# ON THE USE OF MAGNETIC INDICES FOR GEOPHYSICS STUDIES

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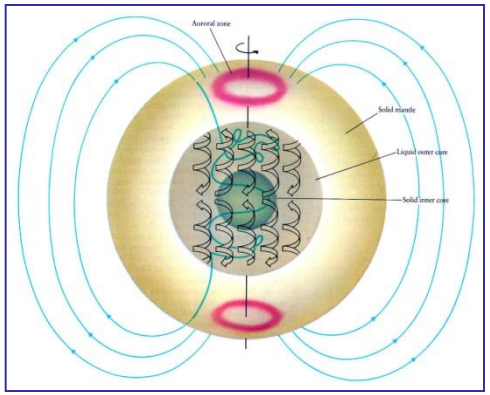
## 4 DYNAMOS IN

**SUN**
**poloidal /toroidal**

**MAGNETOSPHERE**
**Solar wind**
**IMF**

**IONOSPHERE**
**Earth's magnetic field**
**Neutral wind**

**EARTH**
**Motions of the core**

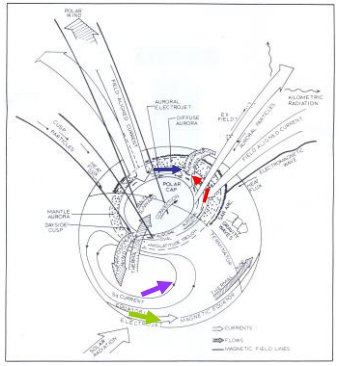



## CURRENT SYSTEMS

**MAGNETOSPHERE**
**Chapman Ferraro**
**Ring current**
**Tail current**

**FIELD ALIGNED**

**IONOSPHERE**
**Auroral electrojets**
**Midlatitude currents**
**Equatorial electrojet**

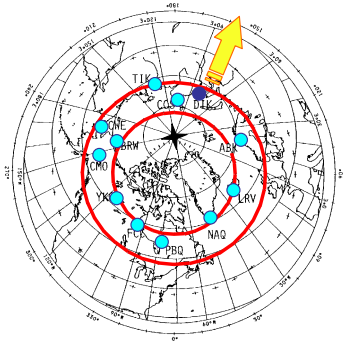


## EARTH's MAGNETIC FIELD -> Transient variations

**Indices -> disturbances**
**Dst,**
**Aa, Kp, Ap**
**Km, Am**
**AU, AL**

**Equivalent currents**

**DP1, DP2,Ddyn**
**$S_R$ <Sq>, $Sq^P$**



# OUTLINES

## WHY MAGNETIC INDICES ?

- THE CONCEPT OF MAGNETIC INDICES
  - K index, $S_R$
- USE OF MAGNETIC INDICES FOR GEOPHYSICS STUDIES
- Kp(ap)/ Km (am)
  - to select quiet days
  - to approach solar wind components
- Aa index
  - signature of the 2 components of the solar magnetic field
  - long term variation of solar activity
  - physics of solar-geomagnetism activity
- Storm Dst index
- Auroral indices AU and AL
  - Electrodynamics high-low latitudes coupling
    - To select some simple case of disturbance dynamo

# WHY MAGNETIC INDICES:
# TO APPROACH A COMPLEX REALITY

## MAGNETIC INDICES ARE PROXIES
## MAGNETIC INDICES ARE COMPLEMENTARY

# EARTH ‘S MAGNETIC FIELD

$$B = B_p + B_a + B_e + B_i$$

main aimantation external induction

INTERNAL SOURCES

EXTERNAL SOURCES

**B = Bp + Ba + Be + Bi**

**Bp = main field**
**(30000-60000nT)**
**Ba = magnetization of the rocks in the Lithosphere**
**(~ 10-20 nT)**
**Be = external field related to Ionosphere and magnetosphere**
**(10nT to 2000nT)**
**Bi = induced field generated by the external field Be , (Kamide and Brekke, 1975)**
**(% of Be)**

**The disturbed D variation is the sum of the effects of the various electric current systems (Cole, 1966)**

**D = DCF + DR + DT + DI + DG**

**DCF : magnetic disturbance due to the Chapman Ferraro current**
**(~ qq nT to 30 nT)**
**DR : magnetic disturbance due to the ring current**
**(~ qqnT to ~ 600nT)**
**DT : magnetic disturbance due to the Tail currents**
**(~ qq nT to 20 nT)**
**DI : magnetic disturbance due to the ionospheric disturbed electric current**
**(~qq nT to 2000 nT)**
**DG : magnetic disturbance due to electric currents flowing in the ground related to external electric current systems (~30 %)**

# MAGNETIC INDICES

## Transient variations of the Earth's Magnetic field

## TRANSIENT VARIATIONS

$[\Delta Bp \sim + \Delta Ba \sim 0]$

$\Delta B \sim \Delta(Be + Bi)$ [Bi ~ % Be]

**External sources**

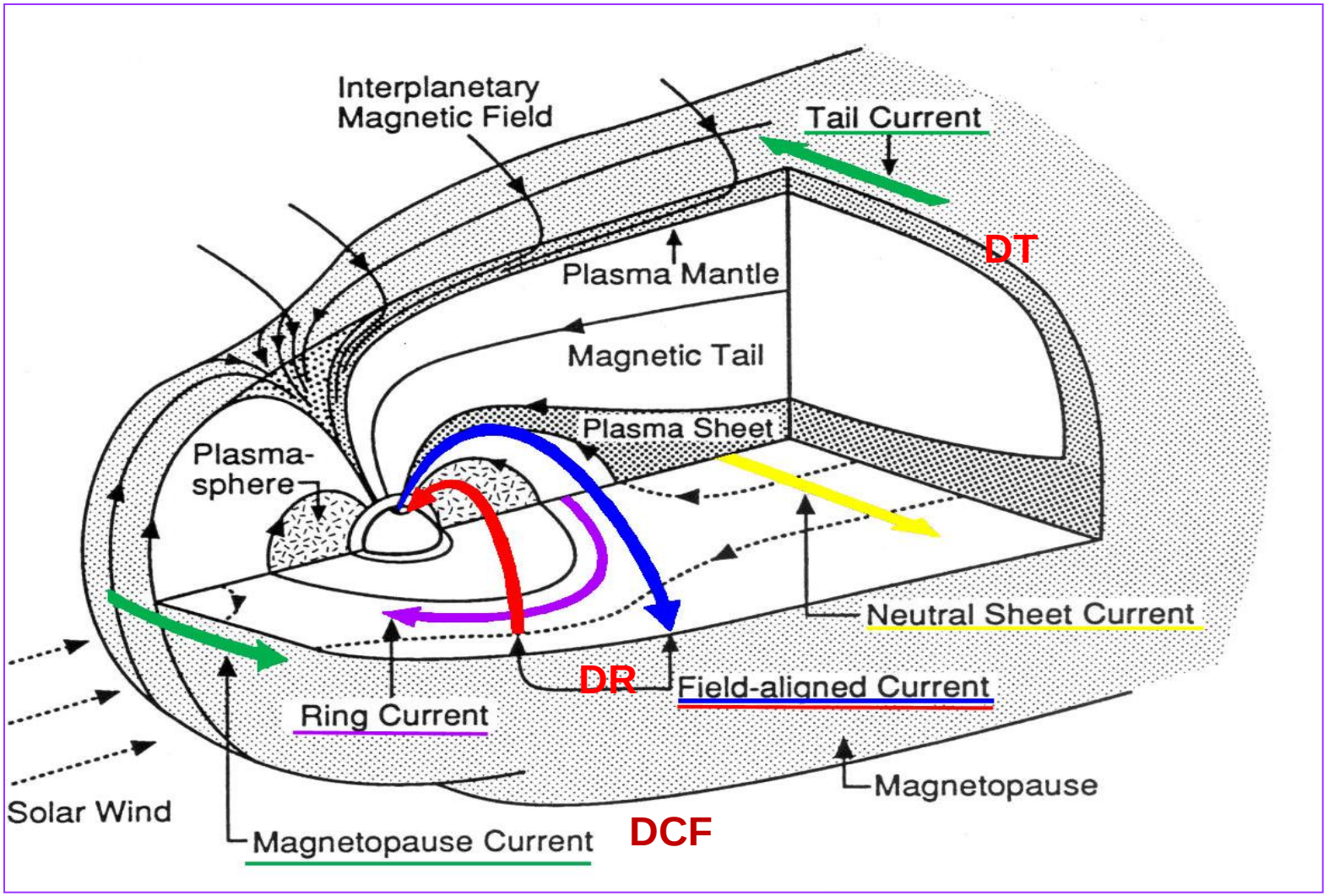
$\Delta B \sim S_R$ (Sq) + D (Sd)

