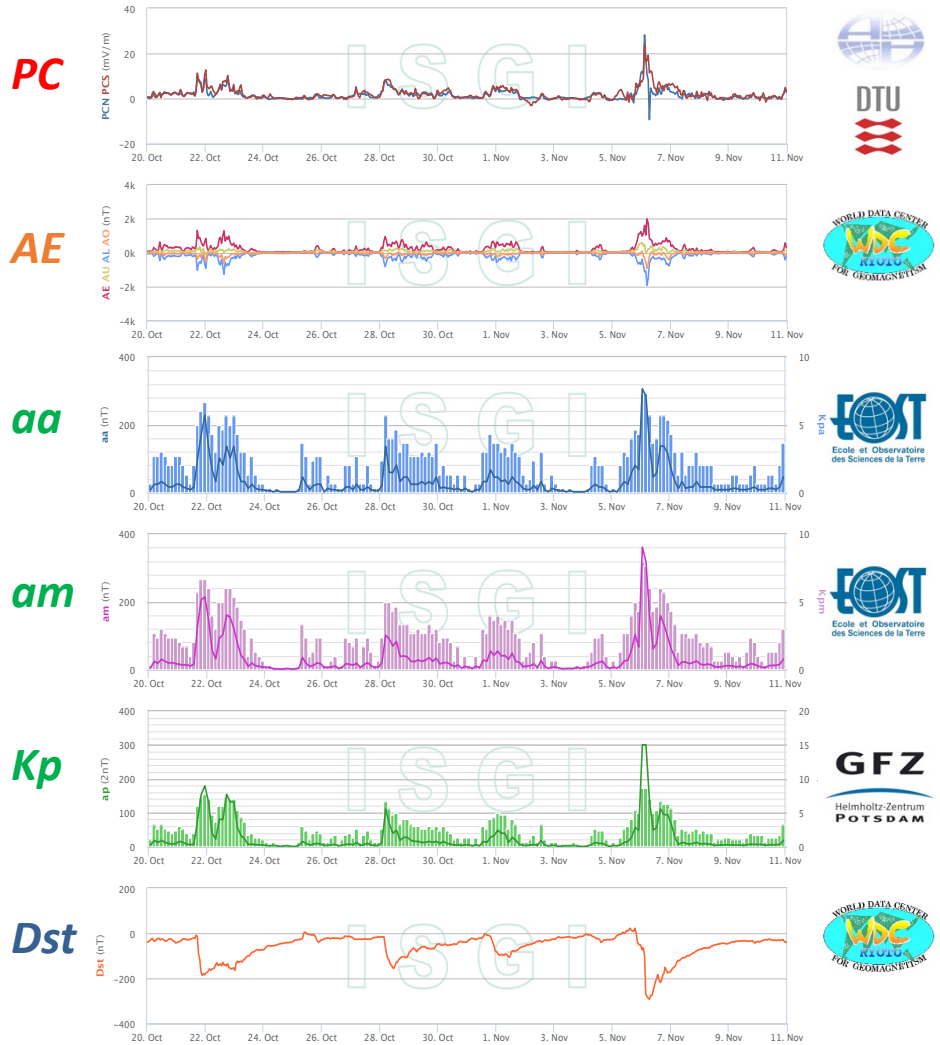
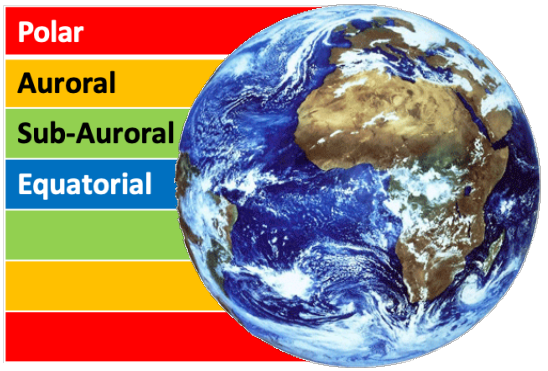
Magnetic activity indices

A. Chambodut

International Service of Geomagnetic Indices



geomagnetic latitude

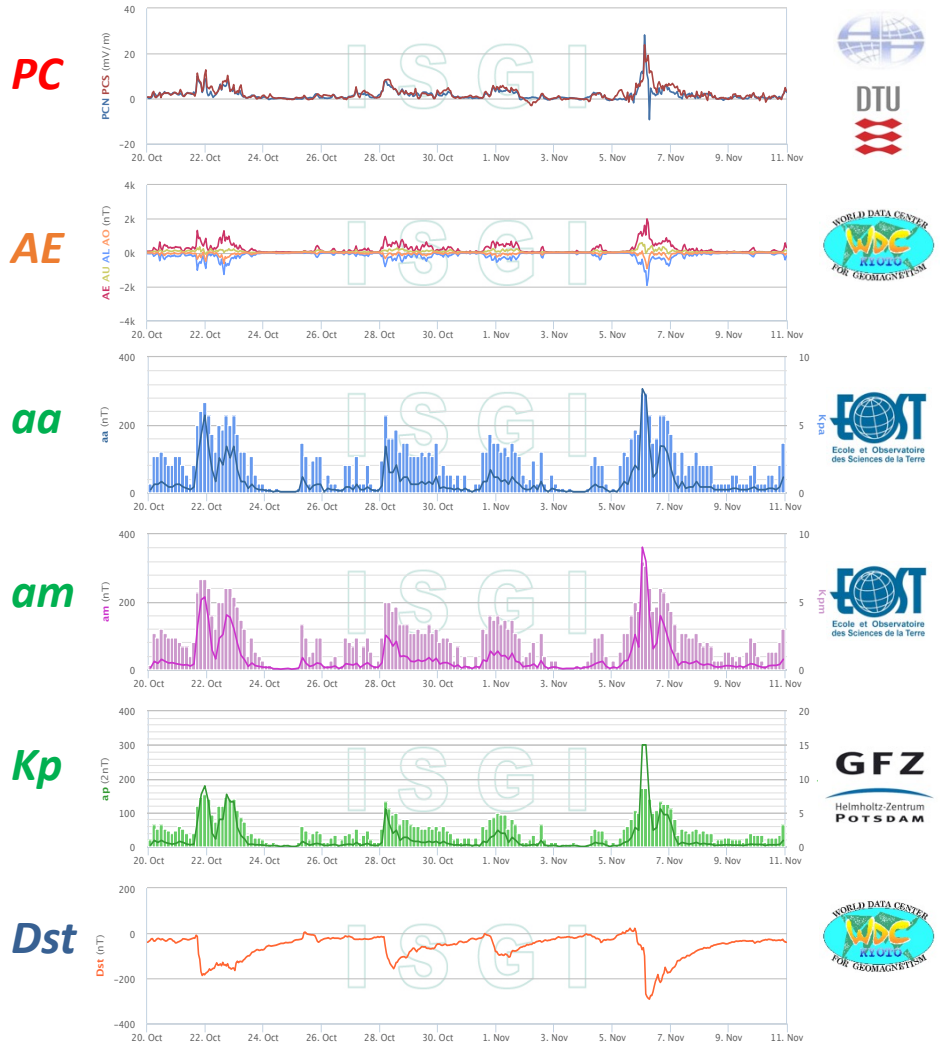


magnetic activity indices:
estimates of ground magnetic activity
*to **quantify idealized physical processes***

ISGI is the service of the International Association of Geomagnetism and Aeronomy (IAGA) for derivation, validation, dissemination and stewardship of geomagnetic indices and lists of remarkable events endorsed by IAGA.
ISGI is the reference service in charge of the diffusion of all the IAGA Bulletins relating to geomagnetic indices.

6 ISGI-Collaborating-Institutes.

International Service of Geomagnetic Indices



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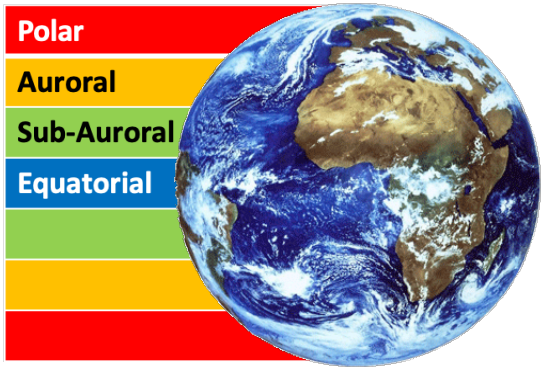


magnetic activity indices:
estimates of ground magnetic activity
*to **quantify idealized physical processes***

Characterisation of a magnetic event at ground

- **Intensity**
  - maximum of *PC, AE, aa, am, Kp*
  - minimum of *Dst*
- **Duration**
  - **start:** determined in case of a 'shock',
    or using the solar wind parameters in L1;
  - **end:** return to the level that prevailed before the event,
    but not simultaneous for each magnetic index....

International Service of Geomagnetic Indices

PC — *North*: 1975 - .. ; *South*: 1995 - ...

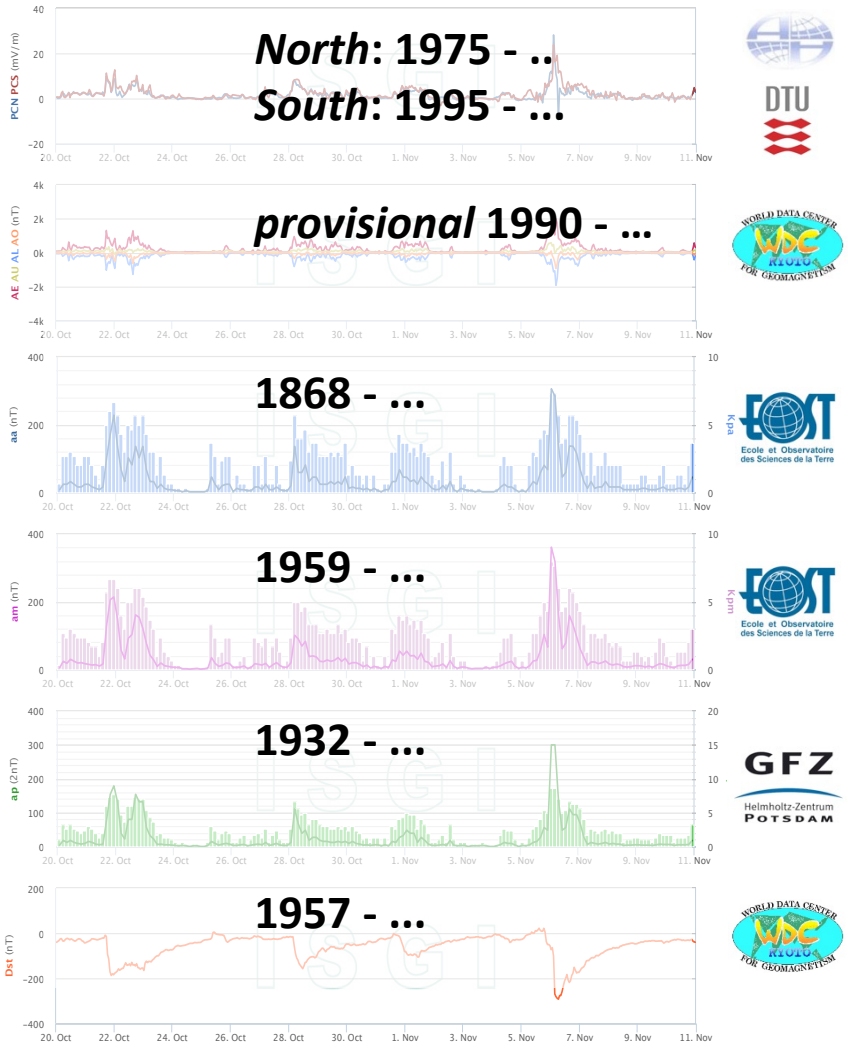
AE — *provisional* 1990 - ...

aa — 1868 - ...

am — 1959 - ...

Kp — 1932 - ...

Dst — 1957 - ...



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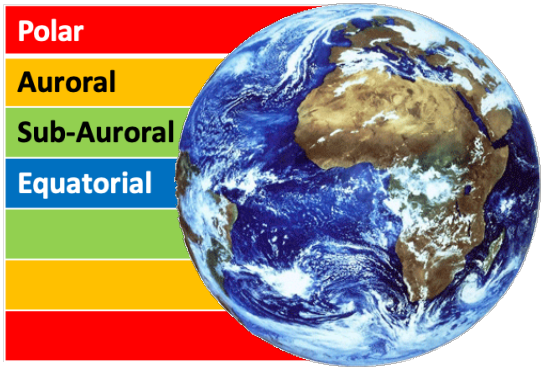

