SEPARATION OF DIFFERENT IONOSPHERIC AND MAGNETOSPHERIC CONTRIBUTIONS TO THE GEOMAGNETIC FIELD VARIATIONS

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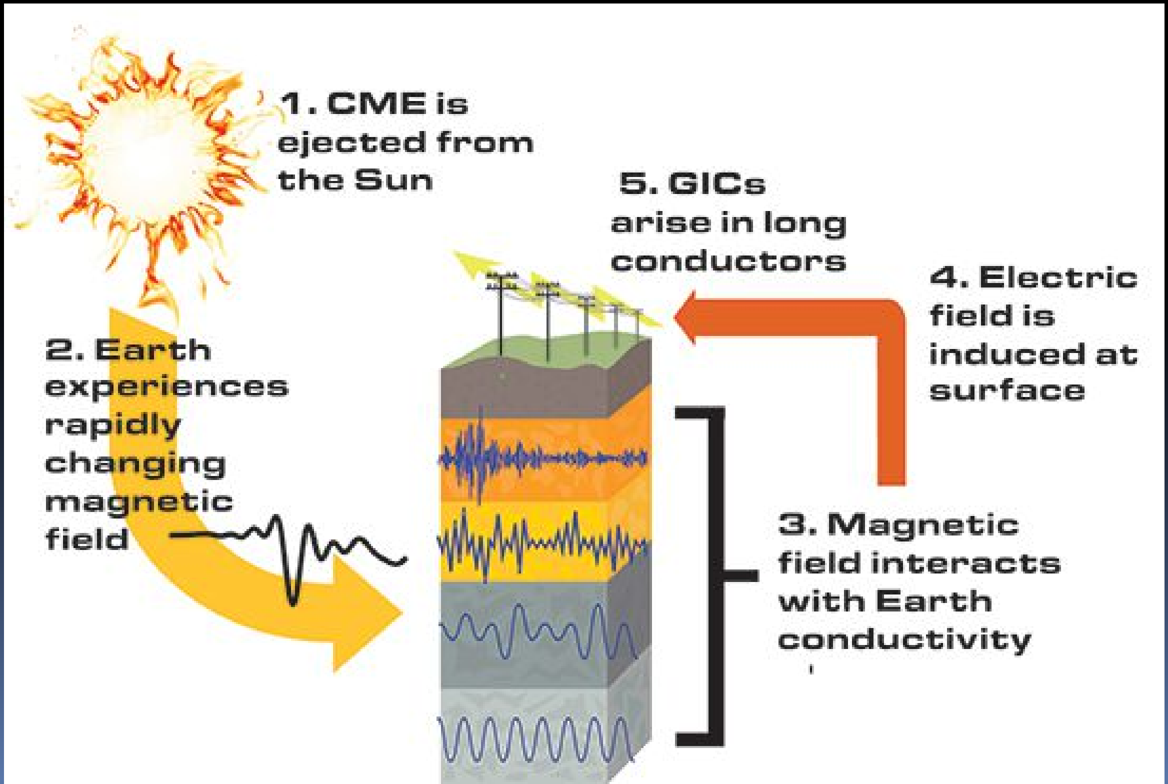
- Geomagnetically induced currents
- Geomagnetic field & its variations
  - Sq (“solar quiet”)
    - Principal component analysis: short review
  - Sq: standard vs PCA
  - Summary
- Future work
  - master student grant

Geomagnetically induced currents

Geomagnetically induced currents

- Quasi-DC GIC flowing through grounded neutral terminals of power transformers located in the northern regions can reach 100 to 300 A. These currents result in deep saturation of magnetic cores, reactive power losses, AC odd and even harmonic generation, reduction of impedance and overheating of windings and magnetic cores



Geomagnetically induced currents

- Mostly affected are regions located at high geomagnetic latitudes: Canada (blackout 13.03.1989, Quebec), northern parts of USA, Scandinavian countries
- GIC-induced transformer failures were observed during intense geomagnetic storms at middle geomagnetic latitudes – South Africa
- Currently studies addressing the local GIC-hazard are done in South Africa, Australia , Kazakhstan, China, Japan, Brazil, Czech Republic, UK, Ireland, Italy and Spain

MAG-GIC

MAG-GIC
Correntes induzidas pelo campo geomagnético no território português
(concurso 02/SAICT/2017)
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A. Pais & F. Pinheiro, REN, 11/10/2018
CITEUC
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UNIVERSIDADE DE COIMBRA
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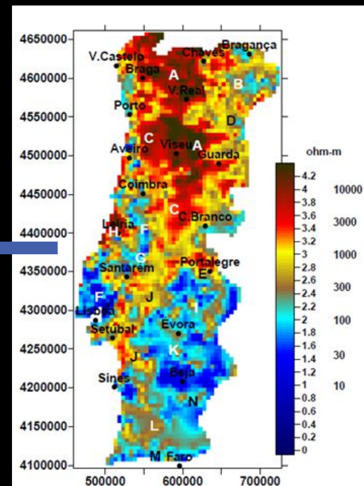
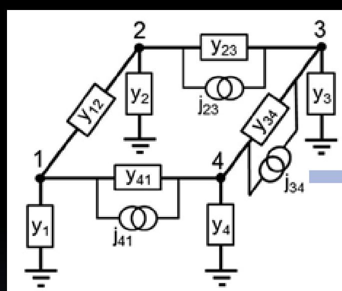
MAG-GIC