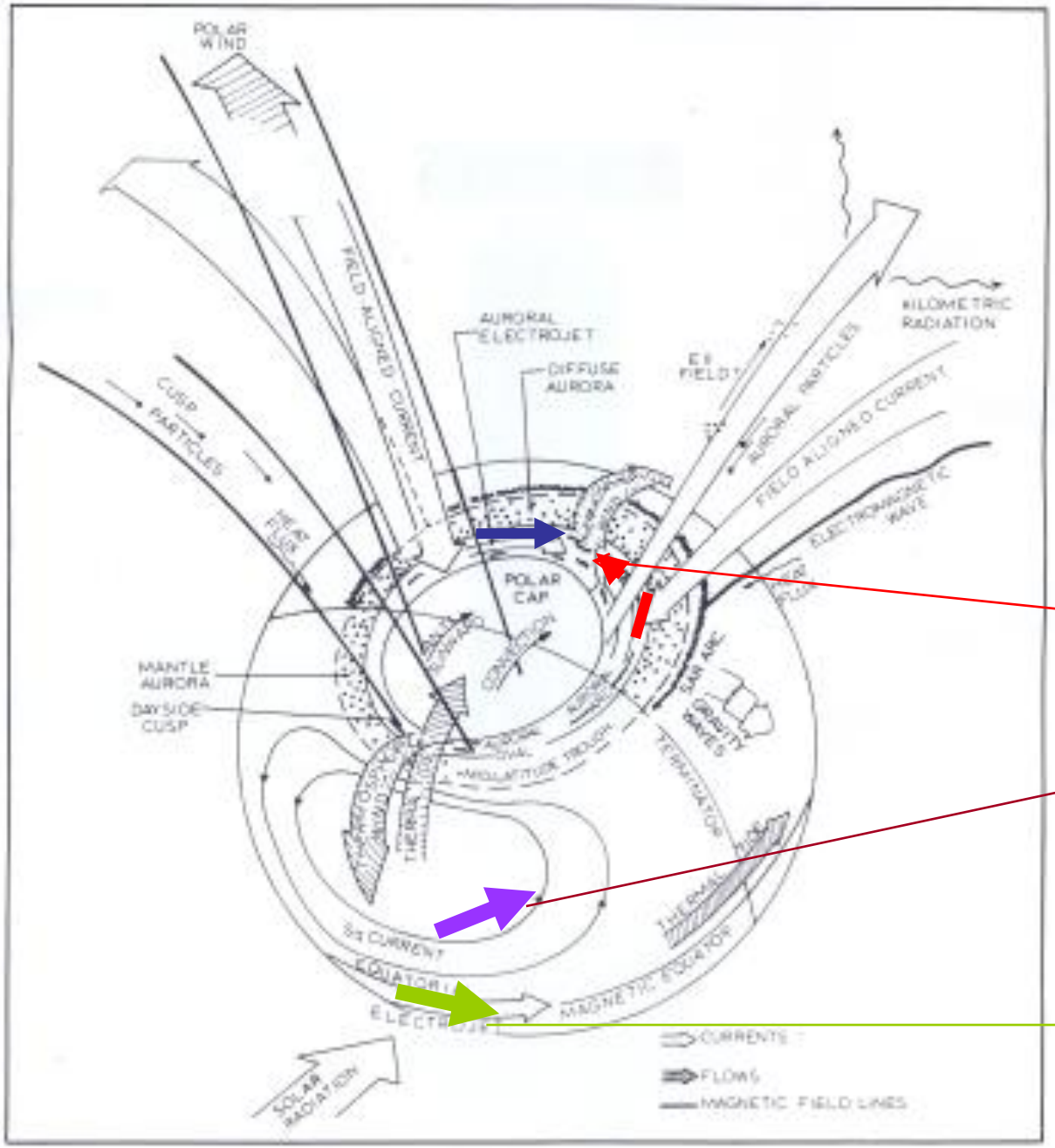
regular/quiet + irregular/disturbed

D = D (Magnetosphere) + D (Ionosphere) + D induction

DCF + DT + DR + DI + DG

# MAGNETOSPHERE
# DCF + DT + DR






**Low latitude dayside IONOSPHERE DI**

**DI = DP2 + $D_{dyn}$**

Auroral

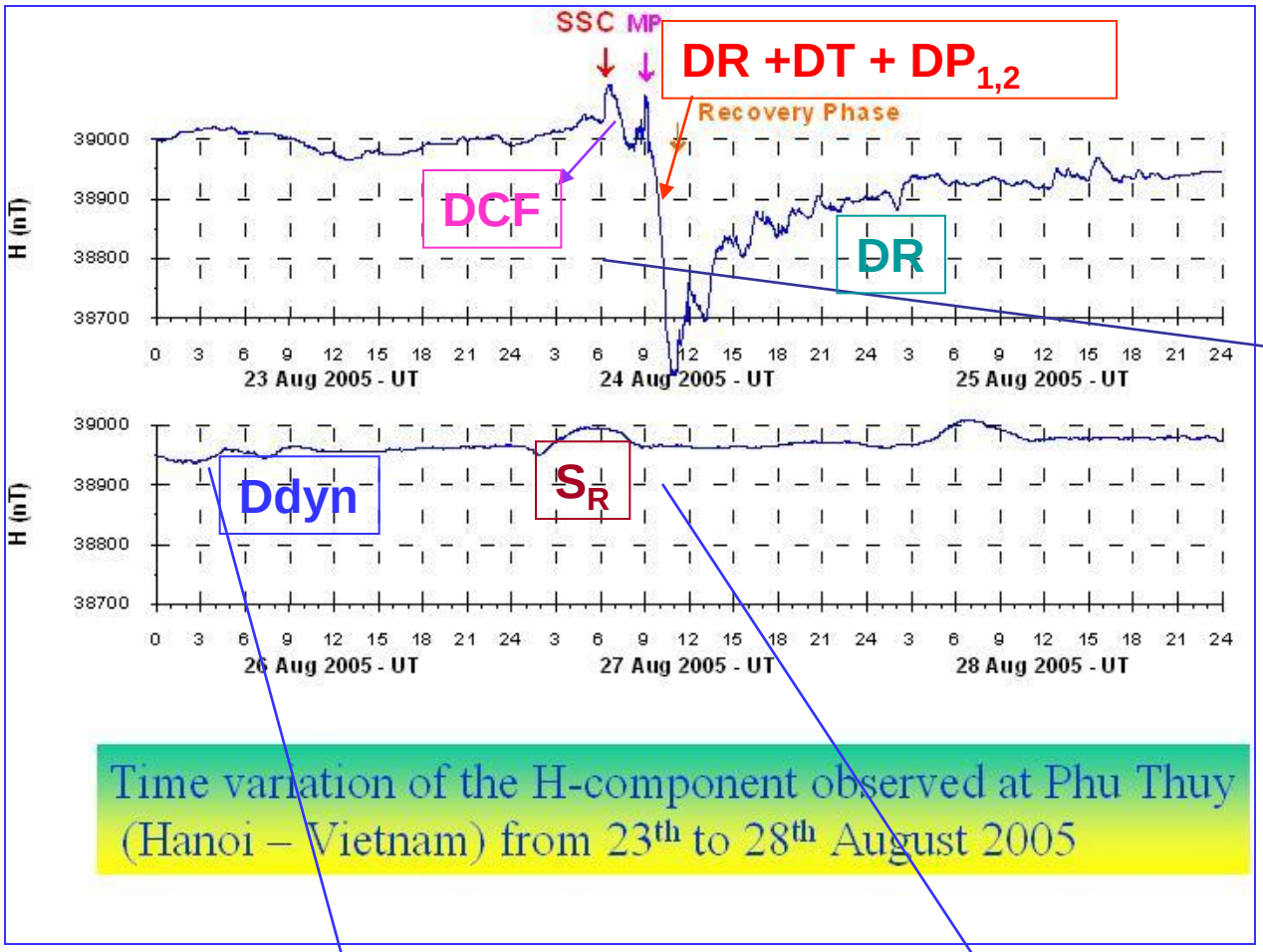
Auroral electrojets

Middle latitudes

**$Sq/S_R$**

Equatorial latitudes

Equatorial electrojet




Time variation of the H-component observed at Phu Thuy (Hanoi – Vietnam) from 23th to 28th August 2005

A knowlegde built during centuries

SOLAR WIND MAGNETOSPHERE DOMINATING

COUPLING SOLAR WIND MAGNETOSPHERE IONOSPHERE

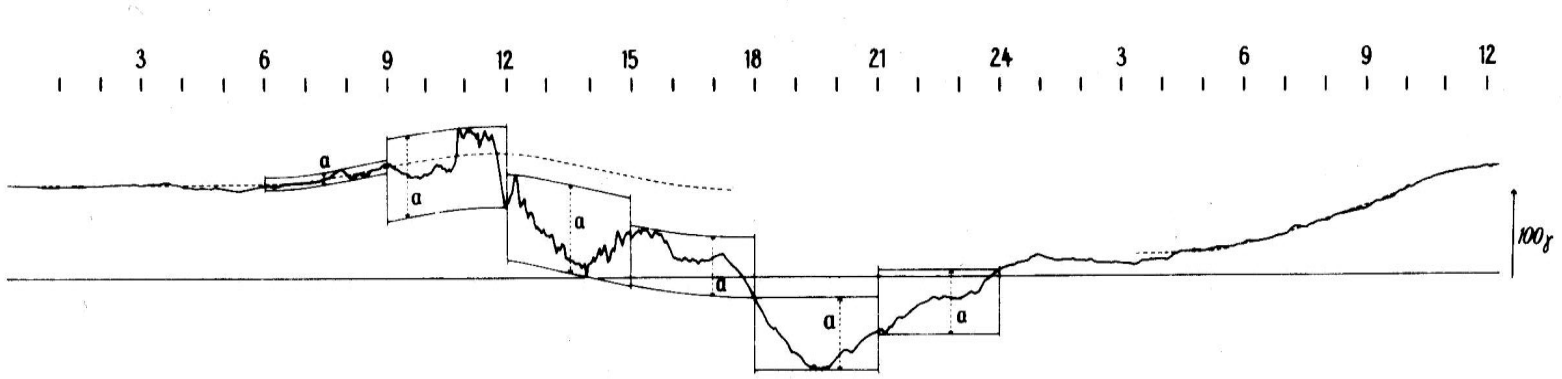
RADIATIONS IONOSPHERE DOMINATING

# THE CONCEPT OF MAGNETIC INDICES

## K INDEX / $S_R$

- Derivation Meaning and Use of geomagnetic indices, Mayaud 1980
- A guide to geomagnetic indices derived from Earth surface data, Menvielle et al, 2008

# The K index estimates a disturbance




$S_R$ # Sq

Figure from Mayaud, 1980

"*An individual K index is an integer in the range 0 to 9 corresponding to a class that contains the largest range of geomagnetic disturbances in the two horizontal components during a 3-hour UT interval. The limits of these classes at a particular observatory are defined with the intent of producing a geomagnetic disturbance characterisation that does not depend significantly on the location of a sub-auroral, mid- or low- latitude observatory. K indices are assigned to successive 3-hour UT intervals (0-3 hr, 3-6 hr, ..., 21-24 hr UT) giving eight K indices per UT day. K indices can be hand-scaled from magnetograms by an experienced observer, or computer derived using one of the four algorithms that are acknowledged by IAGA. (Menvielle et al., 2008)*"

- **K index weak => magnetic quiet day**

  **$S_R$ dominates / radiation**

- **K index large => magnetic disturbed day**

  **Disturbance dominates / solar wind**

**Magnetic indices based on index K**

- **Kp Ap**
- **Km Am**
- **Aa**

Kp (ap)/Km (am)/aa

# FIRST USE OF MAGNETIC INDICES

# TO SELECT MAGNETIC QUIET DAYS

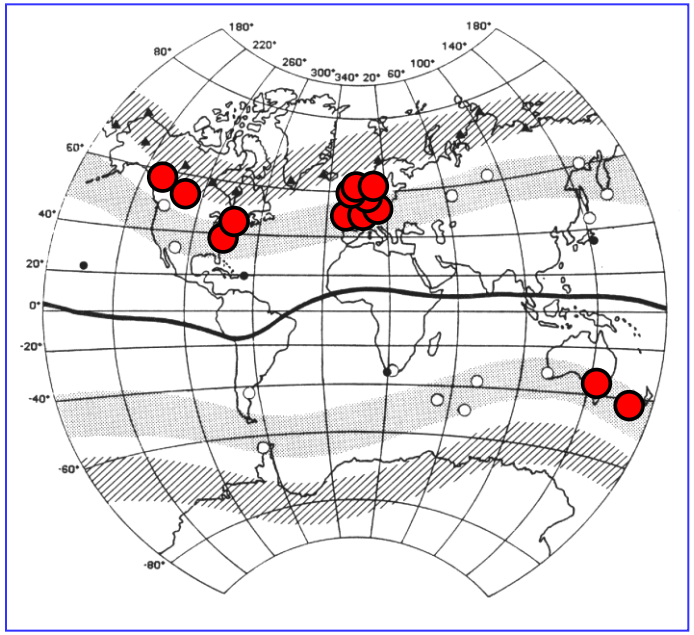
**= > physical processes related to solar radiations are dominant**

**except for quiet days after big storms**
**ionospheric disturbance dynamo**

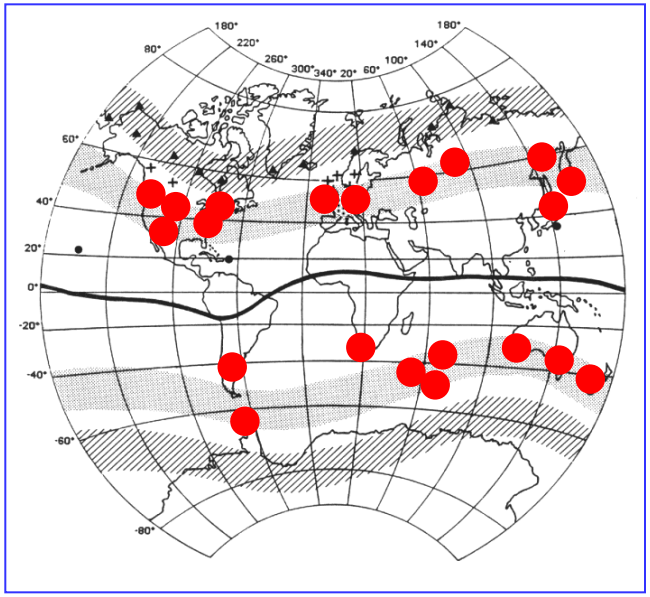
# Stations used for the Kp (ap) and Km(am)