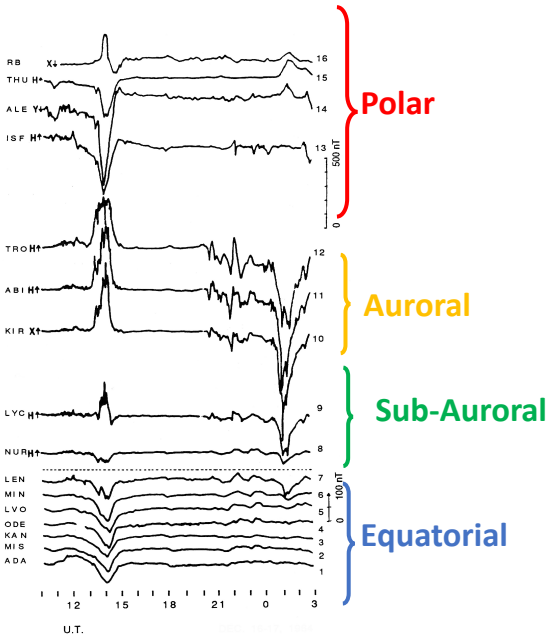

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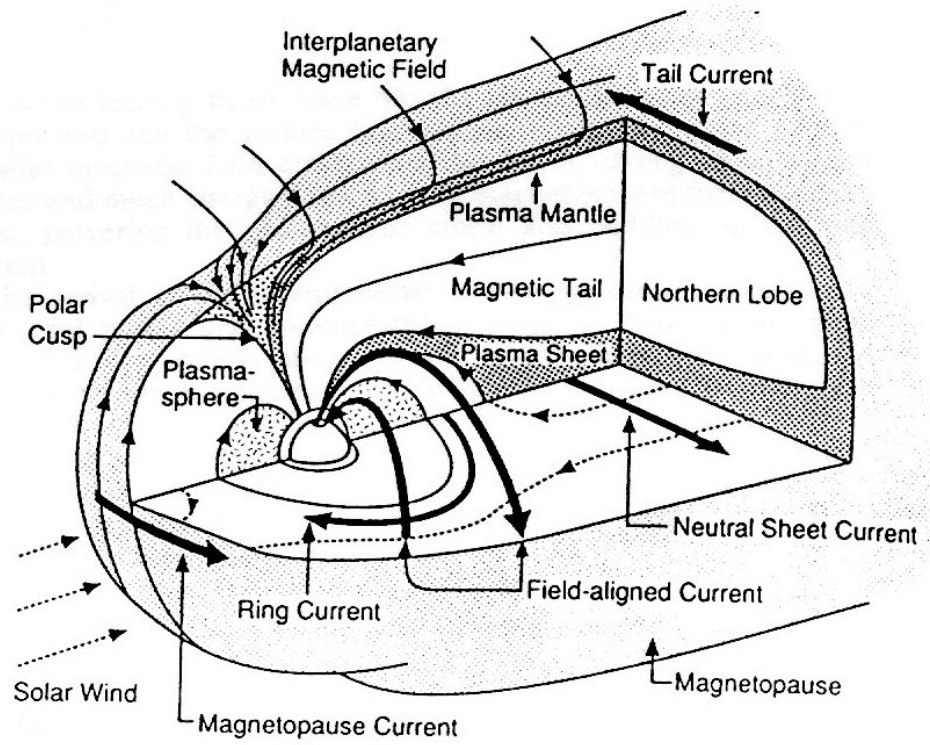

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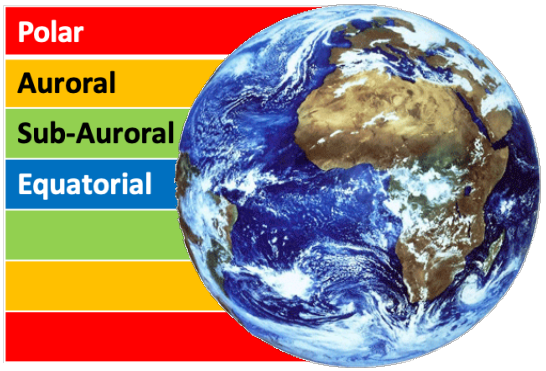

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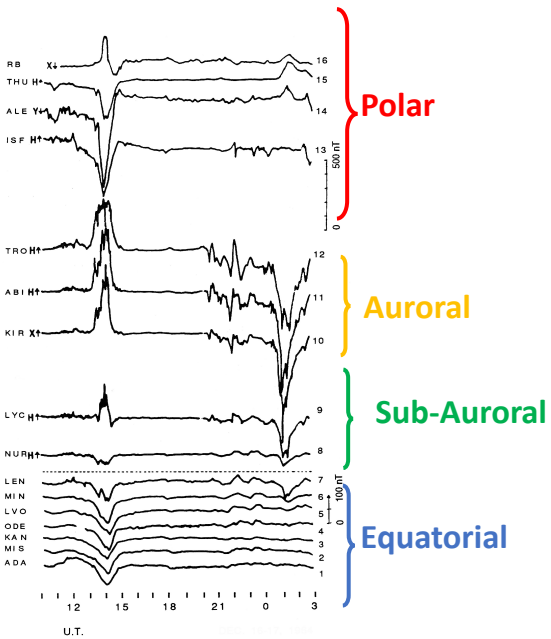
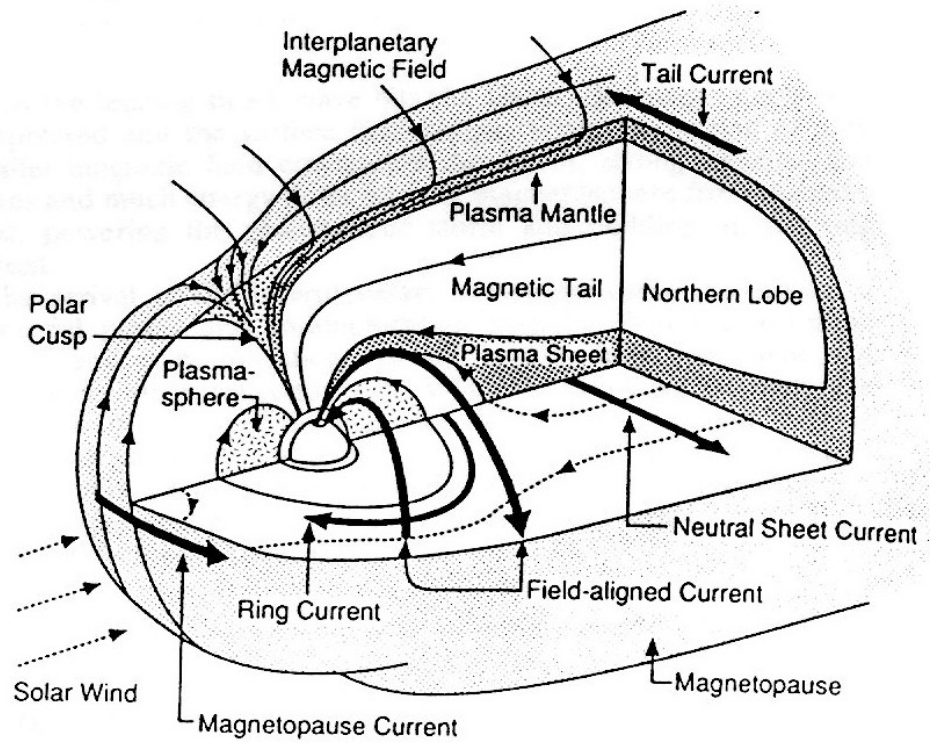




Dst - "Disturbance storm-time"

Sugiura (1964)

Unit: nT
Time resolution: 1-hour (UT) interval

➔ **To monitor the axis-symmetric magnetic signature of magnetosphere currents, including mainly the ring current, the tail currents and also the magnetopause Chapman-Ferraro current.**

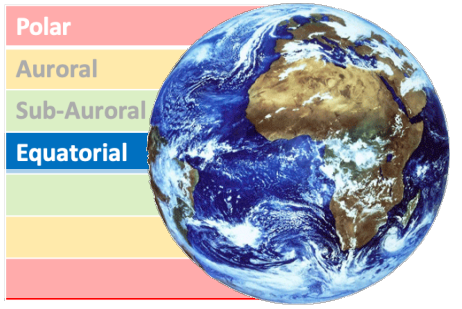
In each station, for the **horizontal field (H) corrected from** core, crust & solar regular daily variation, before being normalized to the dipole equator.

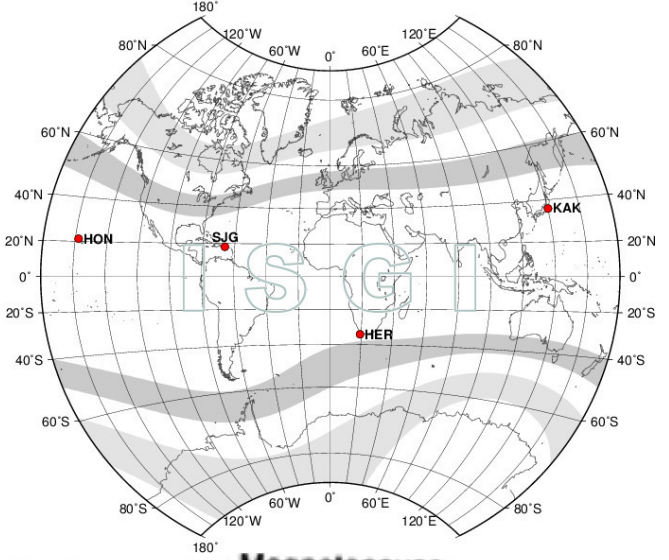
ASY/SYM *(from 1981 onwards)*
6 groups of stations
Unit: *nT*
Time resolution: *minute values*

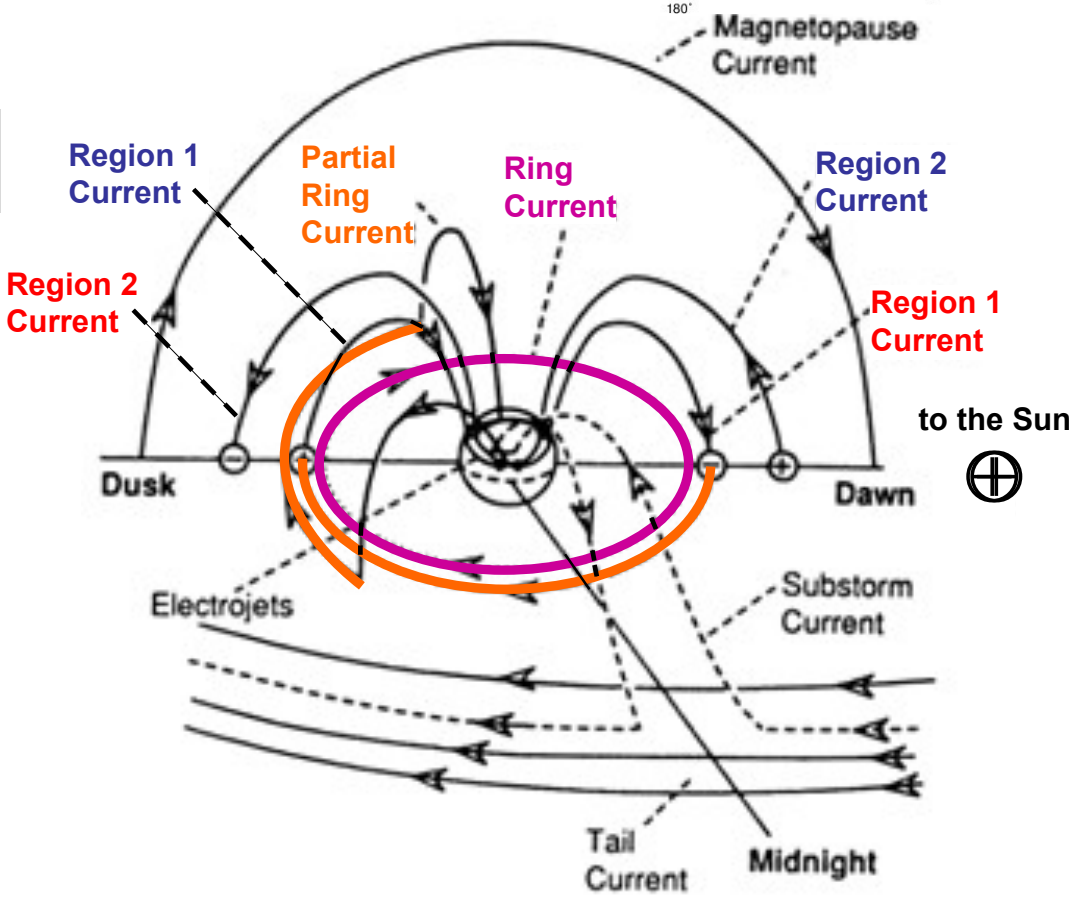
SYM-H – Intensity of the axi-symmetric currents
mostly Chapman-Ferraro magnetopause and Ring currents
ASY-H – non axi-symmetric current flows (partial ring current)

➔ ***Dst*** **and** ***SYM-H*** **mostly capture the magnetic signature of the Ring Current, but are sensitive to other magnetosphere currents**

Derived from 4 low latitude stations







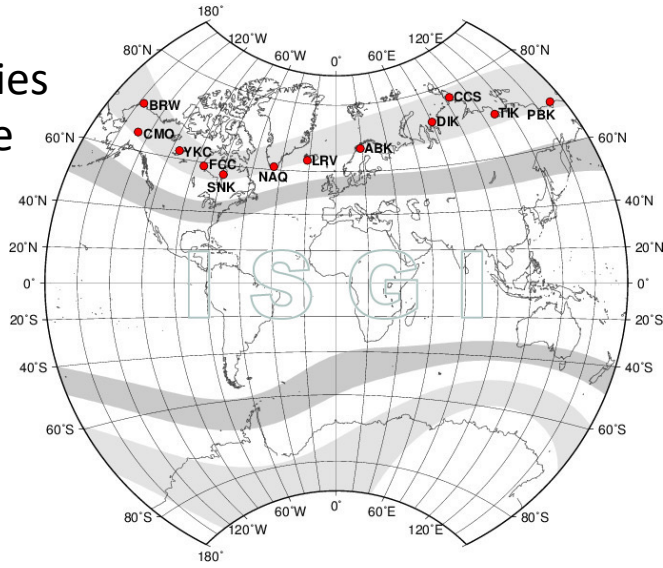
AE - ”Auroral Electrojet"

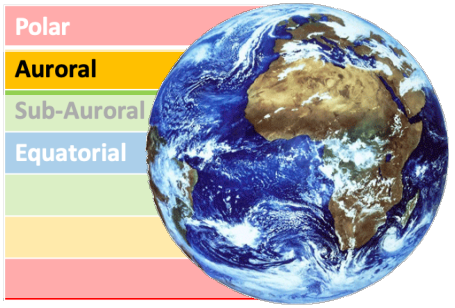
Davis & Sugiura (1966)

Unit: nT
Time resolution: minute values

➔ **To monitor the magnetic signature of the eastward and westward auroral electrojets in the Northern hemisphere**

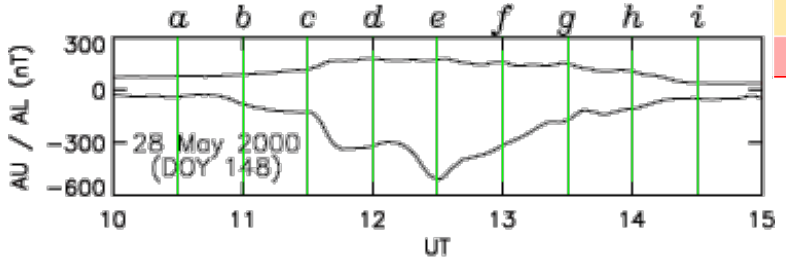
Derived from 12 observatories in the Northern auroral zone

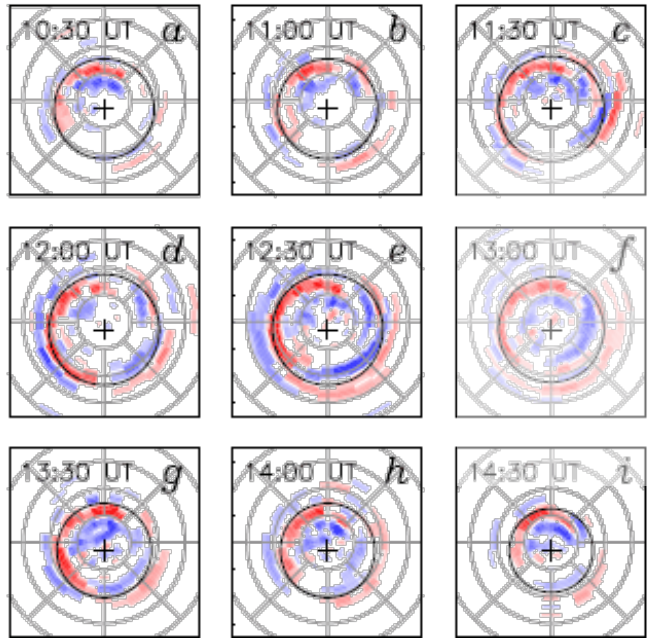




The magnetograms of the horizontal components from the *AE* stations are superimposed.