ground conductivity

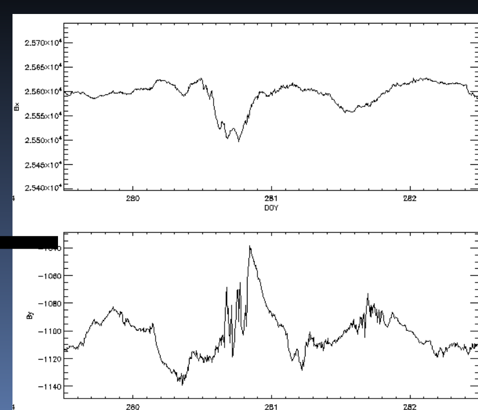
+



power grid geometry

GIC

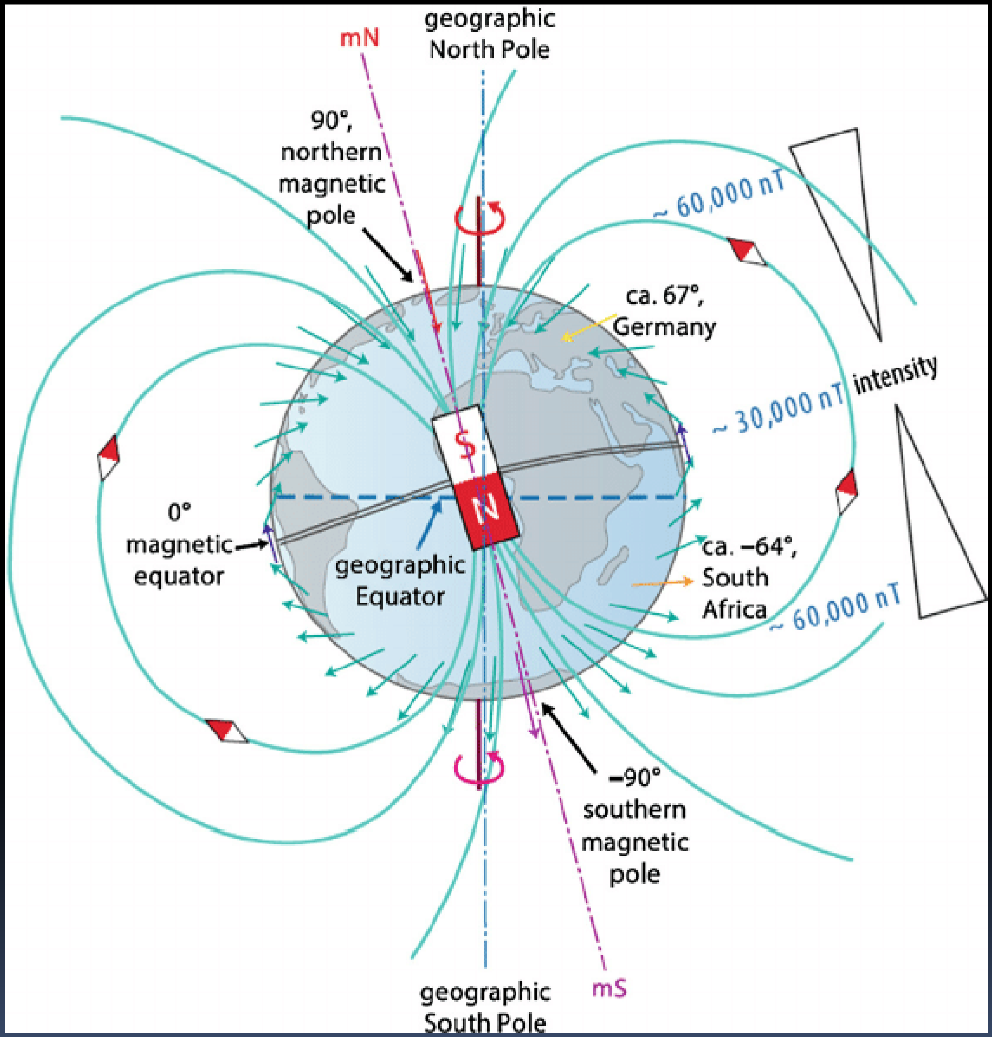
+

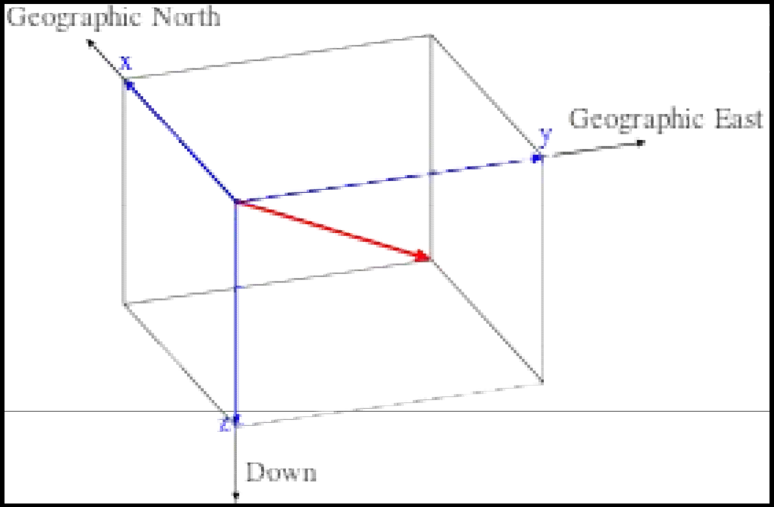


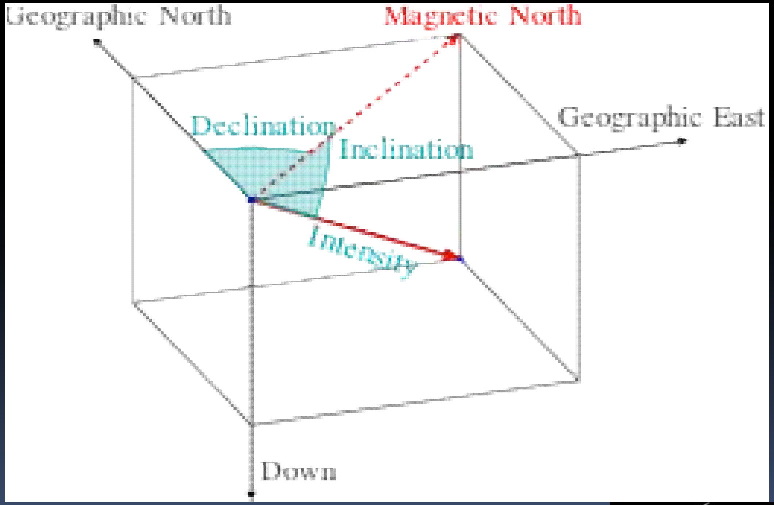
fast dH/dt

Geomagnetic field: short introduction

Geomagnetic field

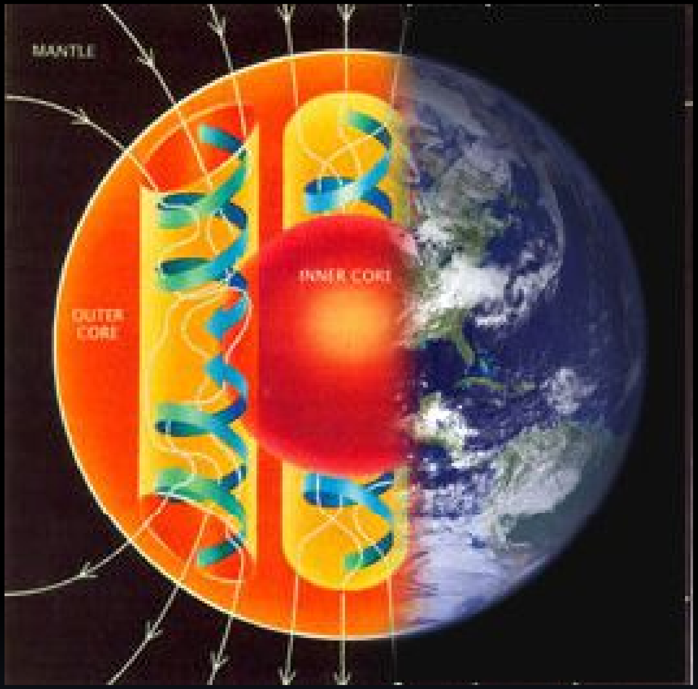


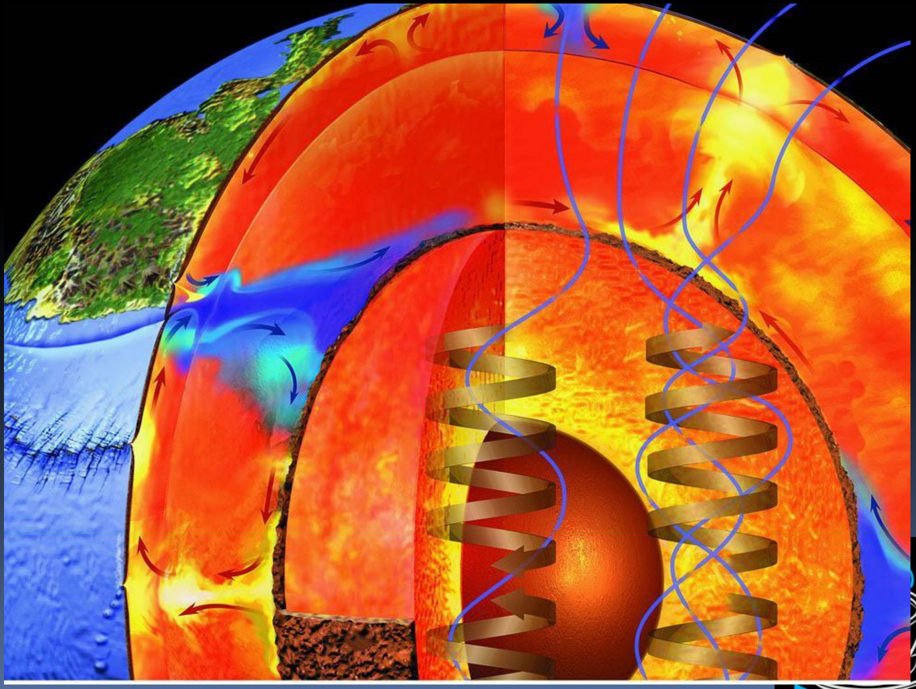




Geomagnetic field

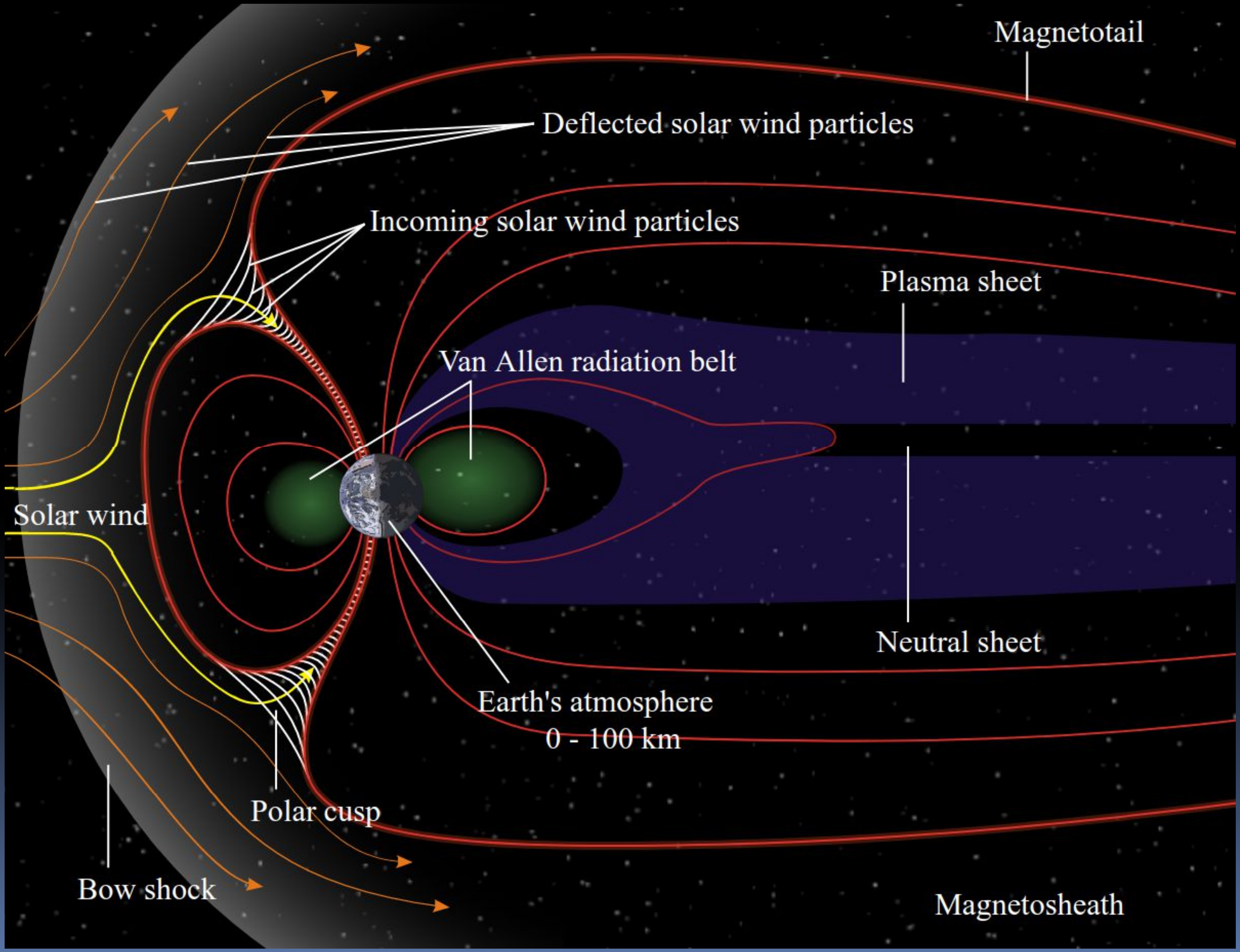
- Internal geomagnetic field





Geomagnetic field

- External geomagnetic filed



Geomagnetic field variations

COI instruments

COI instruments

Recording Variations

Model FGE (Ver. J)
(DMI, 2006)
Serial n.º S0306
Fluxgate Magnetometers

H | D | Z

Fluxgate Electronics

GSM-90F
(GEM Systems, 2007)
Serial n.º 6112154

GPS antenna

Absolute Measurements

F

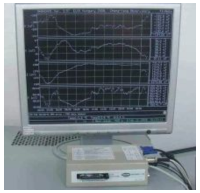
Proton Electronics

D | I

DI-flux:
MAG-01H (A sensor type)+
YOM MG2KP Theodolite
Serial n.º 729H/436

Reference Pier: 4
Absolute House

PC based Data Acquisition Controller
DIMARK - MAGREC-1B
(Magadam1 ver. 3.99, acquisition software)

