa index has been shown to be inhomogeneous due to a station change from Abinger to Hartland in 1957 (e.g., Lockwood et al., 2014).

- We calibrated aa by comparing to Ap index.
- We found that aa inhomogeneity is corrected by dividing the data after 1957 by 1.2168/1.0741=**1.13**. The corrected aa index is denoted as aa_c.



Geomagnetic indices: IDV(1d) index

- IDV(1d) is a daily index and is defined as the absolute difference in the daily averaged horizontal magnetic field component of two consecutive days (Lockwood et al., 2013)

- ➔ Responds to slow variations with a time scale of several days, i.e., magnetic storms

Geomagnetic indices: IDV(1d) index

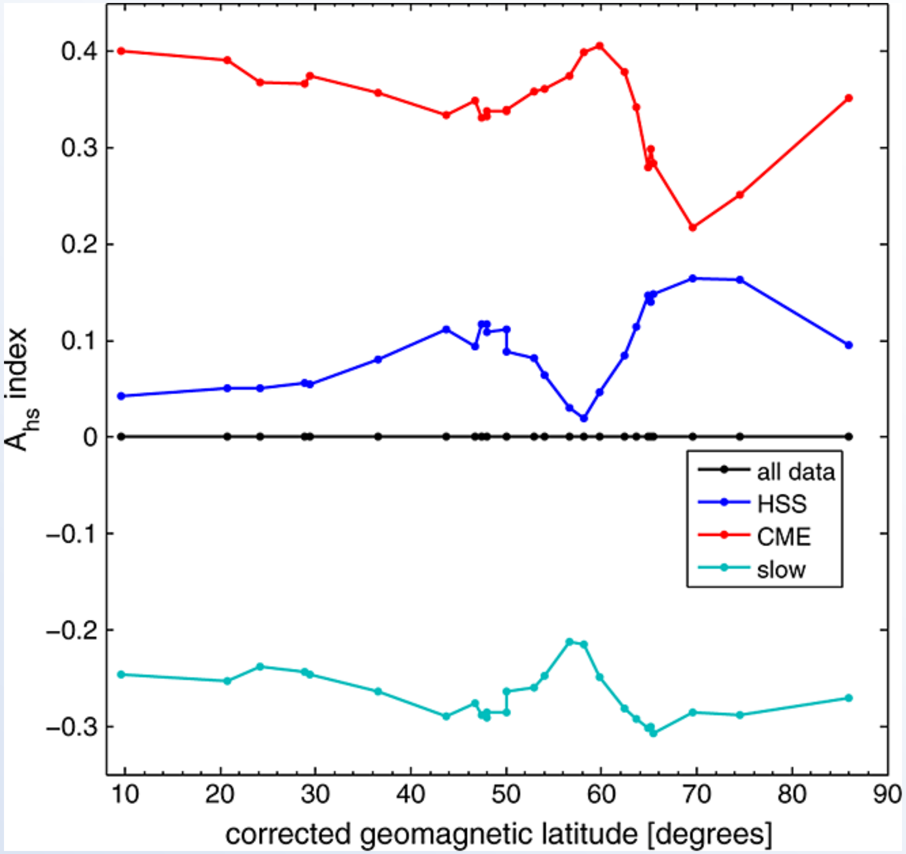
- IDV(1d) index used here is based on data from
  - Parc St. Maur (1883-1901)
  - Val-Joyeux (1901-1936)
  - Chambon la Foret (1936-2014)

- All these stations are at closeby locations in France.