AU = upper envelope
AL = lower envelope
AE = (AU - AL)
AO = (AU + AL)/2

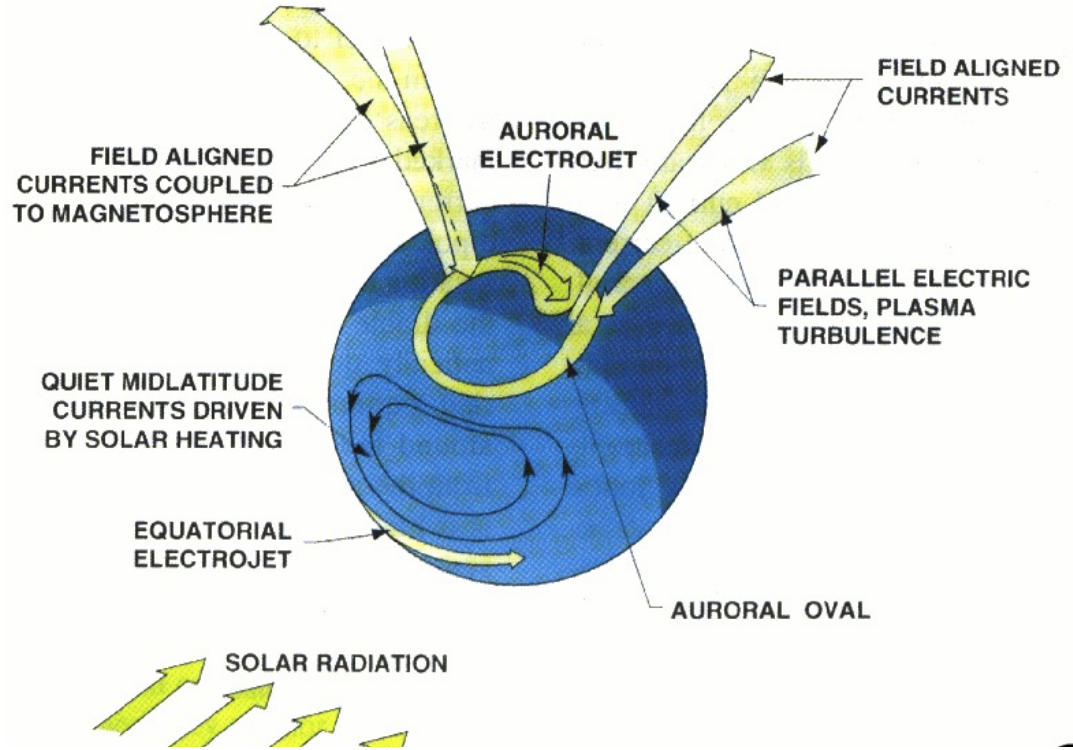




Milan et al. (2017)

Red upwards
blue downwards

scale $\pm 1\ \mu\mathrm{Am}^{-2}$



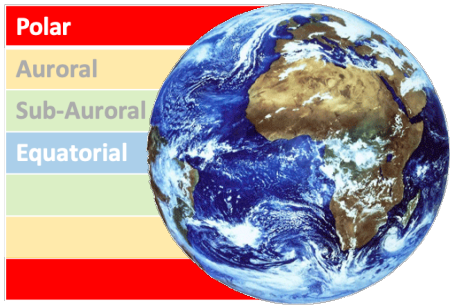
PC - ”Polar Cap"

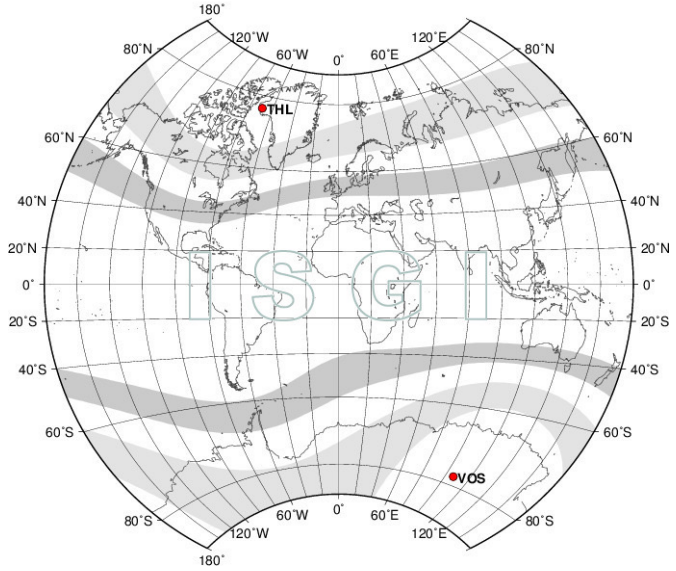
Unit: mV /m
Time resolution: minute values

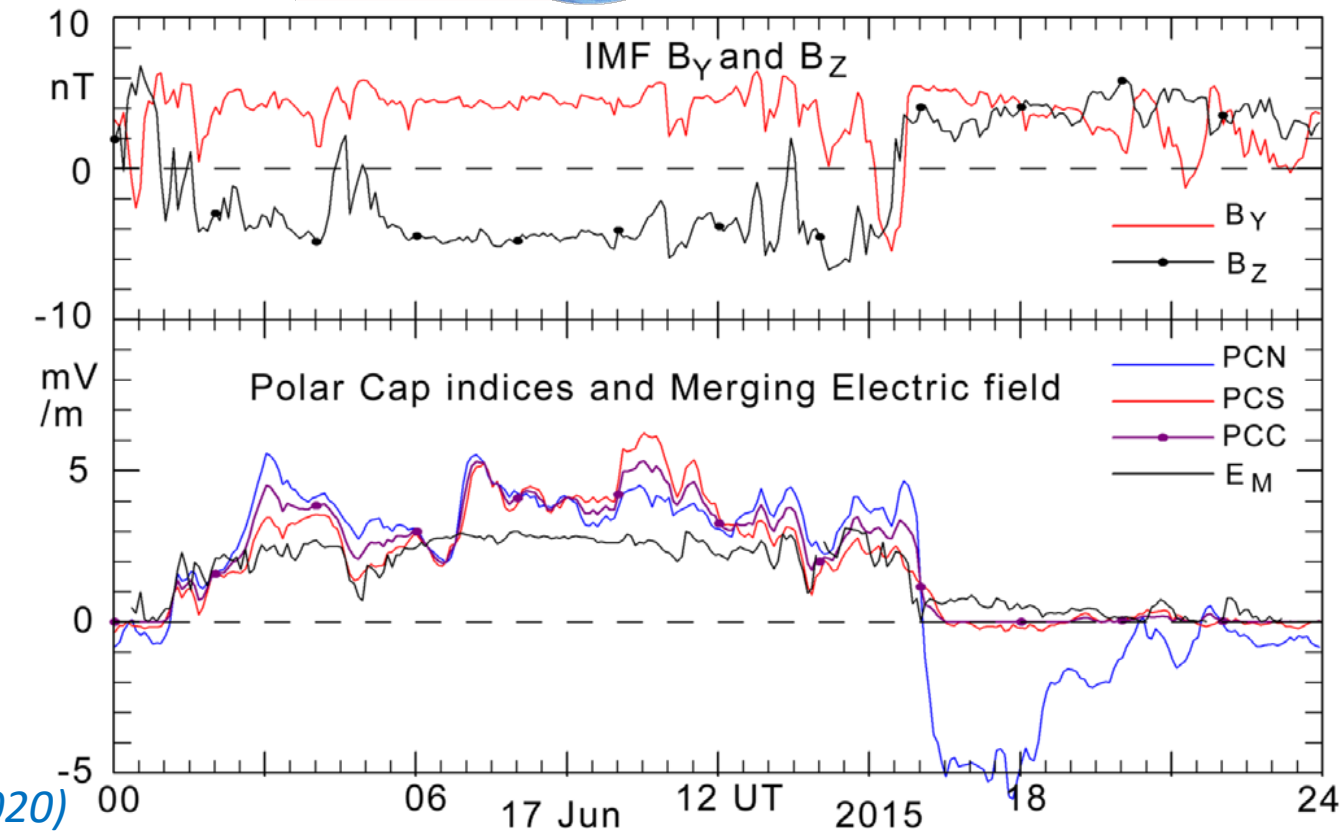
➔ **To monitor the geomagnetic activity over the polar caps caused by changes in the interplanetary magnetic field (IMF) and solar wind, driven by the geoeffective interplanetary electric field irrespective of time, season and solar cycle**

The *PC* index is deduced **from the deviations in the horizontal H and D magnetic field components from the quiet level** at two polar cap stations (Thule and Vostok for respectively the *PCN* and *PCS*).

Derived from 2 polar cap stations.

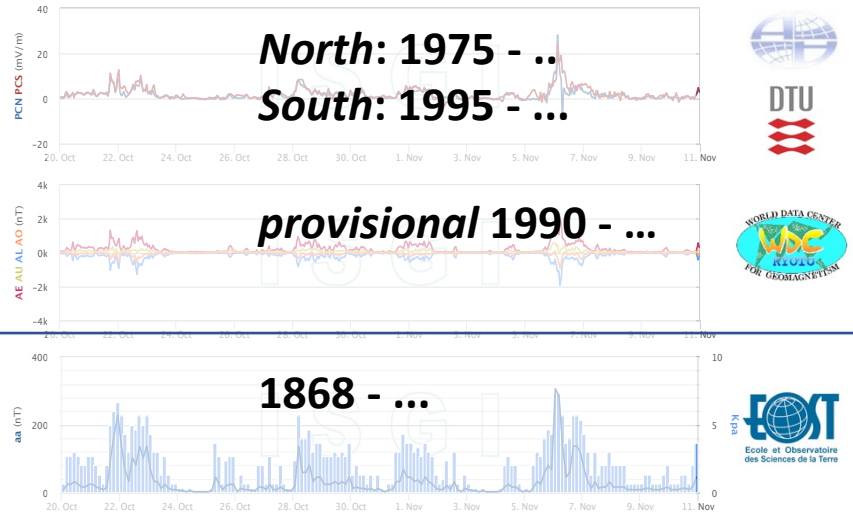


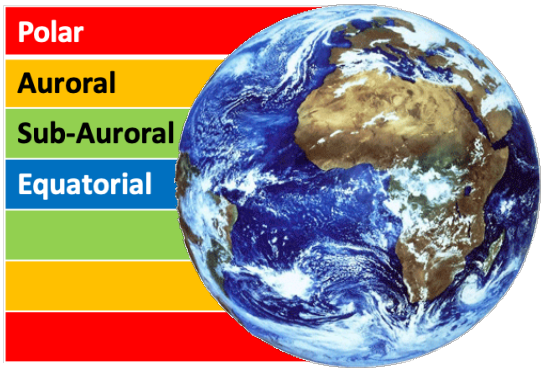




Stauning (2020)