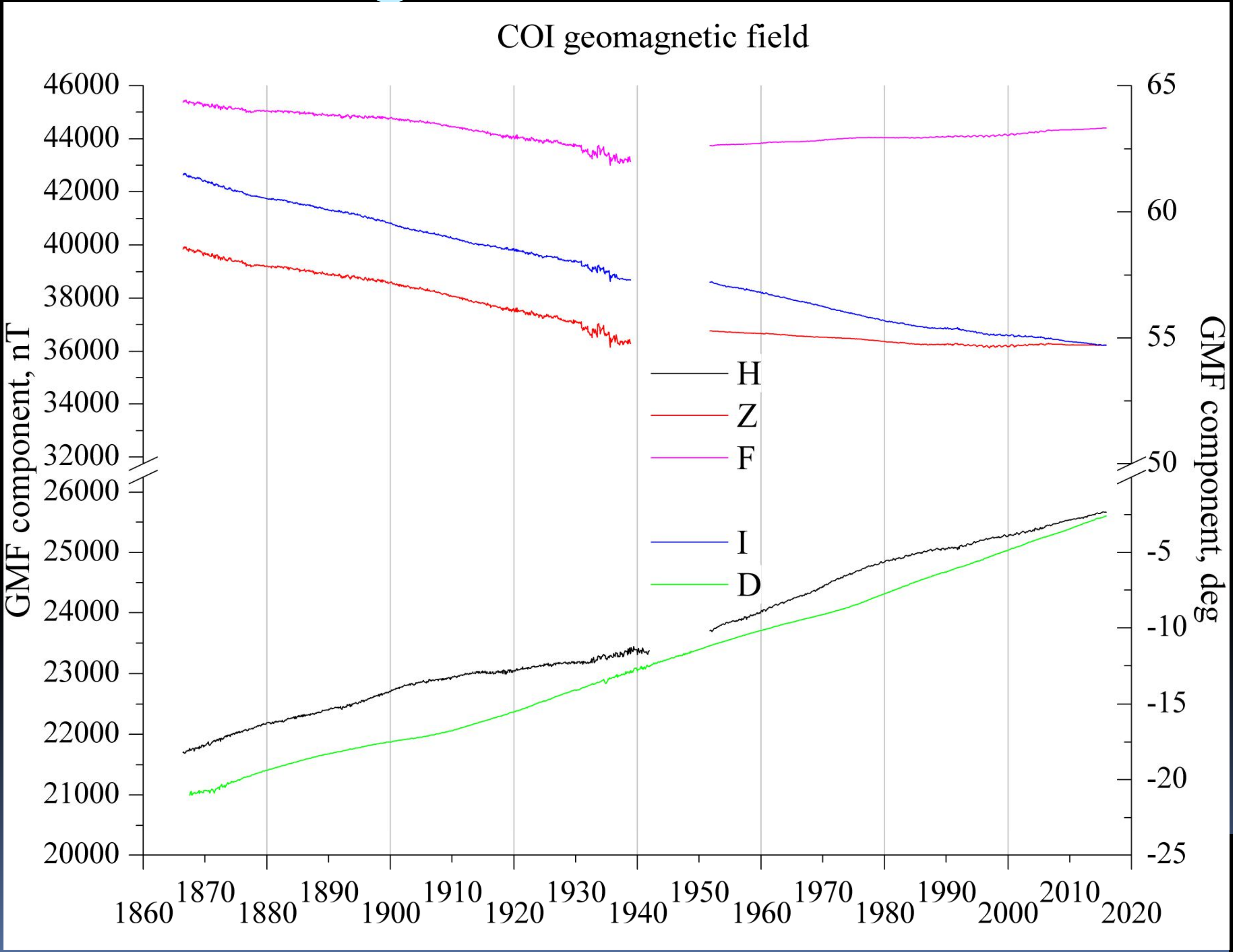


1-second files
1-minute files
Log files

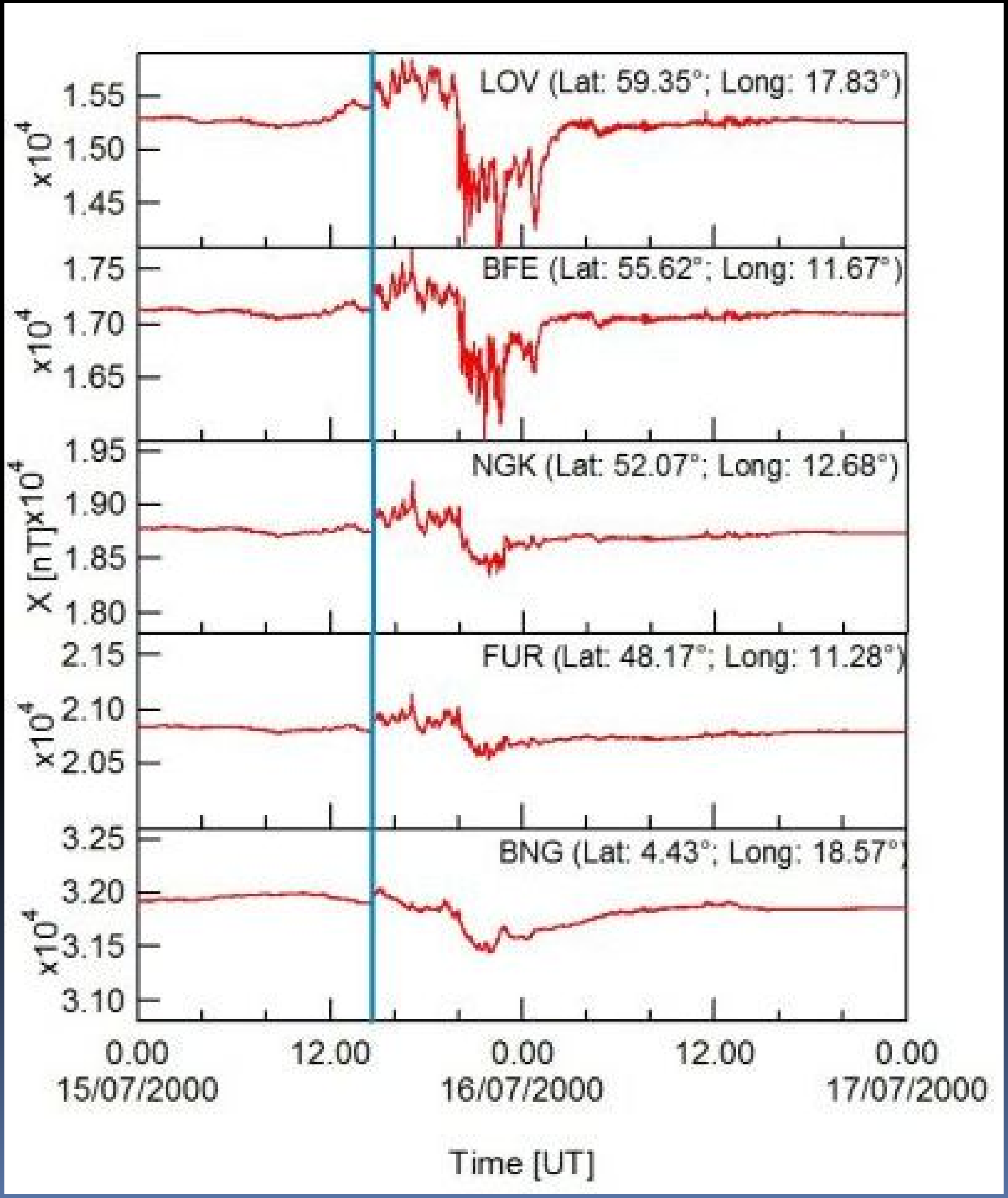
Main building

Variometer (left) and absolute (right) houses

Geomagnetic field - time



Geomagnetic field vs time



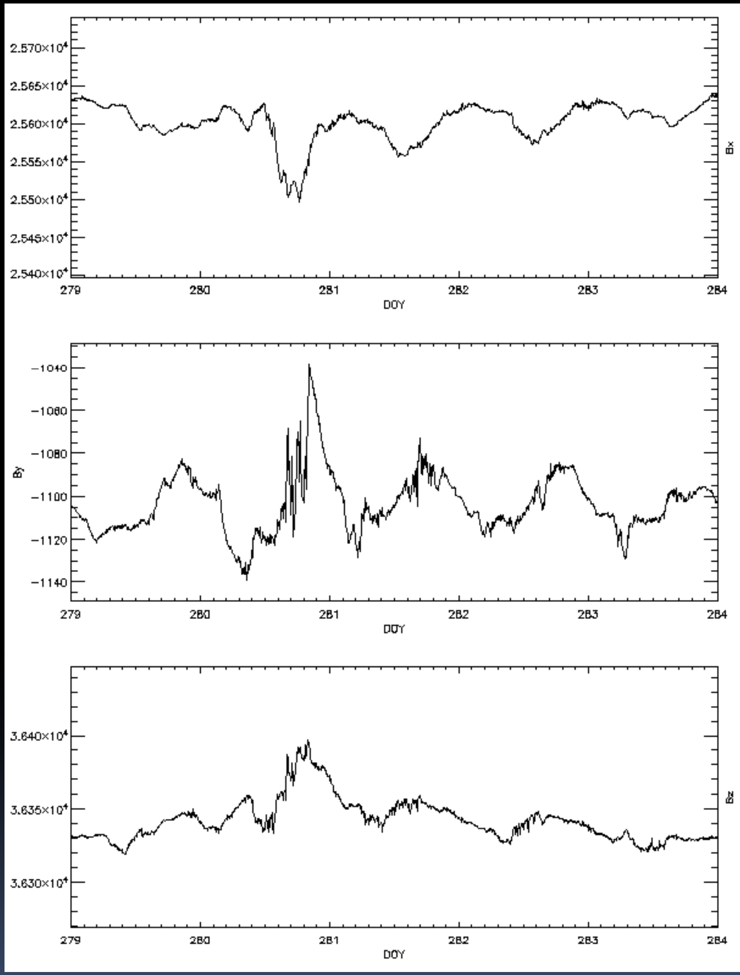
$B = B_{internal} + B_{external\ (longterm)} +$

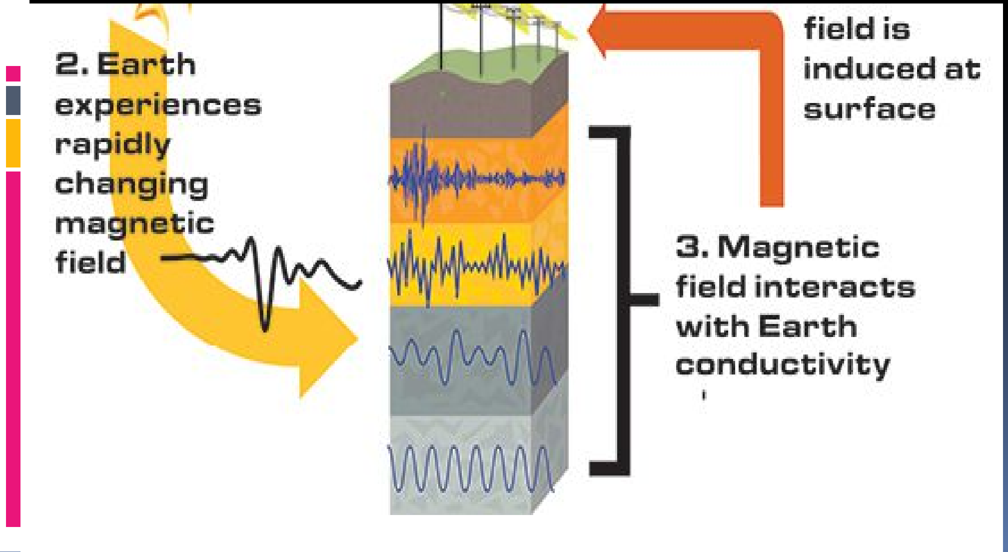
$B_{regular\ (daily)} + B_{disturbed}$

MAG-GIC:
geomagnetic field variations

- Storm time H variations = relatively smooth daily background variations + fast H variations

- Earth crust conductivity is a f(depth)
- Earth crust = filter for different frequencies of H variations





Daily geomagnetic field variations

(Classification by *Chapman, S. and Bartels, J. Geomagnetism, 1940*)

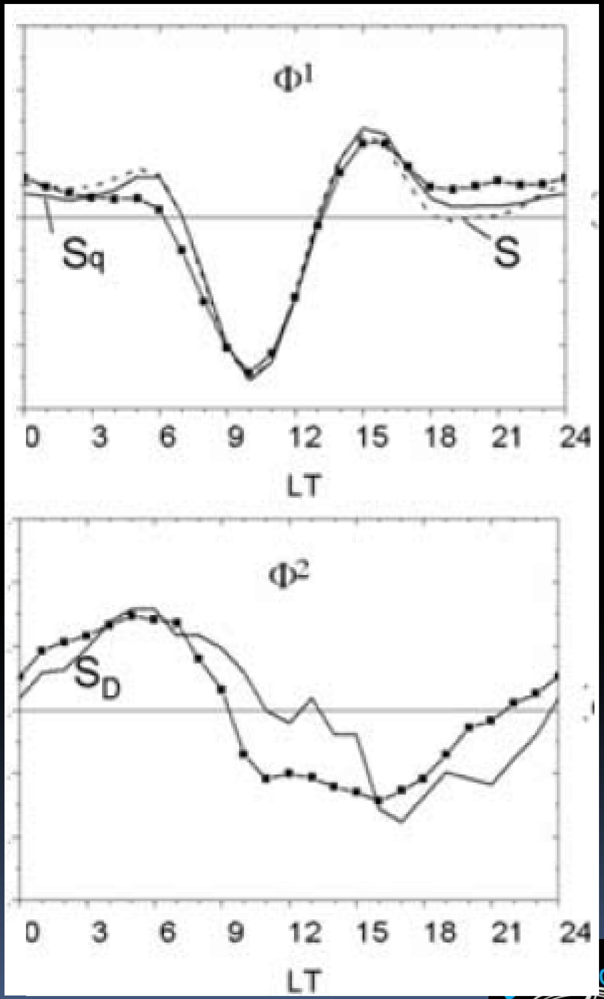
- Solar (denoted as "S_{xx}")
- ~~Lunar (denoted as "L_{xx}")~~
- Disturbances (can be denoted as "Dst")

Daily geomagnetic field variations

"solar" = "diurnal"

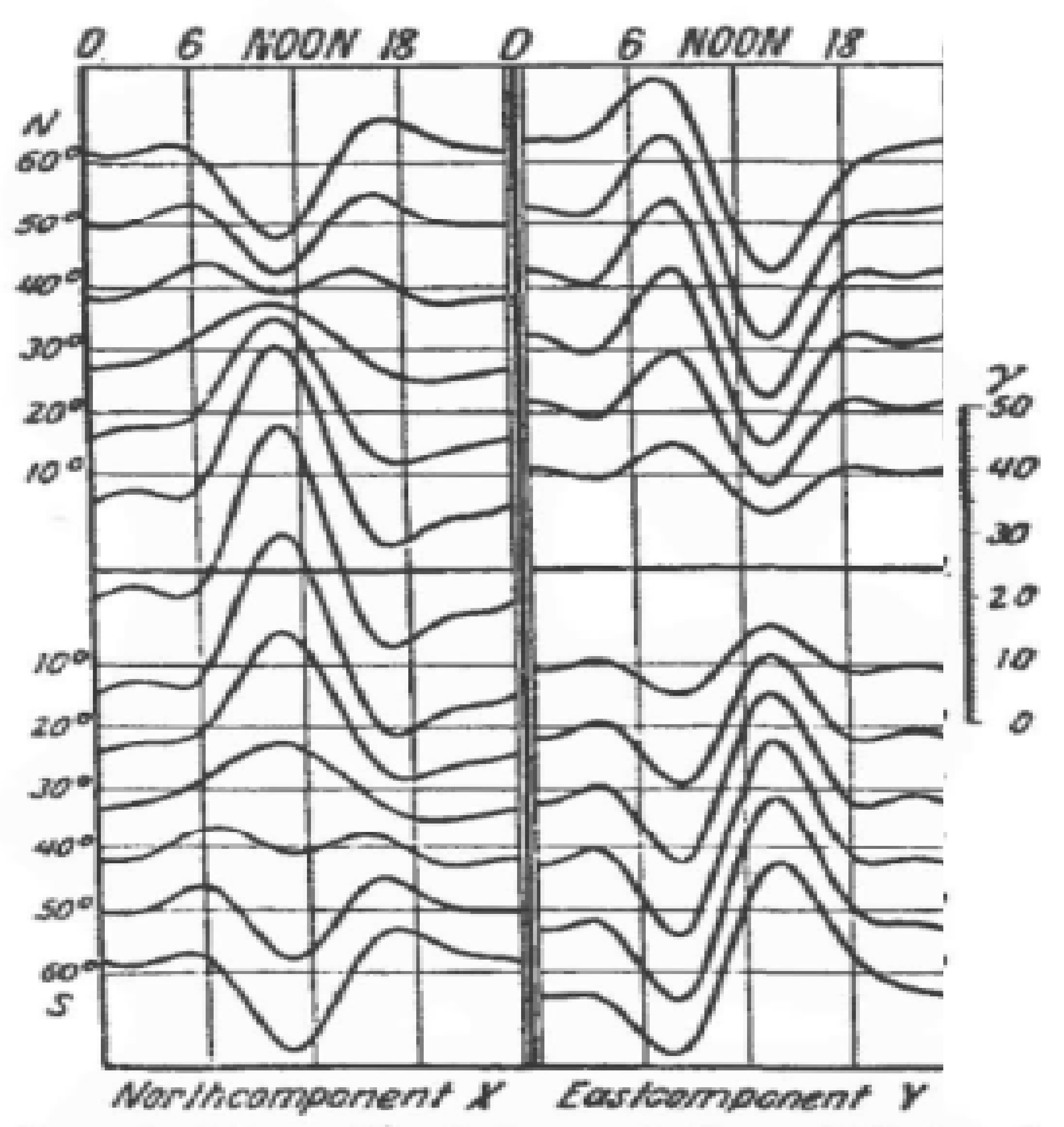
- "solar quiet" (**Sq**):
  - Sq = μ (daily variations) for 5 most quiet days of a month