## Quiet magnetic activity

## am/ap< 20nT=> quiet day ; am/ap < 13 nT => very quiet day with all the Km/Kp < 2+

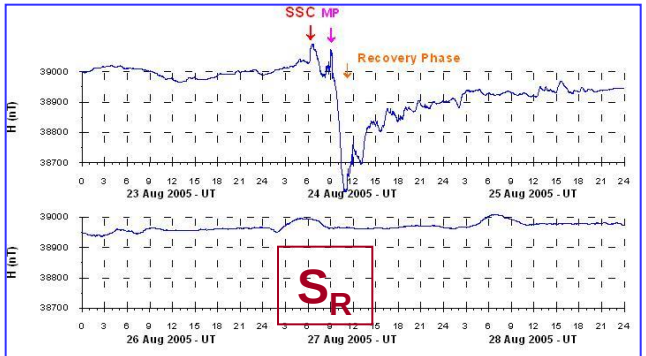


12 observatories
9 in the northern hemisphere
2 in the southern hemisphere



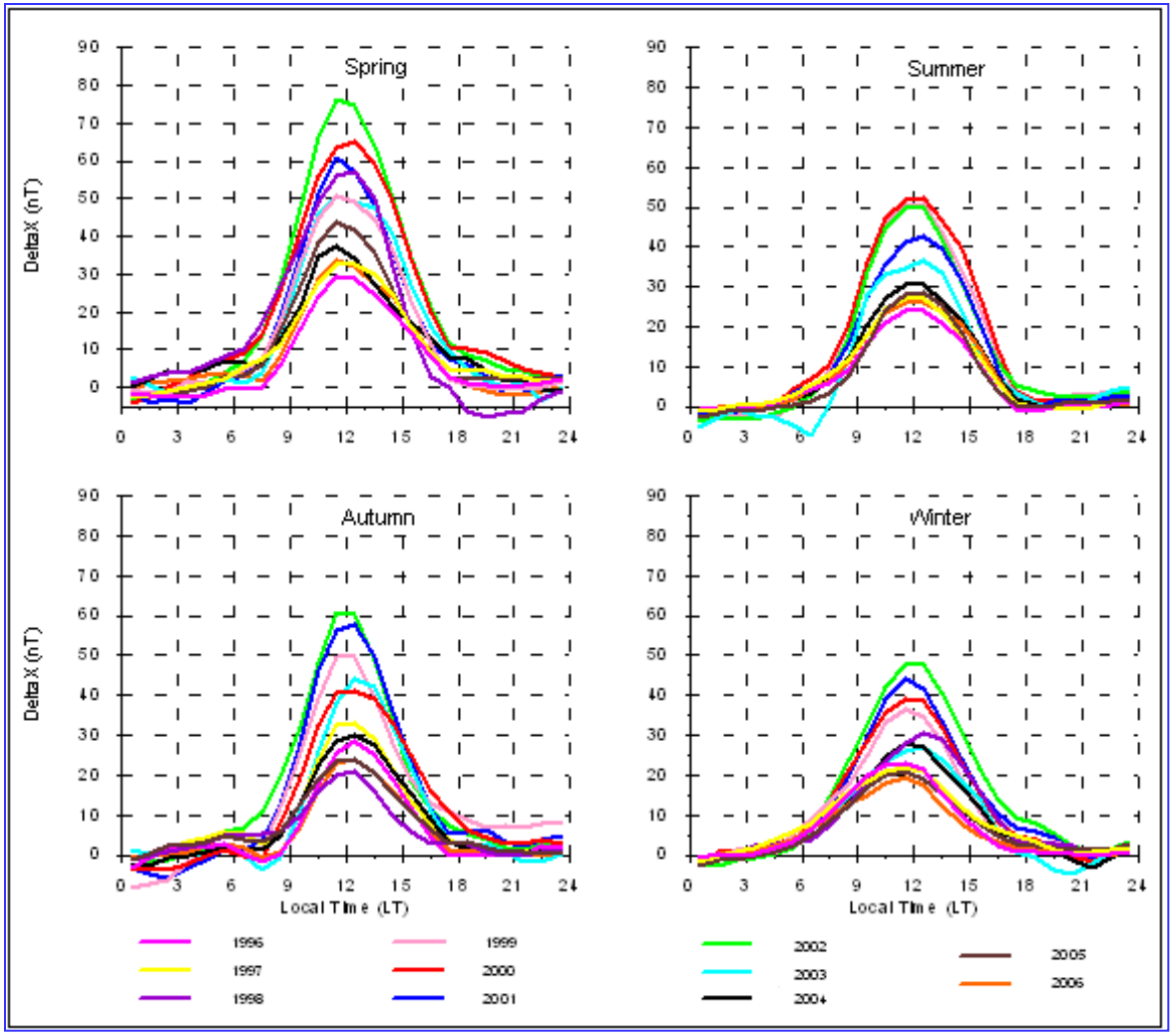
23 observatories
12 in the northern hemisphere
9 in the southern hemisphere
$K_N$ and $K_S$

Aa indice is based on the K index of 2 antipodale stations




Time variation of the H-component observed at Phu Thuy (Hanoi – Vietnam) from 23th to 28th August 2005

# Daily am < 20 nT




**Study on the regular ionospheric dynamo at the origin of the $S_R$**

**The selection of days is essential for all Studies in GEOPHYSICS**

**Pham Thi Thu et al., 2009**

**H component observed at Phu Thuy/Vietnam Solar cycle variations**

Kp (ap) /Km (am)/aa

# SECOND USE OF MAGNETIC INDICES

## TO APPROACH SOLAR WIND COMPONENTS (B, V)
## for example

**Use of magnetic index as proxy of solar wind parameters**
**Data averaged over 1 year**

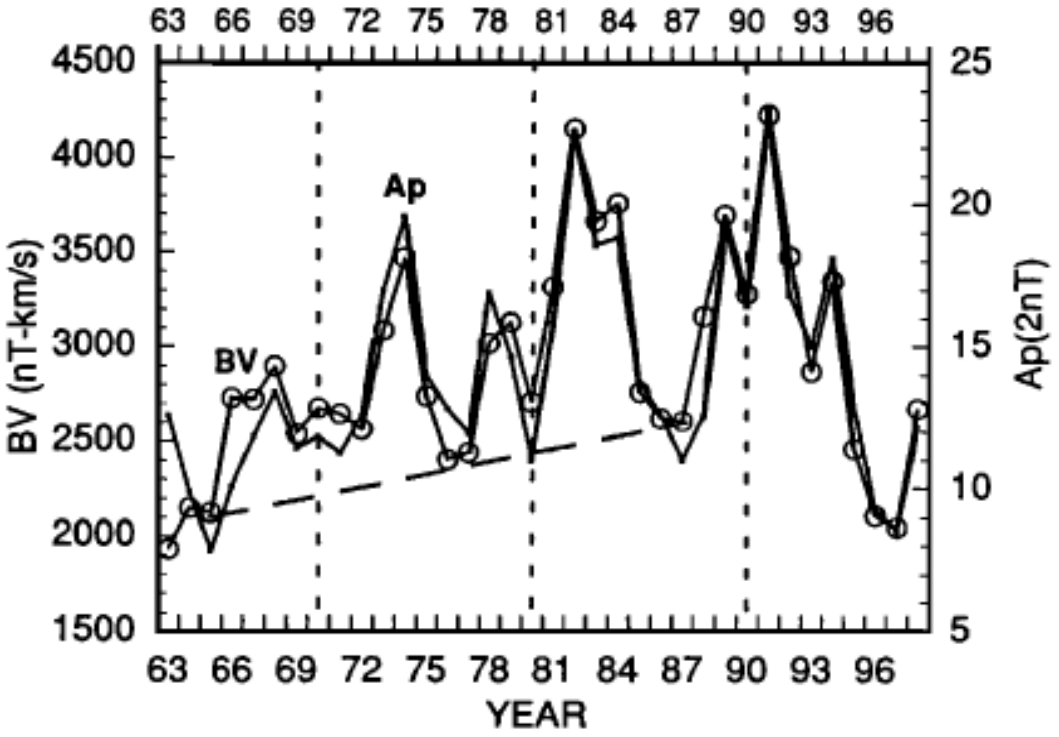



**Figure 4.** Annual mean values of *Ap* and the product *BV* are plotted for the period 1963 to 1998. Vertical dashed lines represent the solar polar field reversal epochs. The long-term trend in the *BV* data is highlighted by the dashed line.