Principal components of geomagnetic activity

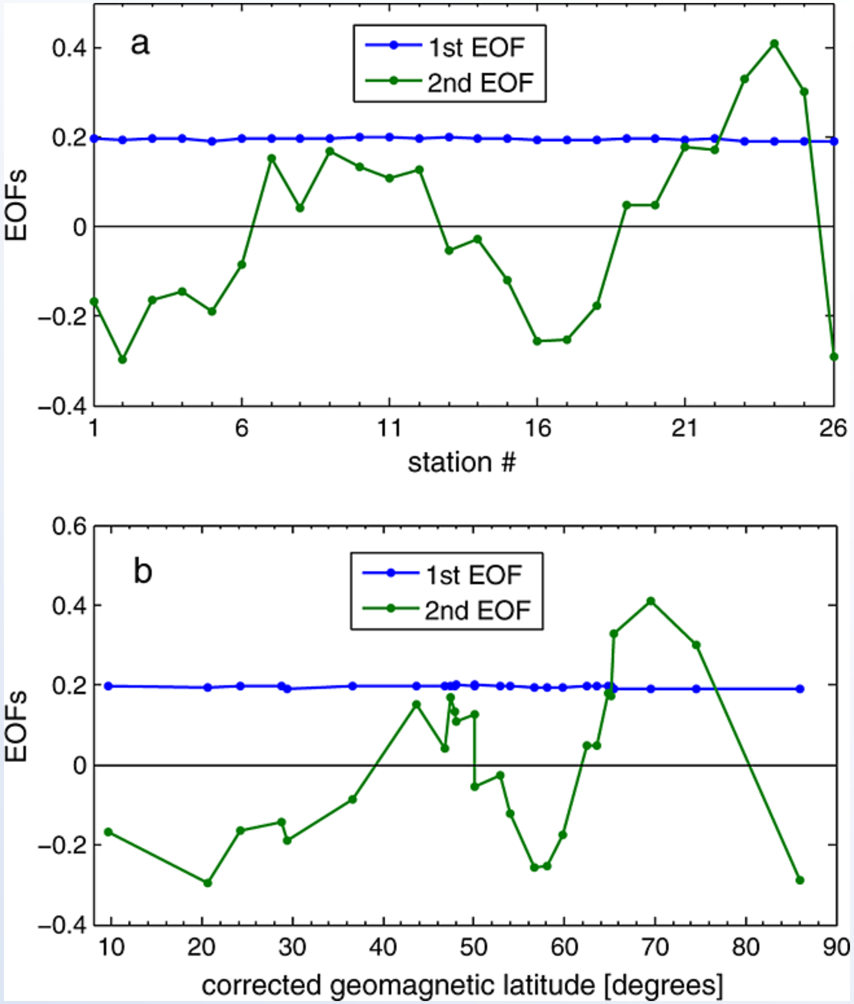
- Spatial (latitudinal) distribution of geomagnetic activity is different in CME and HSS driven disturbances

- Lots of CMEs ➔ red distribution
- Lots of HSSs ➔ blue distribution
- These are nearly mirror images of each other!