- "solar disturbed" (**S_D**)
  - S_D = S – Dst
    - S = μ(daily variations) for all days of a month
    - Dst = μ (daily variations) for 5 most disturbed days of the month
  - S_D similar form to Dst



Sq
("solar quiet")

"solar quiet" (**Sq**)



equinox

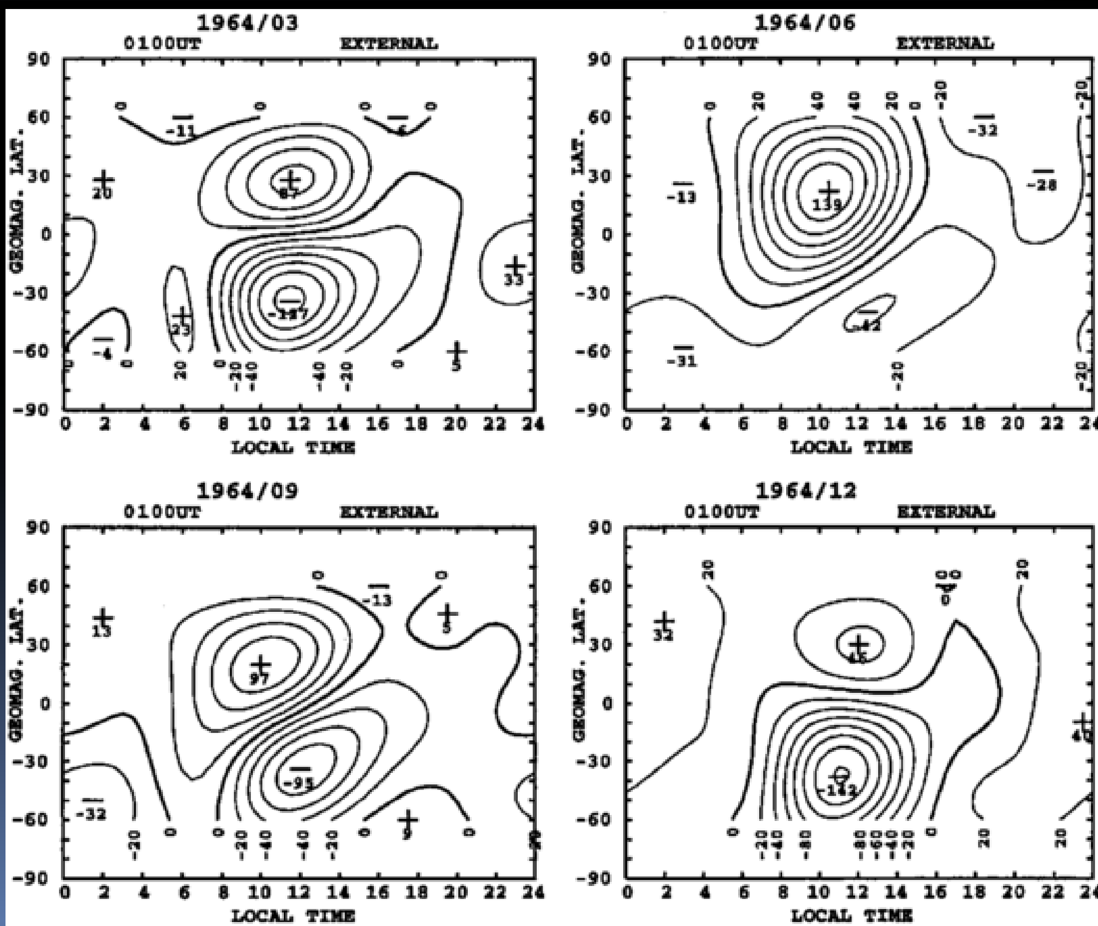
Sq source: ionospheric currents (90-150 km)

differential solar heating => ionospheric plasma

+

Geomagnetic filed

Ionospheric Dynamo



the exact location of the centers of the vortices slightly change from day to day => the form of the Sq variations change from day to day

Sq estimation

- **Standard procedure**: mean daily variations of the 5 most quiet days (QD) of a month
  - not all QD are truly "quiet"
    - actual Sq = "true" Sq + part of S_D + ?
  - final QD definition available after 1-2 yrs
  - 1 curve for all days of a month (with different ionospheric conditions!)

- PCA
- Wavelets
- ....

Sq estimation

- **Principal component analysis**
  - no need to select specific days
  - real-time analysis
  - produces reconstruction of a selected mode for the whole analyzed time interval

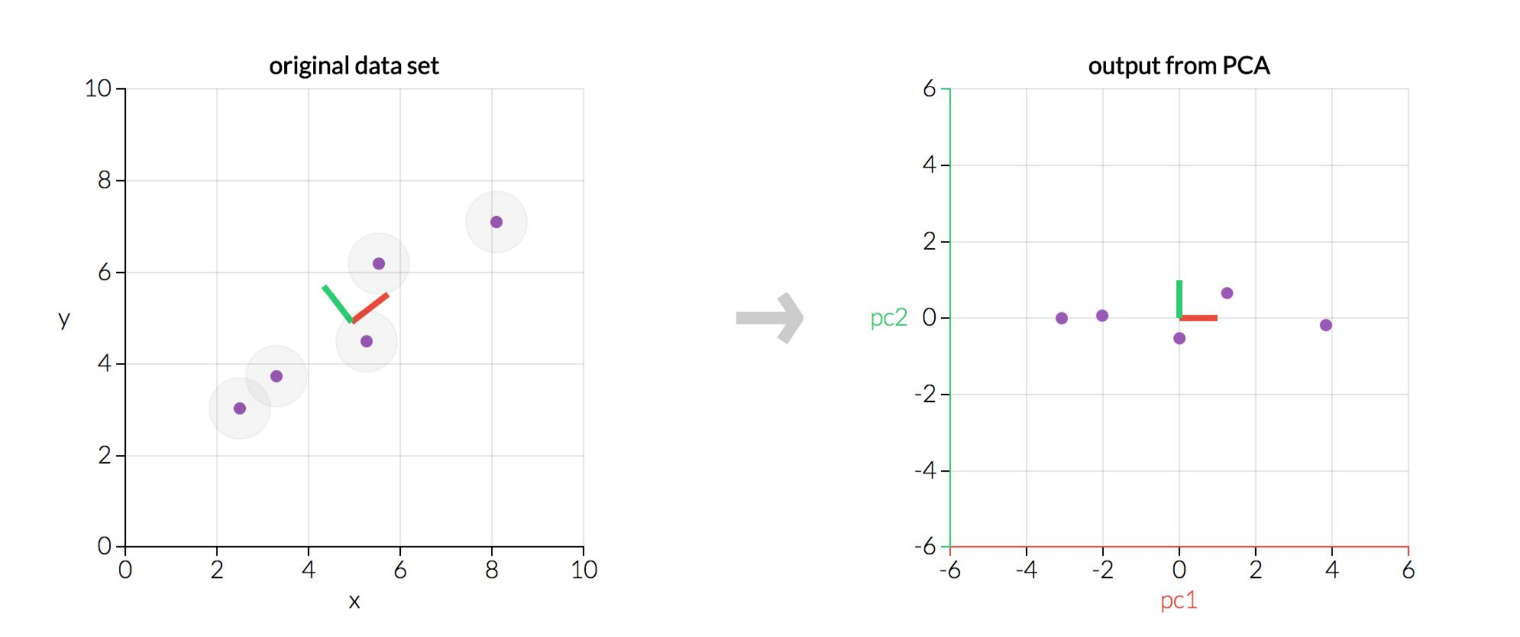
Principal component analysis: short review

PCA

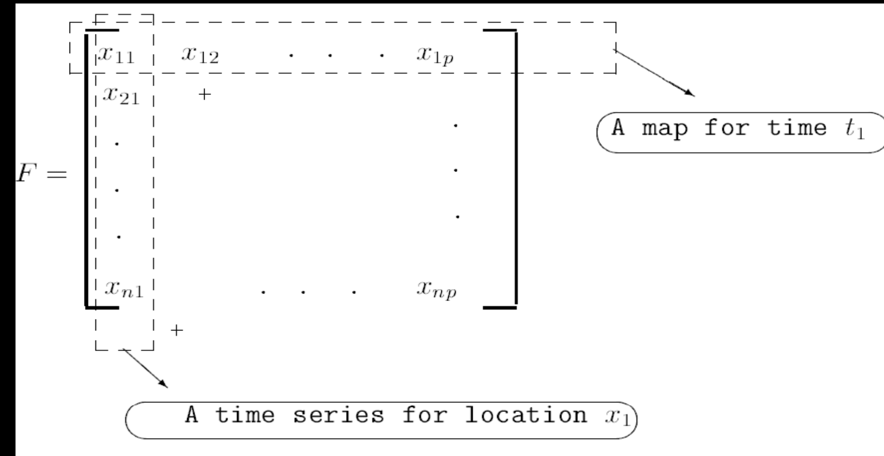
- Orthogonal transformation to convert a set of some input variables (possibly correlated) to a set of linearly non-correlated output variables (principal components - PC)
- All PC are ranked according to their eigenvalues
- Eigenvalues provide the variance fraction of the original data set variability that is explained by corresponding PC

PCA visualization

- Rotation in multi-dimensional data space:
  - the greatest variance is along the 1st coordinate
  - second greatest is along the 2nd coordinate
  - etc.