**Ahluwalia, JGR, Vol; 105, n°A12, 27481-27487, 2000**

Kp (ap)/Km (am)/aa

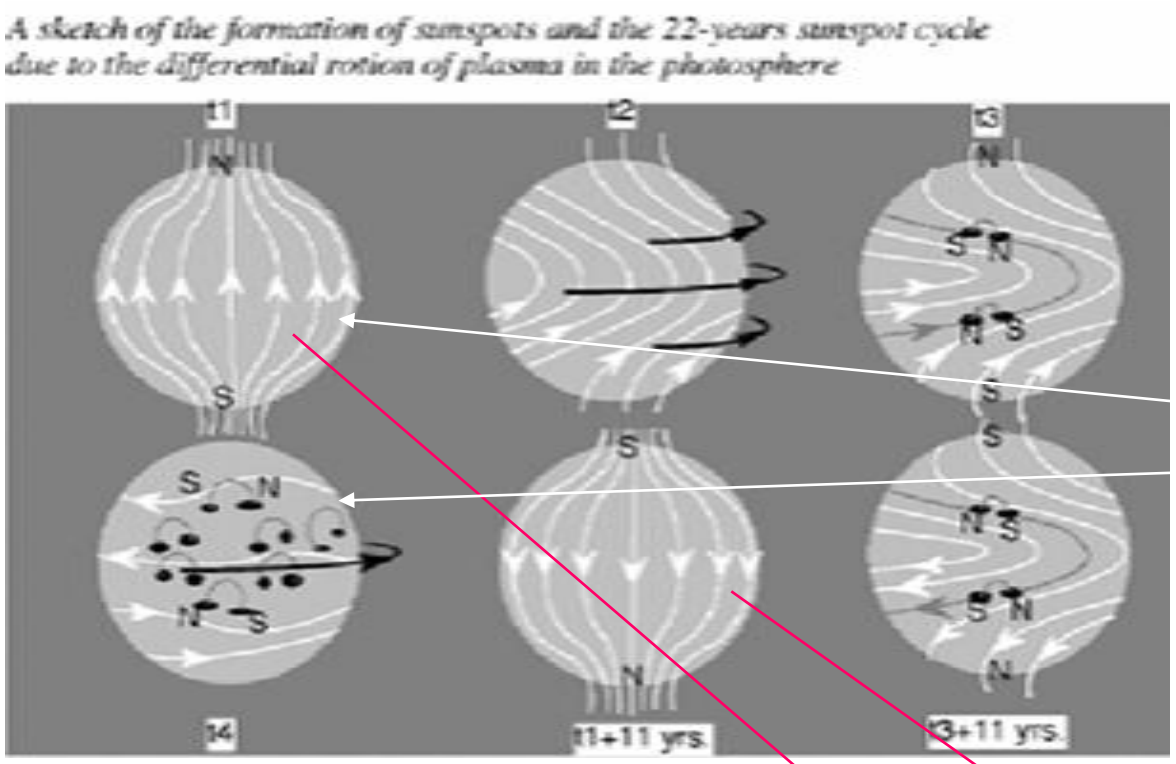
# THIRD USE O F MAGNETIC INDICES

## to study

## -SOLAR ACTIVITY and GEOMAGNETISM

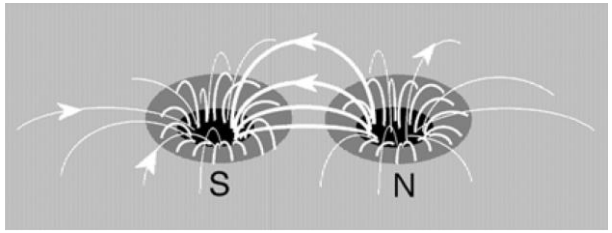
## - LONG TERM VARIATION OF THE SUN

# SOLAR DYNAMO CYCLE

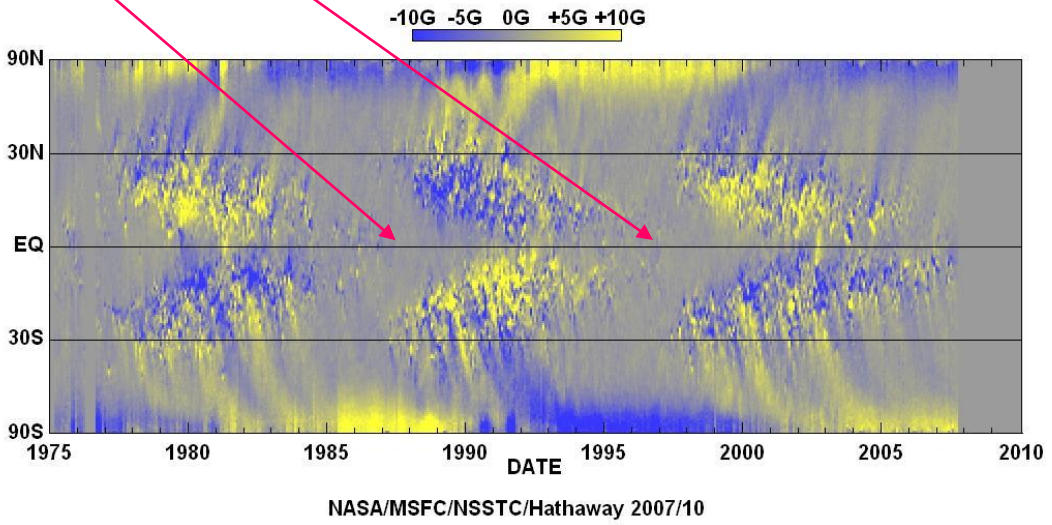



**The two components of the Solar magnetic field**

**Differential rotation**
**27 days at the equator**
**33 days at the poles**
**poloïdal**
**Toroïdal <-> sunspots**



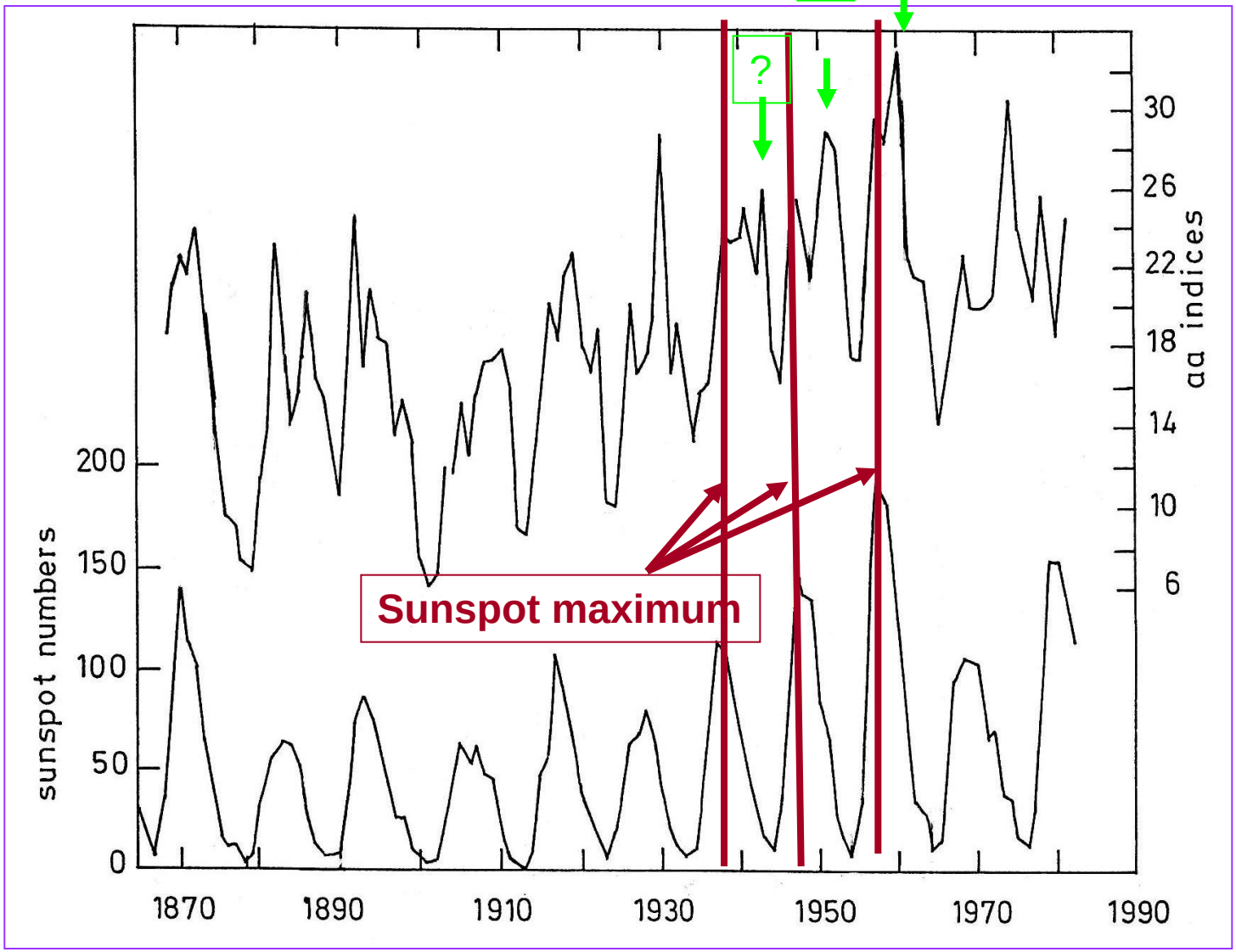

**Yellow – inward /+**
**blue – outward / -**



## Solar activity

**aa index**

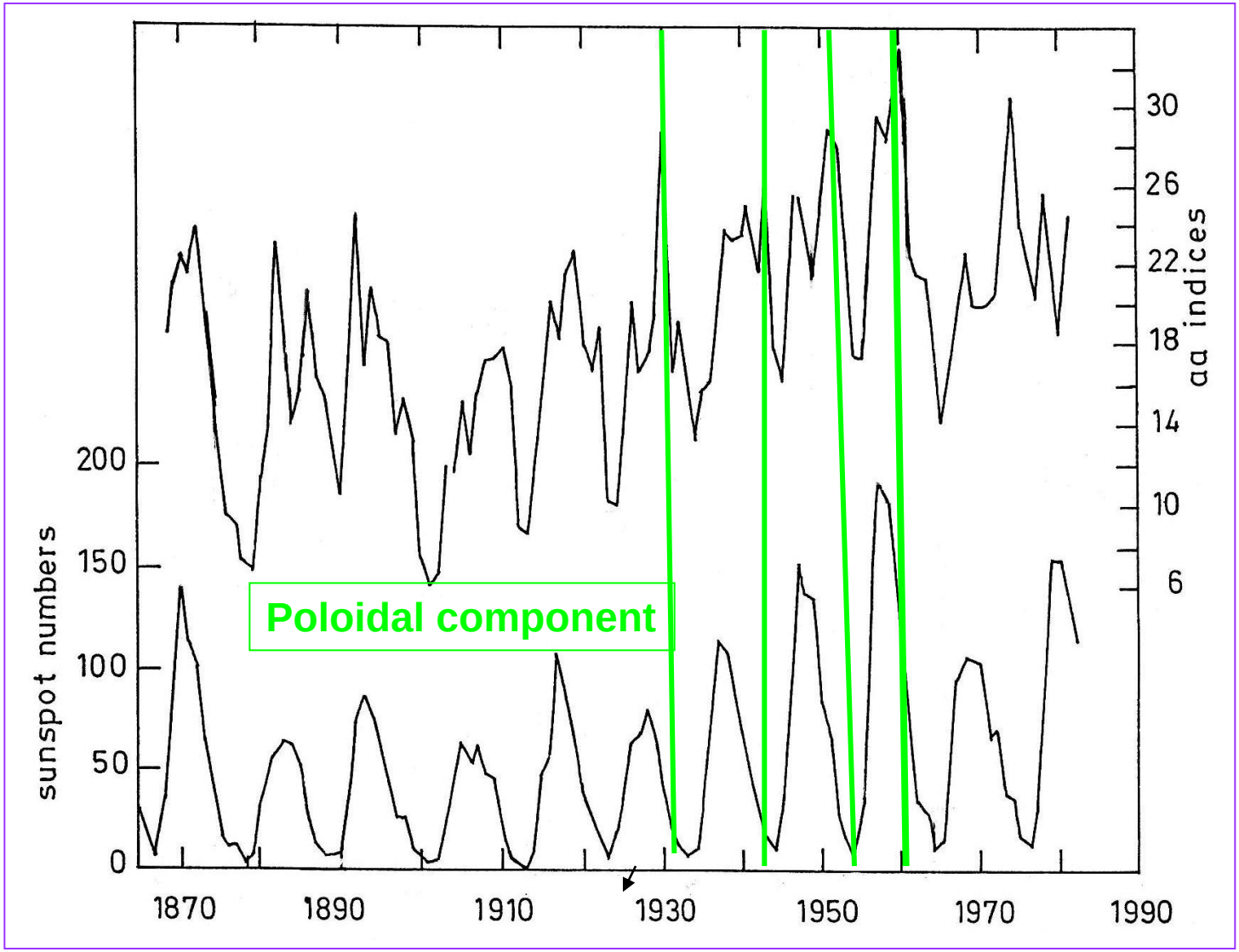
**Double pics**




**Used for many studies in medecine, climate change, solar wind parameters etc**

aa index

Double pics

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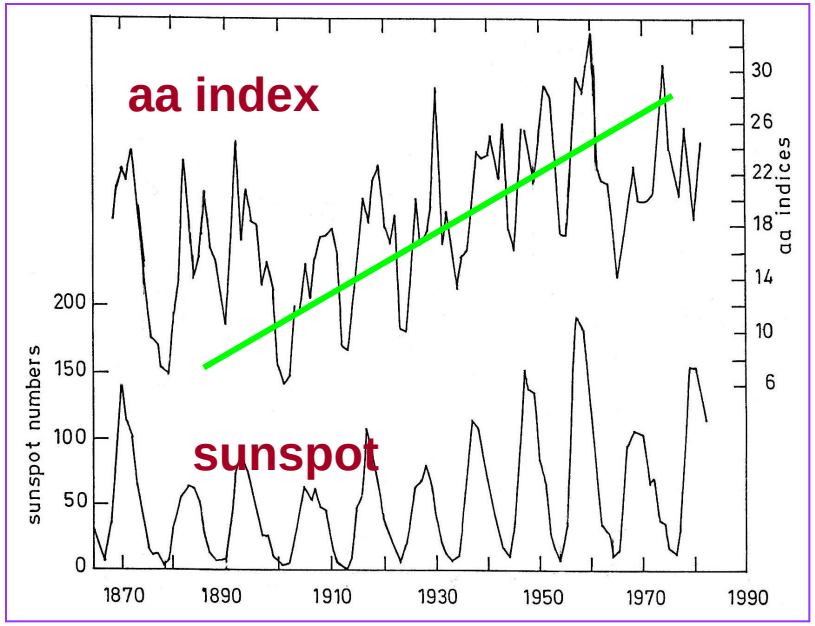
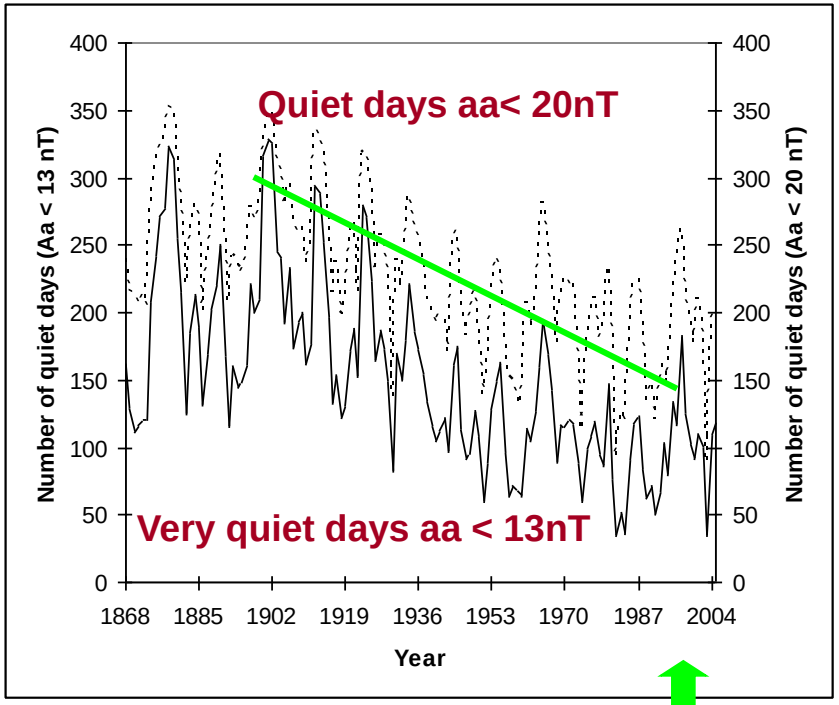
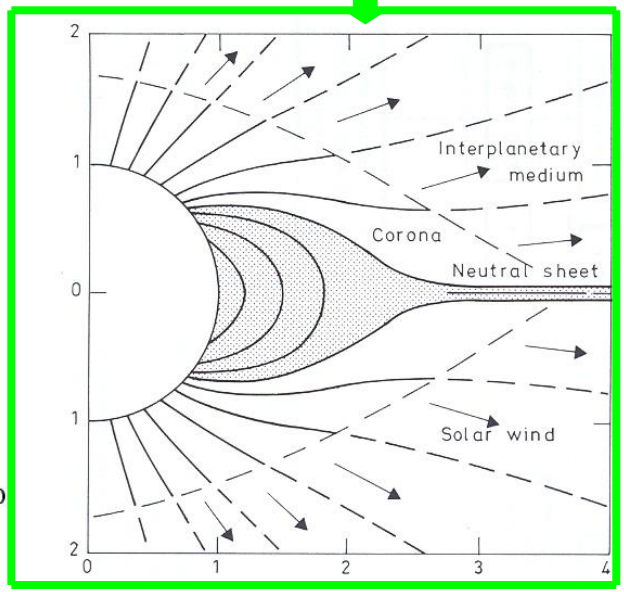
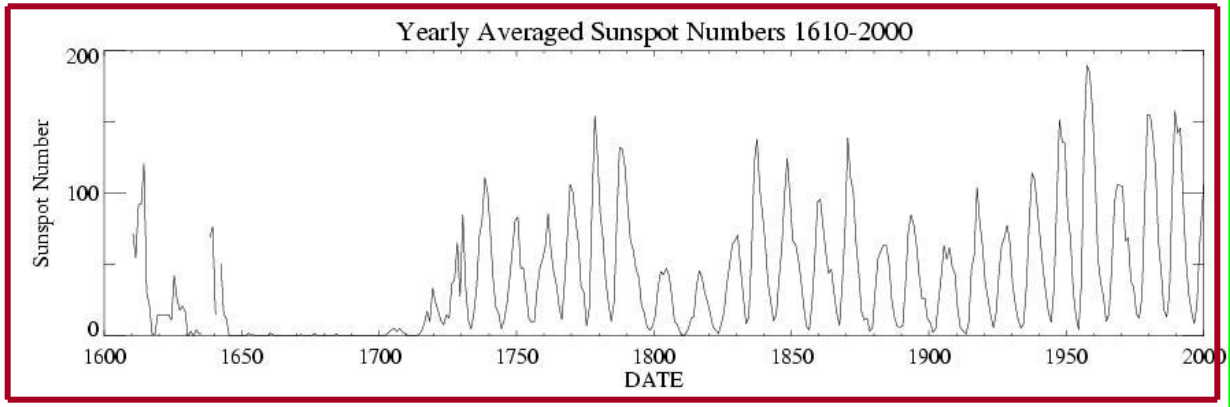
# Long term variation