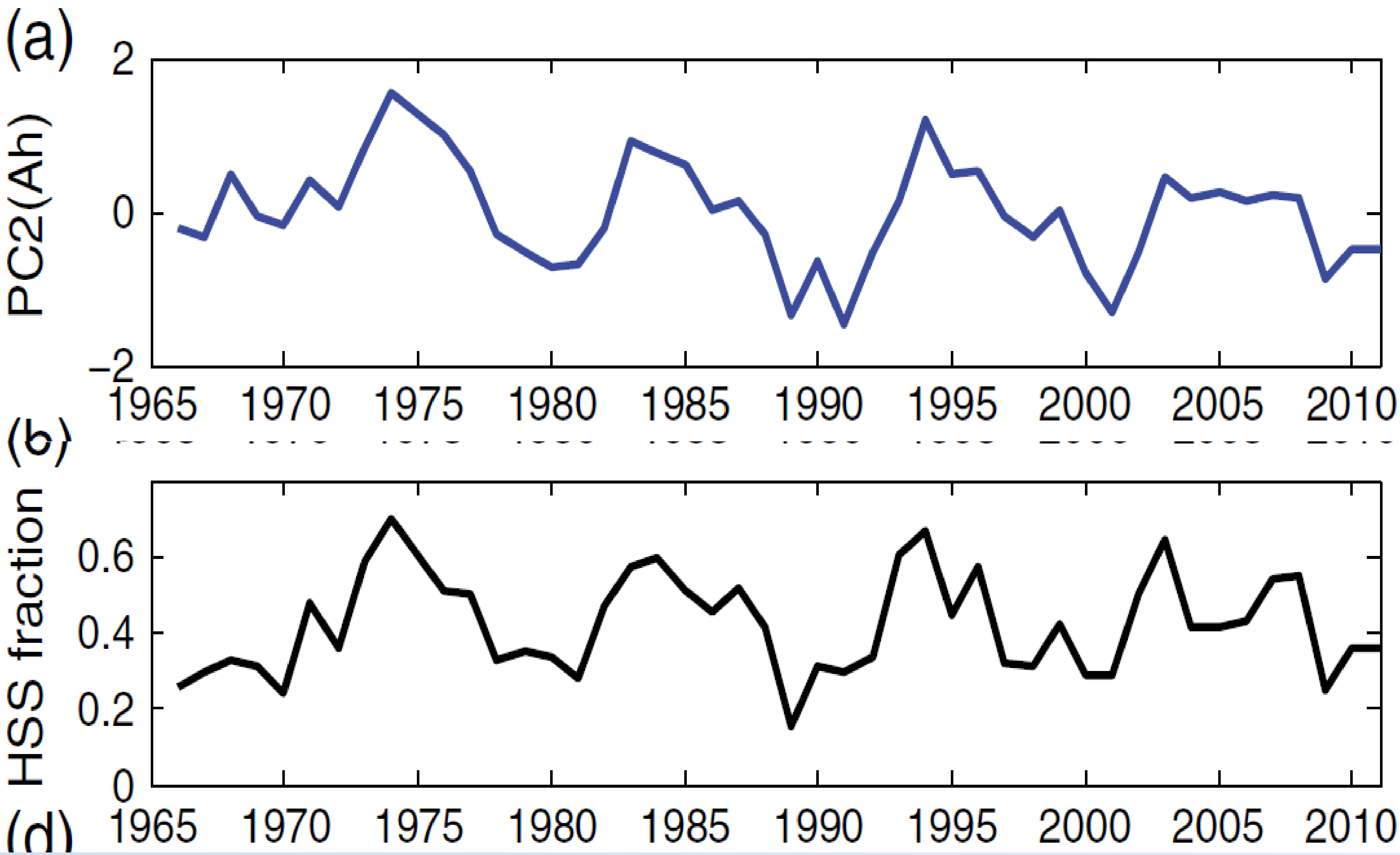
Principal components

- The degree to which the latitudinal distribution resembles that of CMEs or HSSs can be obtained by Principal Component Analysis



- ➔ 2nd PC of local geomagnetic activity is a rough measure for HSS fraction (Holappa et al., 2014a, 2014b)