PCA math



- F – data matrix (matrix size <u>*n x p*</u>)
- $R = F^t F$ – covariance matrix (size *p x p*)
- R C = C Λ
  - C – matrix of eigenvectors (c_i) of R (size *p x p*)
  - Λ – diagonal matrix of eigenvalues of R (size *p x p*)
- Eigenvectors (c_i) - empirical orthogonal functions (EOF, vectors size *p)*
- Principal component: $pc_i = F \times c_i$ (vector size *n)*
- $Mode_i$ – $pc_i \times c_i$ (matrix size <u>*n x p*</u>)

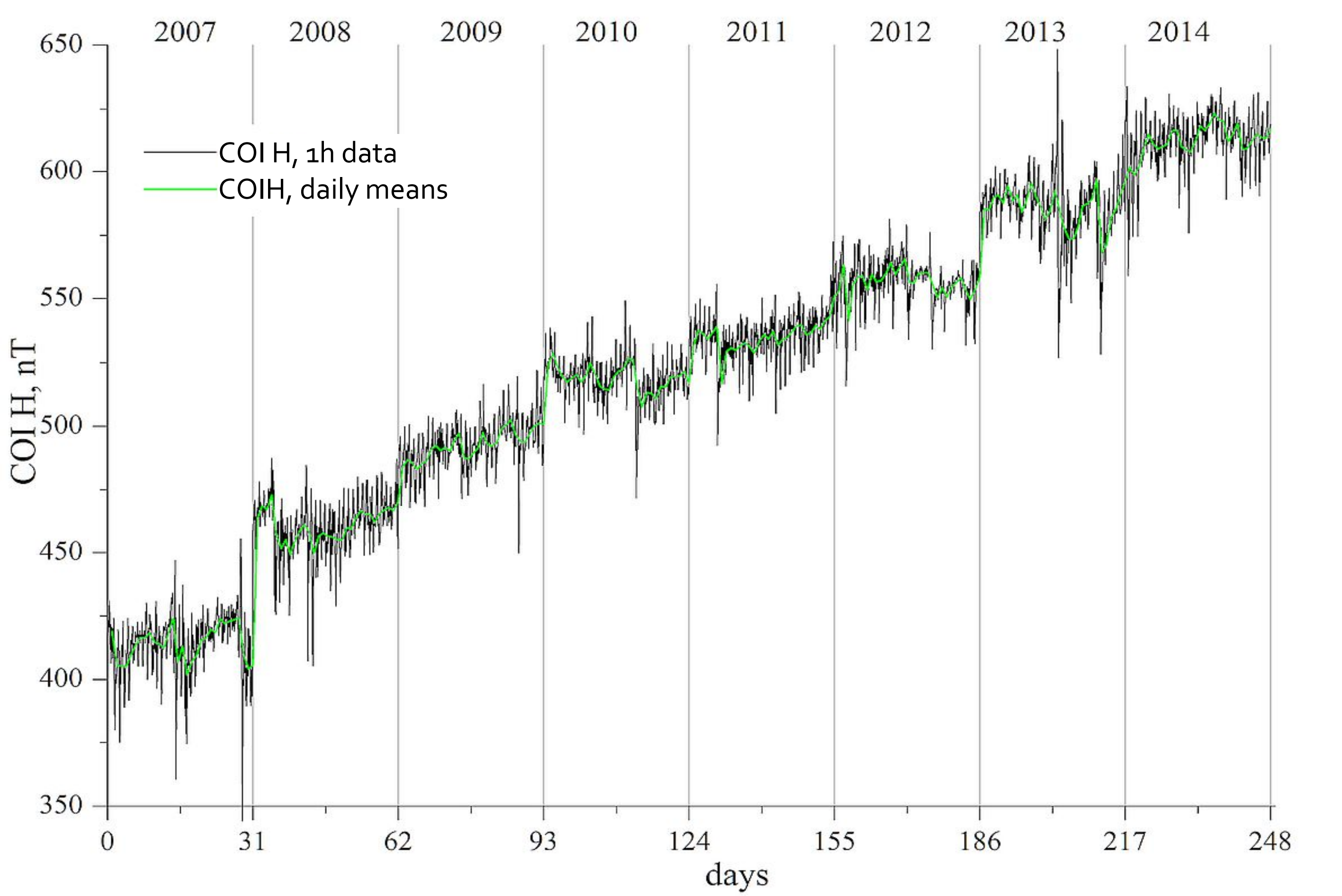
PCA is based on eigenvector analysis

- Simple
- Easy to implement
  - Ready to use functions, codes & packages in many programming languages & statistical software
- Used to reduce dimensionality, detect patterns etc.
- Starting point for some more elaborated tools of the data analysis:
  - canonical correlation analysis
  - factor analysis
  - correspondence analysis
  - K-means clustering
  - ...

Sq:
PCA vs standard

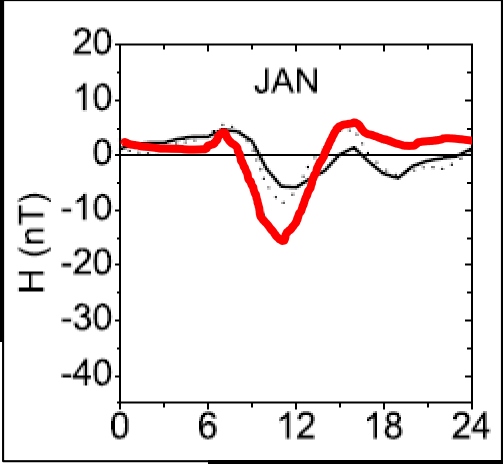
Data: all Januaries 2007-2014 (COI H – 25 000 nT)

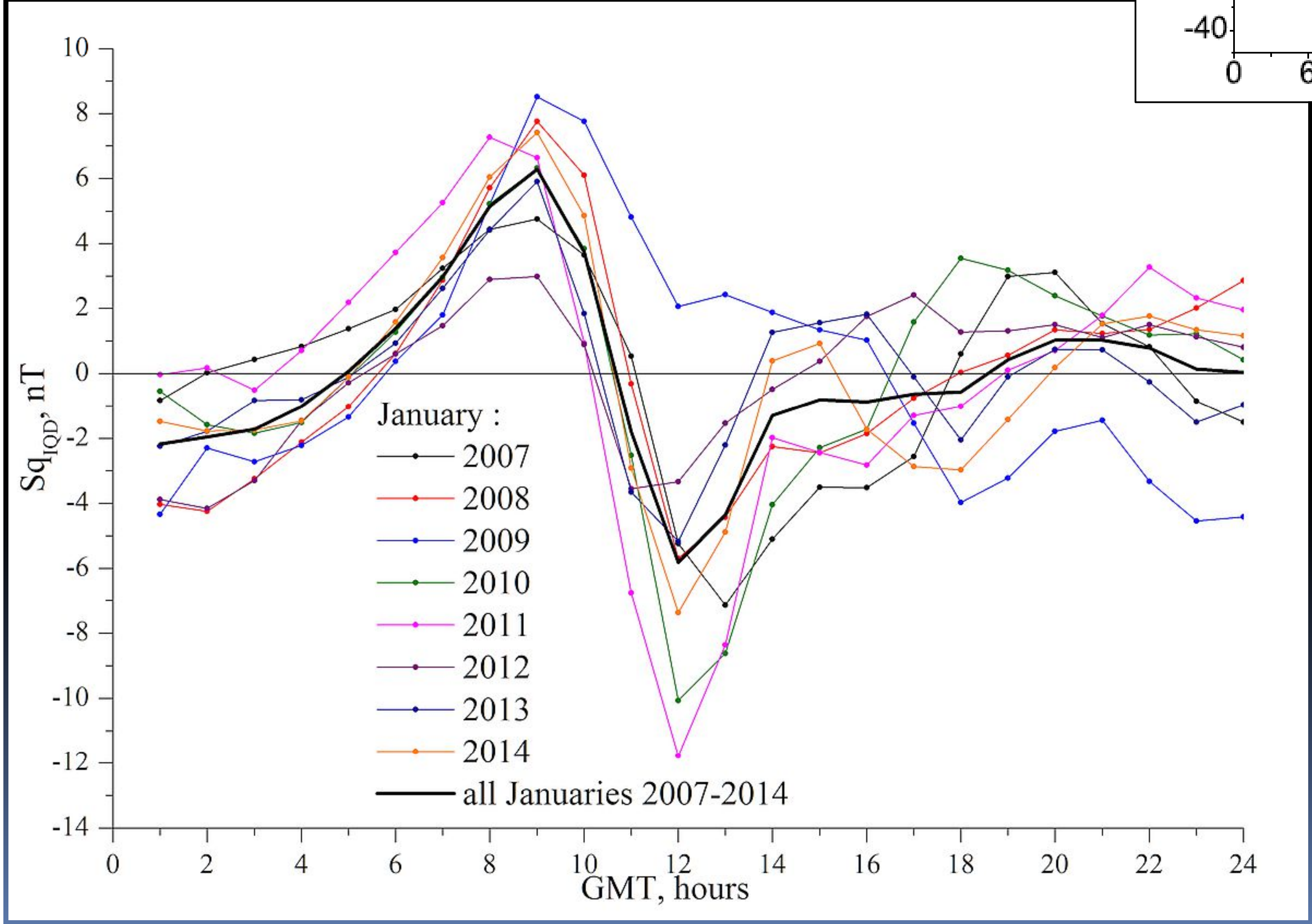
- 2007 -2014
- 1 h series
- interpolated gaps



