Dynamos and electric currents in the Sun Earth System and use of magnetic indices

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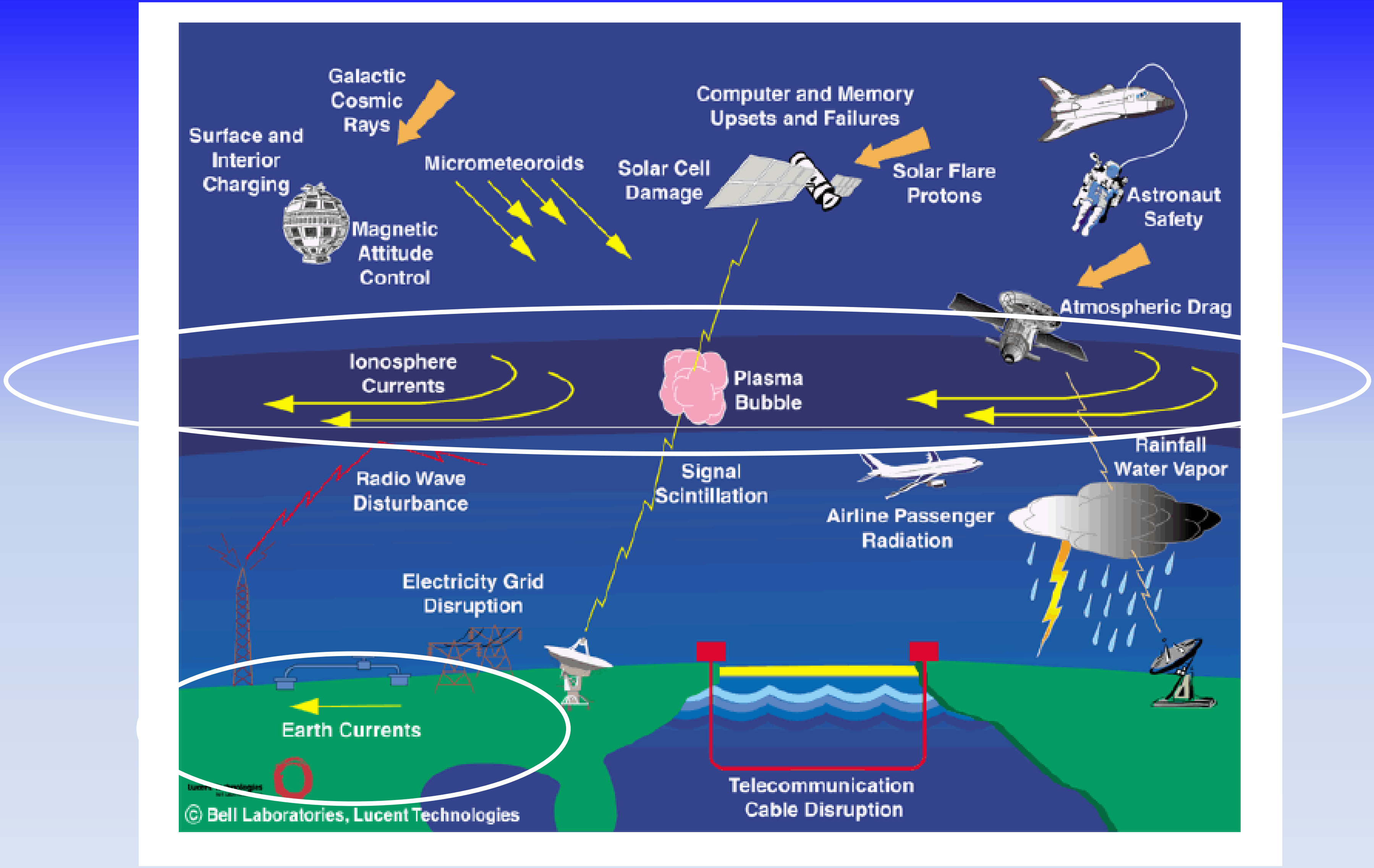
International Space Weather Initiative



Space weather includes many disciplines of the Physics

Solar physics

Studies on solar wind

Magnetospheric physics

Ionospheric studies

Atmospheric physics

Geomagnetism

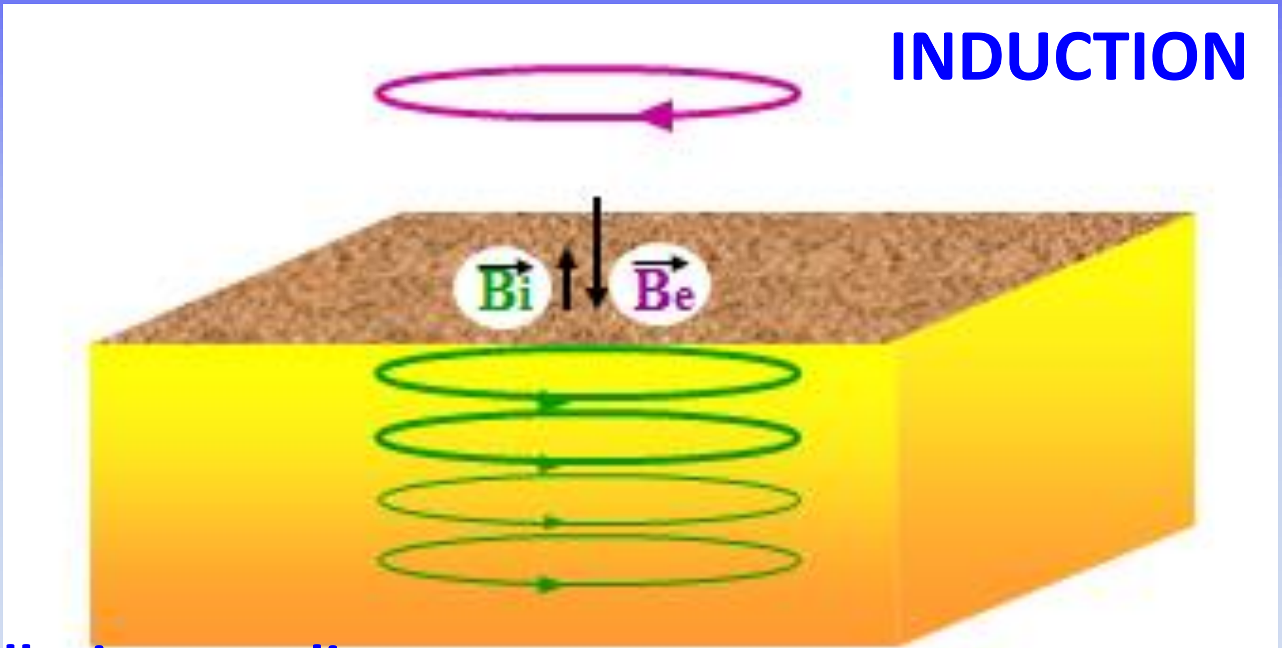
Magnetotelluric studies, Geology

GNSS

Etc…

External currents systems are complex they involved

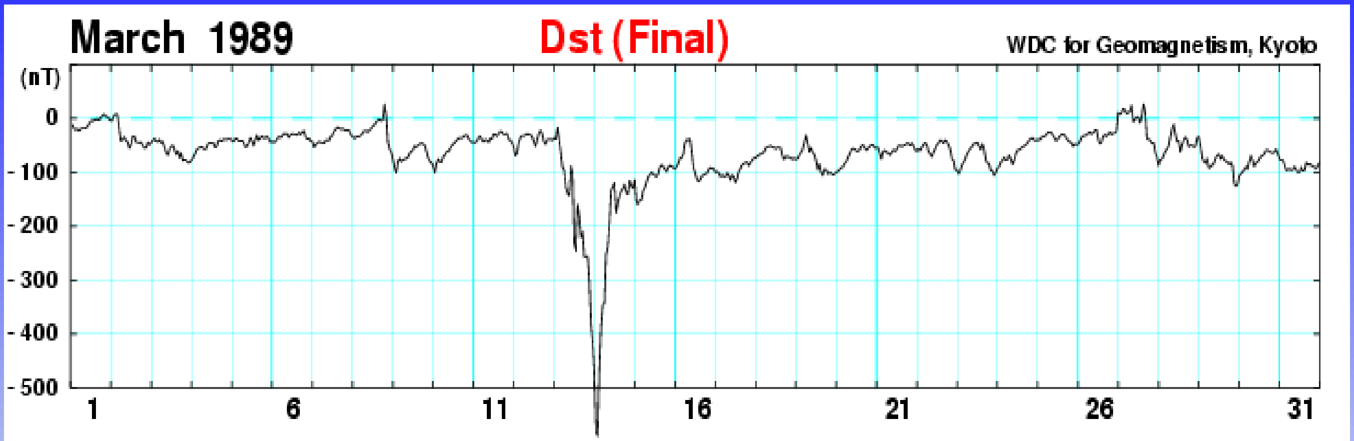
Sun, Solar Wind, Magnetosphere, Ionosphere, Atmosphere

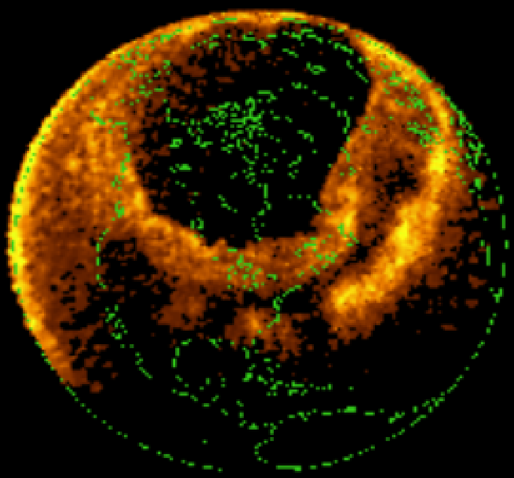


Magnetotelluric soundings

GIC : Ground Induced Current
Use in prospection (Geology)

MAGNETIC STORM OF MARCH 15, 1989
The auroral oval extends toward low latitudes



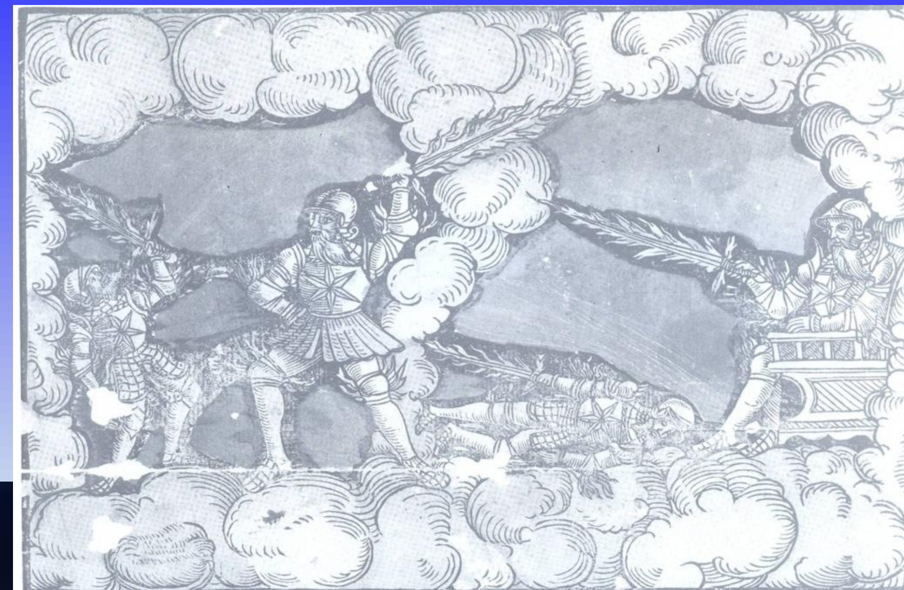


March 13, 1989 - The Quebec Blackout Storm - Most newspapers that reported this event considered the spectacular aurora to be the most newsworthy aspect of the storm. Seen as far south as Florida and Cuba, the vast majority of people in the Northern Hemisphere had never seen such a spectacle in recent memory. Electrical ground currents created by the magnetic storm found their way into the power grid of the Hydro-Quebec Power Authority and the entire Quebec power grid collapsed. Six million people were affected as they woke to find no electricity to see them through a cold Quebec wintry night. This storm could easily have been a $6 billion catastrophe affecting most US East Coast cities.

Space weather effects see the lecture of prof. Endawoke Yigenzaw

Jean DORTOUS DE MAIRAN -17 33
Academician -> reign of the king LOUIS XIV

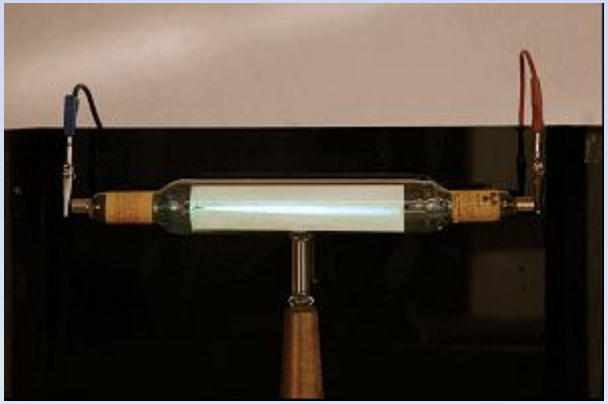
explained the aurora



Picture of the aurorae observed on Jule 24, 1554   in Germany and Switzerland
Legrand et al. 1991
The aurorae is at 100km height



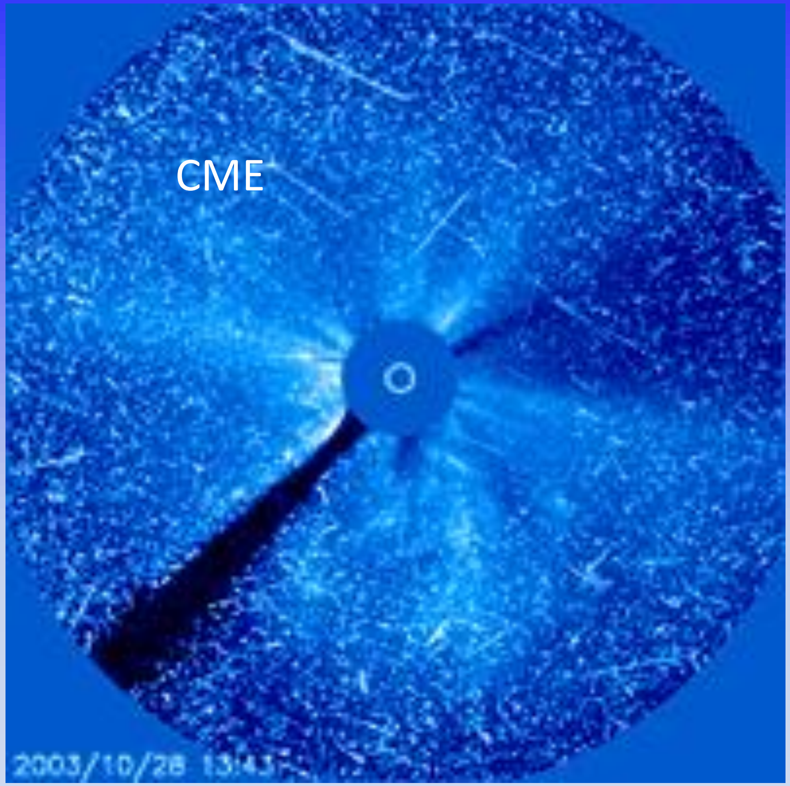


OUTLINES

- **Sun Earth System : a global electromagnetic complex system**
- **Dynamo process and large scale dynamos**
- **Electric currents associated to the different dynamos**
- **Magnetic field to approach electric currents**
- **Magnetic indices**