International Service of Geomagnetic Indices





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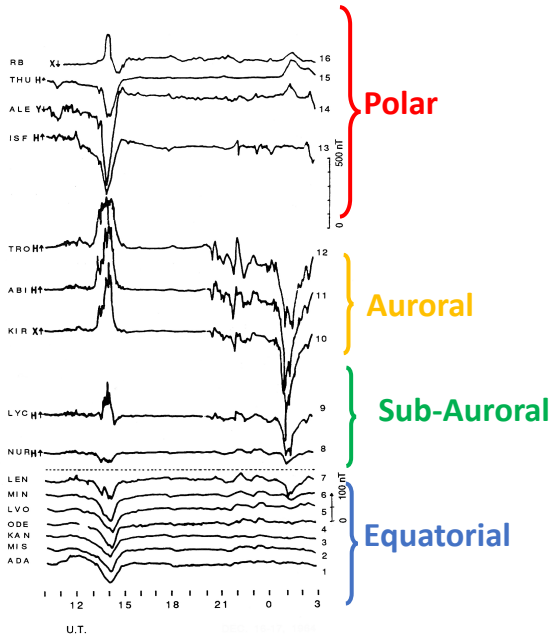
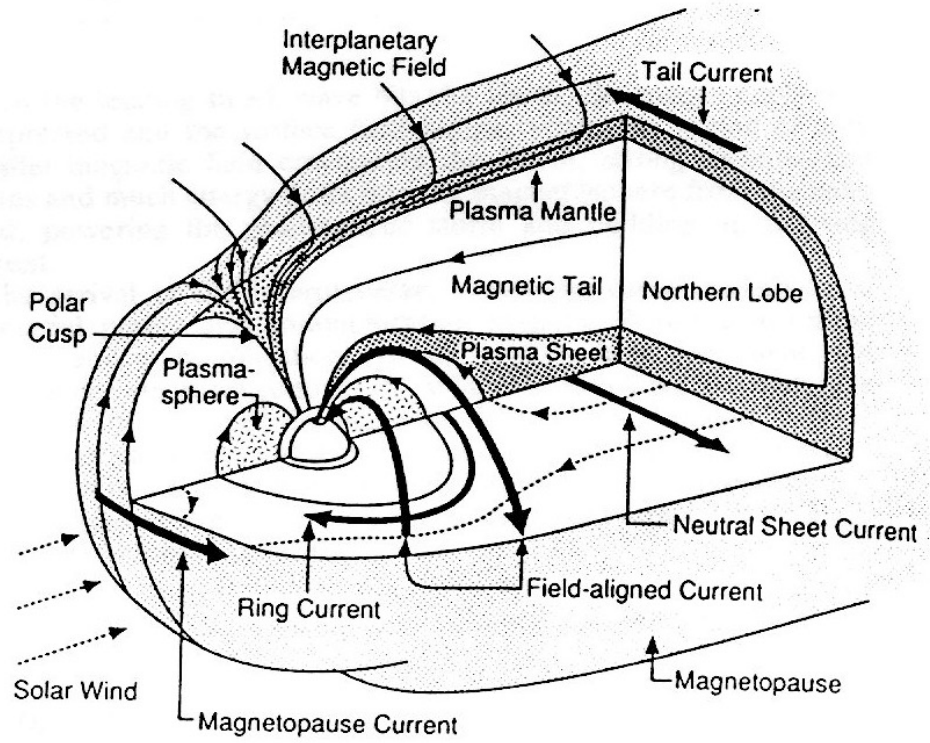
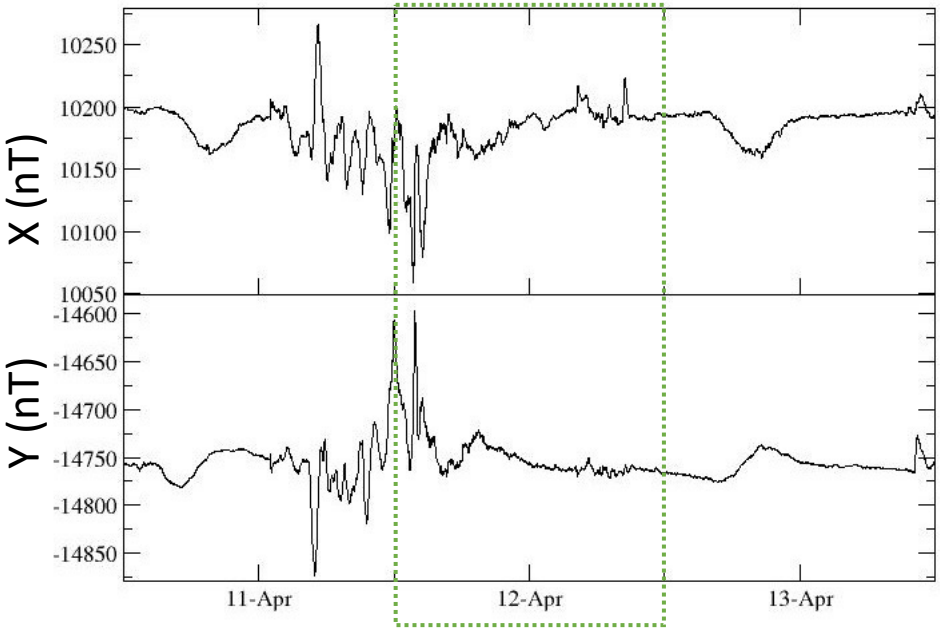




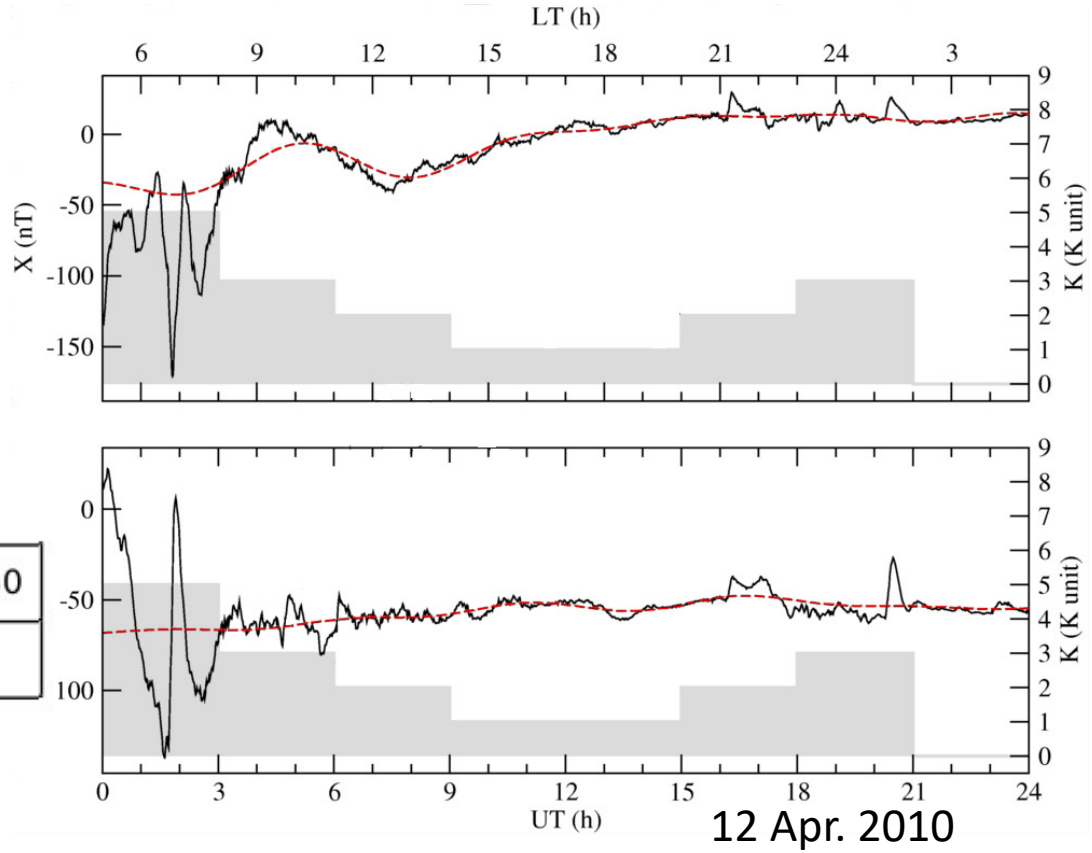
K indices at a station

magnetic field variations at PAF



in 2010

- substract the regular daily variation
  ➔ $\Delta X = X - X_{SR}$ and $\Delta Y = Y - Y_{SR}$
- determine range of irregular variations during 3hUT period
  ➔ max(ΔX, ΔY)
- rank ranges according to limit of classes defined for the station
  ➔ K index



12 Apr. 2010

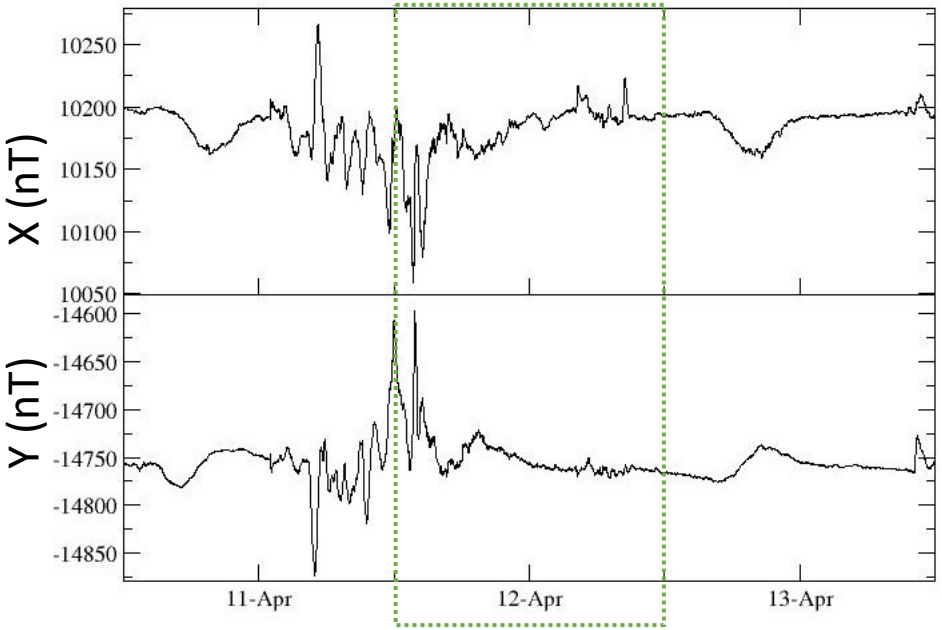
K=9 lower limit is set to 750 nT (e.g.: PAF observatory)

Range (nT)	0	7,5	15	30	60	105	180	300	495	750	>750
K value	0	1	2	3	4	5	6	7	8	9	

ISGI (2014)

K indices at a station

magnetic field variations at PAF



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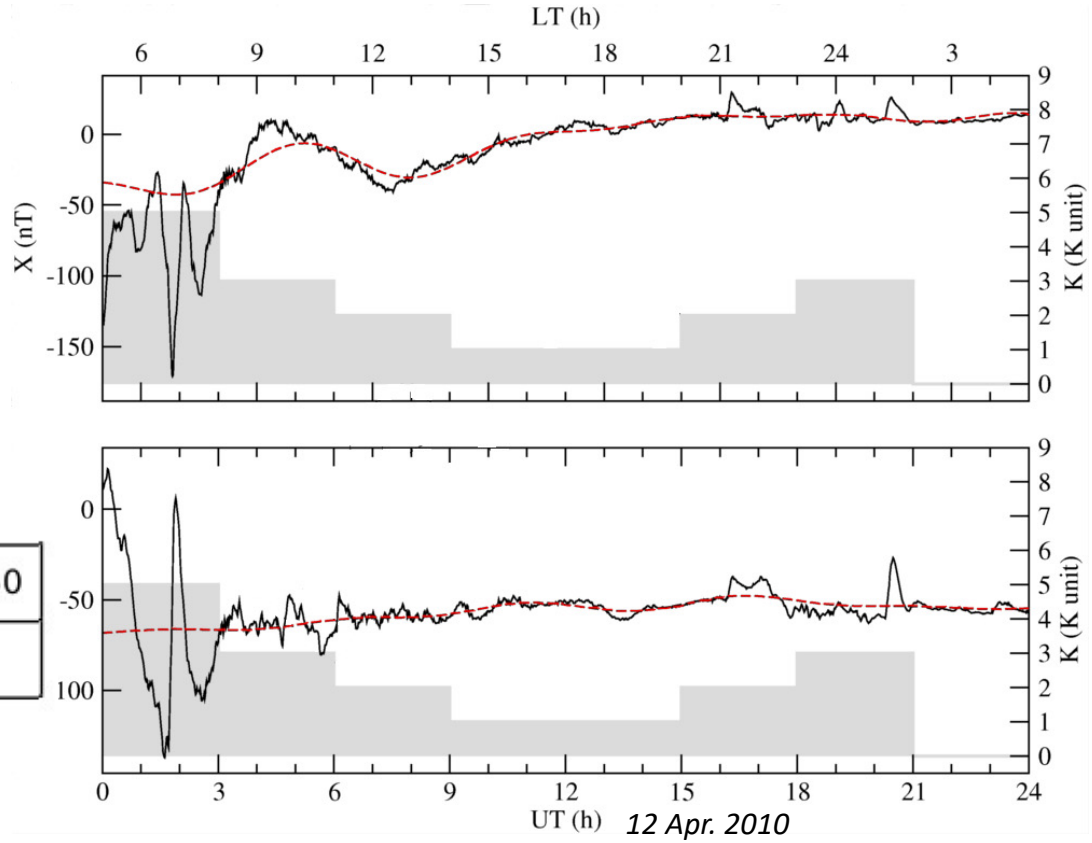