Principal components

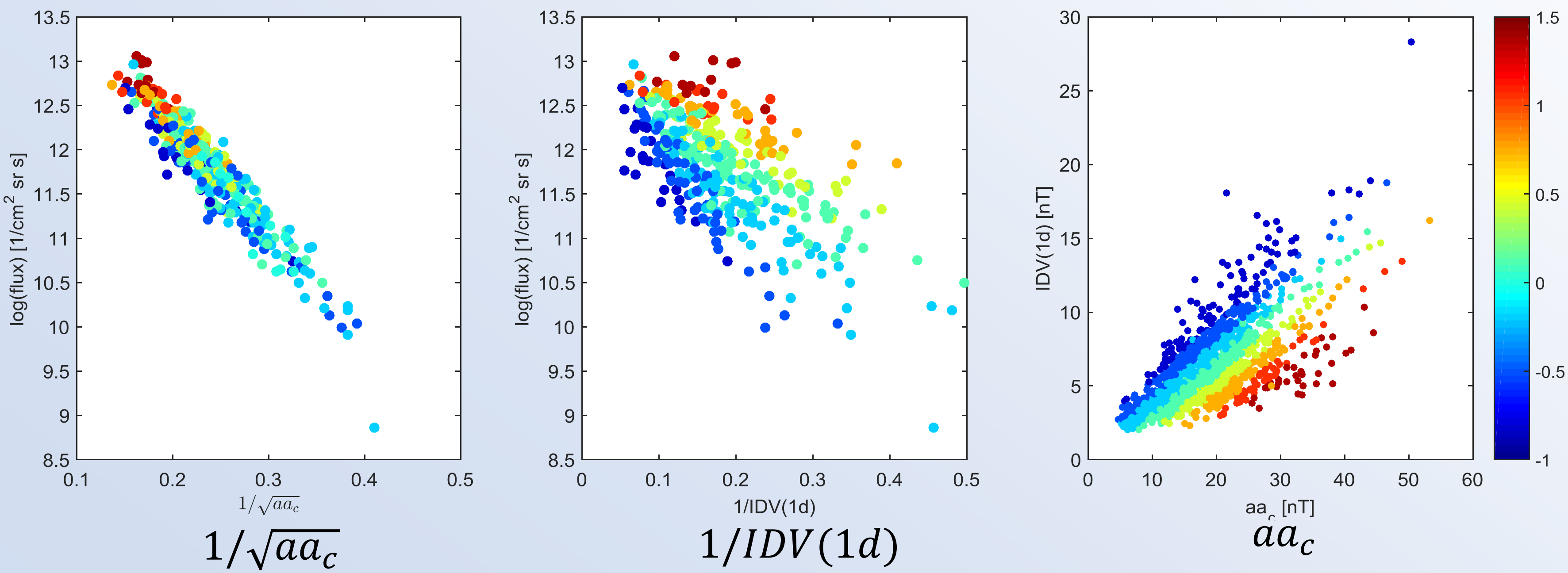


Regression model for fluxes

- We used the following equation to model the monthly average electron fluxes:

$$\log(F) = a(PC_2) + b(PC_2) \times \frac{1}{\sqrt{aa_c}} + c(PC_2) \times \frac{1}{IDV(1d)}$$

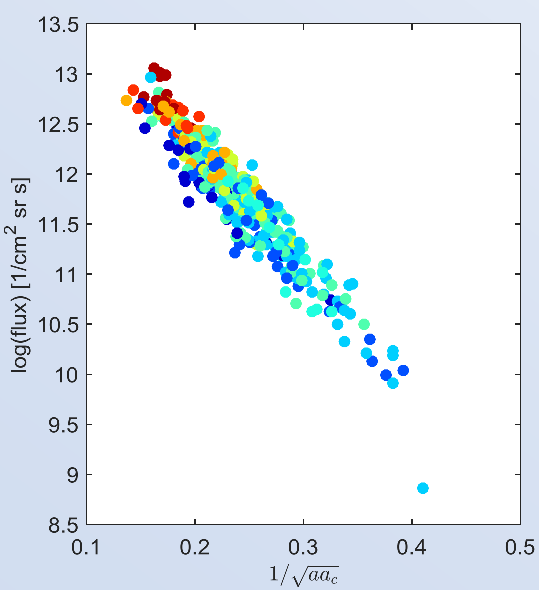
- Regression coefficients are assumed to be functions of PC_2
- Assumed AR(1) noise in error estimates
- Iteratively found an optimal coefficient to calibrate the difference between SEM-1 and SEM-2 satellites requiring maximum R^2 in the model



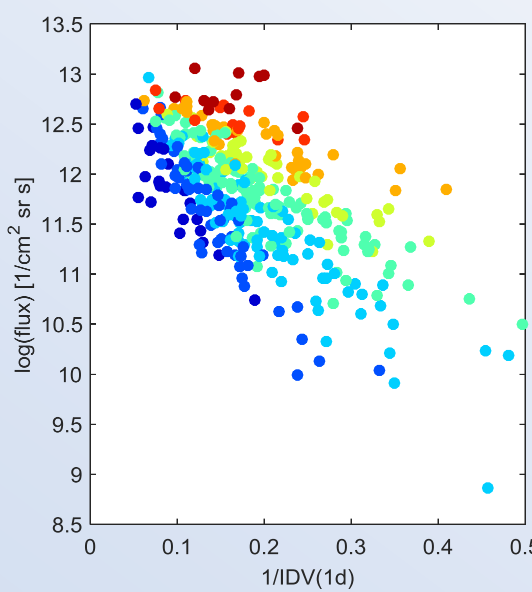
Regression model for fluxes

- Notice that when PC2 is large (dominant HSS driving) a particular value of IDV(1d) corresponds to a larger flux