Sun Earth System



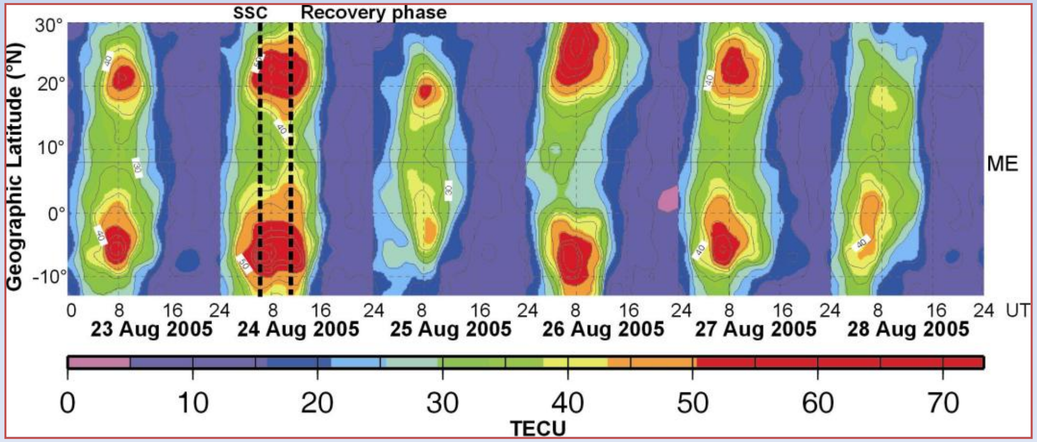
Images du satellite SOHO/NASA

Coronal mass ejection

Shock

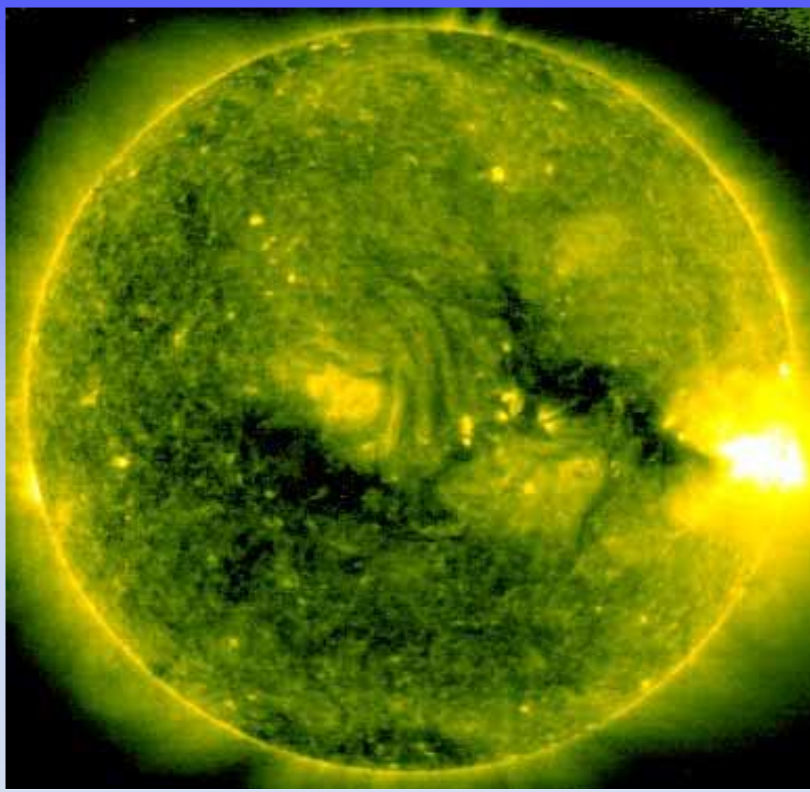
Magnetic storms

Maps of the TEC over Asia



Amory-Mazaudier et al, 2006

Sun Earth System

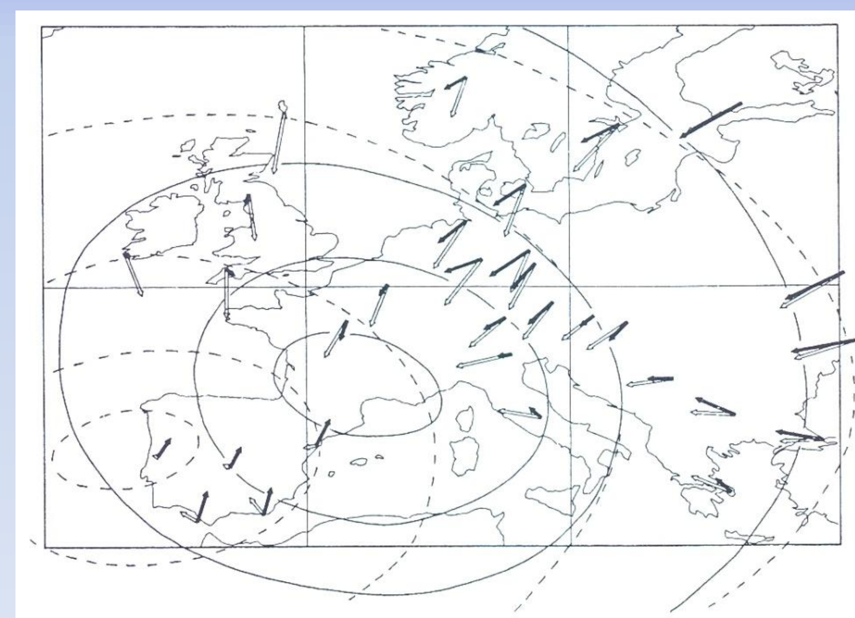


Images du satellite SOHO/NASA

Coronal holes
High speed solar wind

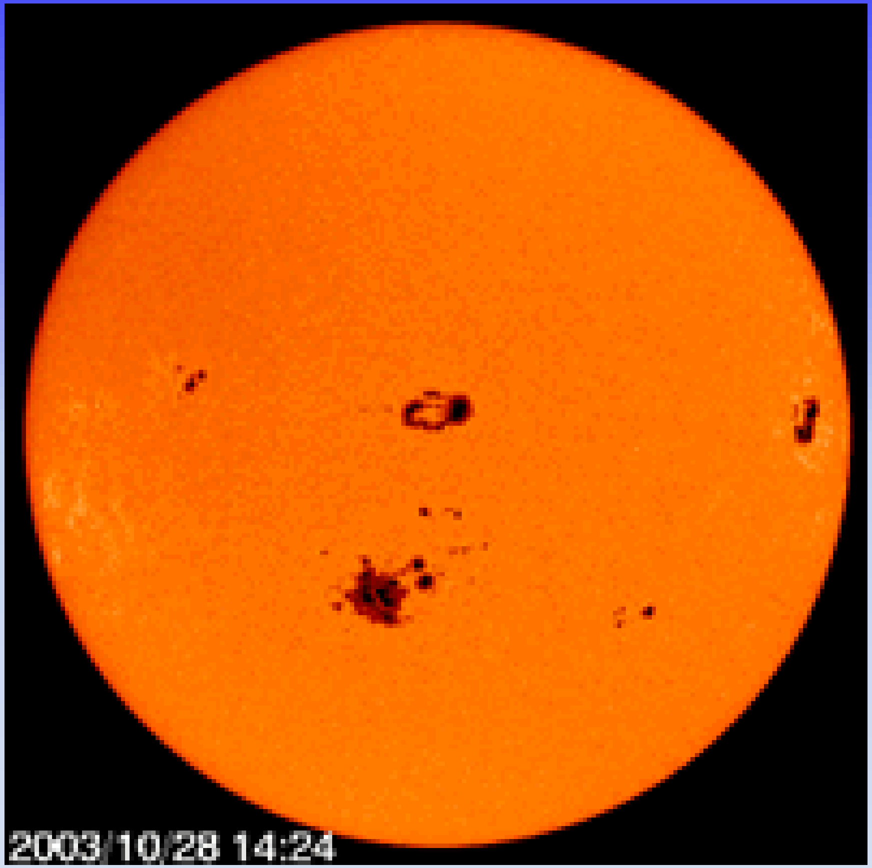
Solar Flare
X ray ….

Geomagnetic disturbance due to
A solar flare / black arrow



Curto et al.,JGR, 1994

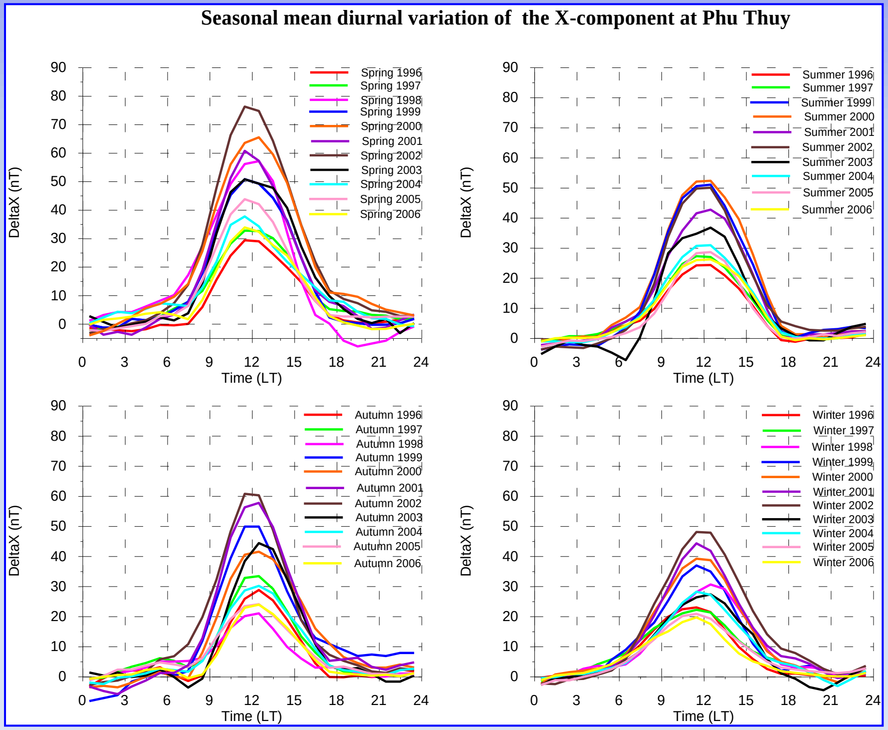
Sun Earth System



Images du satellite SOHO / NASA - ESA

Sunspot
Radiations EUV, UV
Solar cycle

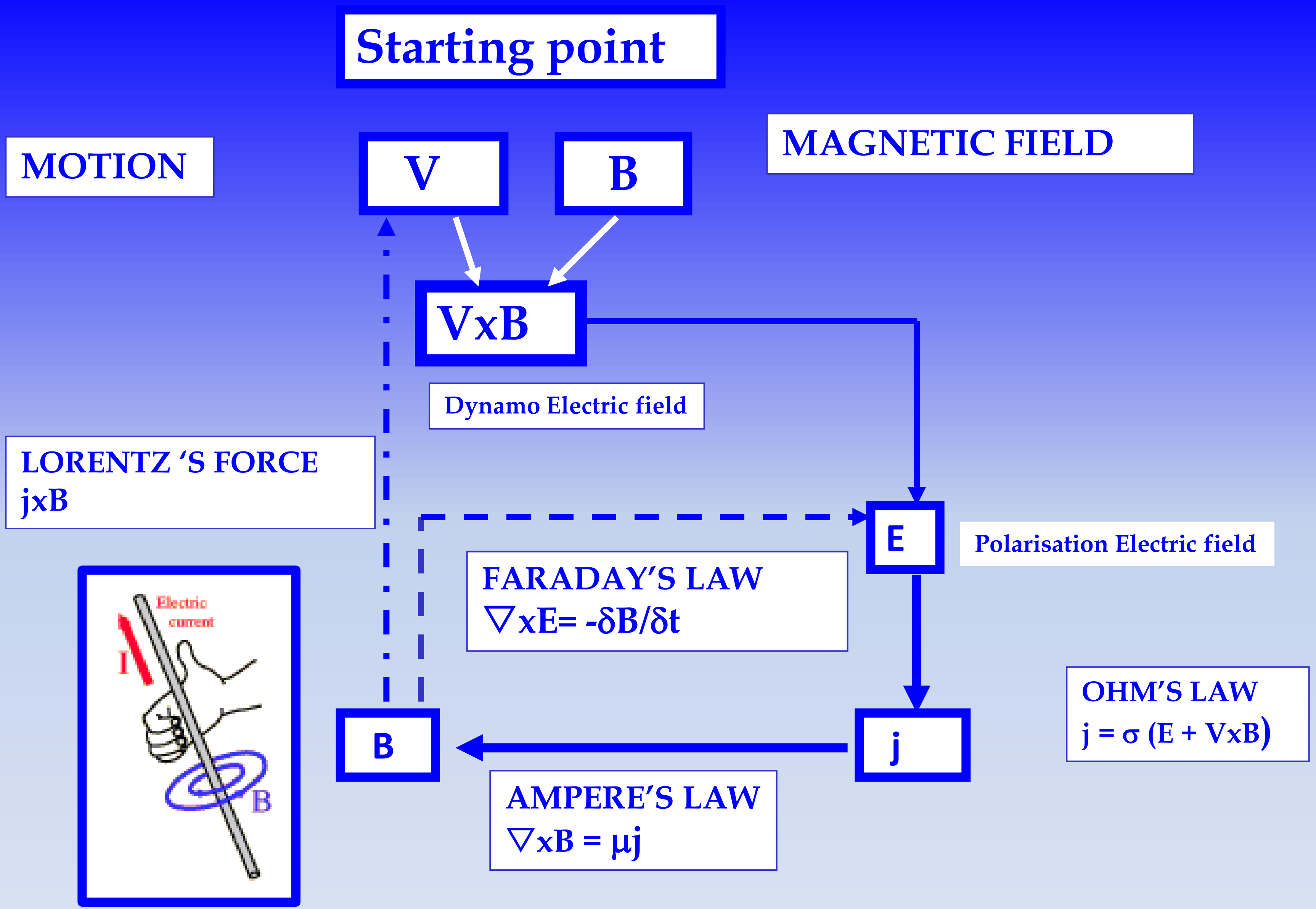
Regular variation of the Earth's magnetic Field at Phu Thuy/ Vietnam



Pham et al, Annales Geo. 2011

The Sun influences all the physical parameters of the Earth's environment through various physical processes.

To improve data analysis it is necessary to know the physical processes acting in the global Sun Earth' system when the data are recorded.