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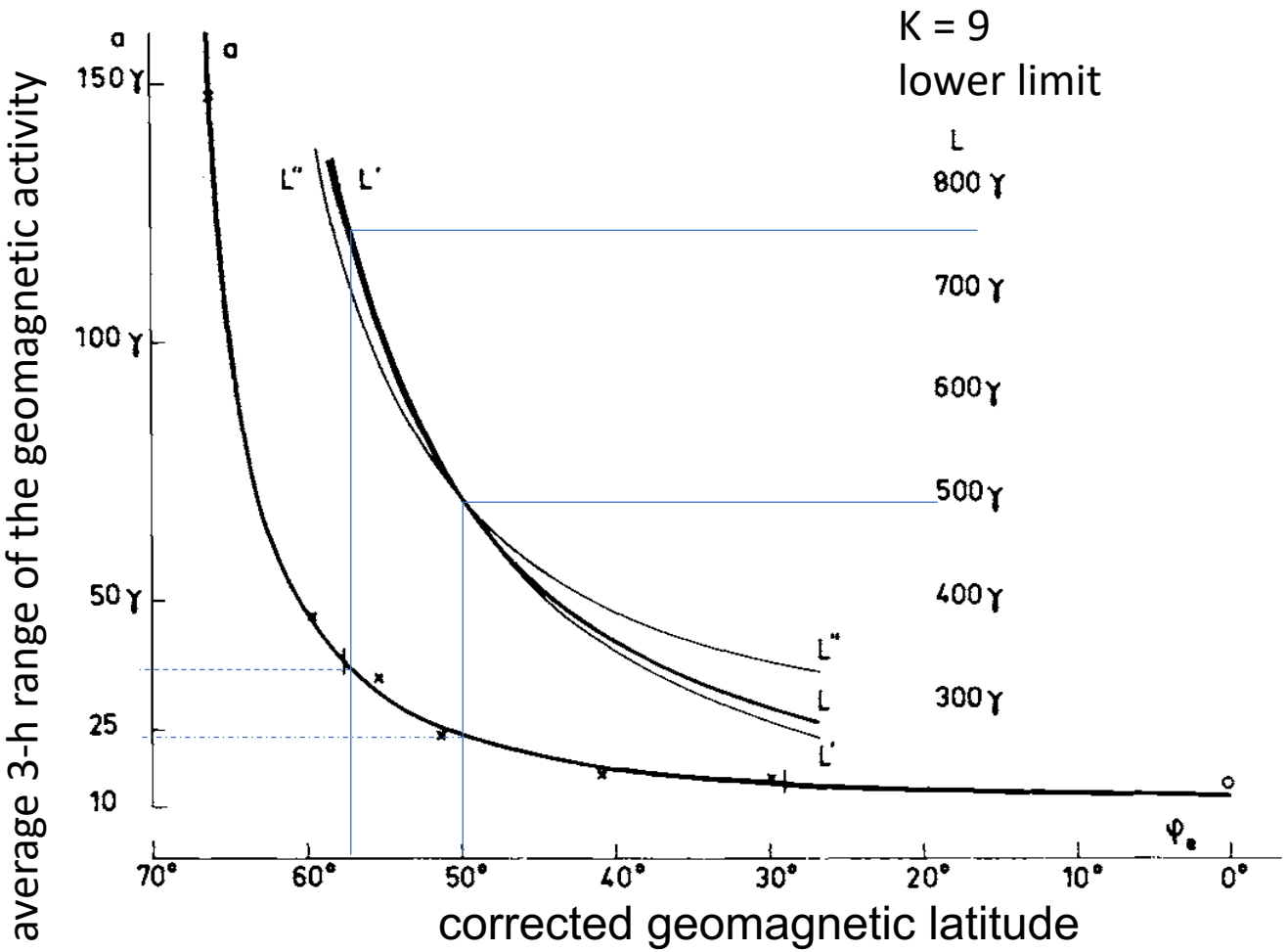
K=9 Lower Limit

ISGI (2014)

K9LL definition



NGK	Θ_{CGM}	= 50°
	δ	= 19°
	L_o	= 500 nT
	s	= L/L_o = 1

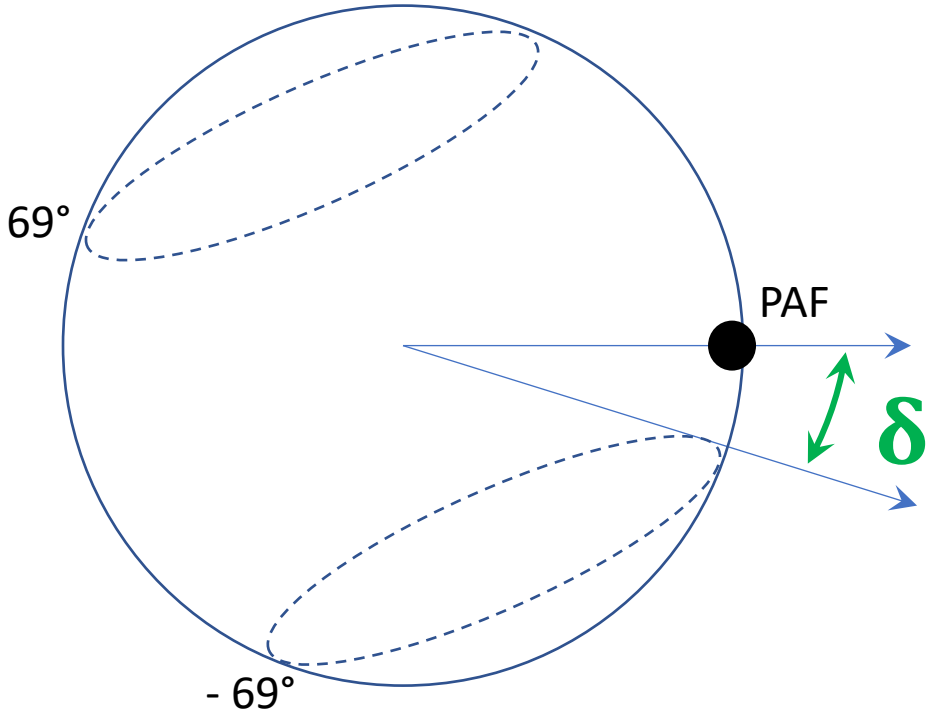
PAF	Θ_{CGM}	= -58.48°
	δ	= 10.52°
	L	= 750 nT
	s	= L/L_o = 1.5

L values are determined directly by the distance to **a nominal oval auroral** (corrected geomagnetic latitude Θ_{CGM} = 69°)

Mayaud (1980)

Each station: (X, Y) mag. Field variations (nT) ➔ max(ΔX, ΔY) ranges (nT) ➔ K

Secular variation of K9LL



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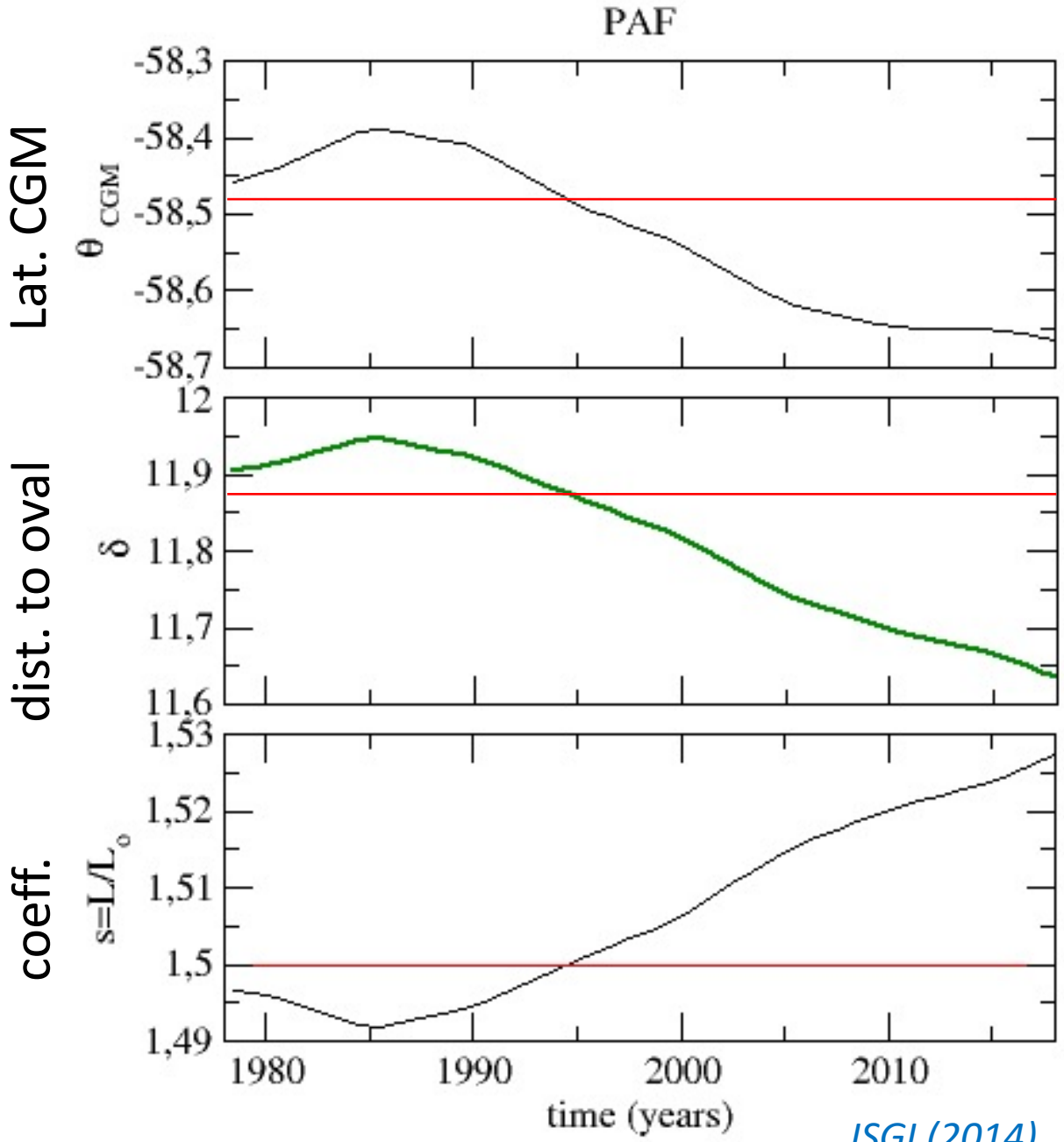


ISGI (2014)

aa geomagnetic index

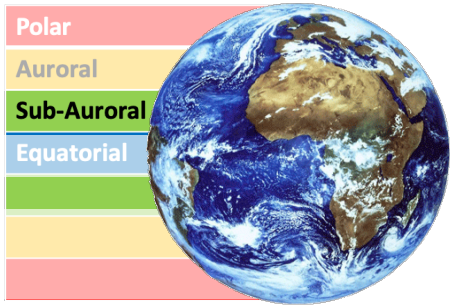
Mayaud (1971)

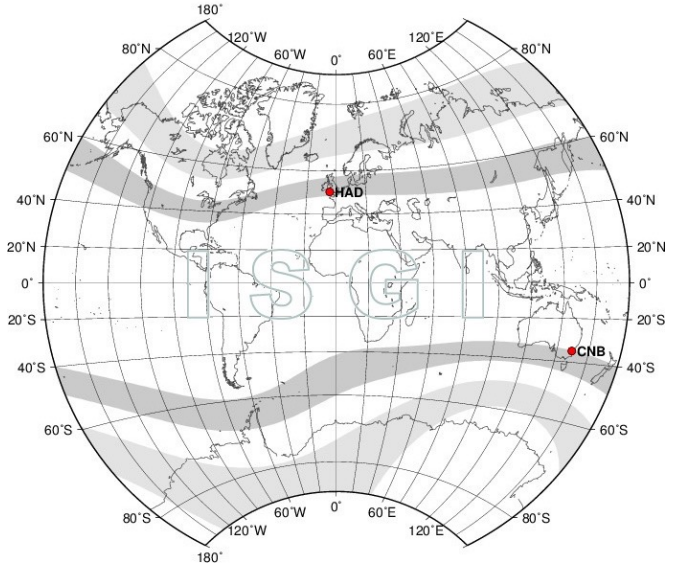
Unit: nT

Time resolution: 3-hourly range index

➔ **To measure the amplitude of global geomagnetic activity normalized to geomagnetic latitude ±50 over the longest possible time period**

Derived from
2 antipodal stations





- Variations of measured magnetic field
- determination of *K* indices
- converted back in mid-class amplitude a_K values
- scaled to take into account
  (i) station changes along time
  (ii) "local induction effects"
- averaged *aa*

Northern hemisphere observatory			*Southern hemisphere observatory*		
period	*observatory*	*weighting factor*	*period*	*observatory*	*weighting factor*
1868-1925	Greenwich	1.007	1868-1919	Melbourne	0.967
1926-1956	Abinger	0.934	1920-1979	Toolangi	1.033
1957-...	Hartland	1.059	1980-...	Canberra	1.084

Conversion table *K* to amplitude for *aa*

Mid-class amplitudes for L9 = 500 nT (L9 being the K=9 lower limit)

K	amplitude (nT)
0	2.3
1	7.3
2	15
3	30
4	55
5	95
6	160
7	265
8	415
9	667

Mayaud, Berthelier & Menvielle

aa geomagnetic index

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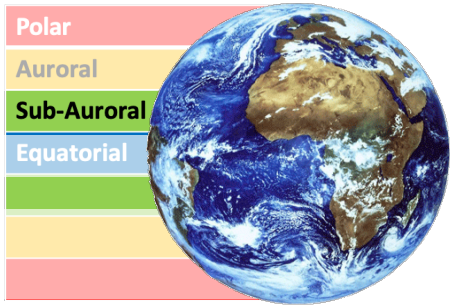

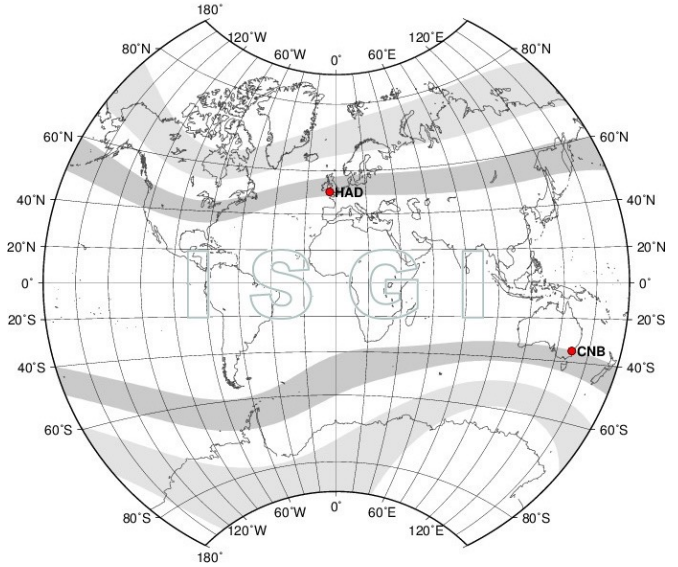

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	667

Known drawbacks:

- secular variation of K indices
- 10 h LT difference
- *[low spatial and temporal resolutions]*