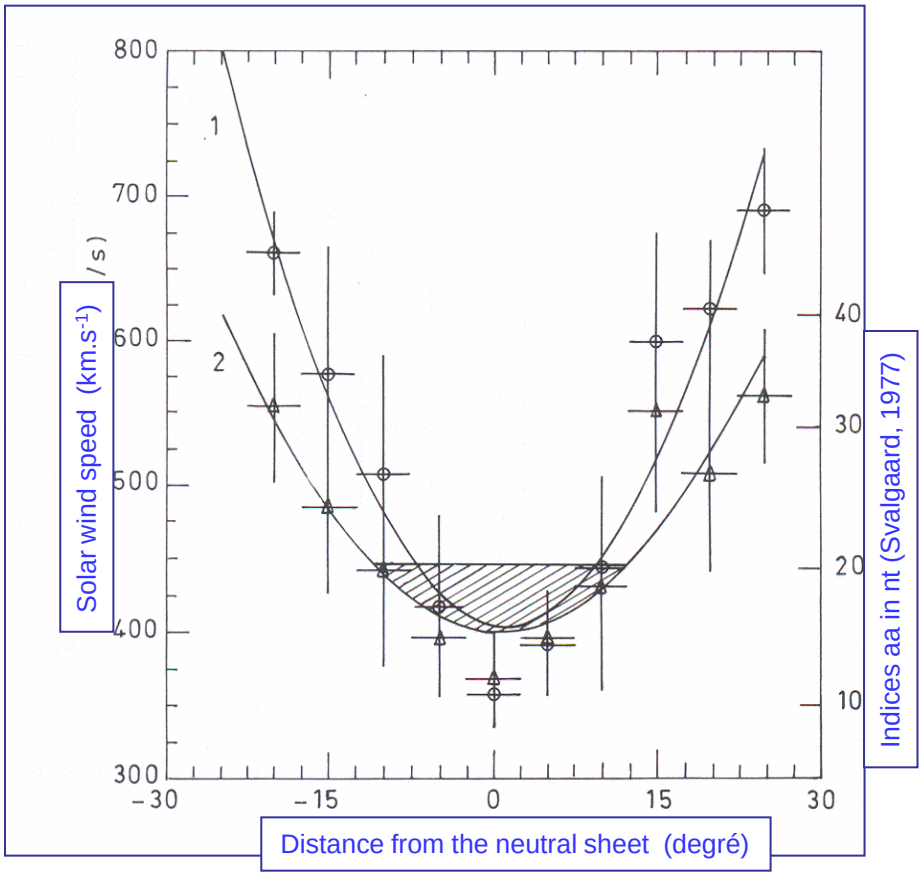




Ouattara et al., Annales Geophysicae 2009

# aa index and solar wind-phenomena

poloidal (91.5%)  toroidal/sunspots (8.5%)




Svalgaard, 1977

**Classification de Legrand et Simon Annales Geophysicae 1989**

**1. Slow solar wind ( v< 450km/s ) are originating from the neutral sheet**
**-> magnetic quiet days**

**2. High speed solar wind streams**
**-> recurrent activity -> periodicity 27d**

**3. Coronal Mass Ejection CME**
**-> strong magnetic storms with SSC**

**4. Fluctuating solar wind**
**-> fluctuating activity**

# Pixels of the magnetic index Aa solar rotation 27days (+ 5 days)

White -> aa < 10 nT
blue -> aa >= 10 nT
Yellow-> aa >= 20nT
Green -> aa >= 30nT
orange -> aa >= 40 nT
light red -> aa >= 60nT
dark red -> aa >= 100 nT

| | 1901 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 jan | | 6 | 9 | 4 | 7 | 27 | 11 | 7 | 5 | 8 | 5 | 5 | 3 | 2 | 5 | 6 | 3 | 4 | 4 | 2 | 4 | 8 | 16 | 29 | 13 | 4 | 5 | 6 | 6 | 4 |
| 28 jan | 5 | 6 | 6 | 4 | 7 | 3 | 4 | 22 | 7 | 3 | 5 | 7 | 6 | 3 | 4 | 4 | 2 | 14 | 9 | 4 | 3 | 2 | 4 | 3 | 21 | 15 | 4 | 27 | 14 | 3 | 3 |
| 24 feb | 27 | 14 | 3 | 3 | 2 | 2 | 3 | 5 | 3 | 6 | 3 | 2 | 4 | 6 | 4 | 6 | 4 | 5 | 4 | 15 | 4 | 4 | 2 | 3 | 9 | 9 | 6 | 7 | 3 | 9 | 42 |
| 23 mar | 7 | 3 | 9 | 42 | 6 | 4 | 5 | 3 | 11 | 5 | 3 | 7 | 12 | 3 | 2 | 3 | 2 | 6 | 6 | 3 | 3 | 5 | 2 | 4 | 12 | 14 | 9 | 3 | 3 | 4 | 2 |
| 19 apr | 3 | 3 | 4 | 2 | 2 | 8 | 5 | 7 | 4 | 3 | 14 | 4 | 3 | 2 | 4 | 5 | 3 | 2 | 2 | 3 | 5 | 4 | 4 | 44 | 18 | 9 | 2 | 5 | 5 | 2 | 2 |
| 16 may | 5 | 5 | 2 | 2 | 4 | 3 | 3 | 3 | 2 | 11 | 12 | 6 | 7 | 6 | 3 | 3 | 3 | 13 | 9 | 6 | 3 | 4 | 2 | 4 | 7 | 8 | 5 | 6 | 3 | 3 | 11 |
| 12 jun | 6 | 3 | 3 | 11 | 9 | 14 | 8 | 4 | 2 | 4 | 5 | 18 | 6 | 6 | 4 | 2 | 2 | 2 | 4 | 11 | 7 | 5 | 3 | 3 | 7 | 3 | 6 | 5 | 4 | 3 | 2 |
| 9 jul | 5 | 4 | 3 | 2 | 6 | 16 | 5 | 2 | 4 | 5 | 18 | 9 | 11 | 11 | 3 | 8 | 4 | 3 | 7 | 5 | 3 | 2 | 3 | 3 | 5 | 3 | 3 | 10 | 6 | 3 | 3 |
| 5 aug | 10 | 6 | 3 | 3 | 6 | 7 | 4 | 4 | 3 | 2 | 2 | 28 | 31 | 11 | 6 | 2 | 3 | 9 | 4 | 6 | 3 | 2 | 3 | 3 | 7 | 2 | 5 | 3 | 6 | 3 | 3 |
| 1sept | 3 | 6 | 3 | 3 | 4 | 3 | 5 | 2 | 2 | 2 | 4 | 31 | 20 | 10 | 3 | 5 | 2 | 10 | 17 | 7 | 2 | 2 | 4 | ≤ | 8 | 6 | 3 | 5 | 4 | 3 | 6 |
| 28 sept | 5 | 4 | 3 | 6 | 6 | 4 | 2 | 3 | 4 | 3 | 3 | 6 | 19 | 23 | 7 | 3 | 4 | 11 | 4 | 5 | 7 | 2 | 2 | 3 | 3 | 5 | 3 | 3 | 2 | 16 | 4 |
| 25 oct | 3 | 2 | 16 | 4 | 2 | 8 | 2 | 2 | 2 | 3 | 4 | 6 | 20 | 12 | 8 | 7 | 2 | 11 | 4 | 13 | 4 | 2 | 3 | 2 | 7 | 3 | 3 | 19 | 6 | 4 | 2 |
| 21 nov | 19 | 6 | 4 | 2 | 2 | 3 | 6 | 3 | 4 | 3 | 2 | 3 | 11 | 16 | 4 | 4 | 10 | 2 | 4 | 7 | 15 | 5 | 3 | 4 | 3 | 2 | 2 | 2 | 3 | 3 | 4 |
| 18 dec | 2 | 3 | 3 | 4 | 5 | 3 | 2 | 2 | 7 | 3 | 4 | 10 | 39 | 11 | 5 | 3 | | | | | | | | | | | | | | | |