Principle of the DYNAMO ACTION

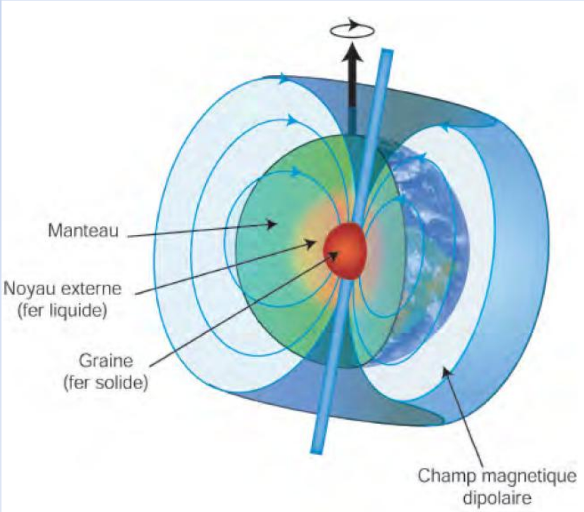
Outlines

- Sun Earth System : a global electromagnetic complex system
- <u>Dynamo process and large scale dynamos</u>
- Electric currents associated to the different dynamos
- Magnetic field to approach electric currents
- Magnetic indices

- B = Bp + Ba + Be + Bi

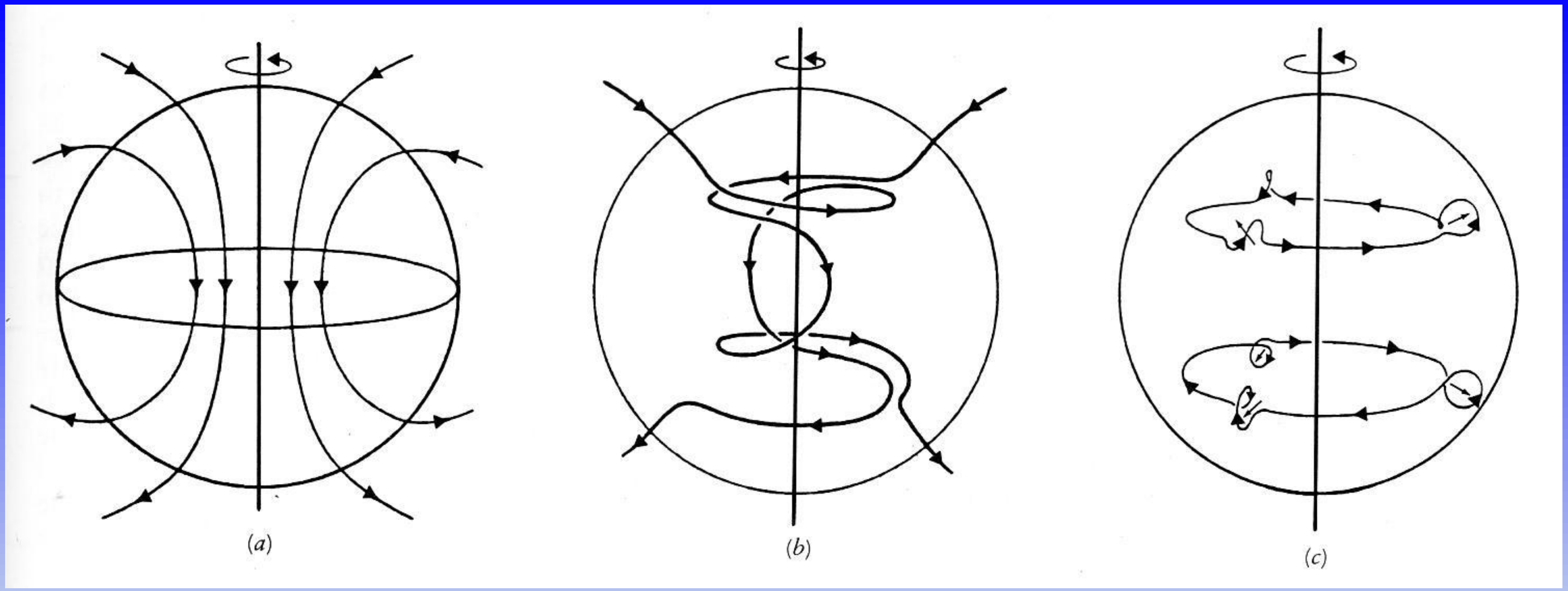
In this section we will present the main dynamos at the origin of Be

Bp : Main field (core)
Ba : Aimantation field (Listosphère)
Be : field related to external sources
Bi : induced by Be



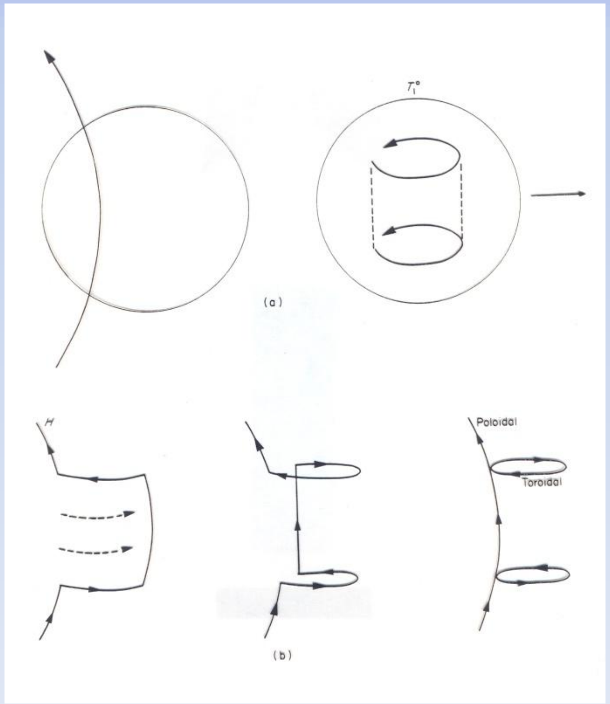
SOLAR DYNAMO

see the lecture of Prof. Munoz



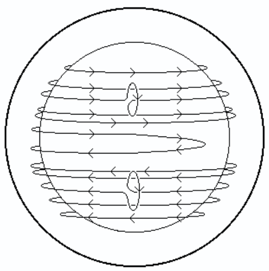
Poloidal field

Toroidal field



SOLAR DYNAMO

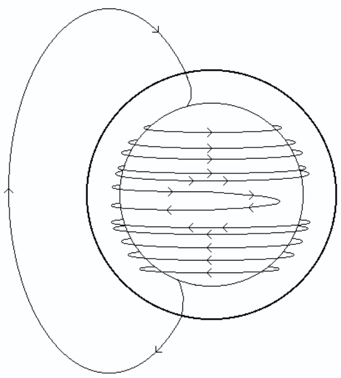
Friedman 1987



The α-effect

http://solarscience.msf.nasa.gov/dynamo.shtml

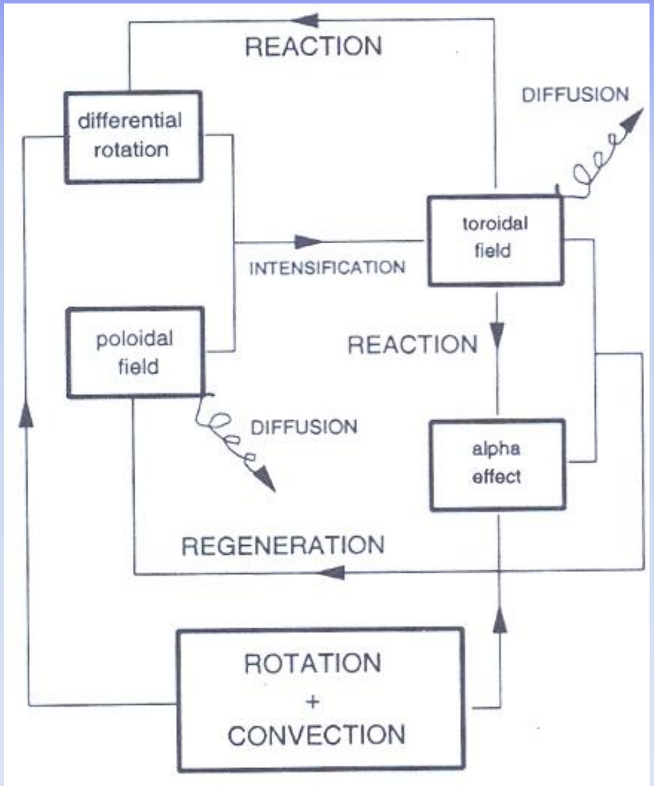
Twisting of the magnetic field lines is caused by the effects of the Sun's rotation α



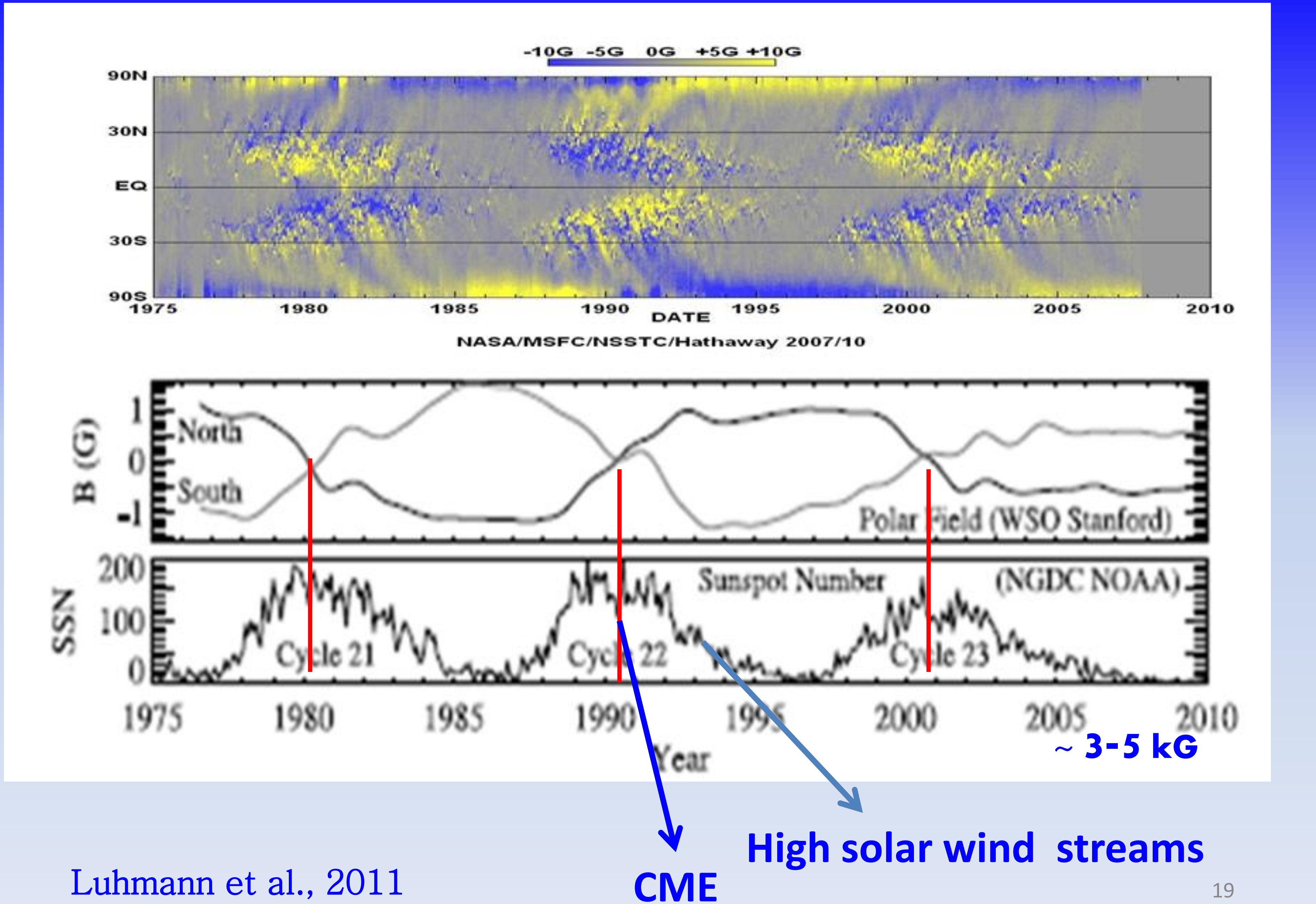
The ω-effect

Differential rotation change in rotation rate as a function of latitude and radius within the Sun $\omega(r,\theta)$

Diagram from L. Paterno, 2006



The solar dynamo ingredients
Motions : rotation and convection
Magnetic field : dipolar component



Luhmann et al., 2011

It is a necessity to reanalyze all the ionospheric data, taking into account new knowledge on the SUN

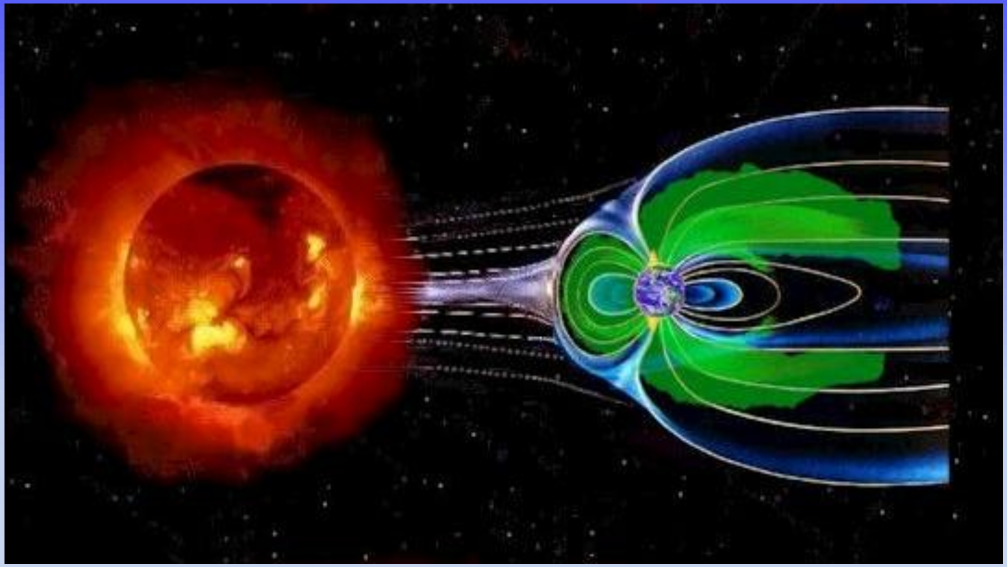
Geophysics -> heliophysics

International Heliophysics Year

Solar Wind – Magnetosphere Dynamo

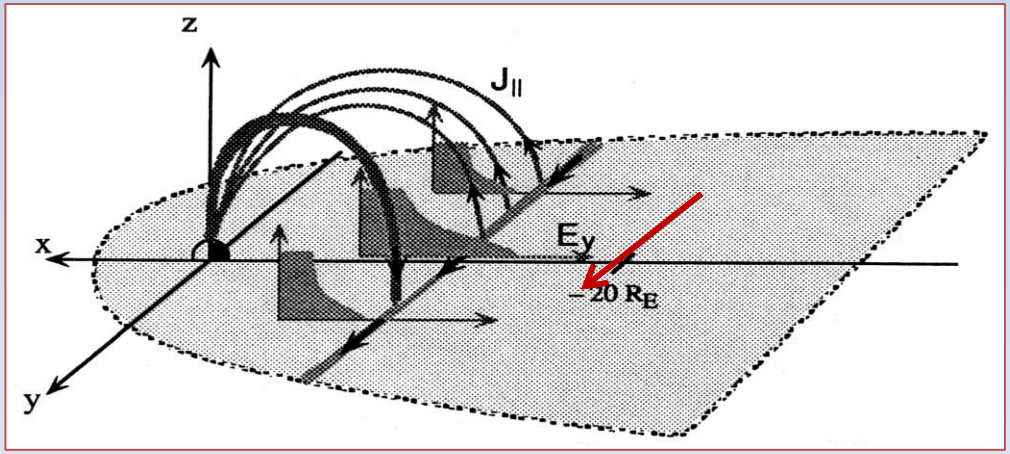
see the lectures of Prof. Miyoshi and Prof. Kikuchi