Northern hemisphere observatory					
period	*observatory*	*weighting factor*			
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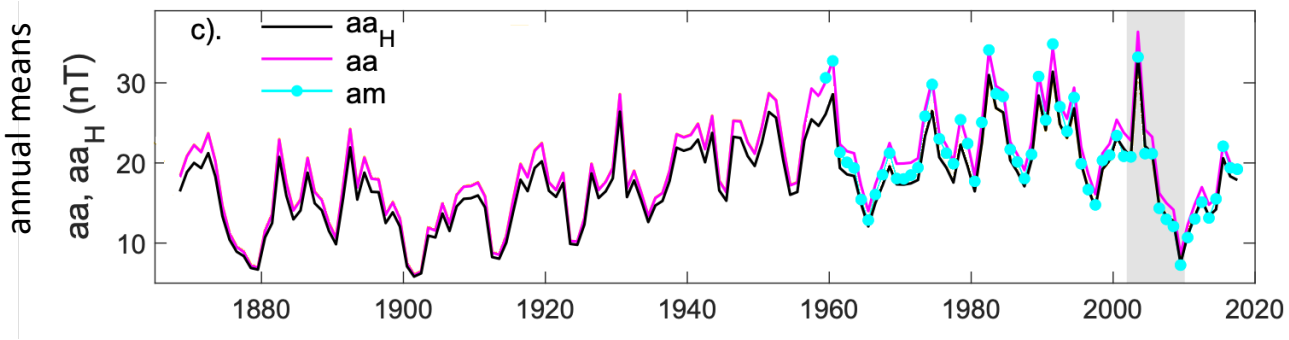
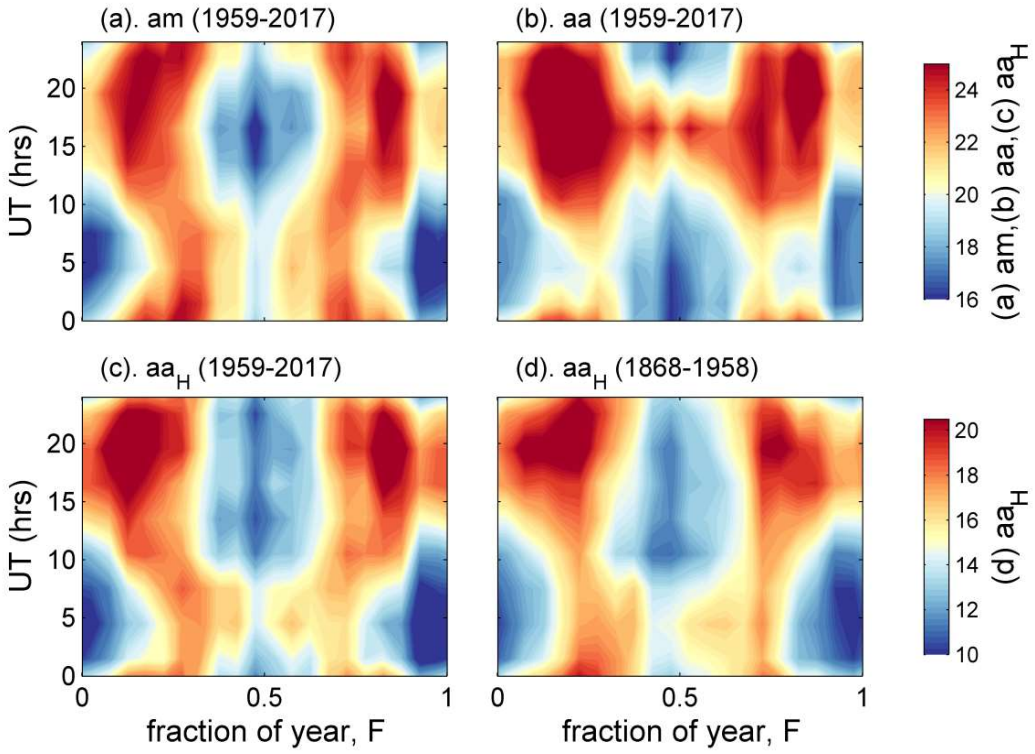
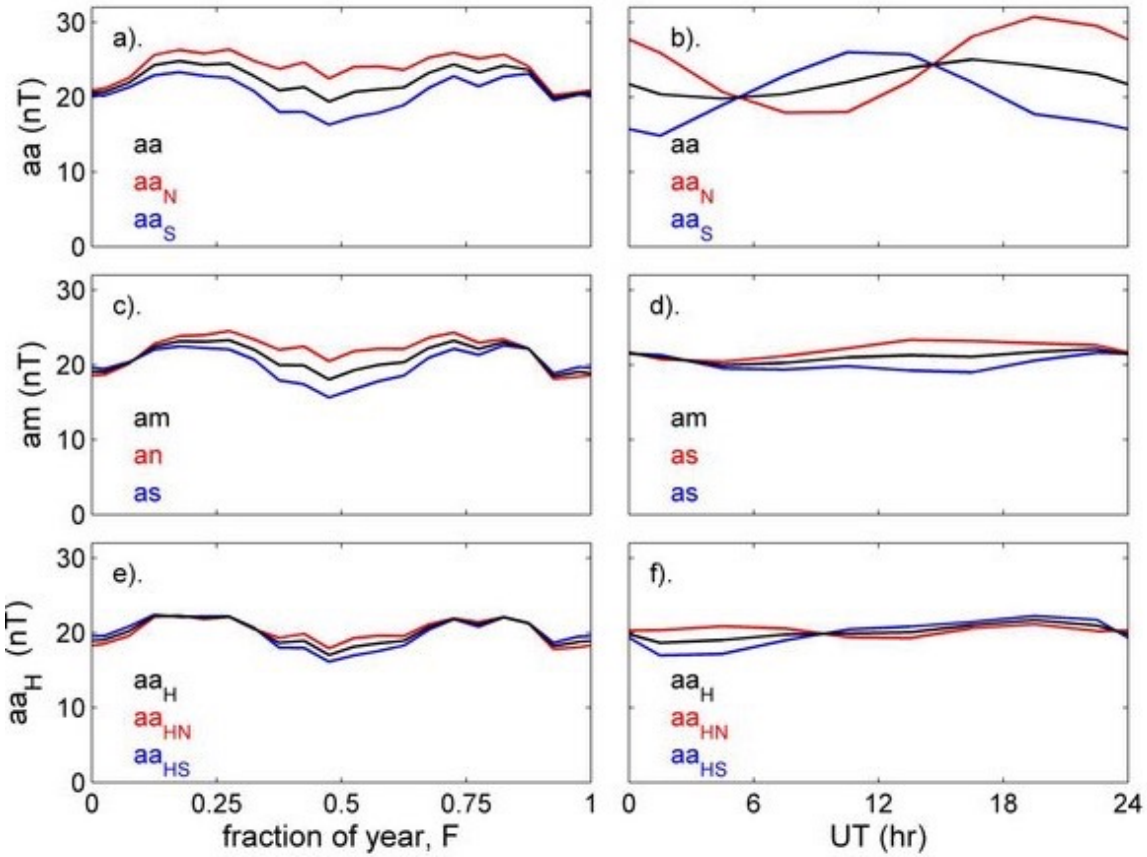
Mayaud, Berthelier & Menvielle

aa geomagnetic index homogeneized





Annual Diurnal



➔ Agreement between the northern and southern hemisphere indices has been improved, in many aspects:

The **equinoctial time-of-day/time-of-year** pattern in the *aaH* index **matches that in *am* (& appears in the aa_{HN} & aa_{HS})**

Lockwood et al. (2018a, 2018b)

am geomagnetic index

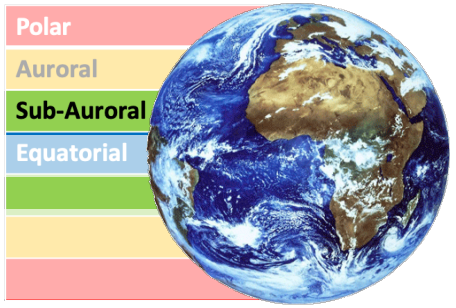
Mayaud (1968)

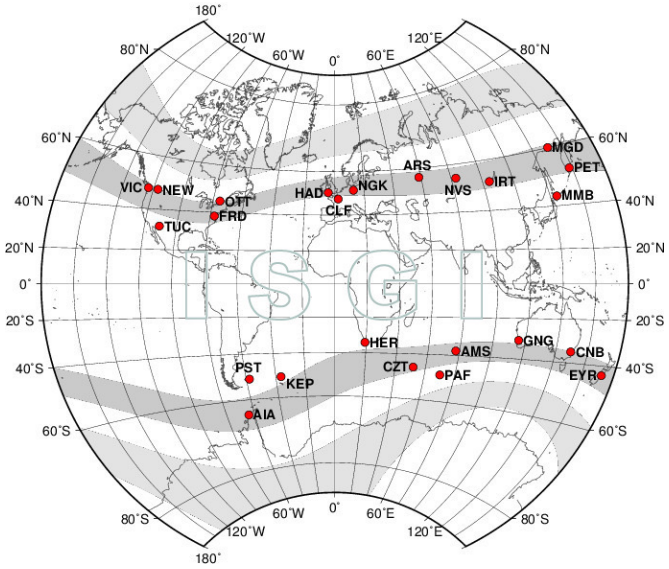
Unit: nT

Time resolution: 3-hourly range index

➔ **To provide a characterization of global geomagnetic activity using a large set of stations representing all longitudes and possible hemispheric discrepancies**

Derived from
5 groups in NH
and 4 groups in SH

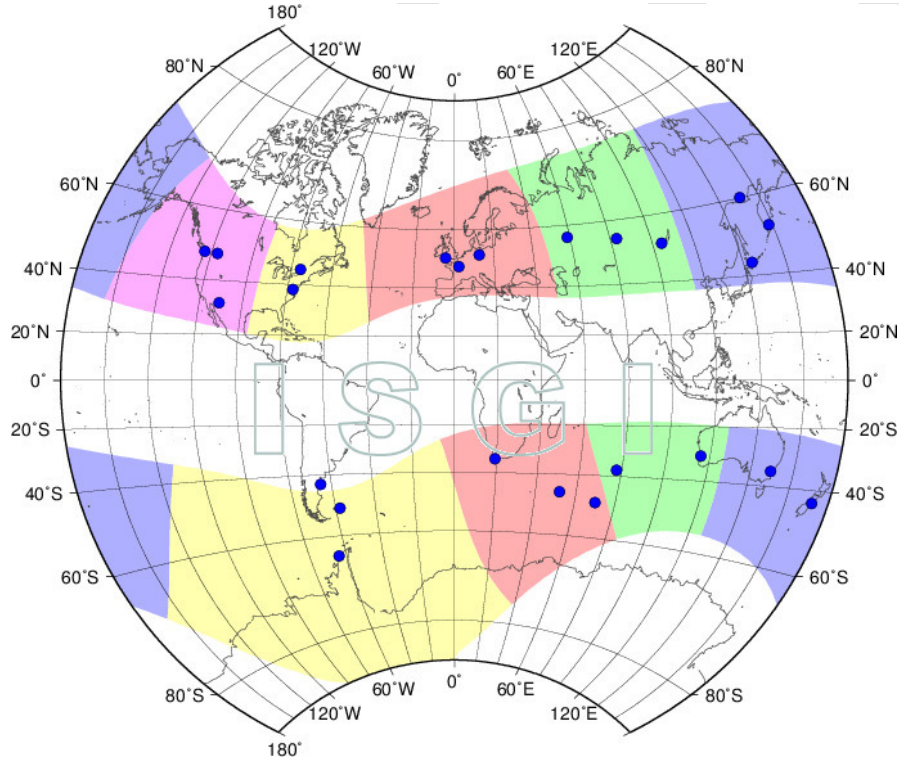




- In each longitude sector, averaged *K* indices (converted into amplitude using mid-class amplitudes)
- In each hemisphere, average with regards to extents of the longitude sector

➔ hemispheric indices *an* (North) and *as* (South

➔ *am* = (*an* + *as*) / 2.



am geomagnetic index

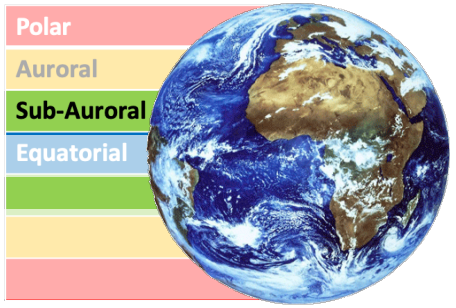
Mayaud (1968)

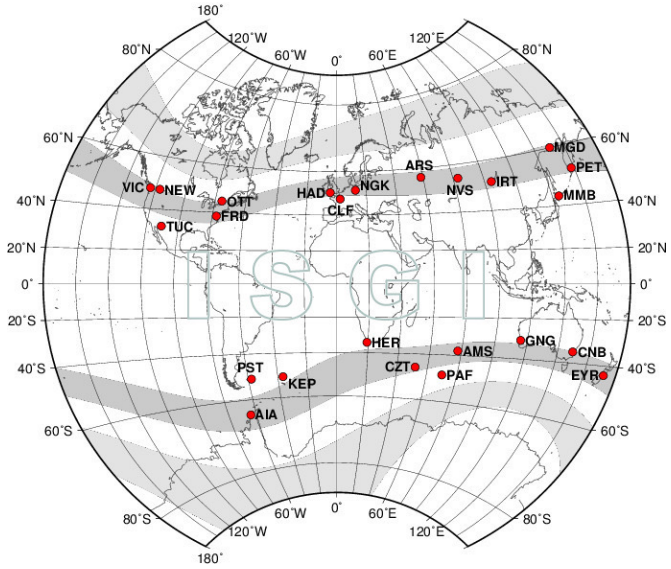
Unit: nT

Time resolution: 3-hourly range index

➔ **To provide a characterization of global geomagnetic activity using a large set of stations representing all longitudes and possible hemispheric discrepancies**

Derived from
5 groups in NH
and 4 groups in SH

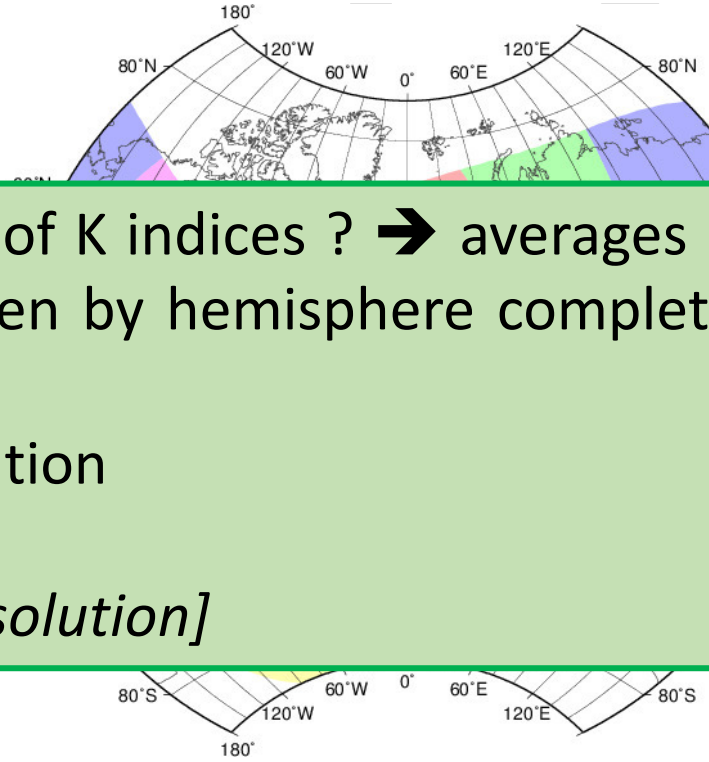




- In each longitude sector, averaged *K* indices (converted into amplitude using mid-class amplitudes)
- In each hemisphere, average with of the longitude sector

➔ hemispheric indices *an* (North) an

➔ *am* = (*an* + *as*) / 2.