| | 2003 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 jan | | | | | | | | | | | | | | | | | | | | | | | 14 | 12 | 40 | 29 | 17 | 8 | 12 | 8 |
| 07 jan | 17 | 8 | 12 | 8 | 7 | 28 | 17 | ≤ 19 | 14 | 18 | 13 | 8 | 16 | 29 | 41 | 30 | 33 | 37 | 32 | 32 | 46 | 39 | 23 | 20 | 34 | 47 | 31 | 28 | 81 | 35 | 52 |
| 03 feb | 28 | 81 | 35 | 52 | 27 | 32 | 27 | 30 | 33 | 29 | 18 | 26 | 14 | 37 | 39 | 32 | 23 | 46 | 24 | 32 | 25 | 22 | 22 | 14 | 10 | 30 | 52 | 37 | 31 | 23 | 36 |
| 02 mar | 37 | 31 | 23 | 36 | 52 | 33 | 48 | 26 | 20 | 20 | 30 | 21 | 16 | 26 | 43 | 49 | 49 | 57 | 41 | 22 | 47 | 49 | 28 | 38 | 12 | 7 | 16 | 46 | 42 | 53 | 57 |
| 29 mar | 46 | 42 | 53 | 57 | 54 | 29 | 44 | 32 | 57 | 43 | 16 | 12 | 38 | 39 | 41 | 25 | 17 | 19 | 30 | 29 | 58 | 46 | 37 | 16 | 24 | 43 | 42 | 33 | 46 | 49 | 35 |
| 25 apr | 33 | 46 | 49 | 35 | 31 | 29 | 34 | 56 | 64 | 27 | 22 | 11 | 25 | 50 | 61 | 65 | 55 | 49 | 381 | 41 | 41 | 46 | 39 | 16 | 15 | 17 | 22 | 21 | 45 | 48 | 31 |
| 22 may | 21 | 45 | 48 | 31 | 44 | 31 | 31 | 52 | 50 | 122 | 75 | 39 | 35 | 60 | 44 | 37 | 23 | 25 | 40 | 53 | 46 | 37 | 26 | 13 | 15 | 46 | 37 | 63 | 71 | 81 | 23 |
| 18 jun | 63 | 71 | 81 | 23 | 23 | 45 | 27 | 37 | 44 | 35 | 34 | 50 | 62 | 41 | 33 | 14 | 26 | 29 | 37 | 32 | 17 | 28 | 5 | 7 | 15 | 66 | 61 | 27 | 26 | 51 | 74 |
| 15 jul | 27 | 26 | 51 | 74 | 37 | 32 | 50 | 32 | 11 | 11 | 16 | 15 | 15 | 44 | 35 | 29 | 59 | 49 | 52 | 61 | 38 | 27 | 21 | ≤ 2 | 46 | 52 | 52 | 28 | 21 | 18 | 45 |
| 11 aug | 28 | 21 | 18 | 45 | 28 | 29 | 23 | 16 | 40 | 110 | 24 | 26 | 78 | 70 | 59 | 33 | 37 | 24 | 19 | 29 | 28 | 23 | 14 | 23 | 20 | 29 | 44 | 31 | 17 | 7 | 11 |
| 07 sept | 31 | 17 | 7 | 11 | 40 | 36 | 27 | 18 | 17 | 9 | 11 | 58 | 90 | 72 | 54 | 42 | 34 | 33 | 29 | 55 | 50 | 29 | 9 | 8 | 7 | 10 | 18 | 16 | 28 | 11 | 12 |
| 04 oct | 16 | 28 | 11 | 12 | 20 | 32 | 16 | 13 | 6 | 3 | 9 | 31 | 60 | 64 | 47 | 50 | 41 | 53 | 50 | 66 | 55 | 12 | 59 | 36 | 23 | 17 | 43 | 299 | 230 | 179 | 41 |
| 31 oct | 299 | 230 | 179 | 41 | 31 | 24 | 55 | 13 | 32 | 15 | 20 | 51 | 48 | 78 | 48 | 76 | 57 | 62 | 61 | 53 | 46 | 24 | 228 | 59 | 46 | 40 | 27 | 27 | 16 | 11 | 11 |
| 27 nov | 27 | 16 | 11 | 11 | 11 | 29 | 17 | 14 | 9 | 13 | 66 | 39 | 29 | 65 | 54 | 67 | 64 | 43 | 45 | 48 | 38 | 19 | 14 | 7 | 4 | 39 | 45 | 35 | 15 | 17 | 12 |
| 24 dec | 35 | 16 | 17 | 12 | 16 | 21 | 25 | 11 | 15 | 39 | | | | | | | | | | | | | | | | | | | | | |

Fluctuating activity

Quiet activity

Recurrent activity

Very quiet activity

CME

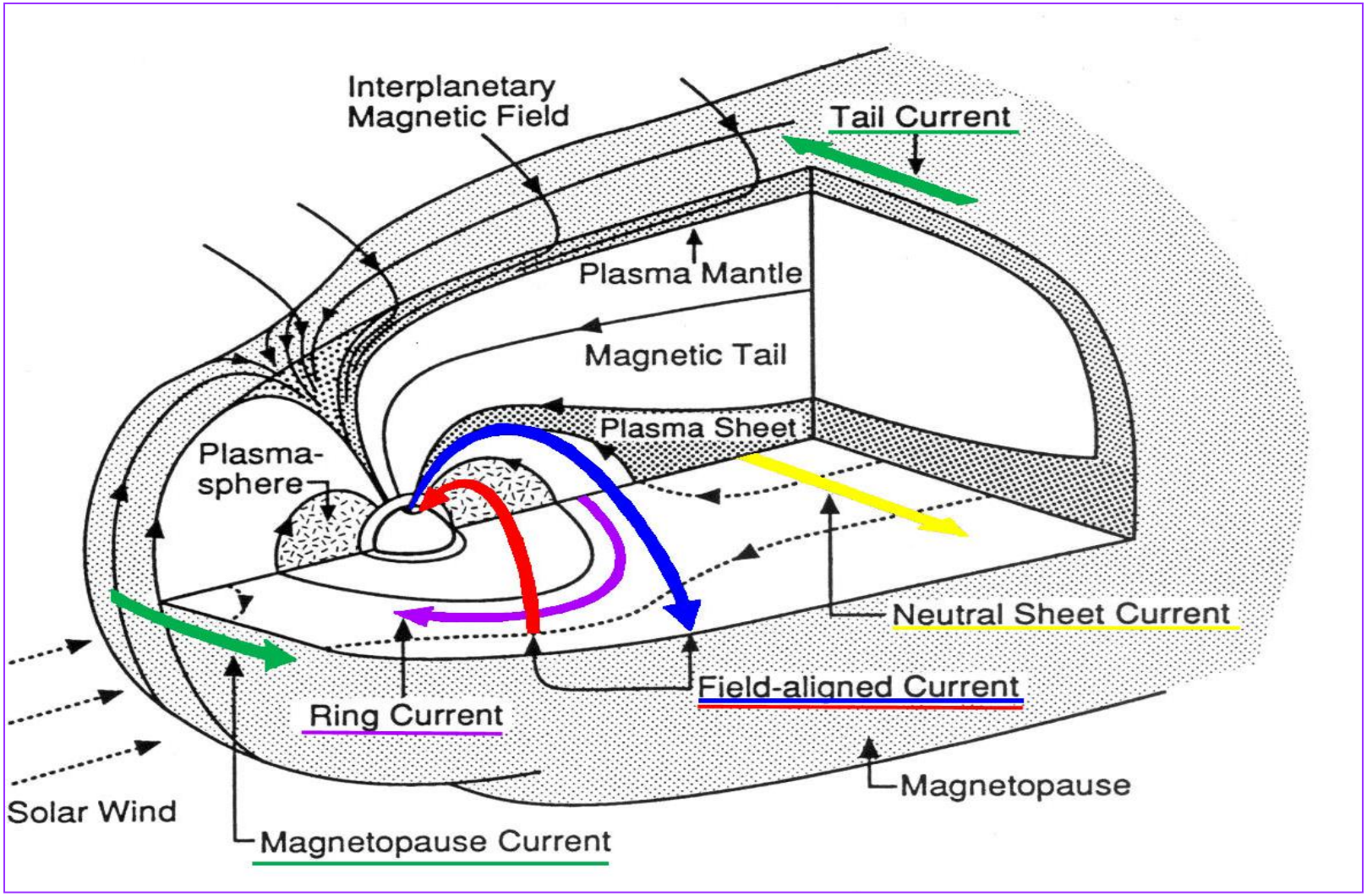
Dst AU and AL

# FOURTH USE O F MAGNETIC INDICES

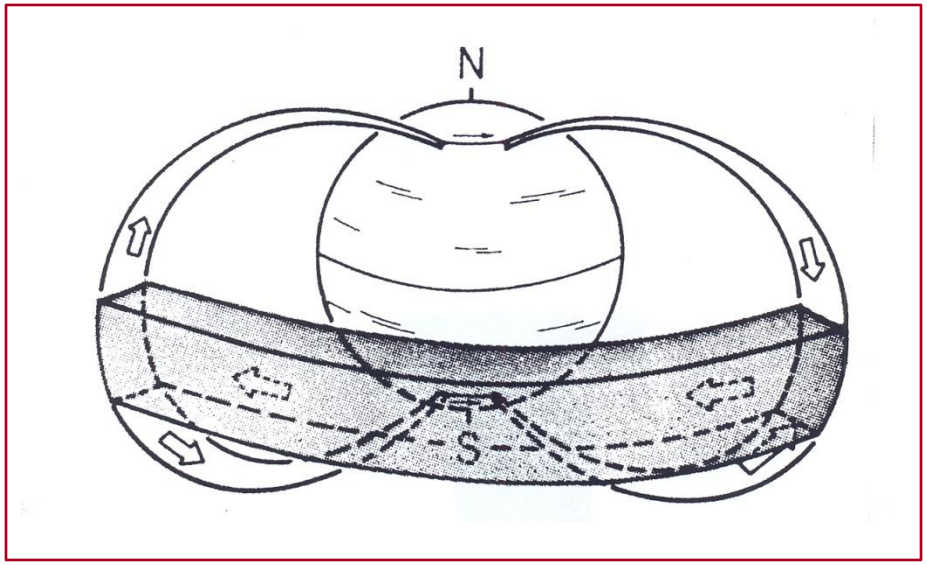
to study

- Magnetic storms
- Ionospheric electric currents
- Electrodynamics between high and low latitudes