The Solar wind magnetosphere Dynamo
Magnetic storm



E = -Vs x Bi

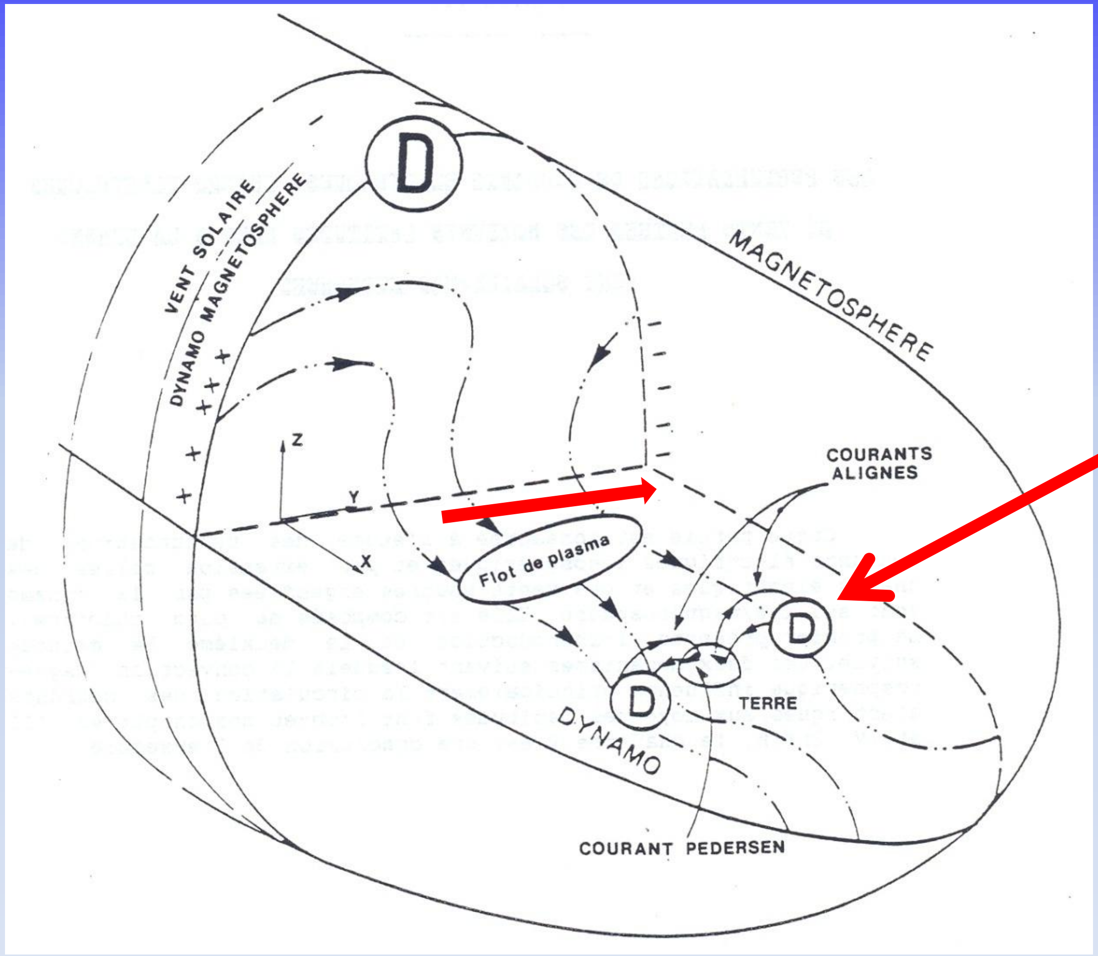
Vs : Solar wind ,
Bi : magnetic field of interplanetary medium



Frame of the magnetosphere

Component Bz of the interplanetary directed toward the south is a condition for a magnetic storm in the majority of the cases.

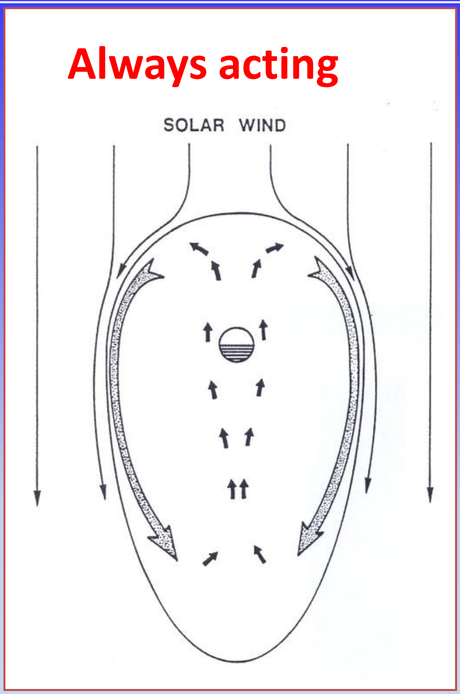
Solar wind – magnetosphere dynamo is continuously acting



Secondary dynamos

Motion of particules from the tail to the Earth ExB drift

The solar wind magnetosphere dynamo / Theories

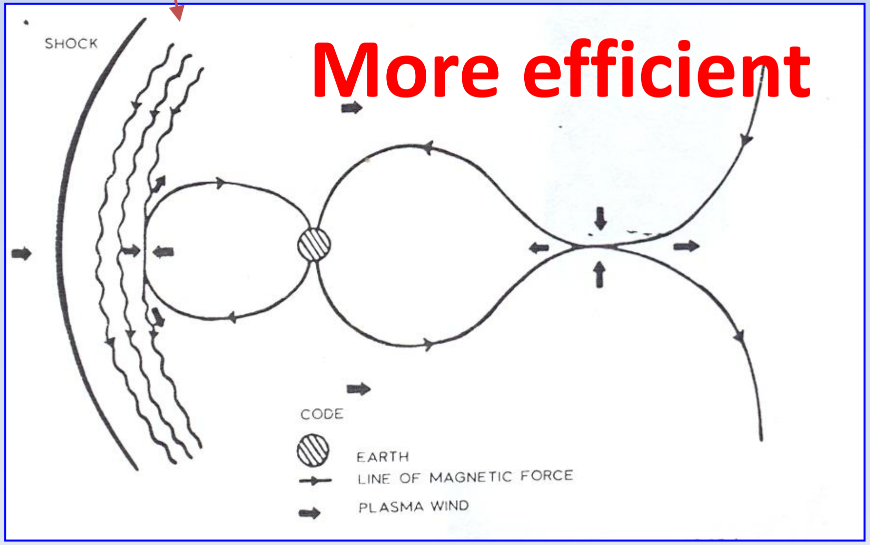


Viscous interaction between the solar wind and the magnetosphere, Axford and Hines, 1961. Interplanetary electric field transmitted to the magnetosphere : $E = -Vsx\ Bi$

Other process -> reconnection Dungey 1961
Connection between the interplanetary magnetic field and the Earth's magnetic field

This process is based on a closed magnetosphere Today the magnetosphere is considered a open

These 2 processes produce motions of particles in the magnetosphere -> electric currents



ATMOSPHERIC WIND
IONOSPHERIC DYNAMO

Photo ionisation

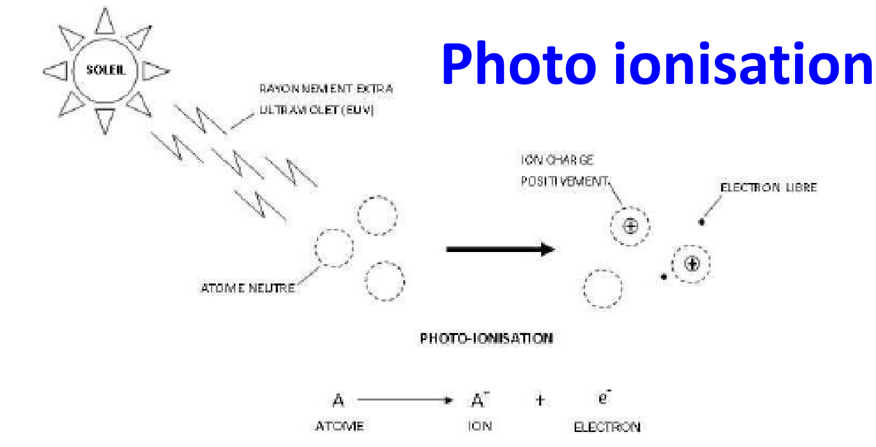
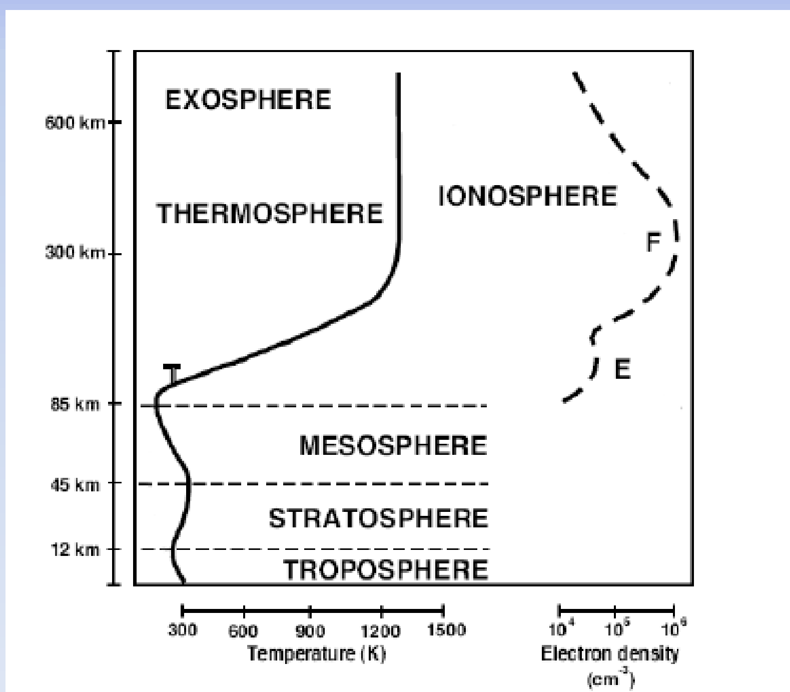
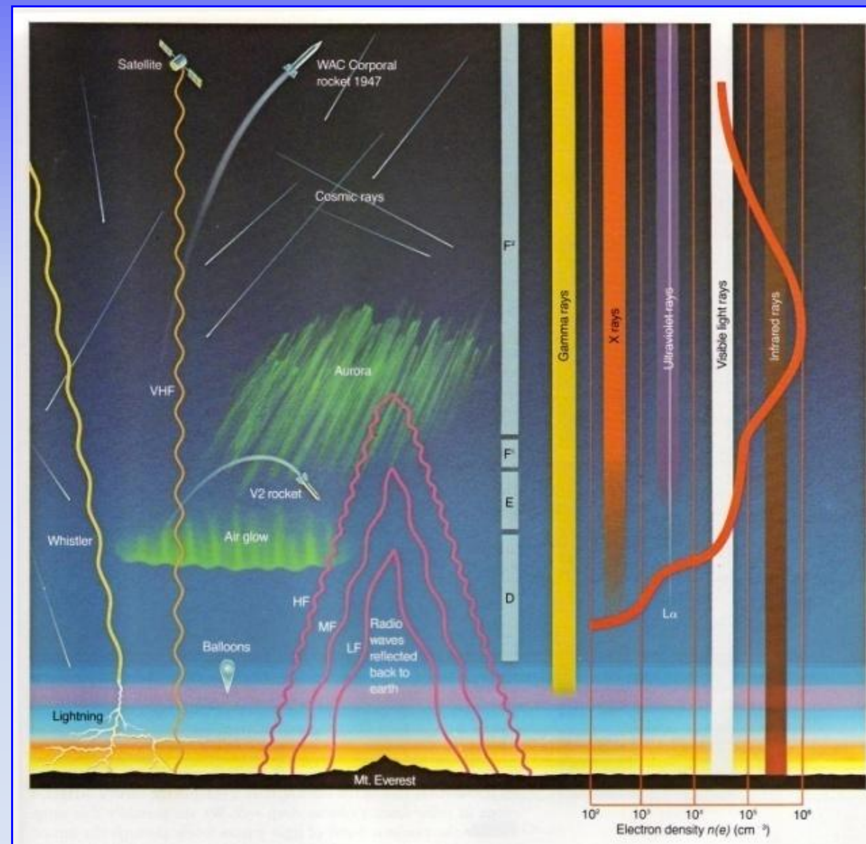


FIGURE 1.6 – *Photoionisation d'un atome neutre A, par un rayonnement ultraviolet extrême (EUV) du soleil, produisant un ion chargé positivement A^+ et un électron libre e^-.*

IONOSPHERIC DYNAMO SOLAR RADIATIONS UV , EUV





Friedman, 1987

IONOSPHERIC DYNAMO: Conductive layer

Motion of the neutral atmosphere — V_n

Earth's magnetic field — B_t

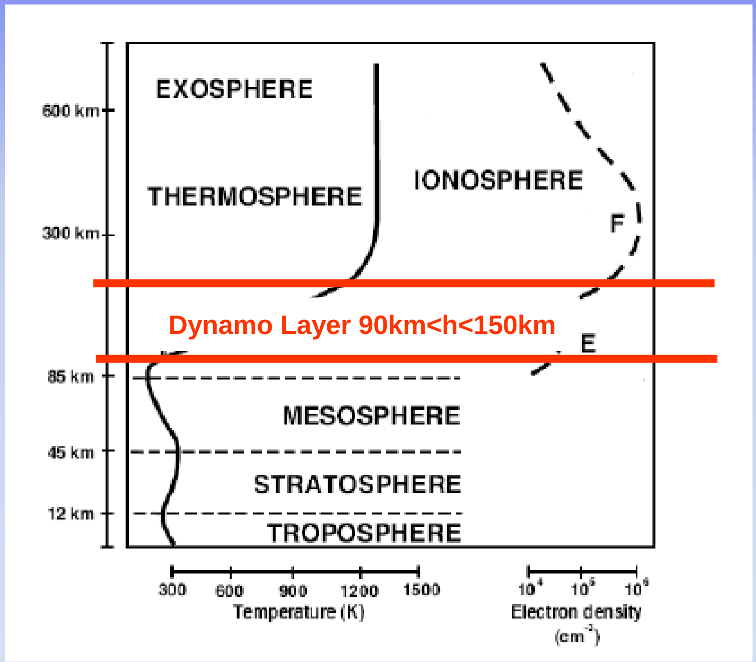
DYNAMO electric field — $V_n x B_t$ → E — POLARISATION electric field