Methods to calculate Sq

1. Quiet days (Sq_{QD})



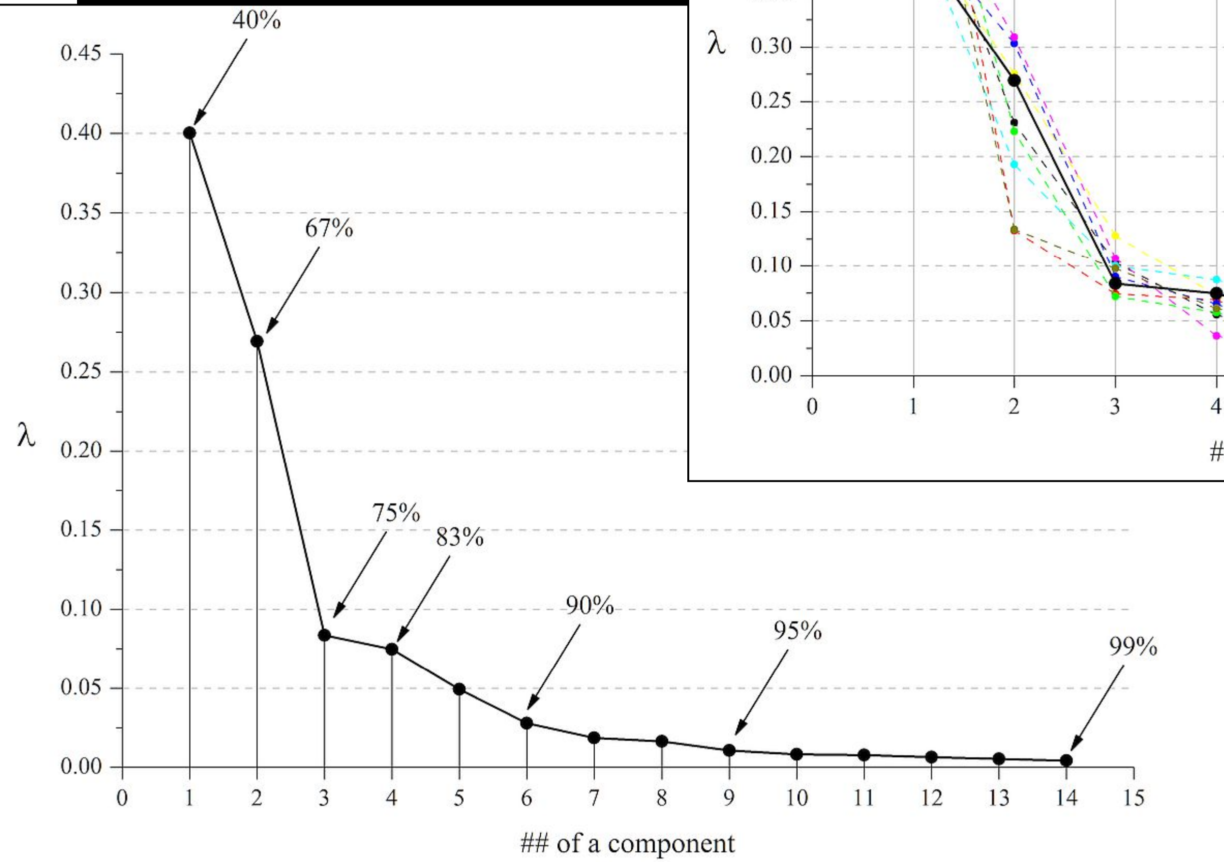


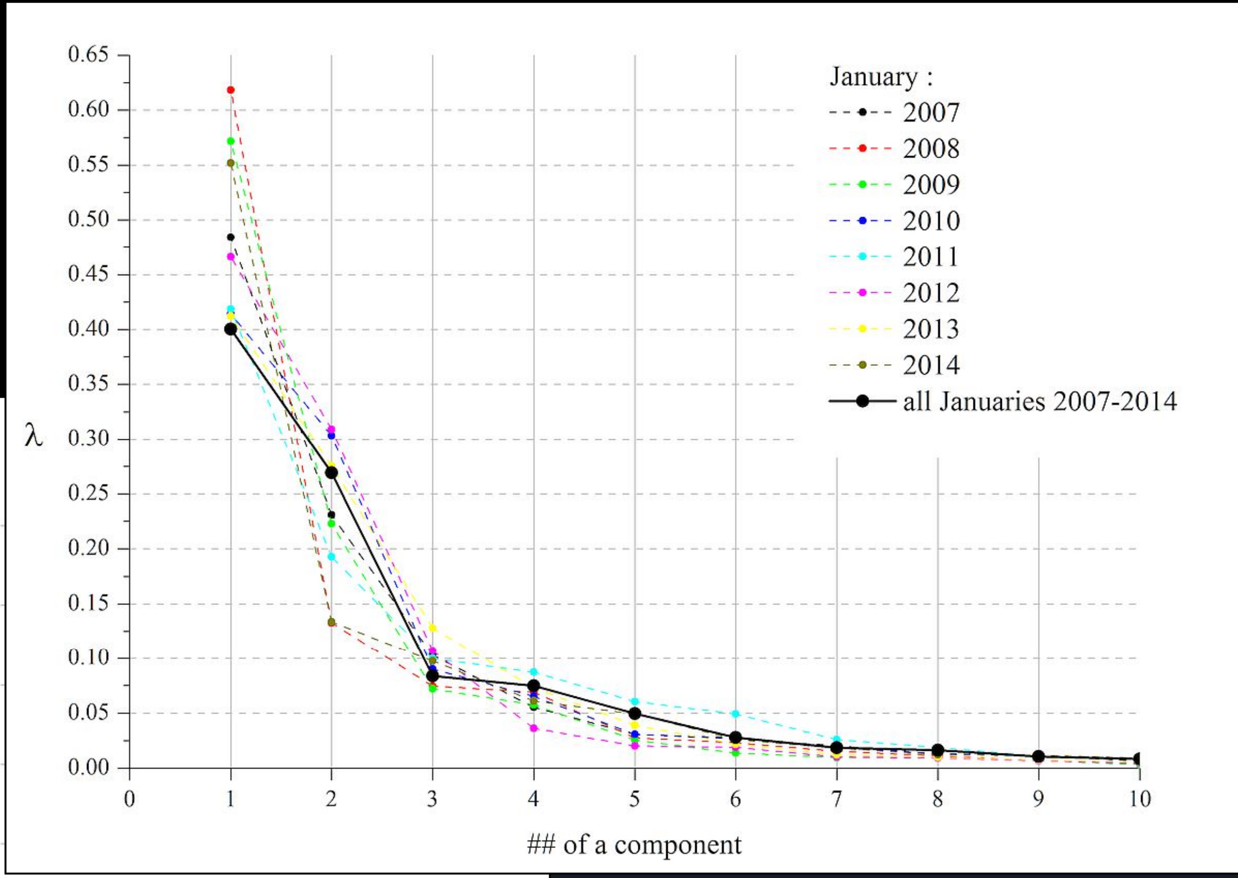
Methods to calculate Sq

2. Principal Component Analysis (Sq_{PCA})

- Input matrix:
  - Rows: hours (1, ..., 24)
  - Columns: days (1 Jan Y1, ..., 31 Jan Y1, 1 Jan Y2, ...31 Jan Y2 etc.)
- Time interval:
  - all Januaries 2007-2014 , together & separately