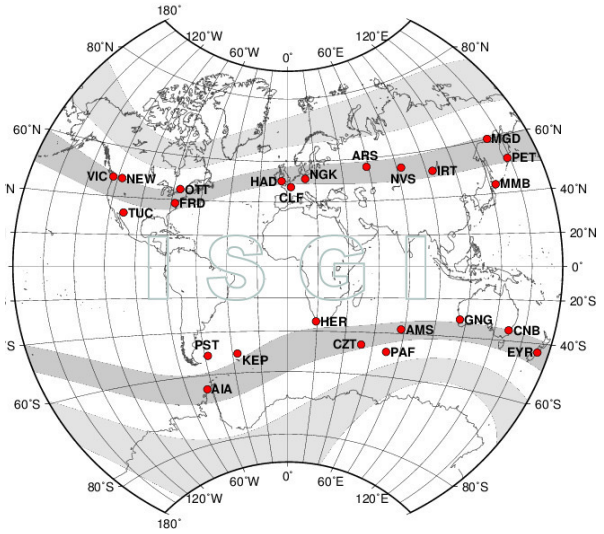
- secular variation of K indices ? ➔ averages by sector of longitude and then by hemisphere completely mitigate this problem
- low spatial resolution

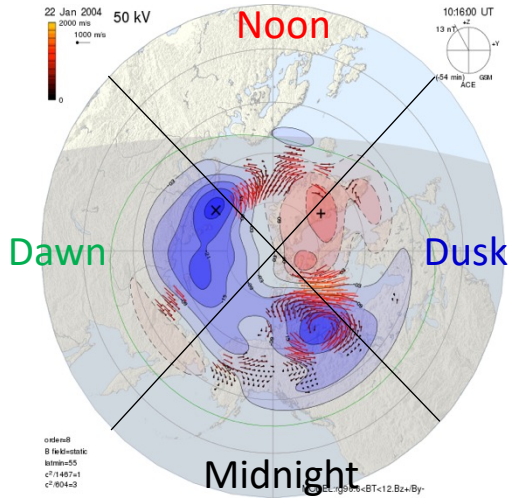
- *[low temporal resolution]*

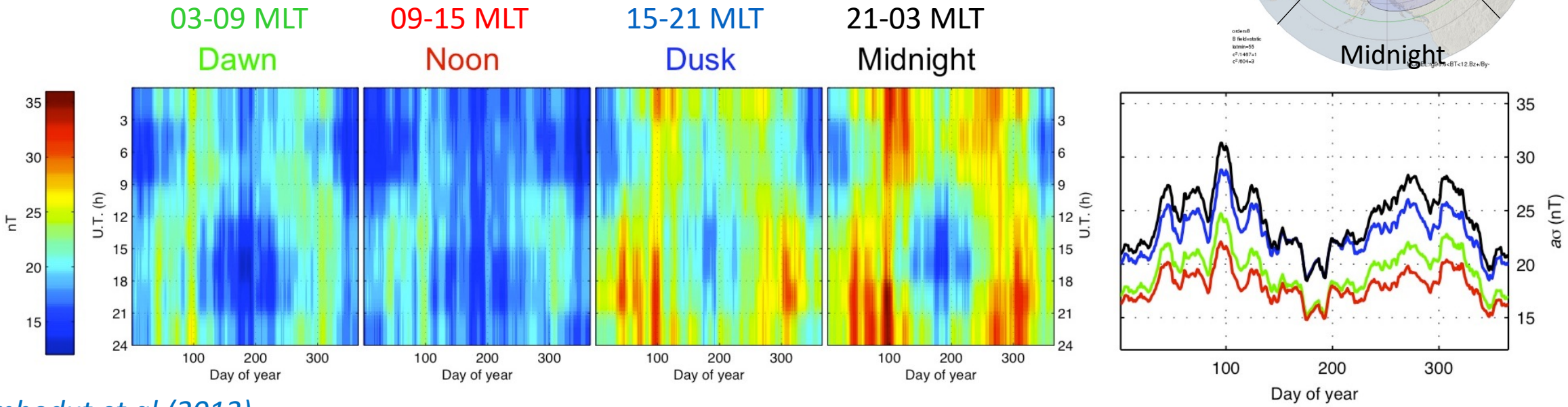
$a\sigma$ *K*-derived MLT-sector indices

- based on *am* network
- from 1959 onwards (over ~6 solar cycles)
- time resolution: 3-hour (UT) interval
- calculated for 4 fixed sectors in MLT

(enhanced spatial resolution compared to am)







Chambodut et al.(2013)

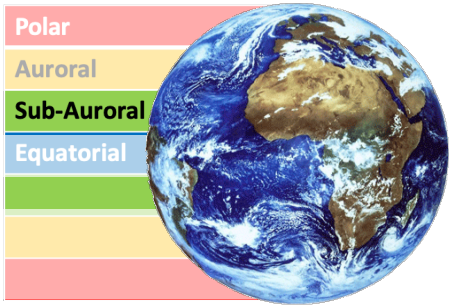
Kp geomagnetic index

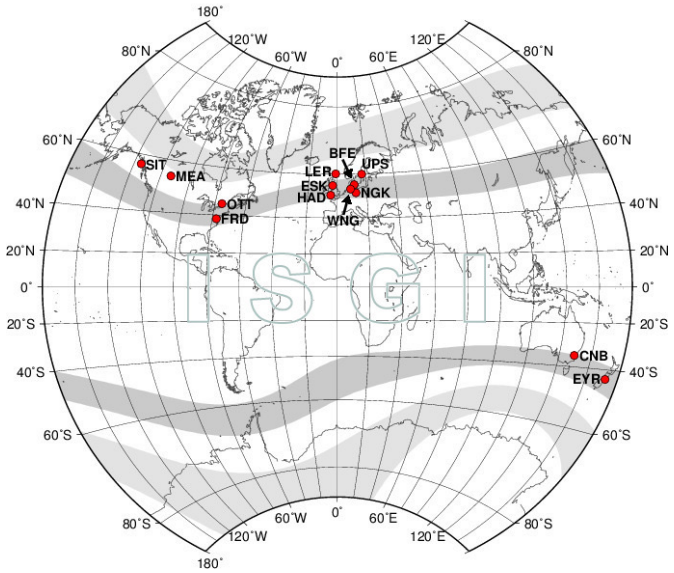
Bartels (1949)

Unit: *K* index
Time resolution: 3-hourly range index

To characterize the intensity of geomagnetic activity on a planetary scale (however because of the historical context at the time of its creation, the *Kp* network **is heavily weighted towards Europe and Northern America**).

Derived from
11 northern and
2 southern stations





Kp is the arithmetic mean of the standardised *K*-indices for the 13 observatories.

The standardisation is carried out using **standardisation tables** (for each observatory) defined by Bartels (1949).

These tables aim to eliminate UT and seasonal variations in geomagnetic disturbances.

Example: standardisation tables of Meanook obs. (MEA)

	JFND									MASO									MJJA								
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	7	5	3	3	4	4	5	6	5	5	3	3	3	3	3	3	2	3	3	3	3	2	2	2	2	3	3
2	10	8	5	5	7	8	9	10	8	8	5	5	6	7	8	8	6	6	5	5	6	6	7	6	6	6	5
3	12	10	7	7	9	10	13	13	11	10	7	7	9	11	13	12	9	8	7	7	8	10	12	10	9	8	7
4	15	13	9	9	11	13	16	16	14	12	9	9	11	14	17	16	12	11	9	9	10	14	17	14	12	11	9
5	18	16	12	11	13	16	19	20	16	14	11	11	13	17	21	20	15	13	10	10	13	17	21	18	15	13	10
6	21	19	15	13	16	19	22	24	20	18	14	14	15	20	24	23	19	16	13	13	16	20	24	22	19	16	13
7	24	22	19	18	19	22	25	25	25	22	18	18	19	22	25	25	25	19	18	18	20	25	25	25	25	19	18
8	26	25	23	23	24	25	26	26	26	26	25	24	25	25	26	26	26	25	25	24	25	26	26	26	26	25	25
9	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27

Winter solstice
Jan., Feb., Nov. and Dec.

Equinoxes
Mar., Apr., Sep. and Oct.

Summer solstice
May, Jun., Jul. and Aug.

Kp geomagnetic index

Bartels (1949)

Unit: K index
Time resolution: 3-hourly range index

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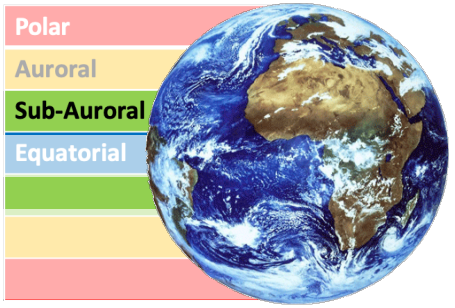
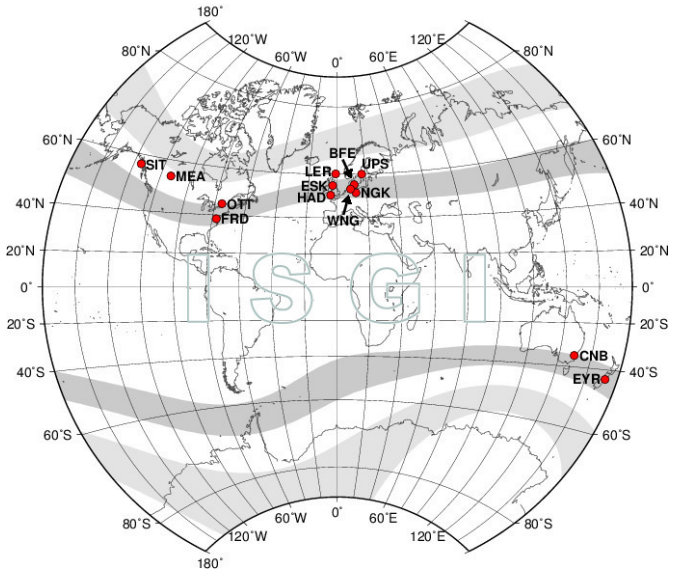




Kp is the arithmetic mean of the standardised K-indices for the 13 observatories.

The standardisatic
standardisation
observatory) defin

These tables aim to eliminate UT and seasonal variations in geomagnetic disturbances.

Example: standardisation tables of Meanook obs. (MEA)

- low temporal resolution
- *[secular variation of K indices and frozen standardisation tables]*
- *[low spatial resolution]*

9	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27

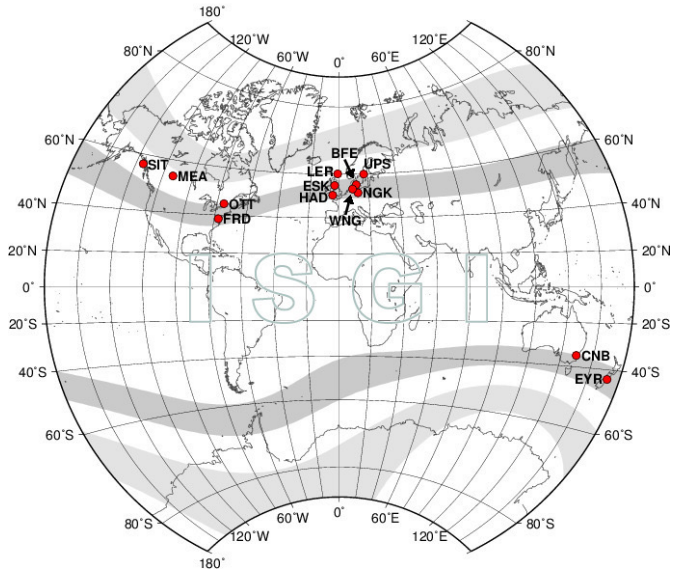
Winter solstice
Jan., Feb., Nov. and Dec.

Equinoxes
Mar., Apr., Sep. and Oct.

Summer solstice
May, Jun., Jul. and Aug.

Hpo geomagnetic index

- based on *Kp* network
- from 1995 onwards
- time resolution: 30 minutes and 1 hour



Exact same scheme as the Kp derivation, only the definition of H class lower limits are adapted to get open-ended indices

Table 1. Lower limits of H30, H60 and K for the Niemegk observatory.