IONOSPHERIC OHM'S LAW

$$\vec{J} = \sigma_p \left(\vec{E}_\perp + \vec{V}_n \Lambda \vec{B}\right) + \sigma_h \vec{b} \Lambda \left(\vec{E}_\perp + \vec{V}_n \Lambda \vec{B}\right) + \sigma_{//} \vec{E}_{//}$$

$$\sigma_p = \frac{N_e e}{B}\left(\frac{\nu_{in}\Omega_i}{\nu_{in}^2 + \Omega_i^2} + \frac{\nu_{en}\Omega_e}{\nu_{en}^2 + \Omega_e^2}\right)$$

$$\sigma_h = \frac{N_e e}{B}\left(\frac{\Omega_e^2}{\nu_{en}^2 + \Omega_e^2} - \frac{\Omega_i^2}{\nu_{in}^2 + \Omega_i^2}\right)$$



$$\Omega_e = \frac{eB}{m_e} \qquad \Omega_i = \frac{eB}{m_i}$$

Gyrofrequencies of electrons ans ions

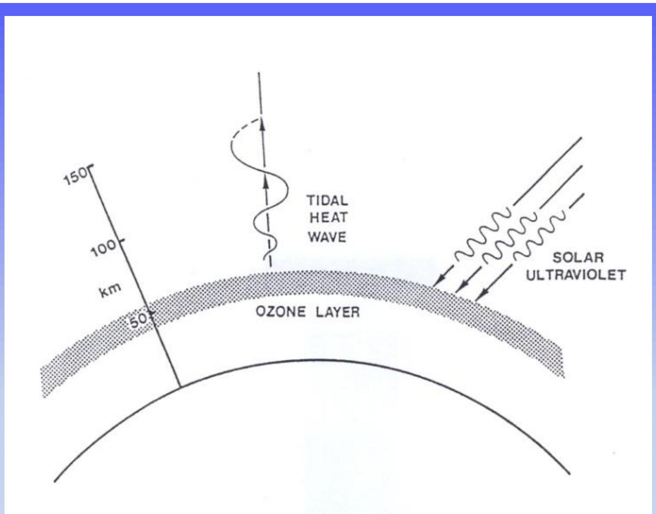
σ_p: Pedersen conductivity ⊥ B et // E

σ_h: Hall conductivity ⊥ B et E

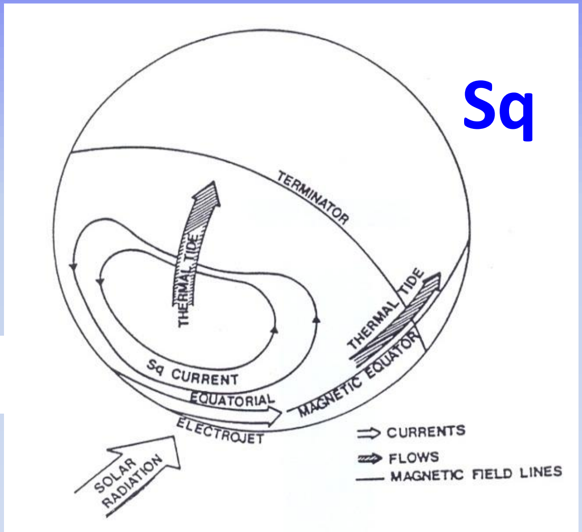
υ_{in} et υ_{en}: collisions frequencies

IONOSPHERIC DYNAMO / Neutral winds

Stratosphere Atmospheric Tides , Evans 1977

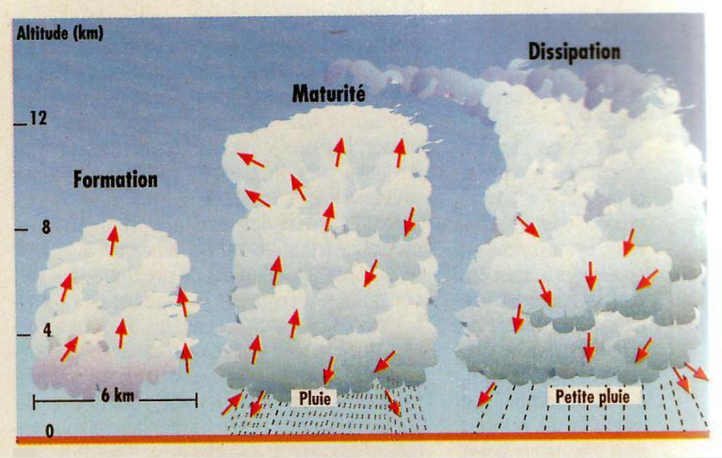


Diurnal process
E Region of the
Ionosphere
(90km< h< 150km)



Sq

Deep convection in the troposphere : non migrating tides

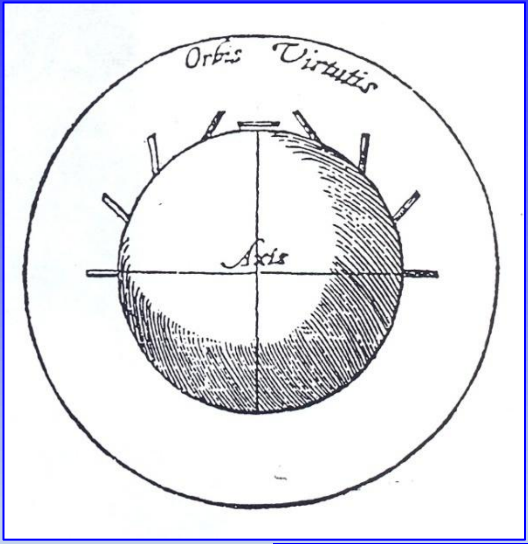


Vertical coupling
Dynamics of the Atmosphere
Ionospheric Electrodynamics
Atmospheric electricity

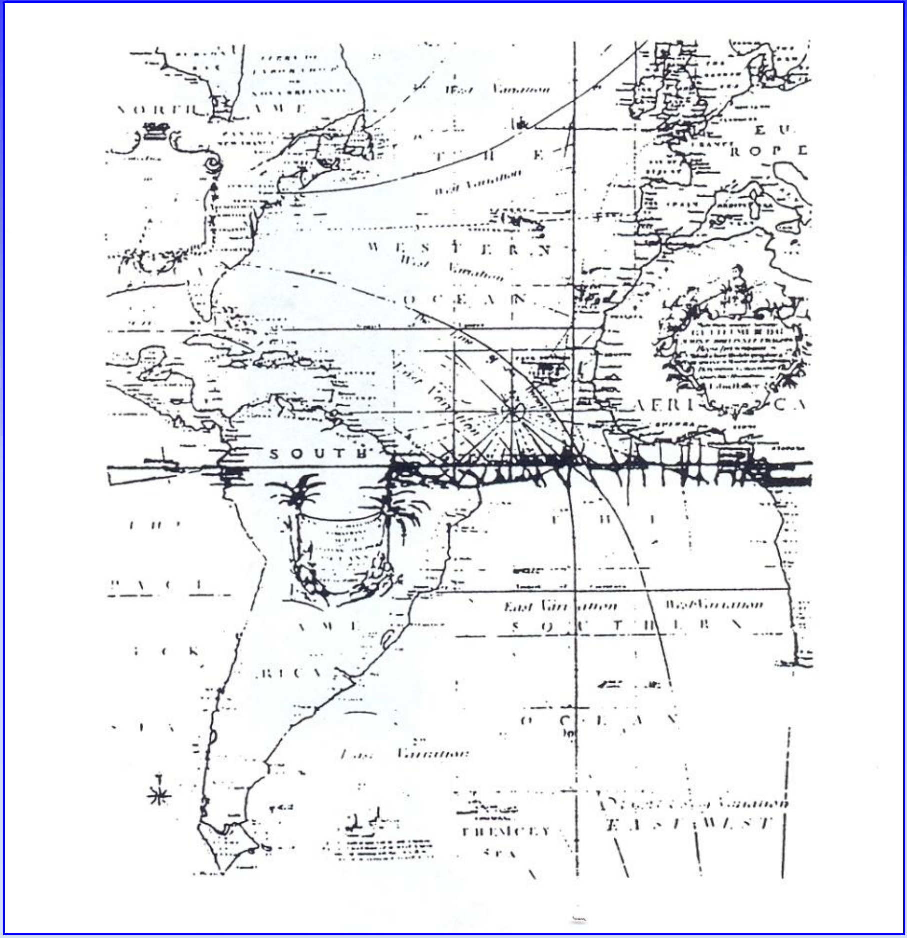
Field to inestigate

EARTH' s DYNAMO

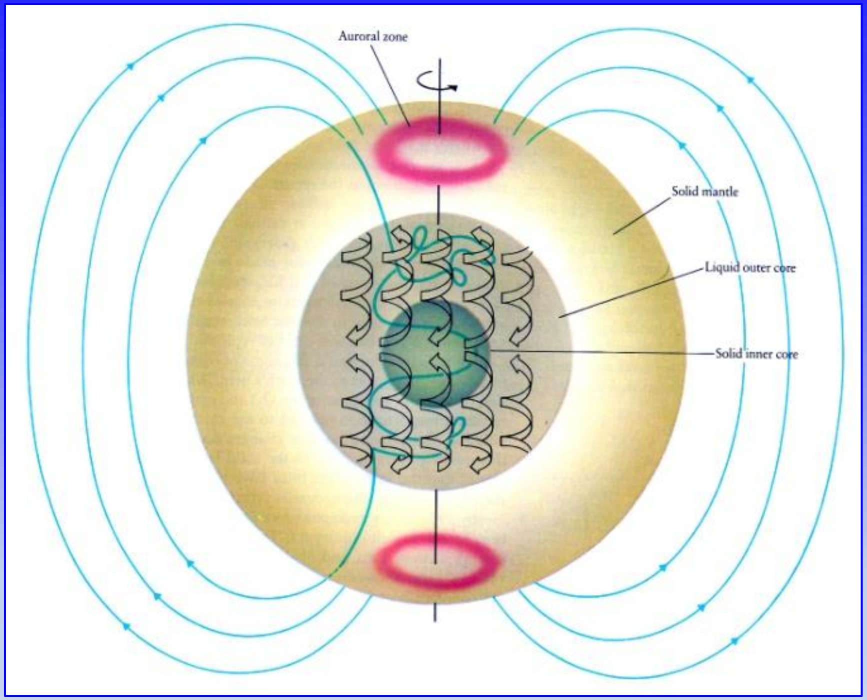
EARTH'S DYNAMO
Earth's magnetic field known since more 2 millenaries



Gilbert, 1600 -> Dipole



First map of the Earth's magnetic field Halley 1701



Internal Earth's dynamo -> Bp + Ba

Bp : main field , Ba : aimantation field (Lithosphere)

IGRFmodel

http://www.iugg.org/IAGA/iaga_pages/pubs_prods/igrf.htm

Dynamo	Motions – V	Magnetic field B	Order of Magnitude
Sun	Sun Rotation and convection	Sun : 2 components Dipolar Toroïdal = sunspot	rotation speed : ~ 7280km/h at the equator Dipolar component : ~10 G Toroidal component : ~3-5 kG
Solar wind Magnetosphere	Solar wind	Interplanetary medium -> Bi	speed ~ [400km/s to 1000km/s] Bi ~ qq 10 nT
Atmospheric wind Ionosphere	Atmosphere	Earth's -> Bt	speed ~ 100m/s Bt ~ qq 10 000 nT
Earth's Dynamo inside the Earth	Metallic core	Earth's -> Bt	Indirect measurements deduced from the Earth's planetary magnetic field and the secular variation Velocity ~ qq km/year Bt ~ qq 10 000 nT

OUTLINES

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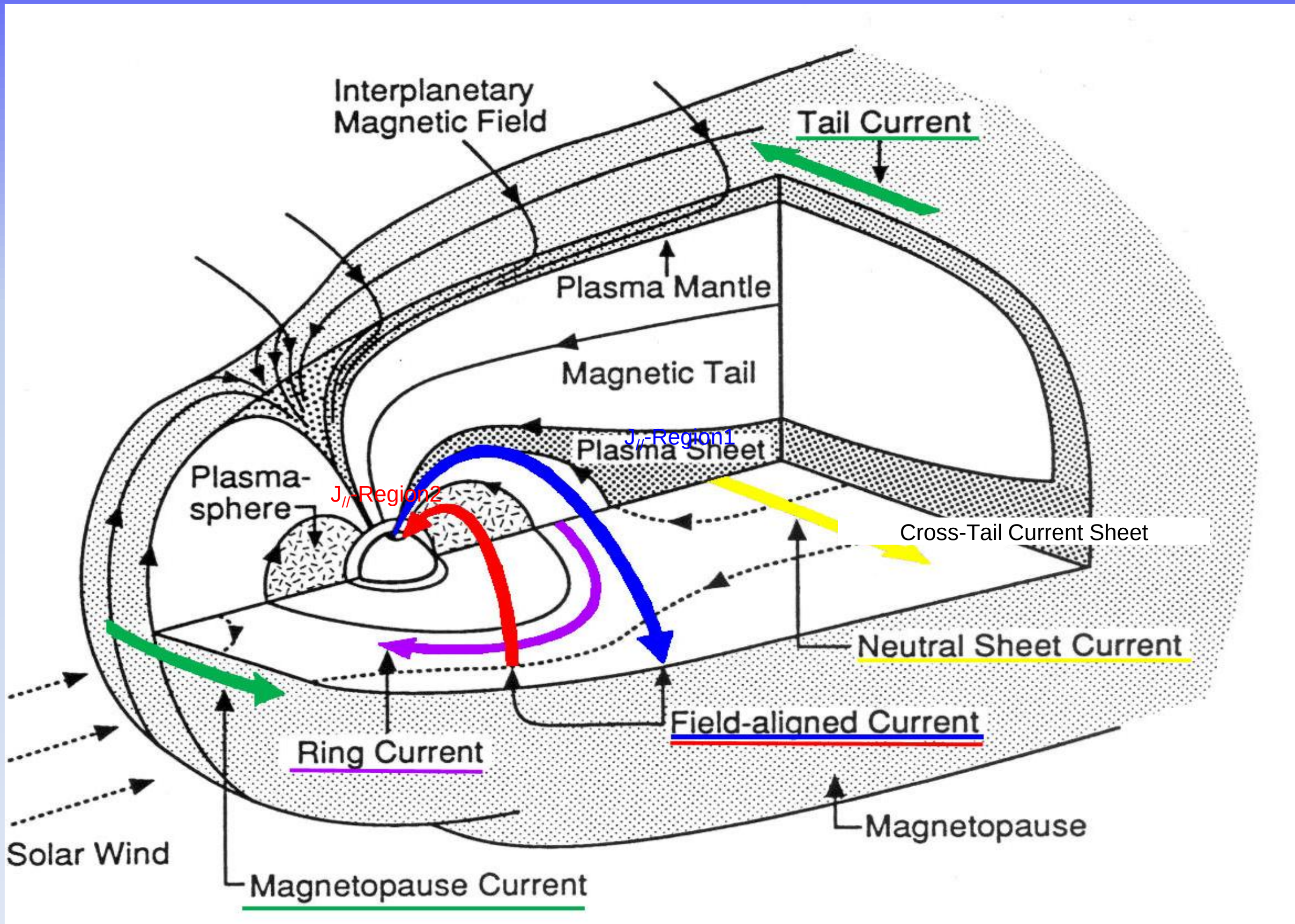
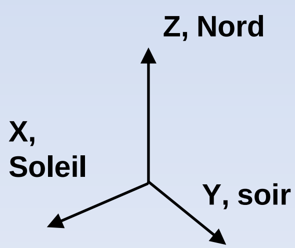
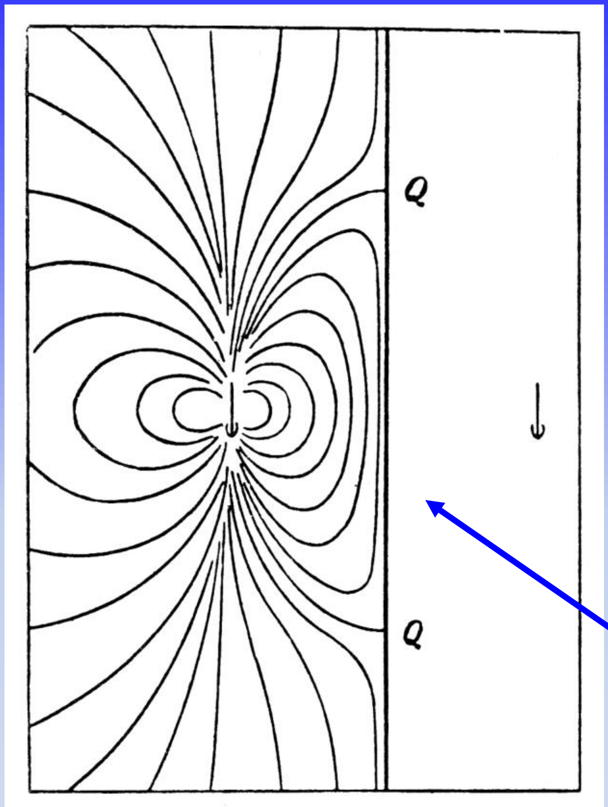
Solar wind magnetosphere dynamo (Vs, Bi)
Electric currents in the magnetosphere