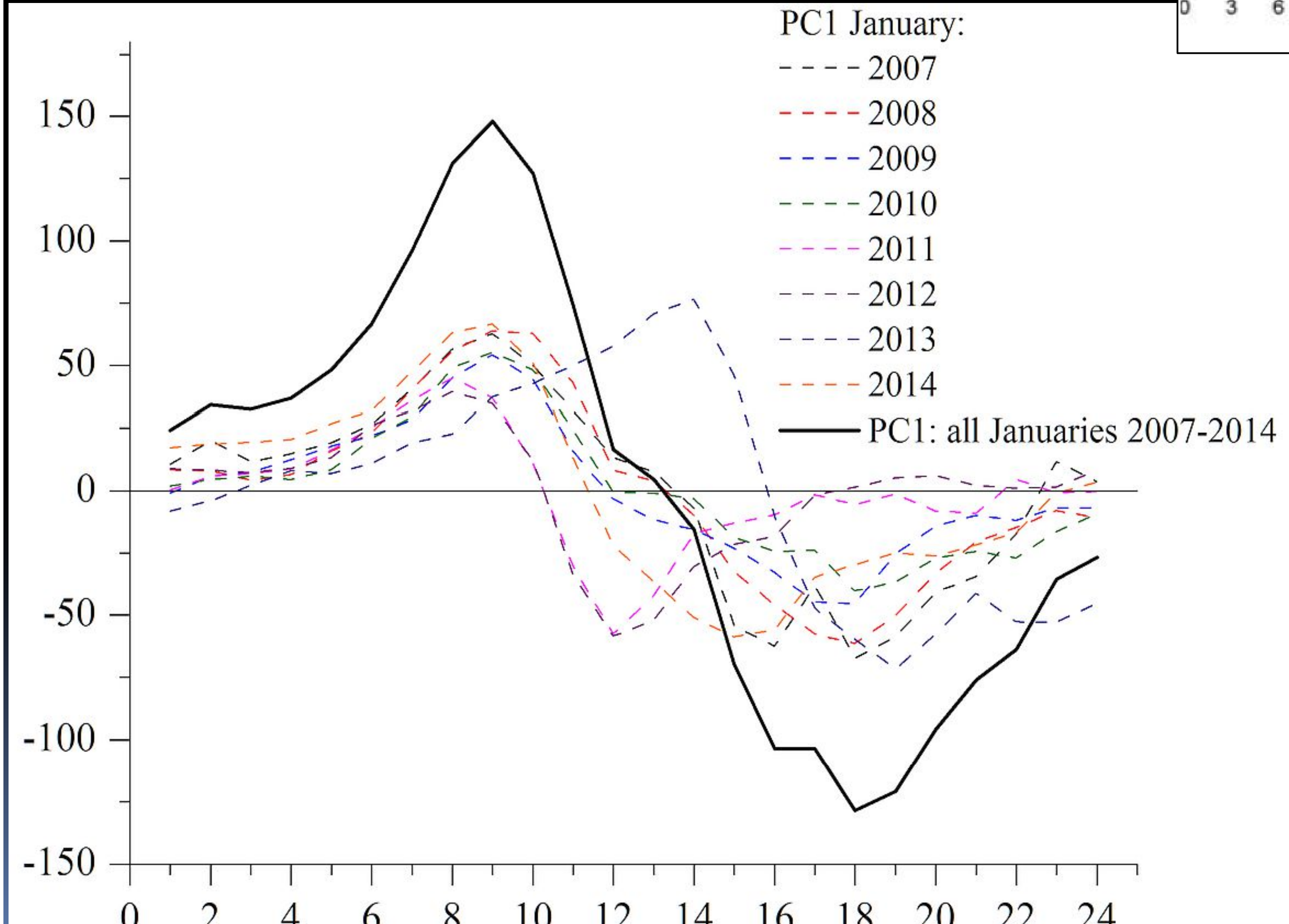
PCA: January - Variance fraction

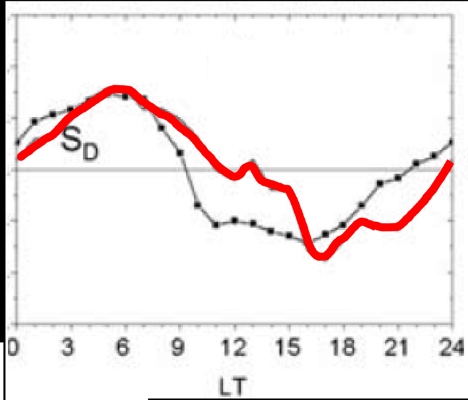




Sq$_{PCA}$: January

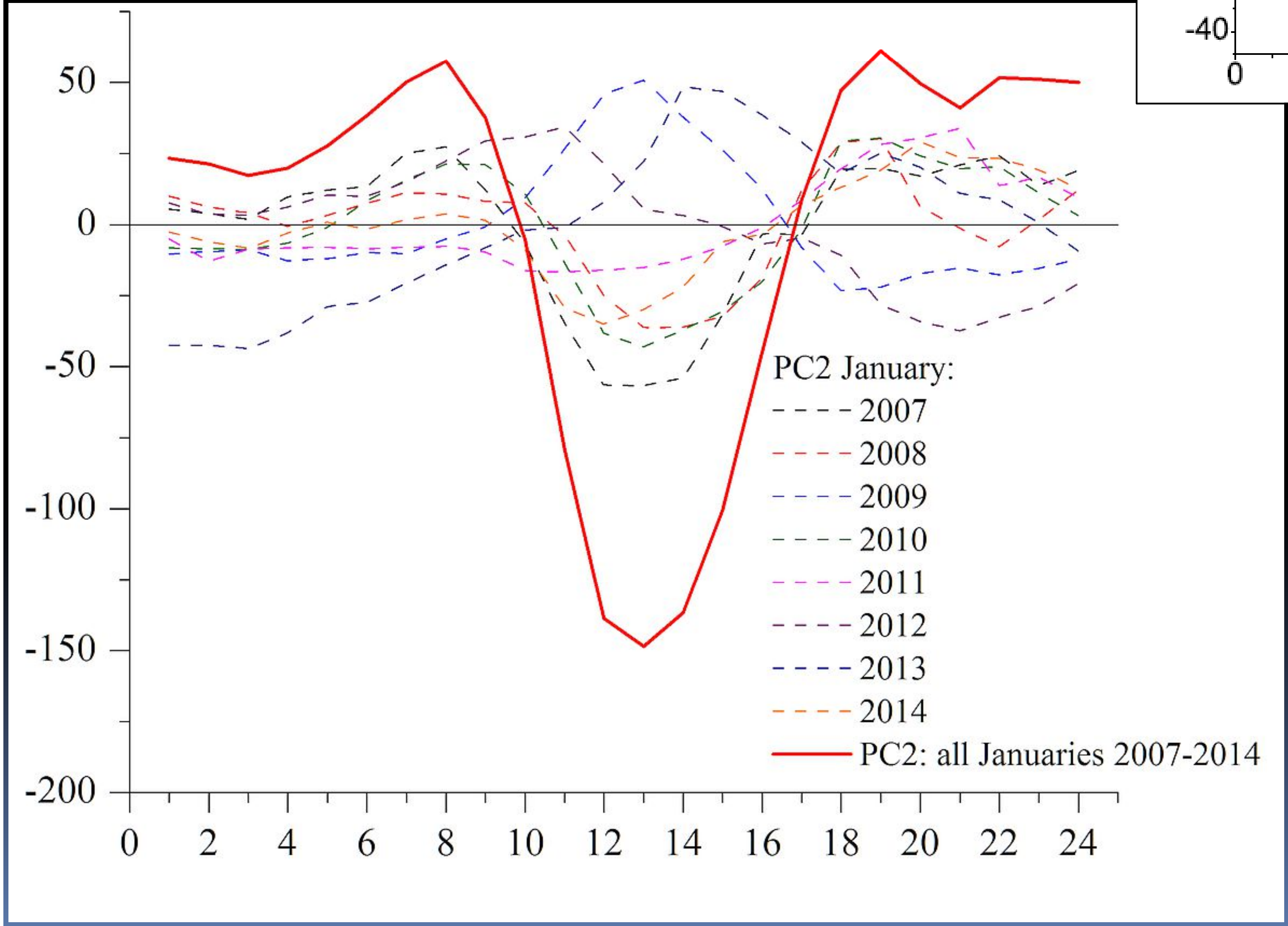
- PC1

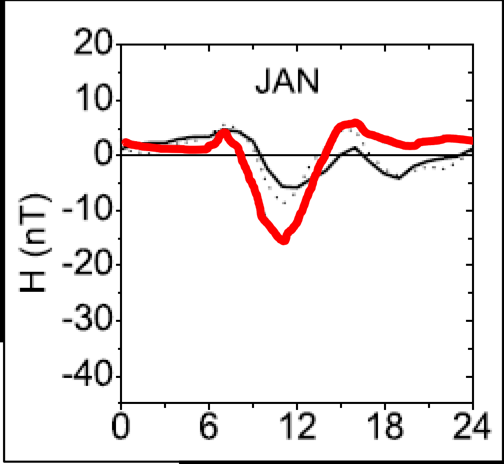




Sq_{PCA}: January

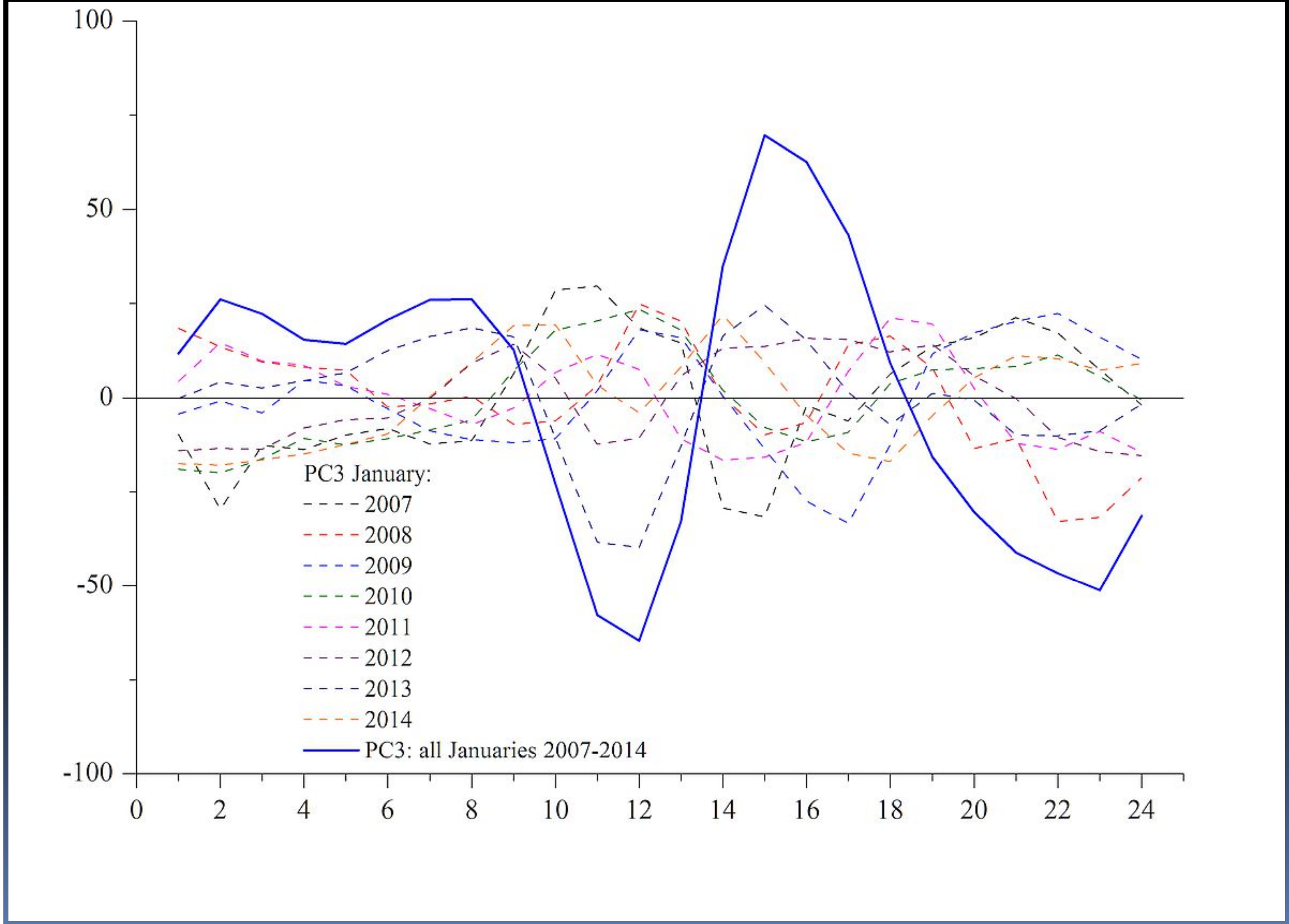
- PC2





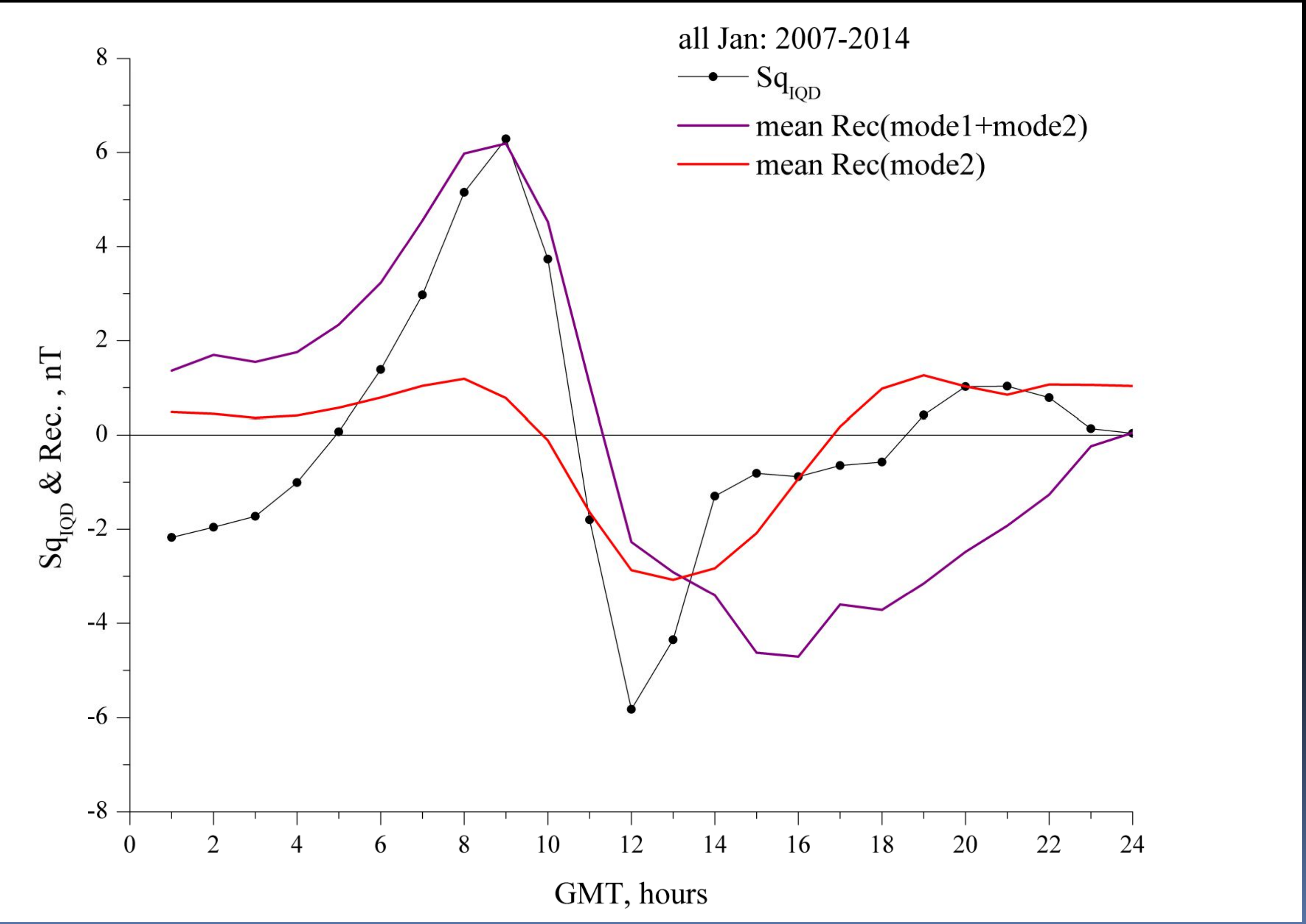
Sq_{PCA}: January

- PC3



Sq_{PCA} vs Sq_{QD}: January

- PC2 & PC2 vs Sq_{QD}



Sq_{QD} vs PCs: correlation coefficients

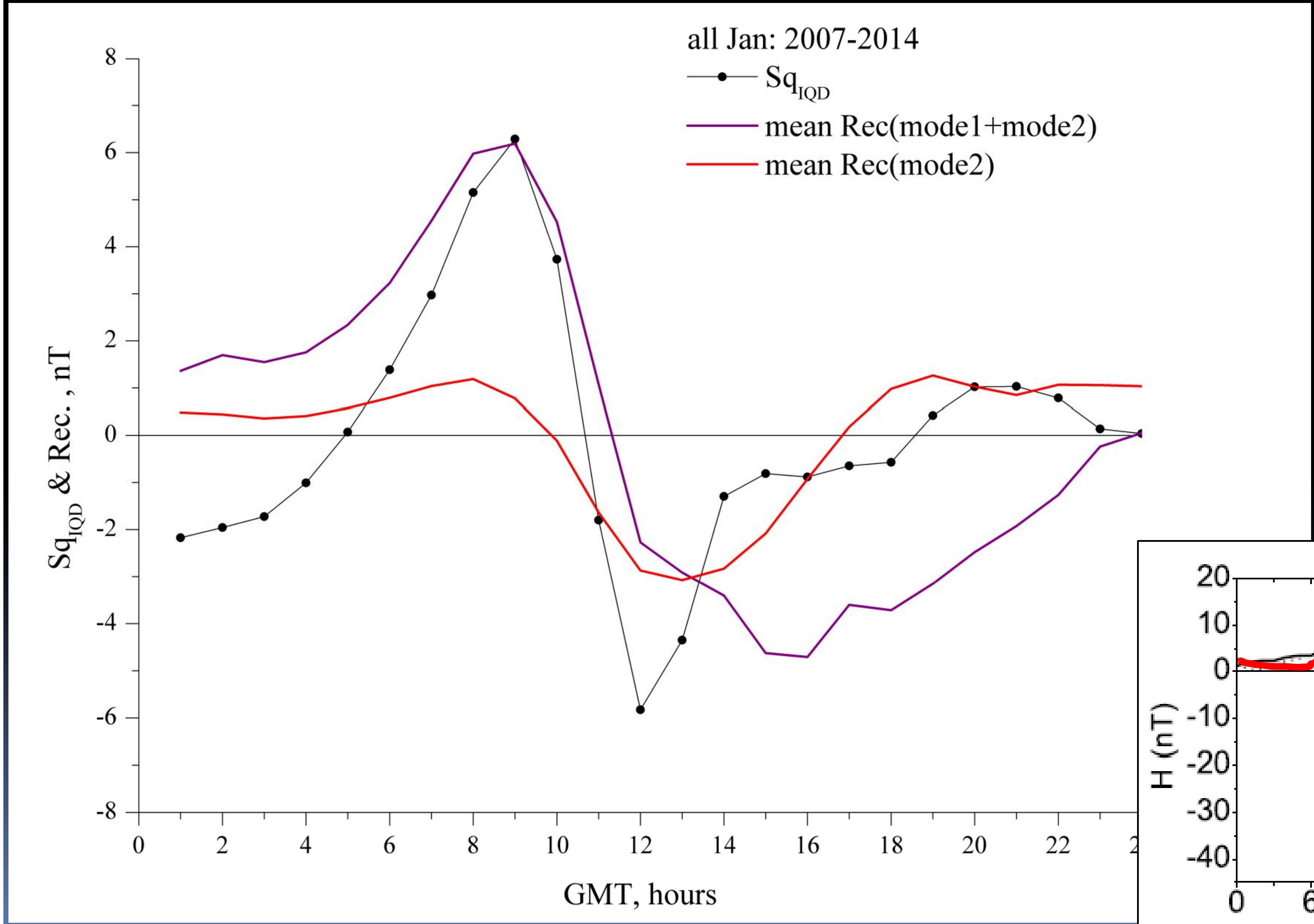
	2007	2008	2009	2010	2011	2012	2013	2014	all
PC1	0.34	0.42 (0.12)	**0.62**	0.2	**0.94 (<0.01)**	0.46	0	**0.59 (0.02)**	0.4 (0.1)
PC2	**0.77 (0.05)**	0.47	**0.55**	**0.9 (<0.01)**	0.25	0.3	0	0.41	**0.62 (0.08)**
PC3	0.18	**0.57 (0.06)**	0.31	0.18	0.16	**0.63 (0.02)**	**0.76 (0.02)**	**0.55 (0.1)**	0.18
PC1 + PC2	**0.76 (0.02)**	**0.5 (0.04)**	**0.71**	**0.63 (0.07)**	**0.94 (<0.01)**	0.36	0.11	**0.65 (0.01)**	**0.62 (<0.01)**

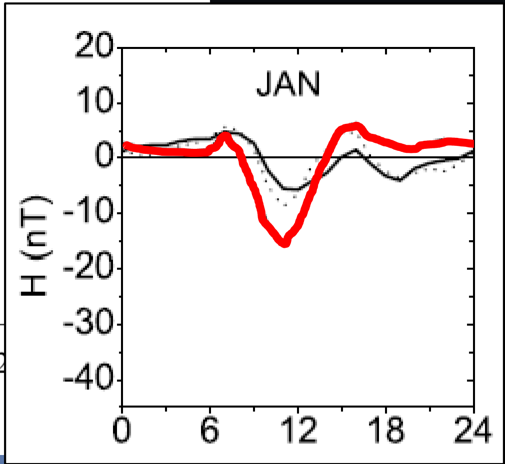
PCA vs QD: preliminary conclusion

- PCA is a good method to extract Sq-type variations
- In most cases (PC1 + PC2) explains 25-88% of the Sq_{QD} variations ($r = 0.5 \div 0.94$)
- For the geomagnetically disturbed time intervals PC3 is needed

- But…

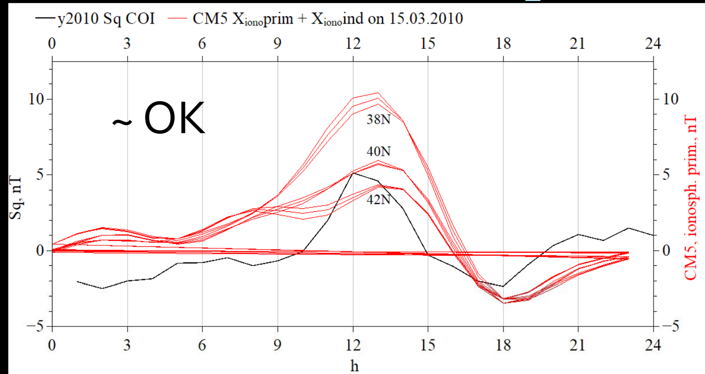
Do Sq_{QD} and Sq_{PCA} represent the "true" ionospheric component?