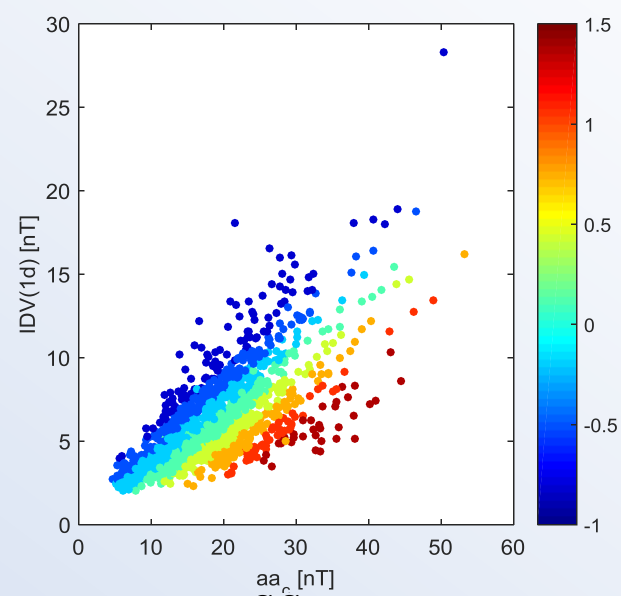
- ➔ In declining phases PC2 gives an extra contribution to the flux on top of the part described by aa index.



$1/\sqrt{aa_c}$



$1/IDV(1d)$



aa_c

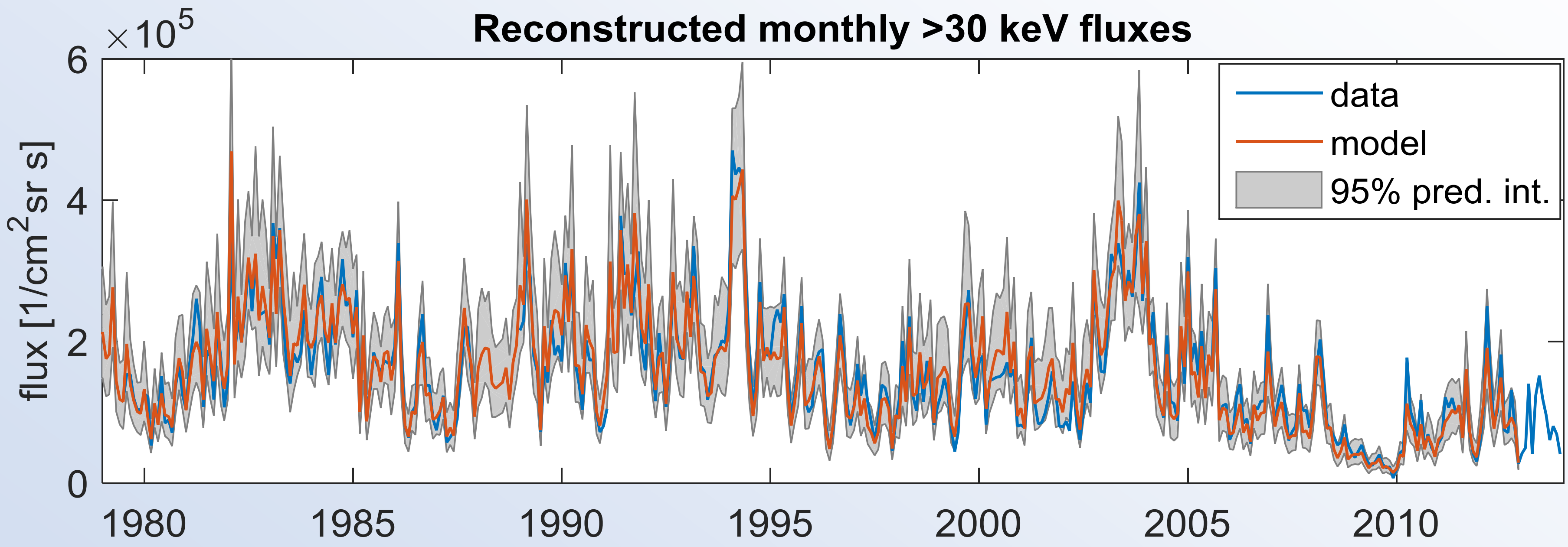
Regression model performance

- Monthly fluxes are extremely well modeled!