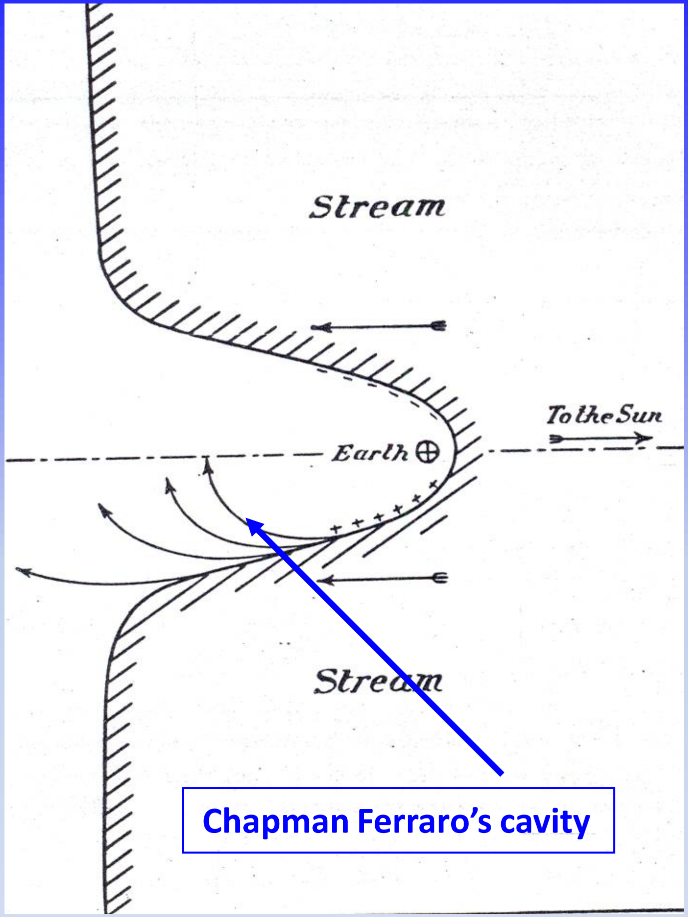




Chapman Ferraro currents/ 1935
Noze of the Magnetopause



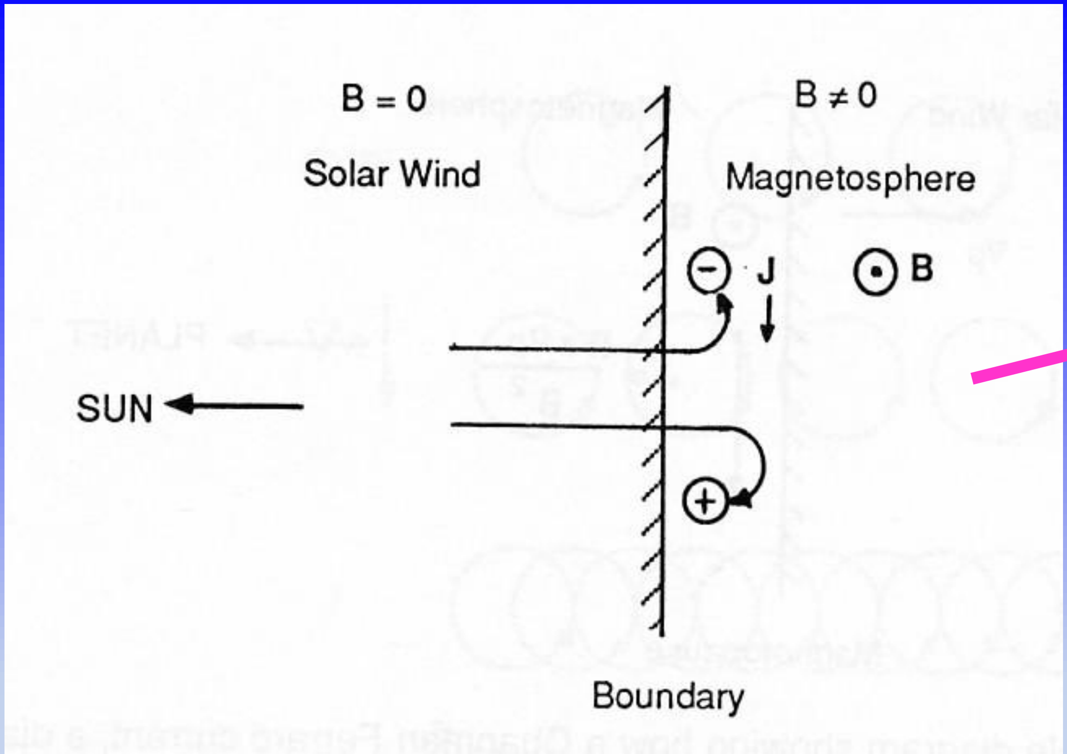
2 dimensional conducting sheet

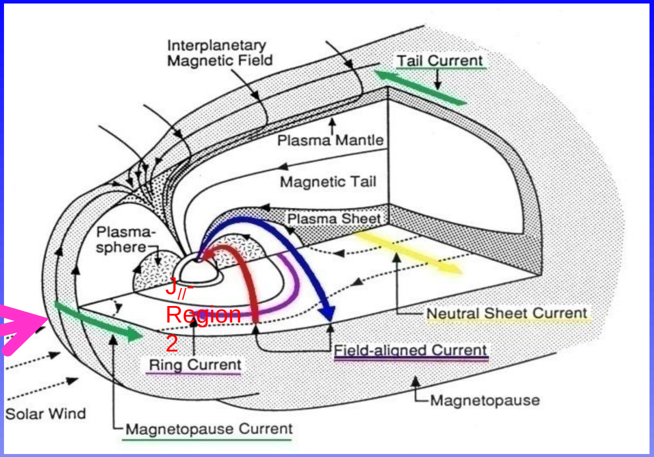


Chapman Ferraro's cavity

Chapman and Ferraro in 1935 explained magnetic storms by the interaction of a cloud of neutral mixture and ions and electrons (today named plasma) approaching the Earth's dipole. When the cloud of 'plasma' approaches the Earth, electric currents would be induced in it, producing magnetic disturbances.

See lecture of Prof. Watanabe





See lecture of Prof. Watanabe

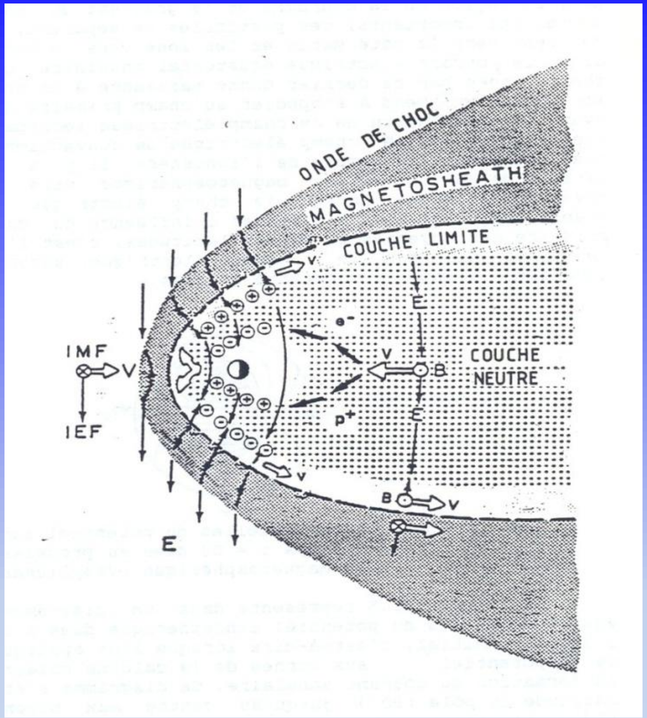
The Chapman Ferraro currents flow in the Magnetopause layer, the boundary between the solar wind and the geomagnetic field. At the nose of the magnetopause the geomagnetic field pressure is balanced by the dynamic pressure of the solar wind

$$K_1 N_i m_i V_i^2 = \frac{B_{mp}^2}{2\mu_0}$$

dynamic pressure of the solar wind ⇔ geomagnetic field pressure

K_1 is the correction factor for flow deflection in magnetosheath and compression of B. The order of magnitude of the Chapman Ferraro current is ~ 30 nT (Gosling et al. 1990).

See lecture of Prof. Miyoshi



Ring current

Dawn-dusk voltage drop difference to the magnetosphere

↓

Particles follow trajectories from the tail of the magnetosphere toward the Earth

↓

In the region where the curvature and gradient of the Earth's 's magnetic field are strong, particles are separated, the electrons are diverted to the morning side and the ions to the evening side.

Formation of the ring current

The expression of the drift due to gradient and curvature and the resulting current is:

$$\vec{V}_{gc} = \frac{1}{2} m V_{\perp}^2 \frac{B \times \nabla B}{qB^3} + m V_{LL}^2 \frac{B \times (b.\nabla)\hat{b}}{qB^2}$$

$$J_{gc} = NqV_{gc}^{ions}$$

This current is mainly carried by ions.

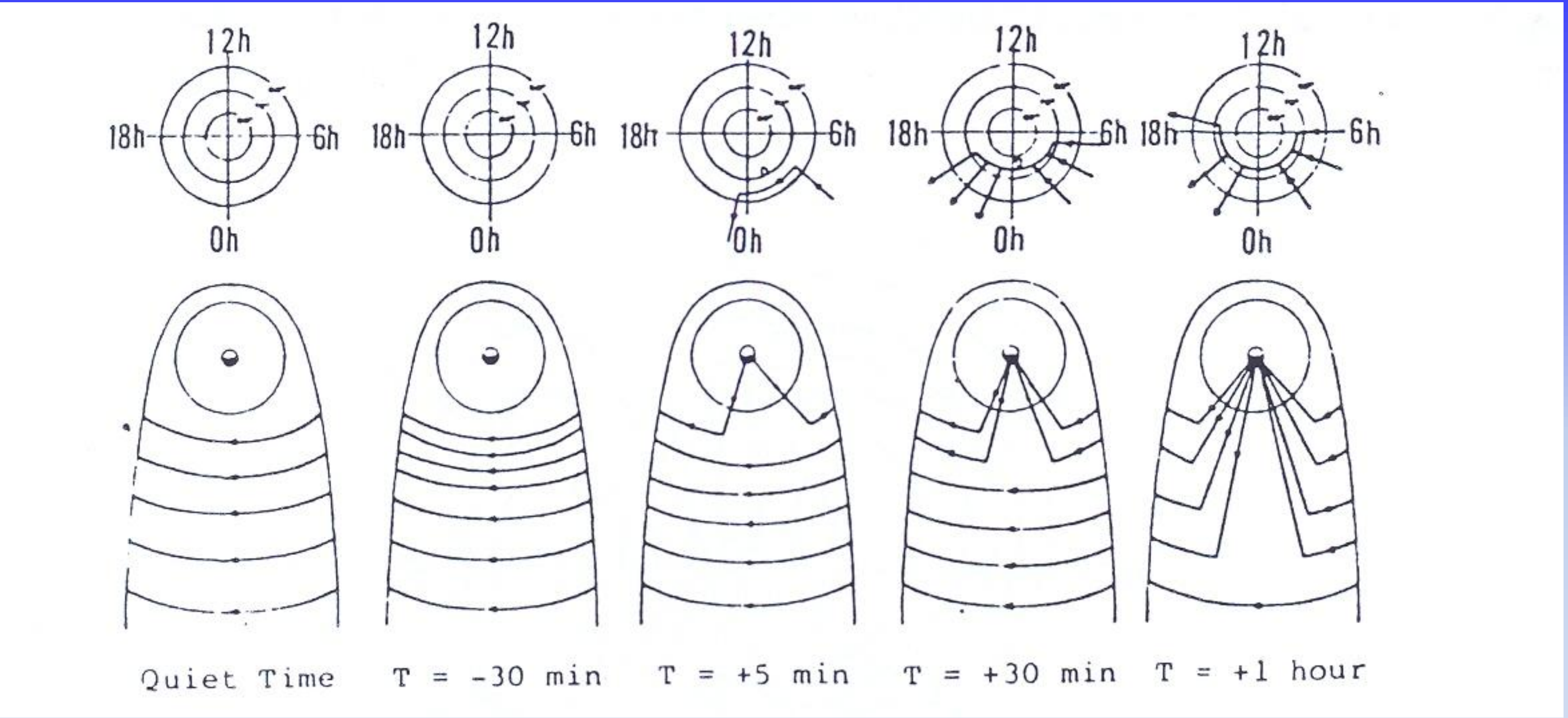
There is also an additional contribution of the magnetic moments of all particles:

$$\vec{M} = -N_i \frac{1}{2} \frac{m_i V_{i\perp}^2}{B} \hat{b} - N_e \frac{1}{2} \frac{m_e V_{e\perp}^2}{B} \hat{b}$$

$$\vec{J}_m = \nabla \times \vec{M}$$

The ring current keeps the pressure gradient and the Lorentz force in balance.