Index	0	1	2	3	4	5	6	7	8	9
H30 (nT)	0	2.16	4.46	8.89	17.9	33.9	65.7	119	190	267
H60 (nT)	0	2.97	6.11	12.1	24.3	44.7	82.7	144	218	337
K (nT)	0	5.00	10.0	20.0	40.0	70.0	120	200	330	500

10	**11**	**12**	**13**	**etc**
360	469	562	675	...
455	591	710	852	...

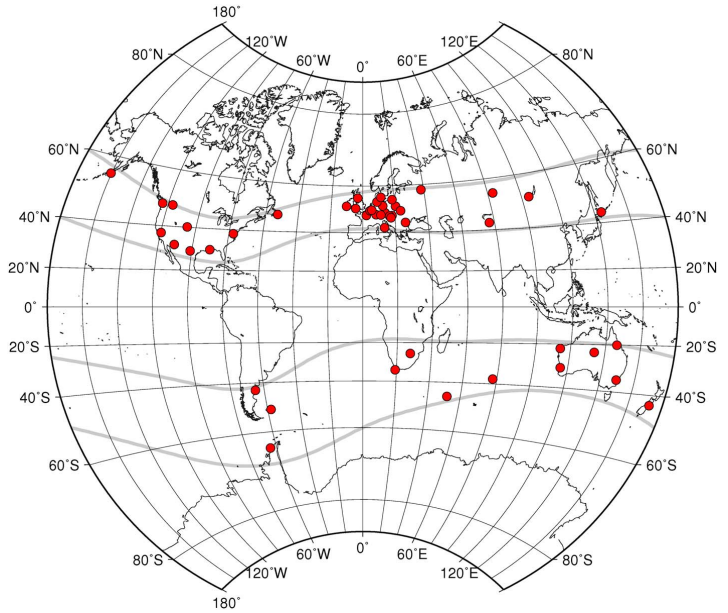
x 1.35 x 1.30 x 1.20 x 1.20 x 1.20 etc

Yamazaki et al. (2022)

Development of new indices

an example: α indices

- based on ***adaptative*** **network**
- from 1991 onwards (over > 2 solar cycles)
- time resolution: 15 minutes

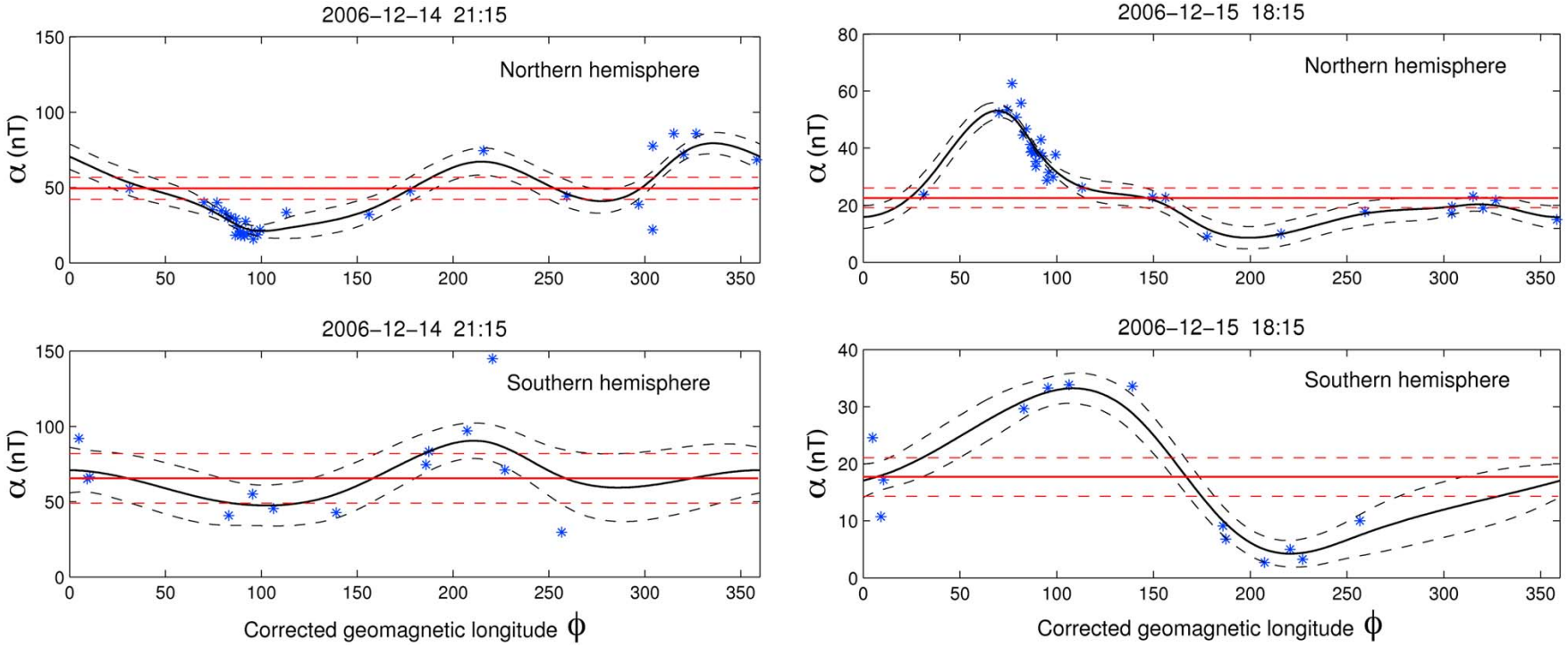


➢ not *K*-derived but based on:

$$\Delta H(t) = \sqrt{(\Delta X(t))^2 + (\Delta Y(t))^2},$$

$$\Delta H_{15}(t) = \frac{1}{15} \sum_{i=1}^{15} \Delta H(t + i - 8).$$

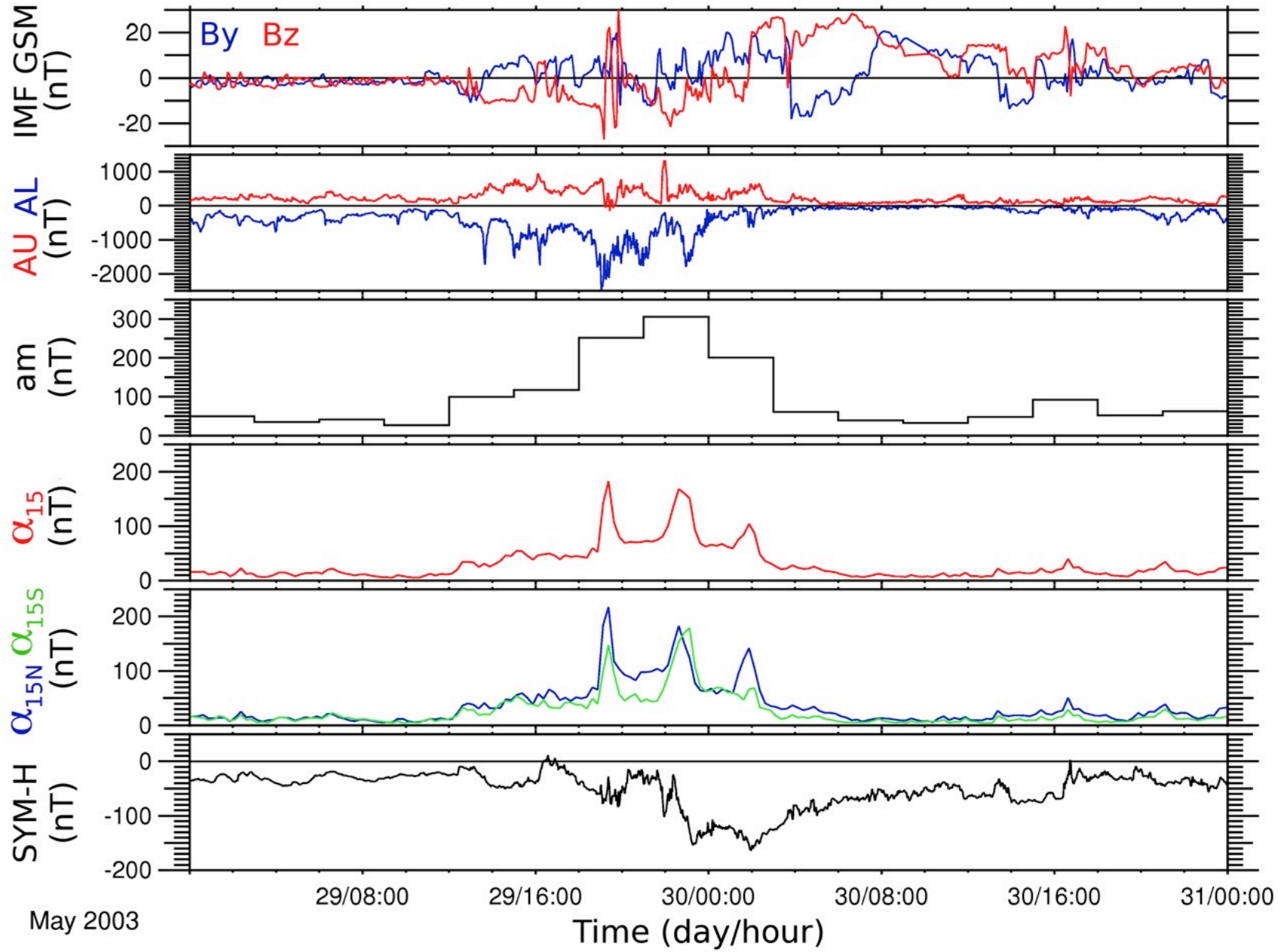
Chambodut *et al.*(2015)



Development of new indices

an example:

α indices



Take home message and conclusion

IAGA-endorsed geomagnetic activity indices constitute unique data series of tremendous importance for all our understanding of the Earth system.

BUT IAGA-endorsed geomagnetic Indices were developed during other time, under specific societal and technological conditions.

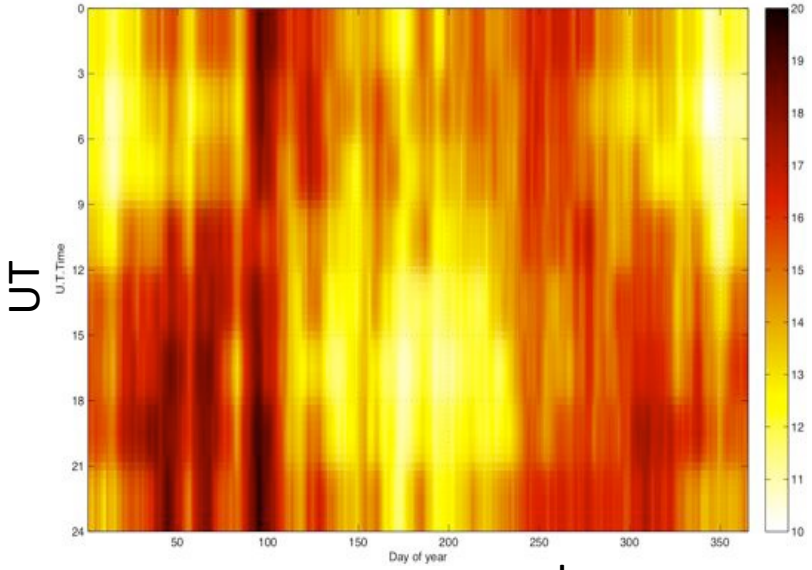
IAGA-endorsed geomagnetic Indices were developed **to fit a purpose.**
(There are index criteria for endorsement of indices by IAGA and a strict process to follow.)

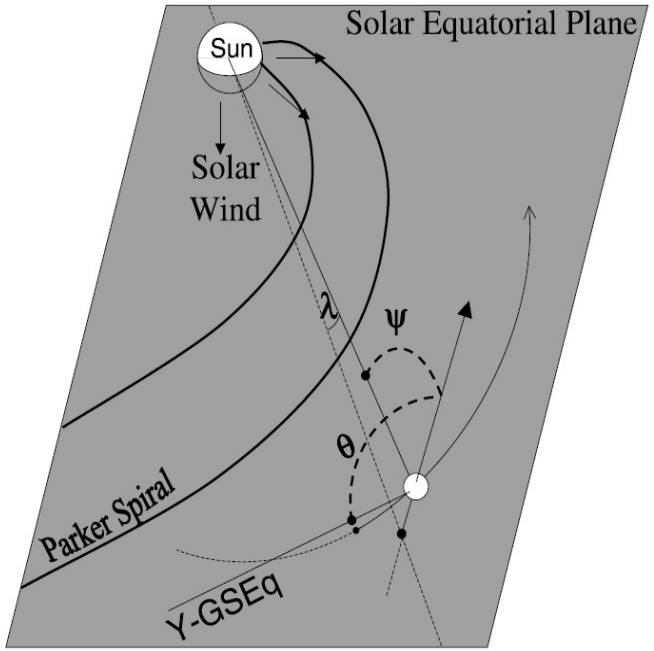
Nowadays there are two aspects of development among the research group federated around ISGI:

- **to expose possible mitigations of historical indices' drawbacks**
- to develop new, high spatial and temporal resolution, geomagnetic activity indices

Seasonal and diurnal variation of *am*

- maximum close to the equinoxes;
- minimum close to solstices (around 06:00 UT for December solstice and 18:00 UT for June solstice);
- complex pattern of Earth's magnetic activity clearly identified in statistical studies of planetary indices such as *am*.





From O'Brien and McPherron, 2002

possible effects ? :

- Axial effect
  - varying heliographic latitude λ of the Earth along the course of a year
  - displays seasonal but not diurnal variations
- Russell-McPherron effect
  - varying angle θ of the Earth's dipole in the plane perpendicular to the Earth-Sun line
  - displays seasonal and diurnal variations
- Equinoctial effect
  - varying the magnetic colatitude ψ of the subsolar point
  - reproduce very well the complex seasonal/diurnal pattern of Earth's magnetic activity