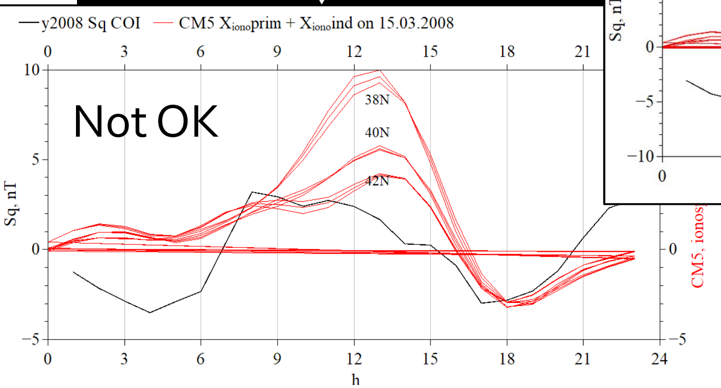


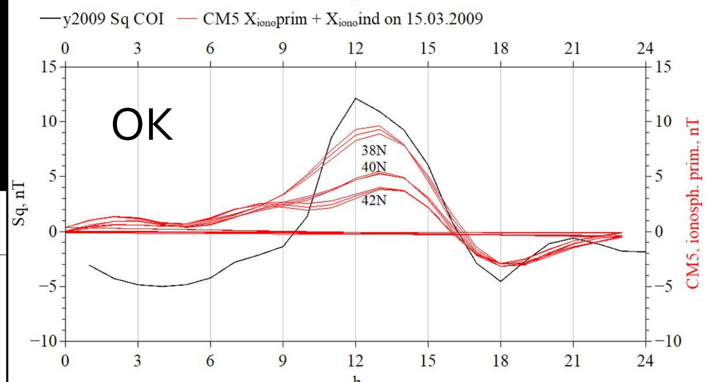
Ionospheric model vs Sq_{QD}

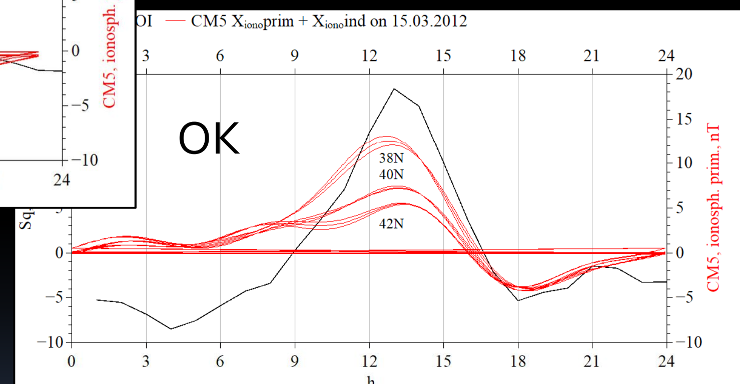
CM5 is an empirical inverse model derived from pre-Swarm satellite data & ground observatory data from August 2000 to January 2013.

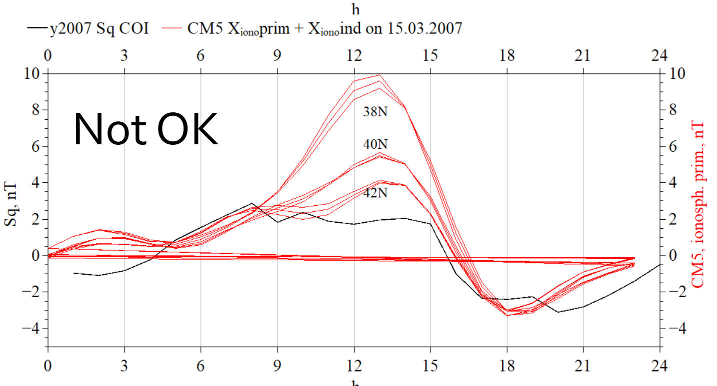


Contamination by Dst

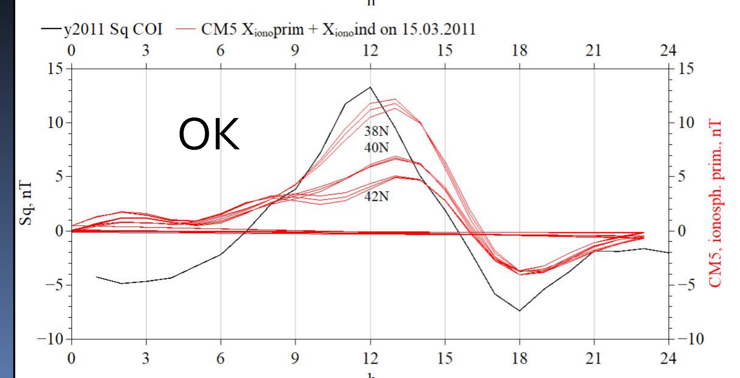






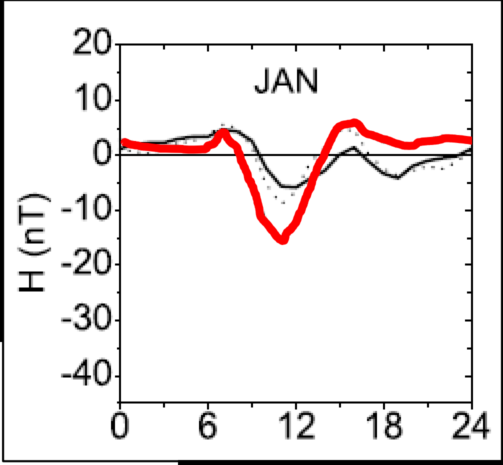


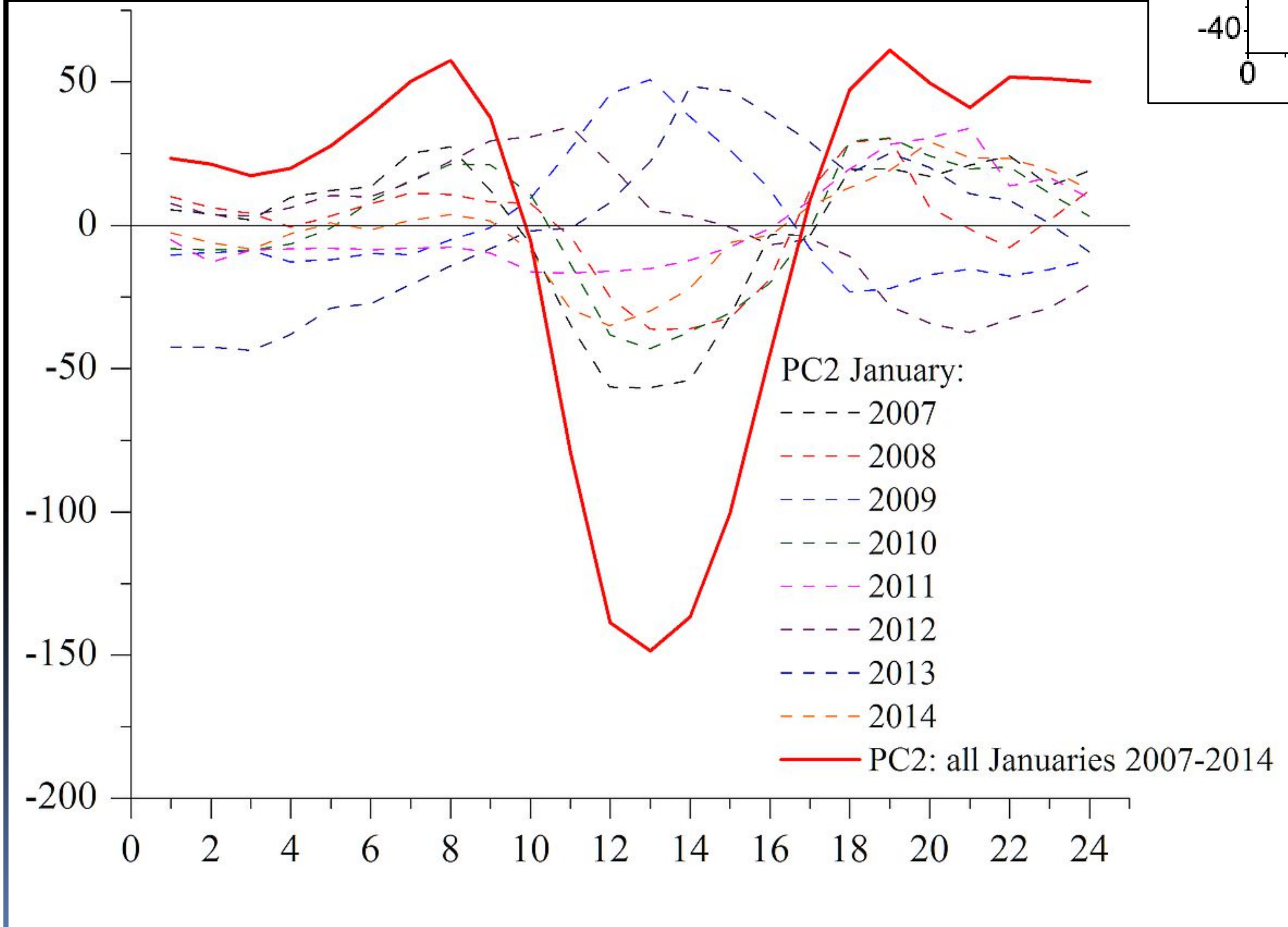
March, 2007 - 2012



Ionospheric model vs Sq_{PCA}

- PC2 for [8*31 days] ≈ “true” Sq





Sq_{PCA} vs Sq_{QD}: Conclusions

- $Sq_{QD} \sim Sq_{PCA}$
- Both kind of Sq can be contaminated by the disturbance field
- PCA: the larger time interval, the better separation of the “quiet” and “disturbed” variations
- Ionospheric and magnetospheric models are needed
  - to “prove” that the obtained Sq-type variations are of ionospheric origin
  - to select of a PC that correspond to the “true” Sq

(= ionospheric contribution)

Future work

- Different input time intervals
  - Different months/seasons
  - Different epoch of solar activity cycle
  - Short time intervals (around storms)

VS

Long time intervals (several months)

- Ionospheric & magnetospheric models: modelled daily variations

VS

Sq_{QD} & Sq_{PCA}

Future work
+ master student grant (to start in September 2019)

First-hand experience with

- ⇨ PCA
- ⇨ Statistical analysis of observational data
- ⇨ Models for ionosphere & magnetosphere

⇦ Knowledge of programming languages/software (Python, R, Matlab) to perform PCA

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Questions?