Model performance for log-fluxes (all correlations highly significant, $p<10^{-11}$)	E>30 keV	E>100 keV	E>300 keV
Monthly values (correlation R, R^2, mean relative error Δ)	**R=0.9598 R^2=0.9211 Δ=1.2%**	**R=0.9545 R^2=0.9110 Δ=1.9%**	**R=0.8891 R^2=0.7904 Δ=4%**
Annual averages (correlation R, R^2, mean relative error, Δ)	**R=0.9746 R^2=0.9499 Δ=0.8%**	**R=0.9801 R^2=0.9607 Δ=1.0%**	**R=0.9259 R^2=0.8572 Δ=2.4%**

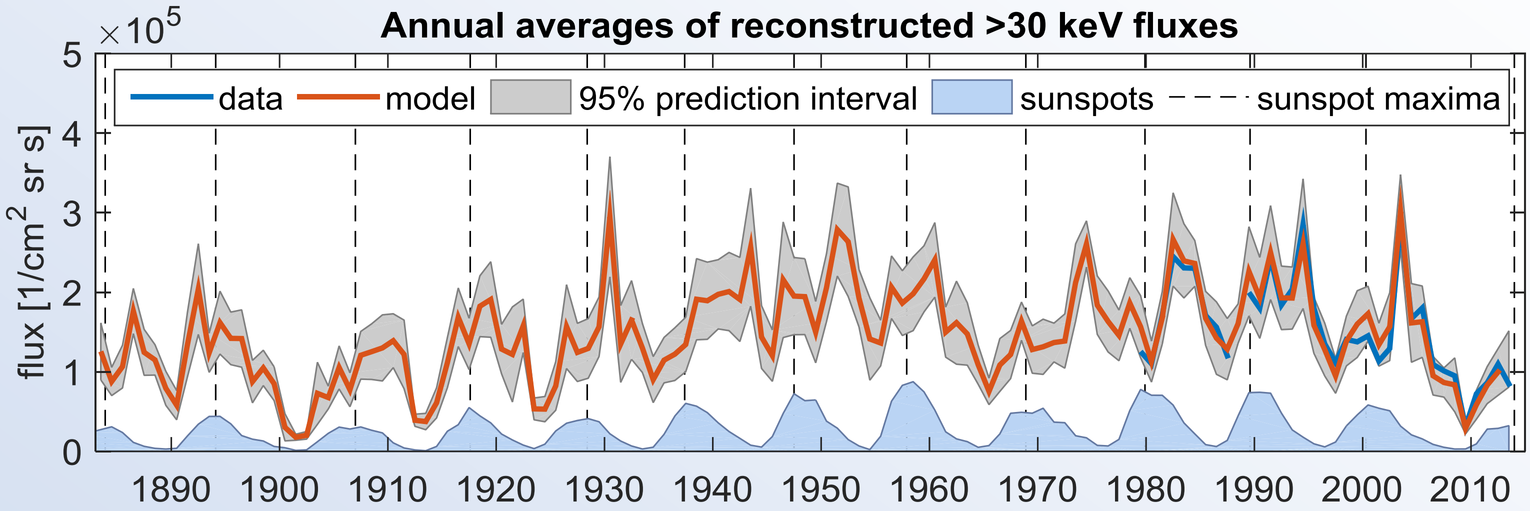
Example of monthly modeled fluxes

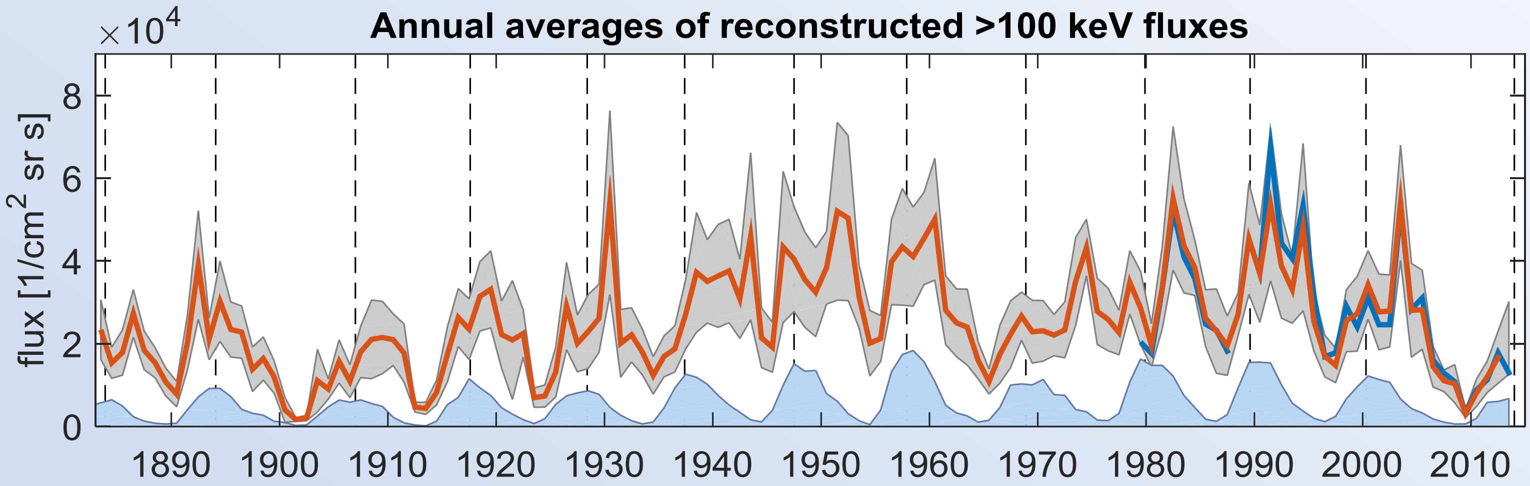
- Model follows data pretty well



Centennial reconstruction

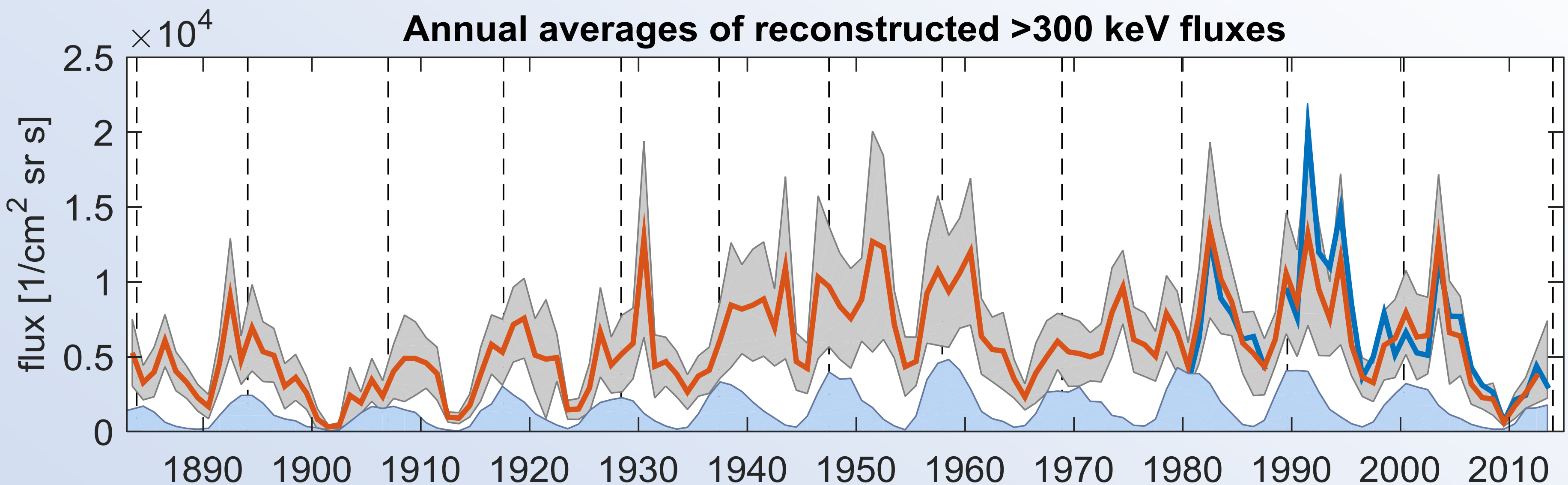
- Regression model gives us a reconstruction of electron fluxes from 1883 to present.
- In each solar cycle the fluxes peak in the declining phase!