# Dst – STORM index <-> Ring Current DR

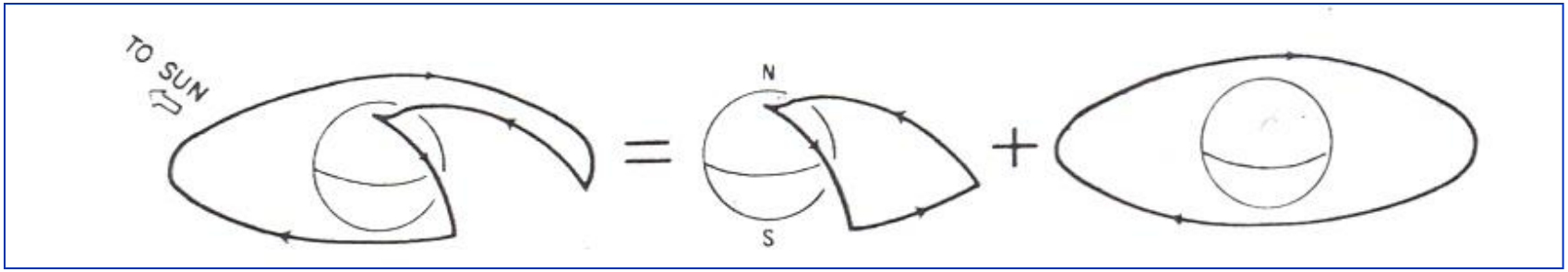


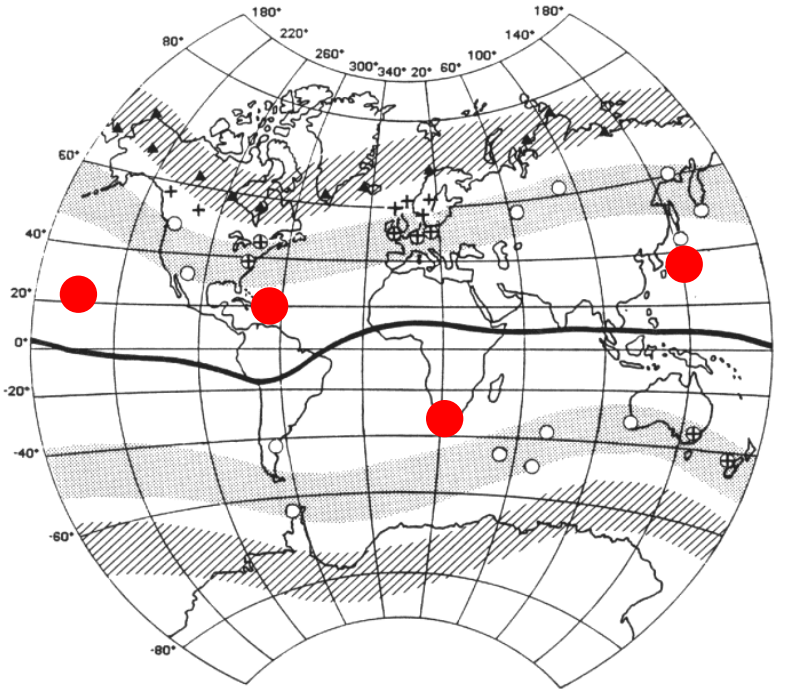
# Partial ring current




Cummings, JGR, 1966

Fukushima and Kamide, 1973





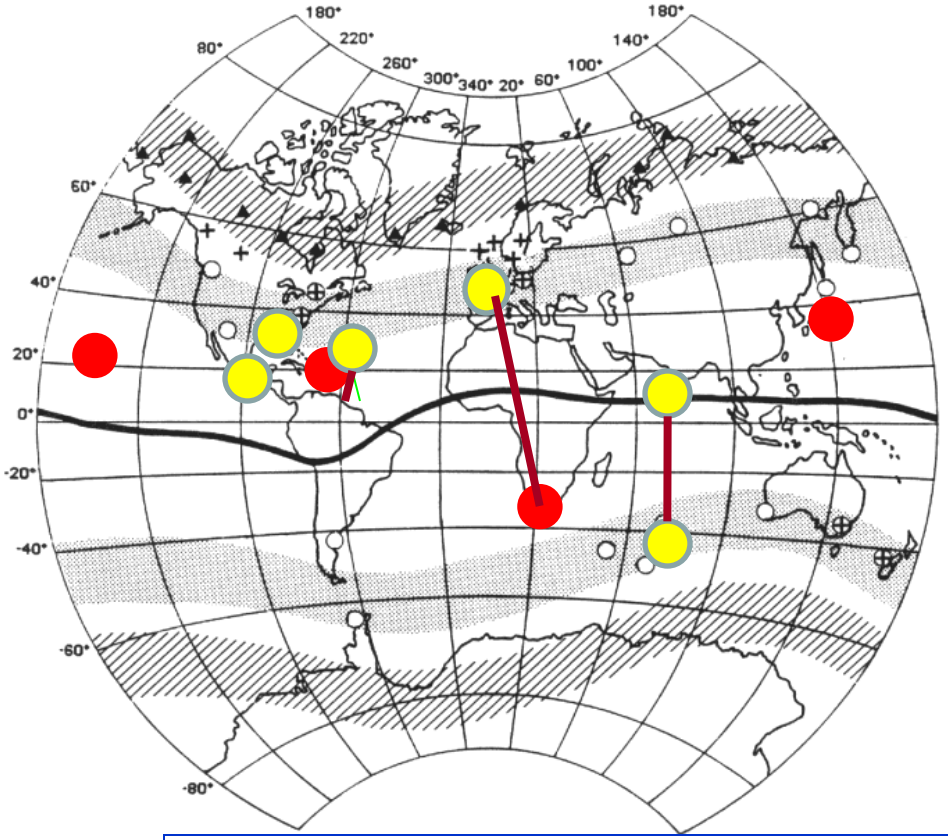

**Dst index** ⟺ **symmetric part of the ring current**

"*Dst is computed using 1-minute values from four low latitude observatories The locations of which are sufficiently distant from the auroral and equatorial electrojets to inhibit noise from these two sources.*
*Local Dst values are computed at each "Dst" observatory at one instant in time. Contributions to H from the background field (non-transient field of core and crustal origin) and the solar regular daily variation $S_R$ are first subtracted from the observed value of H. The local Dst value is deduced from the so-obtained residual D through normalization to the dipole equator. For each 1-hour UT interval, the Dst index is the average of the local Dst hourly mean values at the four "Dst" observatories*." (Menvielle et al., 2008).

SYM + ASY

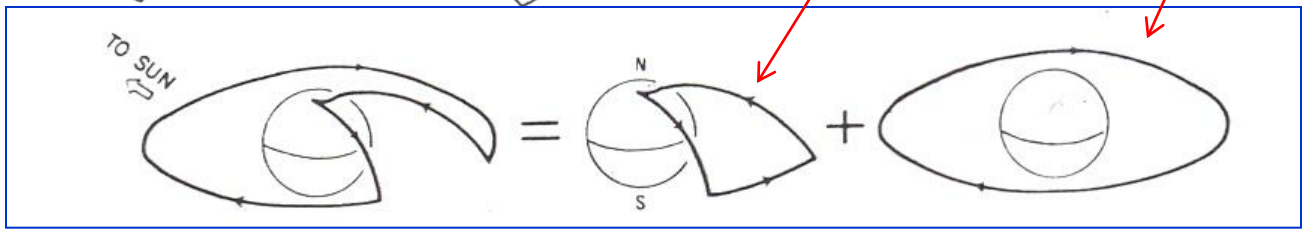
Dst

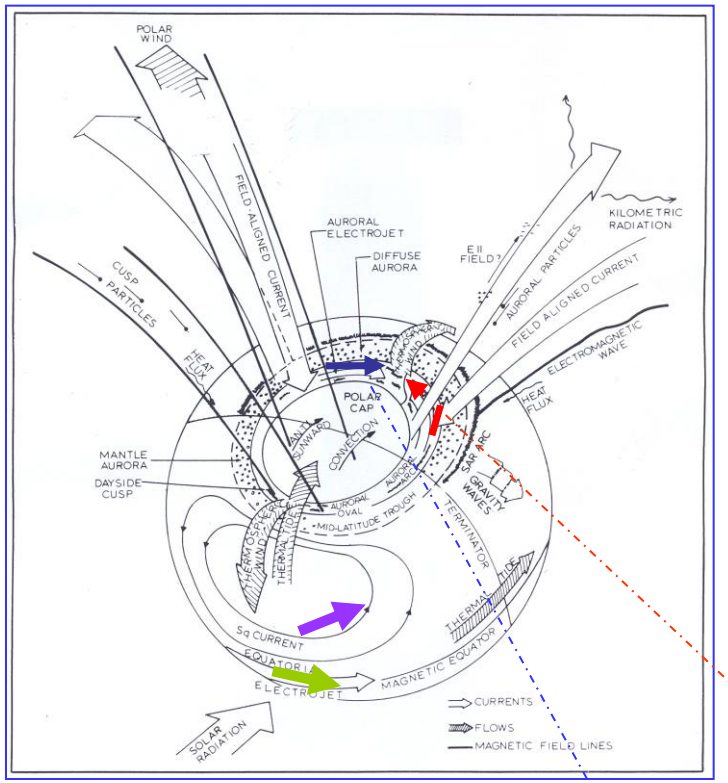
# New indices SYM and ASY
# SYM (1') ⇔ Dst (1h)



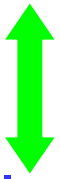

**ASY**

**SYM ~ Dst**

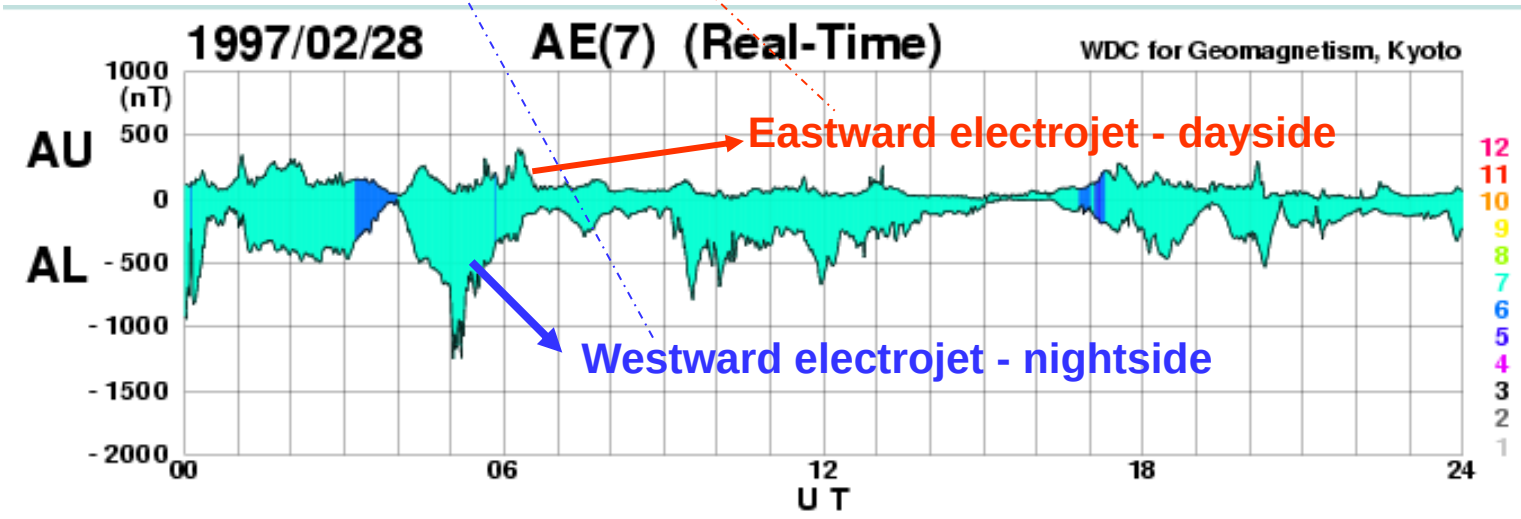




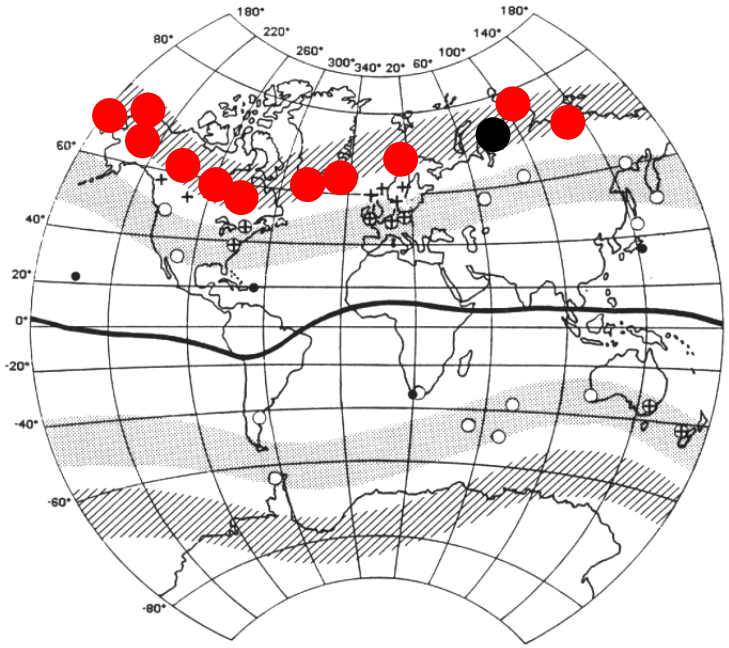

# Auroral indices

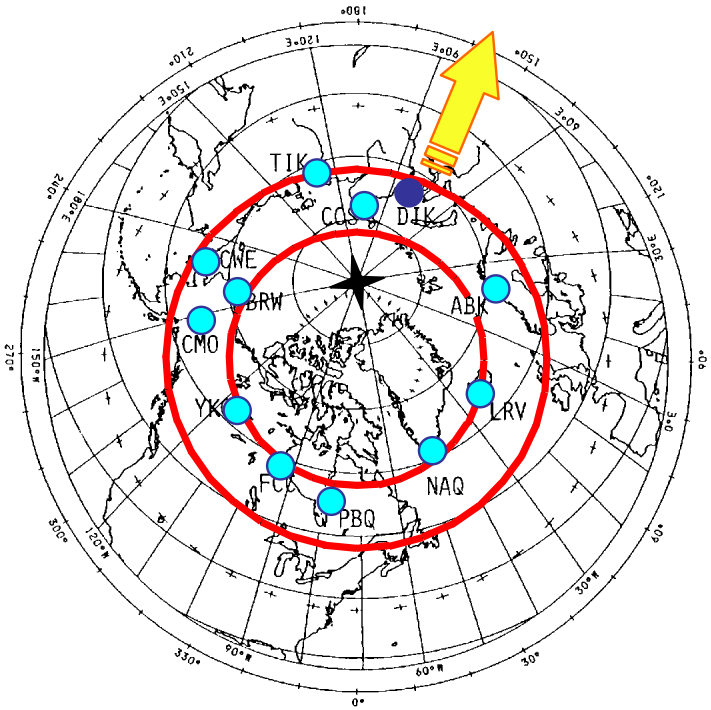


# Auroral electrojets



# AU, AL
# auroral electrojets






"*The H magnetograms from the "AE" stations are superimposed: the upper envelope defines the AU index, and the lower envelope defines the AL index; AE = (AU+AL) / 2 and A0 = (AU-AL) / 2. From 2005 onwards, the AE indices are calculated from data from up to 12 sites in the northern auroral zone. AE is expressed in units of nT*" (Menvielle et al., 2008)