Tail currents / 1972



Proposed by Akasofu in 1972, the tail currents flowing at the boundary of the plasma sheet are disrupted and deflected toward the Earth on the evening side. These currents via Birkeland (field aligned current) be converted to a westward electrojet

Tail currents

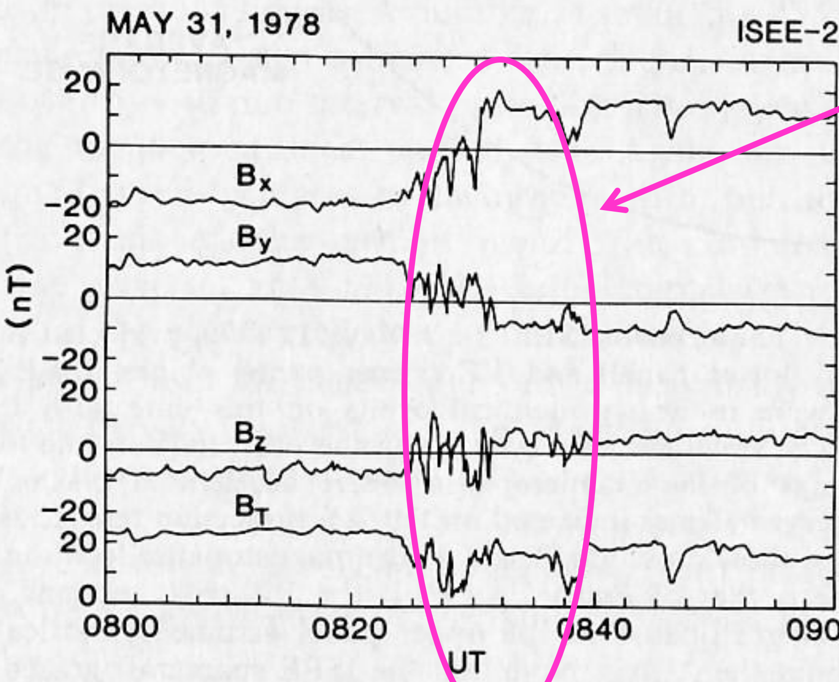
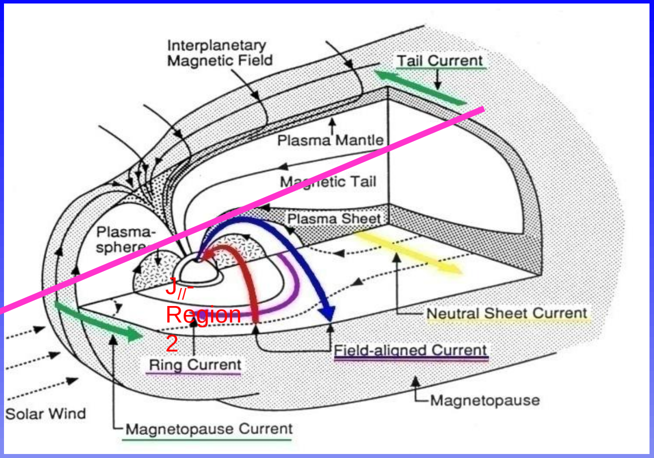
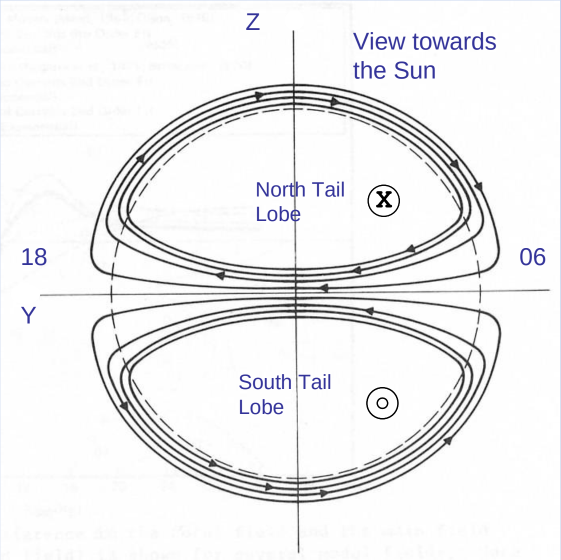


Fig. 2. Magnetic field data from ISEE 2 surrounding the ~0830 UT magnetopause crossing on May 31, 1978. From top to bottom the quantities plotted are the x, y, and z components (GSE coordinates) of the field and the total field magnitude.

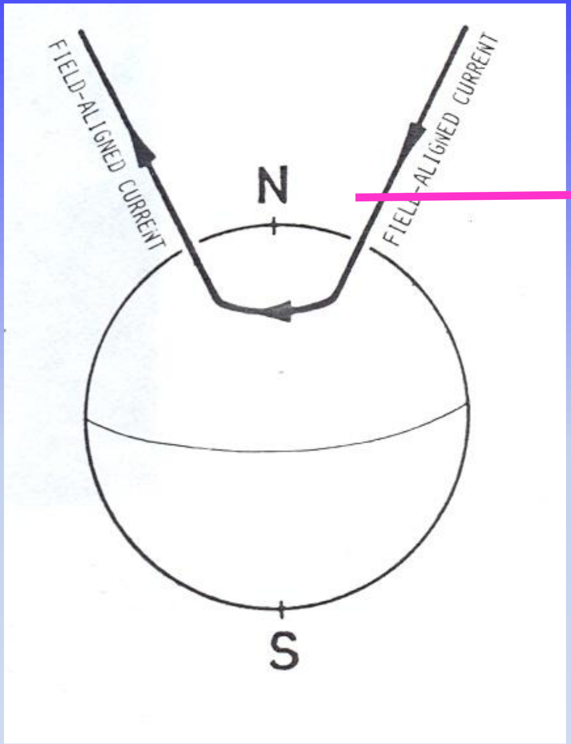


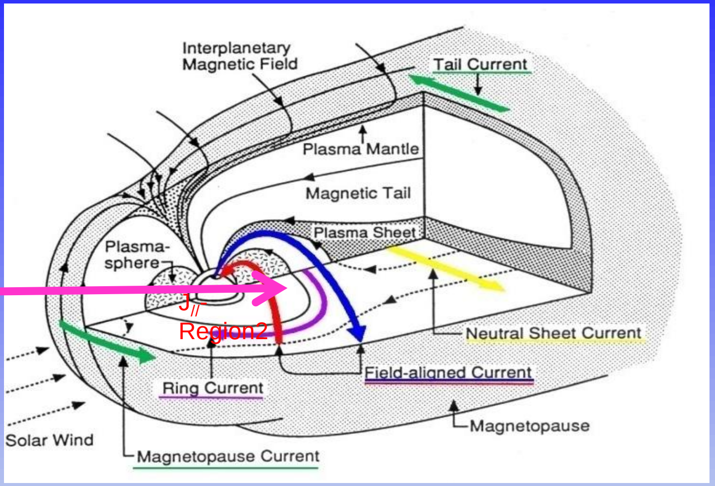
crossing of the magnetopause



Field aligned currents/1908

see lecture of Prof. Kikuchi



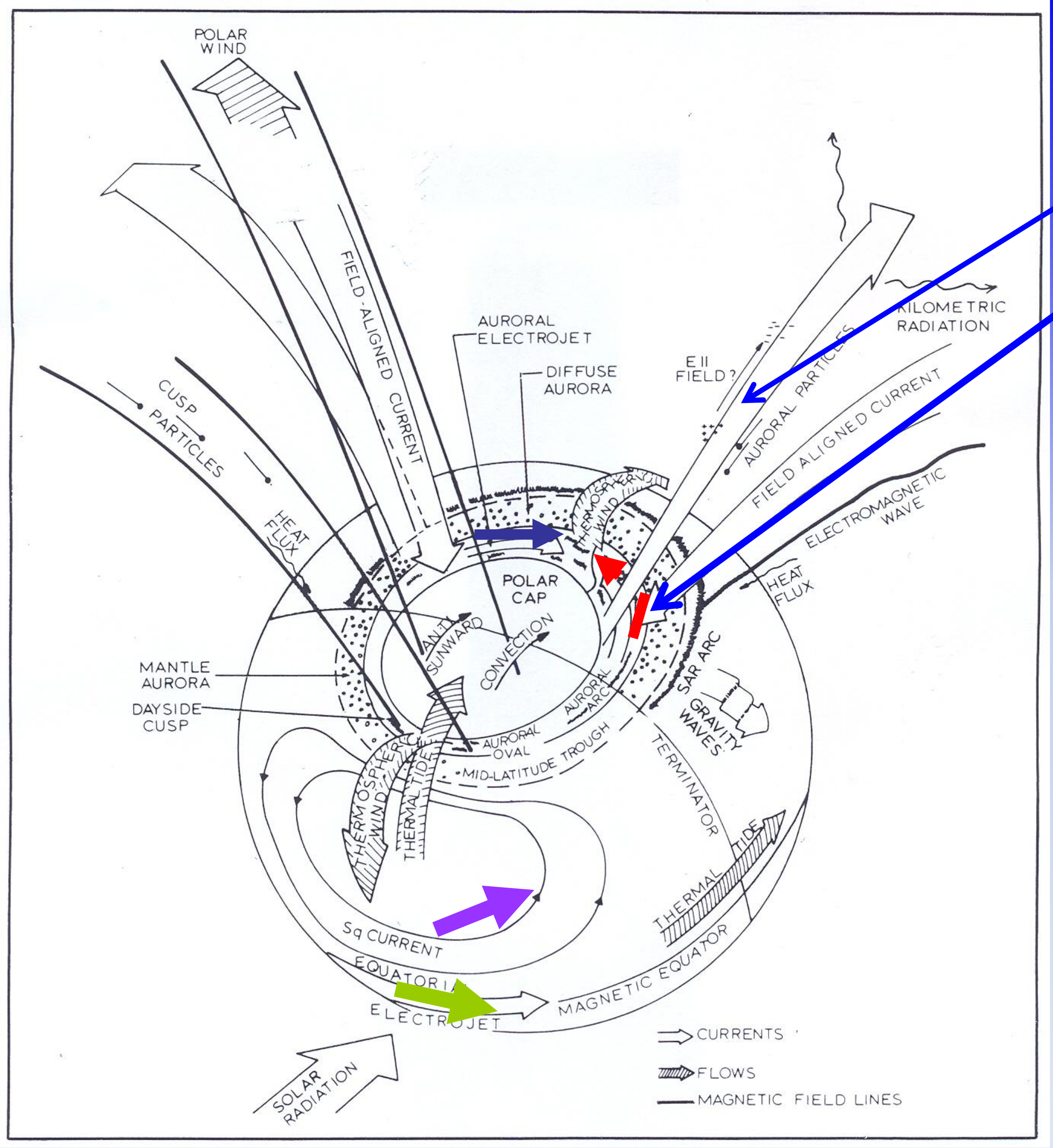


Birkeland, 1908

$$\nabla \vec{j} = \nabla_{\perp} \vec{j}_{\perp} + \nabla_{II} j_{II} = 0$$

The closure of the magnetospheric current loops requires field aligned currents flowing into and out of the ionosphere. The origin of the field aligned currents is near the equatorial edge of the magnetopause (region1), in the plasma sheet where the ring current is divergent (region 2) and at the magnetopause at high latitudes in the dayside.