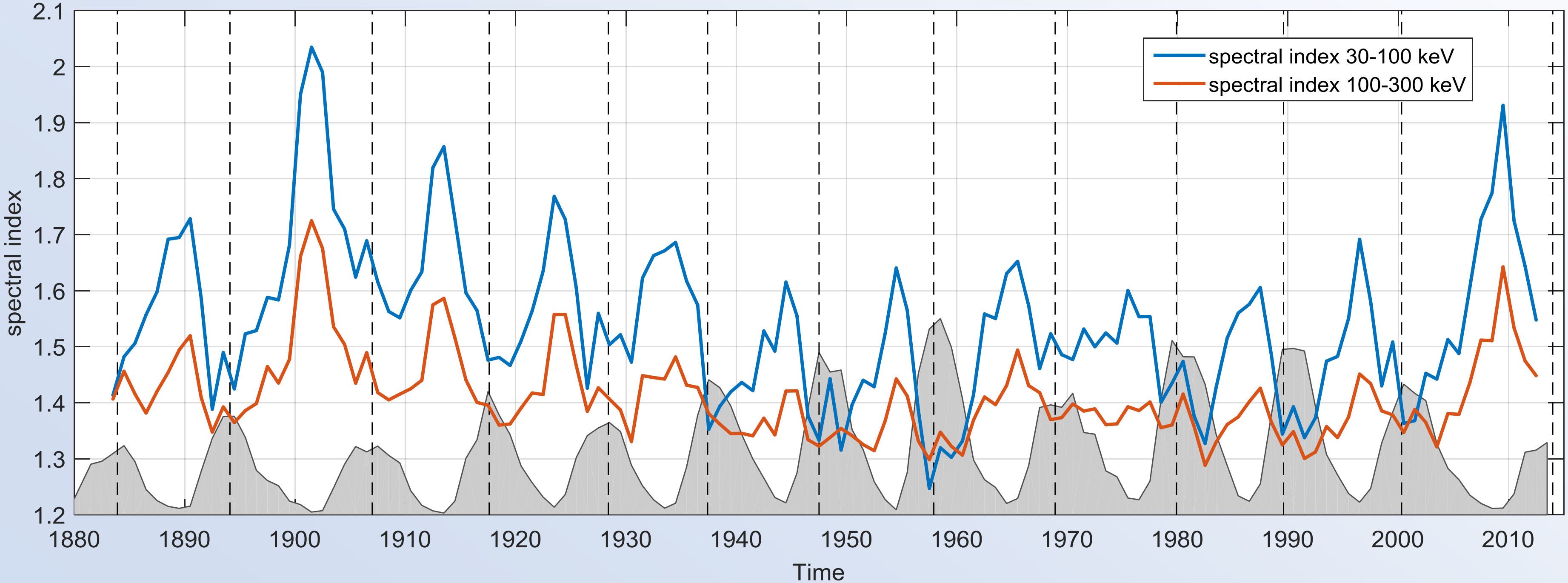
Centennial reconstruction

- Uncertainties grow larger with energy ➔ Geomagnetic indices explain the lower energies better



Centennial reconstruction: spectral index

- Different energy channels show slightly different long-term changes
- Spectral index (i.e., steepness of energy spectrum) shows solar cycle variation and centennial variation
- In beginning of 20th and 21th centuries the spectrum was softer than in the middle of 20th century
- ➔ Implications for atmospheric ionization, chemistry, climate effects?



Summary

- Corrected MEPED data from NOAA/POES satellites allows us to study energetic electron precipitation directly for over 3 solar cycles
- ➔ Enough data to build a statistical model
- We built a model based on aa, IDV(1d) and their 2nd principal component
- aa index can reproduce majority of electron flux variation
- However, the declining phases are not well represented by aa alone ➔ Underestimates flux!
- Resulting centennial estimate can be used, e.g., to estimate atmospheric ionozation and climate effects on centennial time scales