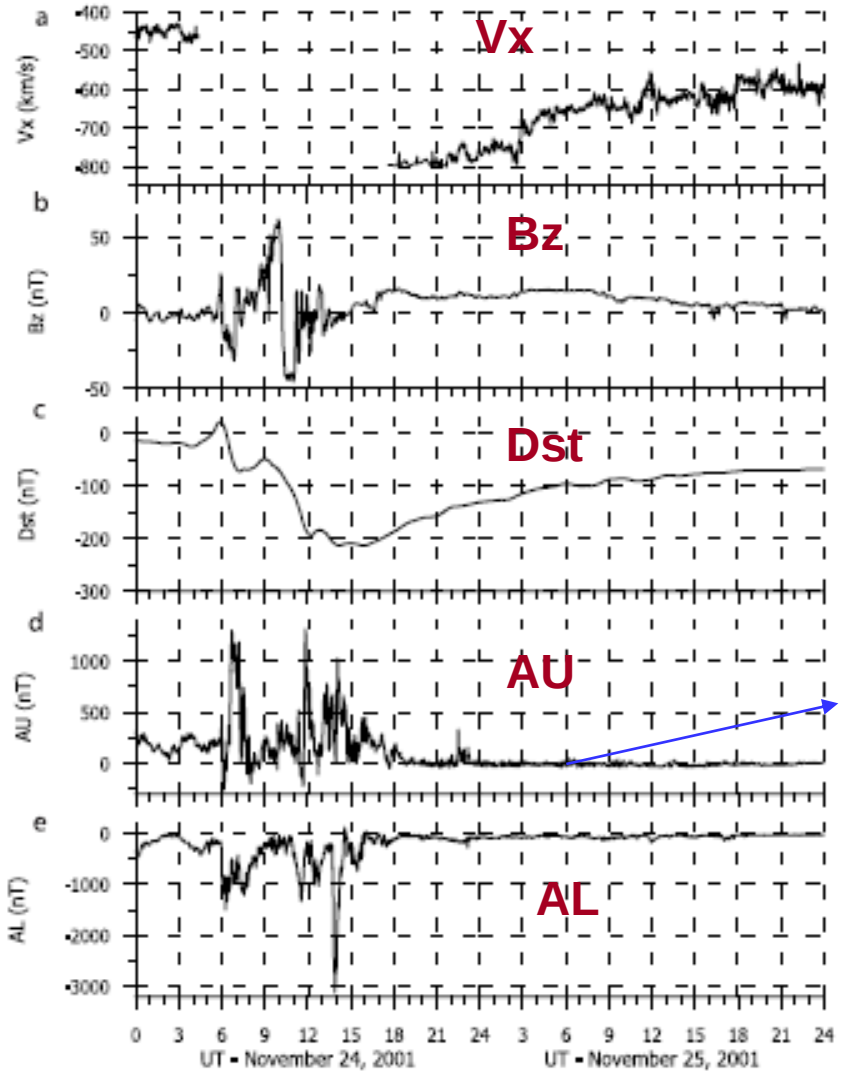



Figure 1. Solar wind and magnetic indices on 24 and 25 November 2001. (a) Solar wind *X* component, (b) *Z* component of the IMF field, (c) Variations of the *Dst* magnetic indices, (d) *AU* index, and (e) *AL* index.

**Ionospheric disturbance dynamo**

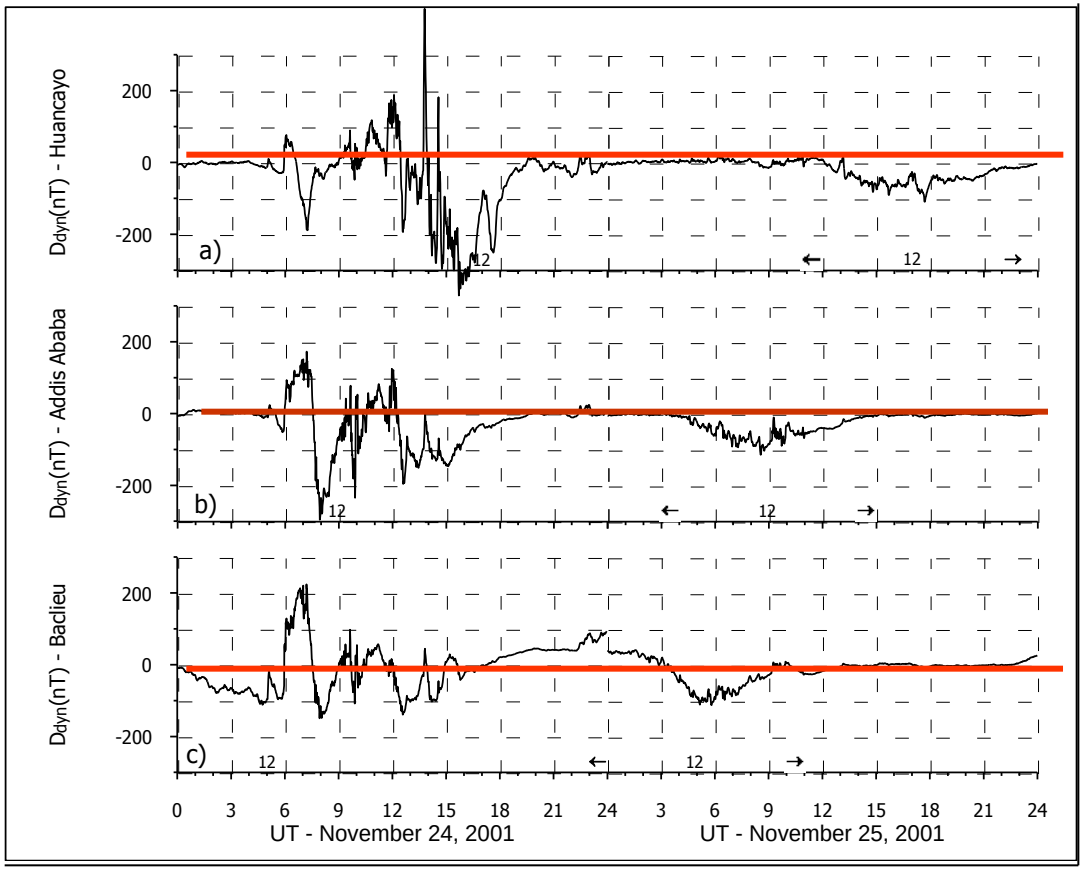
**No auroral activity after a storm**

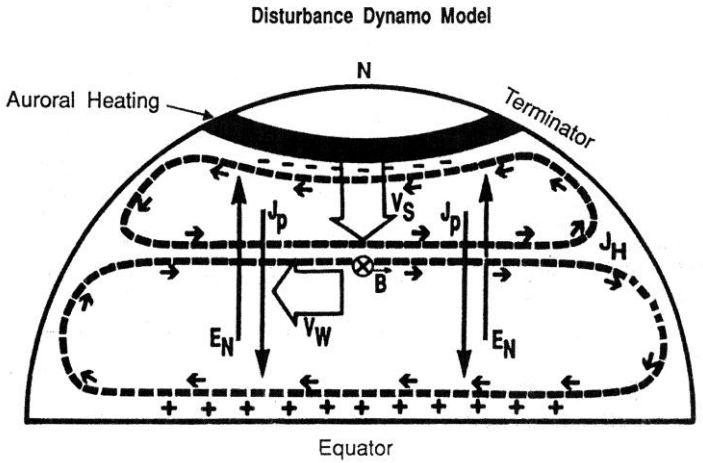
**Criteria to select days to analyse the effect of a storm on atmosphere and ionospheric dynamo**

# Magnetic signature of the Ionospheric disturbance dynamo

## Le Huy and Amory-Mazaudier, 2005

Figure 9.




**Ionospheric disturbance dynamo**
**Westward deviation**
**ΔH <0**

**Regular ionospheric dynamo**
**Eastward electrojet**
**ΔH >0**

**For selected events**

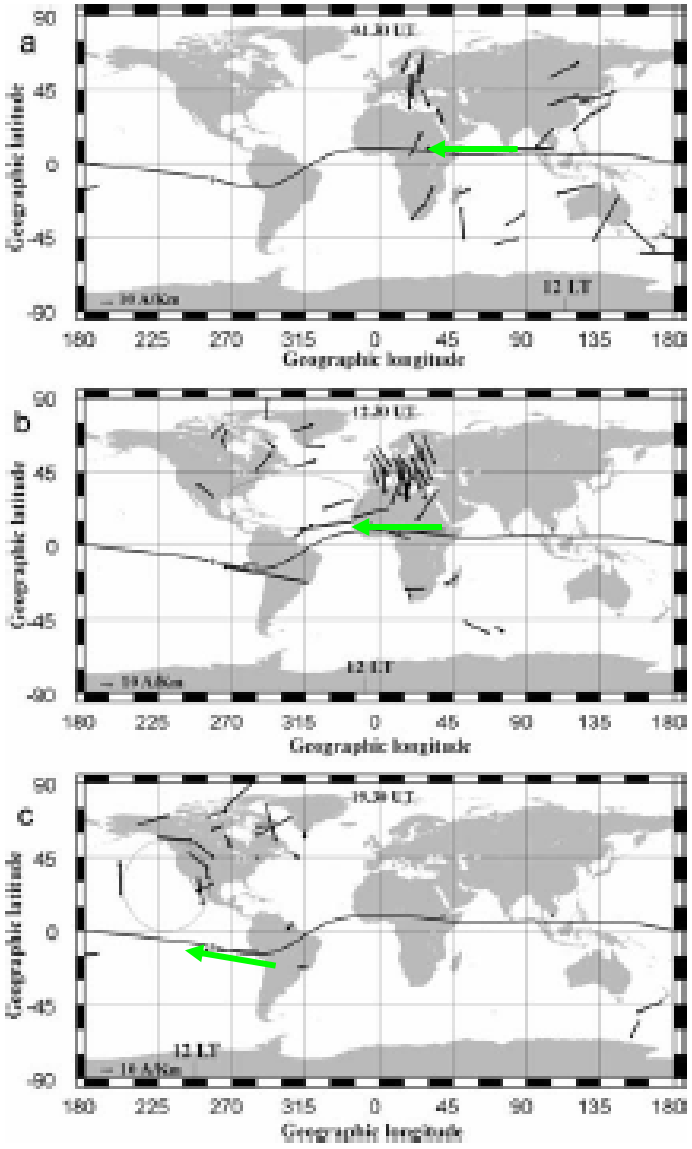



Figure 3. Planetary maps of the magnetic signature of the ionospheric disturbance dynamo based on the INTERMAGNET network on 25 November 2001, at (a) 0430 UT, (b) 1230 UT, and (c) 1930 UT.

**Ionospheric disturbance dynamo**

**Map of equivalent currents**

**A reversed electrojet is observed In the 3 longitude sectors**

**Aa indices are used to select these events :**
**23 events like this one between 1868 and 2008**
**aa > 100nT, the first day**
**aa < 20 nT, the second day**

**Le Huy and Amory-Mazaudier, JGR 2008**

# CONCLUSION

- **Magnetic indices are**
  - **Continuously computed**
  - **Avalaible on the web**
  - **Essential to**
    - **Classify days**
    - **To define the geophysical contexy**
    - **To approach physical parameters**
    - **etc….**

    **TRANS DISCIPLINARY TOOLS**