Courants électriques Ionosphériques



Field aligned current

Auroral electrojets

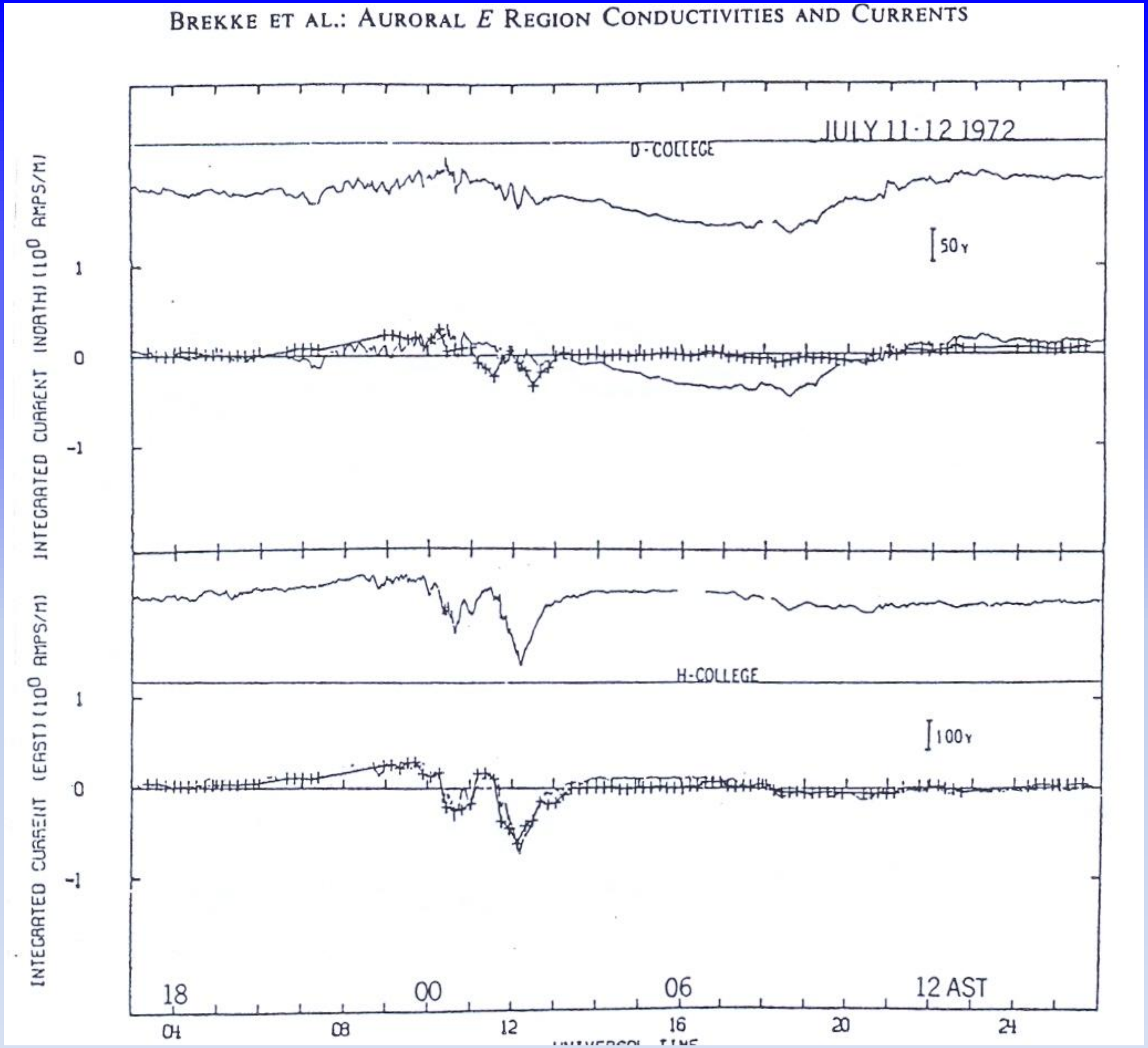
Precipitation of particles

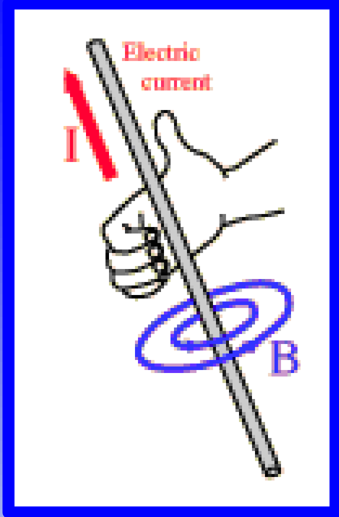
Electric field

Auroral

Middle latitudes

Equatorial latitudes

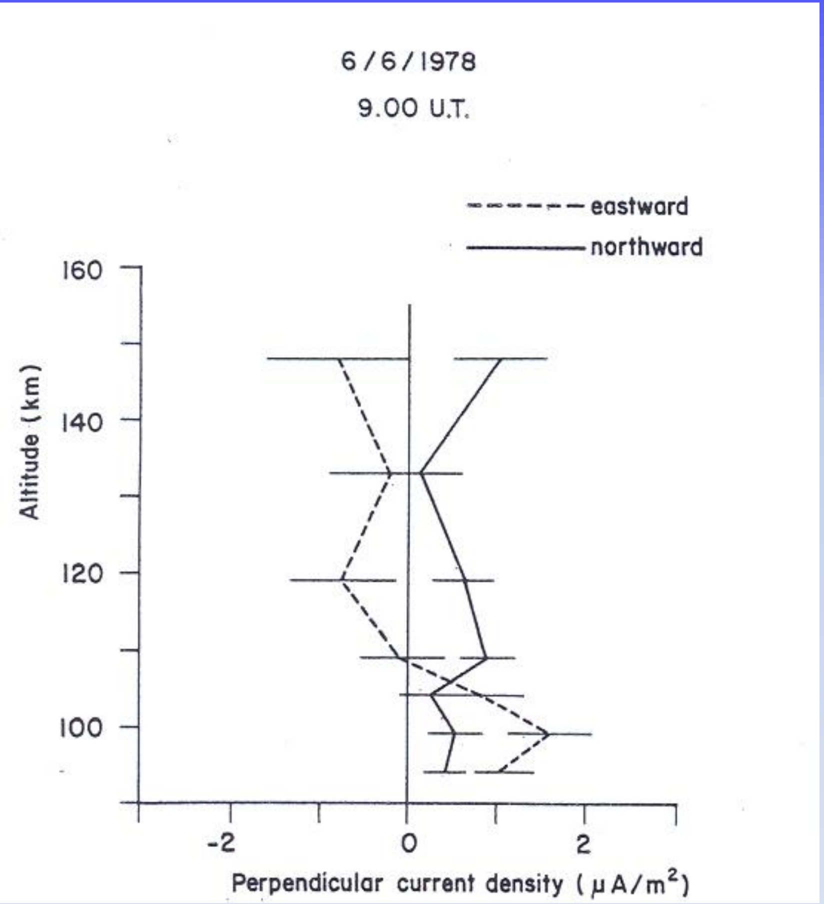




H : horizontal component
D : declination

In situ measurements of electric height integrated electric current densities with the Chatanika incoherent scatter sounder and comparison with the variations of the Earth's magnetic field, on July, 11, 1972 [after Brekke et al., 1974]. AURORAL ZONE

In situ measurements of electric current densities at midlatitudes with the incoherent scatter sounder of Saint-Santin, Mazaudier, 1981

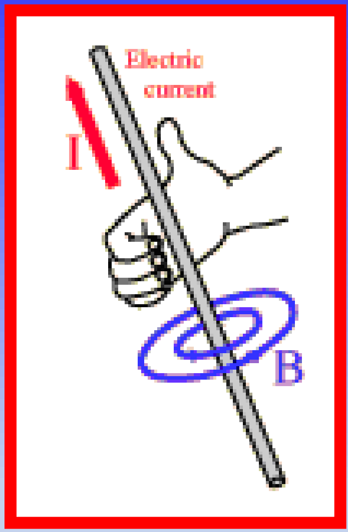


THERE ARE FEW MEASUREMENTS OF REAL ELECTRIC CURRENT

EQUIVALENT CURRENT SYSTEMS ARE DEDUCED FROM MAGNETIC DATA

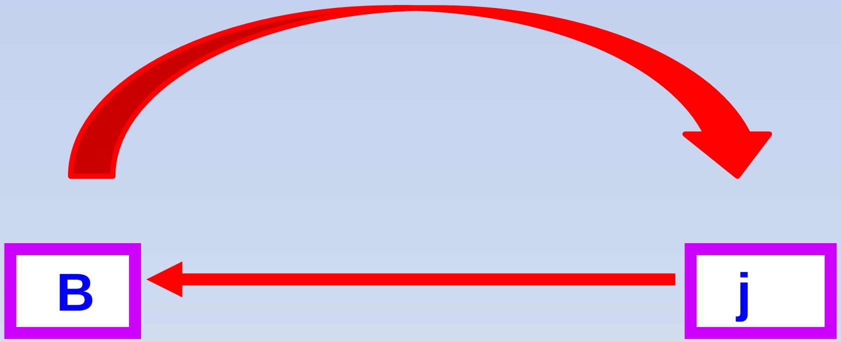
Integrated electric current densities : Amp/km = nT

$J = \sigma(E + V_n x B)$: Loi d'ohm ionosphérique



There are very few measurements of electric currents and many measuments of magnetic fields

We will use the magnetic data to approach the electric currents

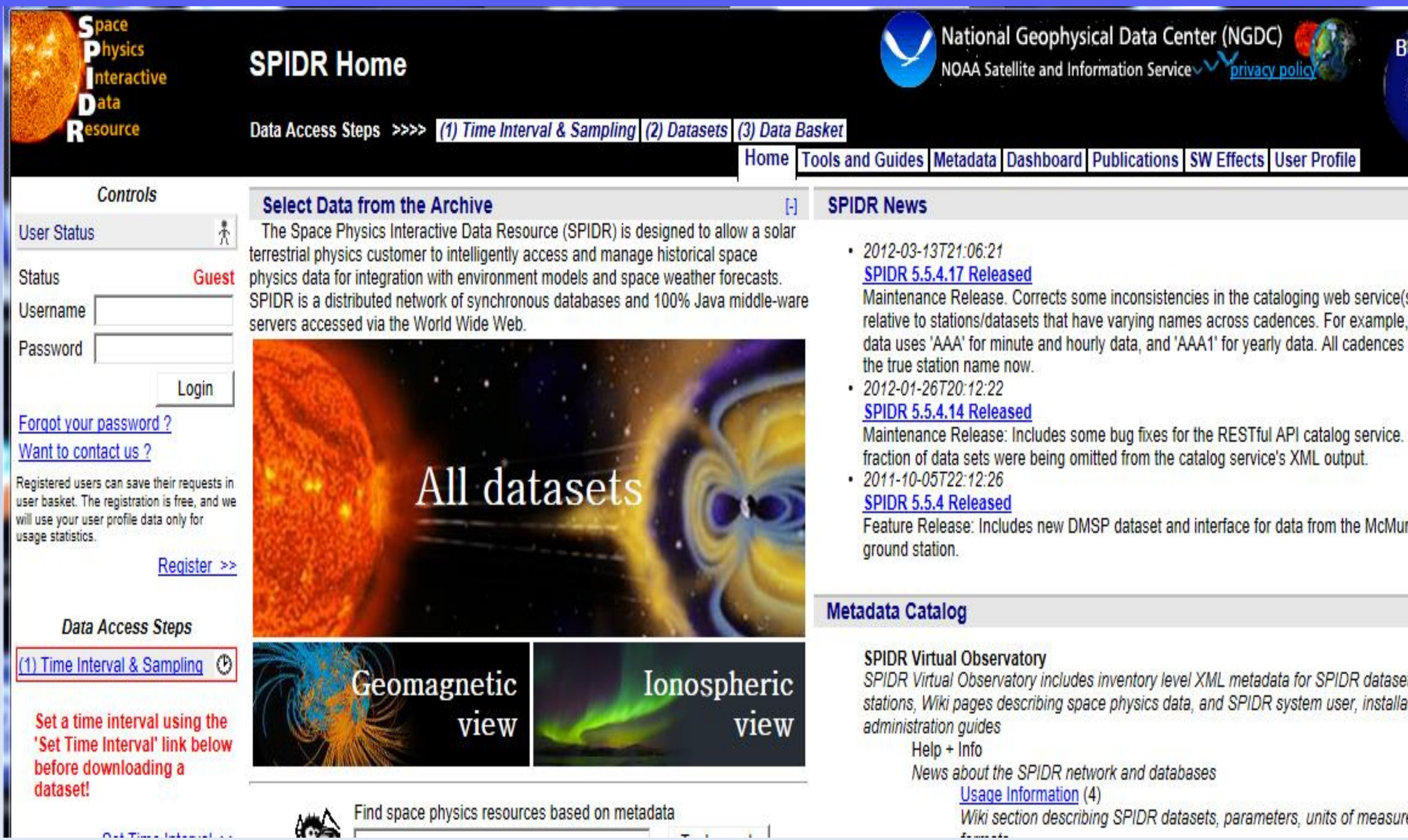


OHM'S LAW
$j = \sigma (E + V \times B)$

AMPERE 'S LAW
$\nabla \times B = \mu j$

Exercice: Use of the SPIDR

Space Physics Interactive Data Resspurce



OUTLINES

*Sun Earth System : a global electromagnetic complex system

*Dynamo process and large scale dynamos

*Electric currents associated to the different dynamos

Magnetic field to approach electric currents

*Magnetic indices

$B = B_p + B_a + B_e + B_i$

B_p = main field
(30000-60000nT)
B_a = magnetization of the rocks in the Lithosphere
(~ 10-20 nT)
B_e = external field related to Ionosphere and magnetosphere
(10nT to 2000nT)
B_i = induced field generated by the external field B_e, (Kamide and Brekke, 1975)
(% of B_e)

The main field changes very slowly : secular variation

The aimantation field is constant

↓

Transient variations of the earth's magnetic field are due to external electric currents and are indirectly a measure of these currents

- **Transient variations of the Earth's magnetic field :**

$$\Delta B = Be + Bi$$

$$\Delta B = S_R + D$$

Solar regular variation + Disturbance

Sq = $\langle S_R \rangle$

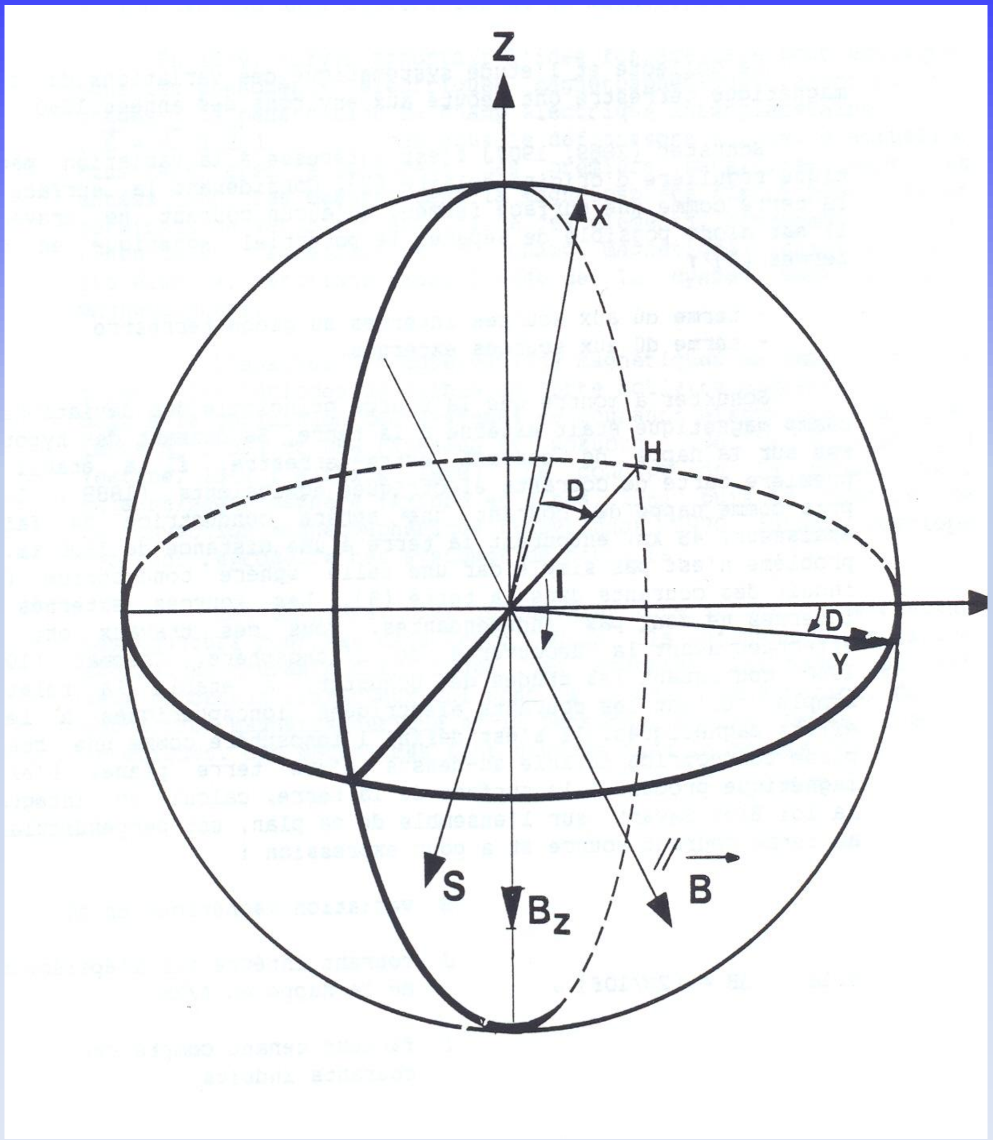
average of the variation of the quiet days

The disturbed D variation is the sum of the effects of the various electric current systems existing in the Earth's environment (Cole, 1966), Law Biot and Savart

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

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 (DP1, DP2, Ddyn)
(~qq nT to 2000 nT)
DG : magnetic disturbance due to electric currents flowing in the ground related to external electric current systems (~30 % or more) cause of power failure

THE EARTH MAGNETIC FIELD



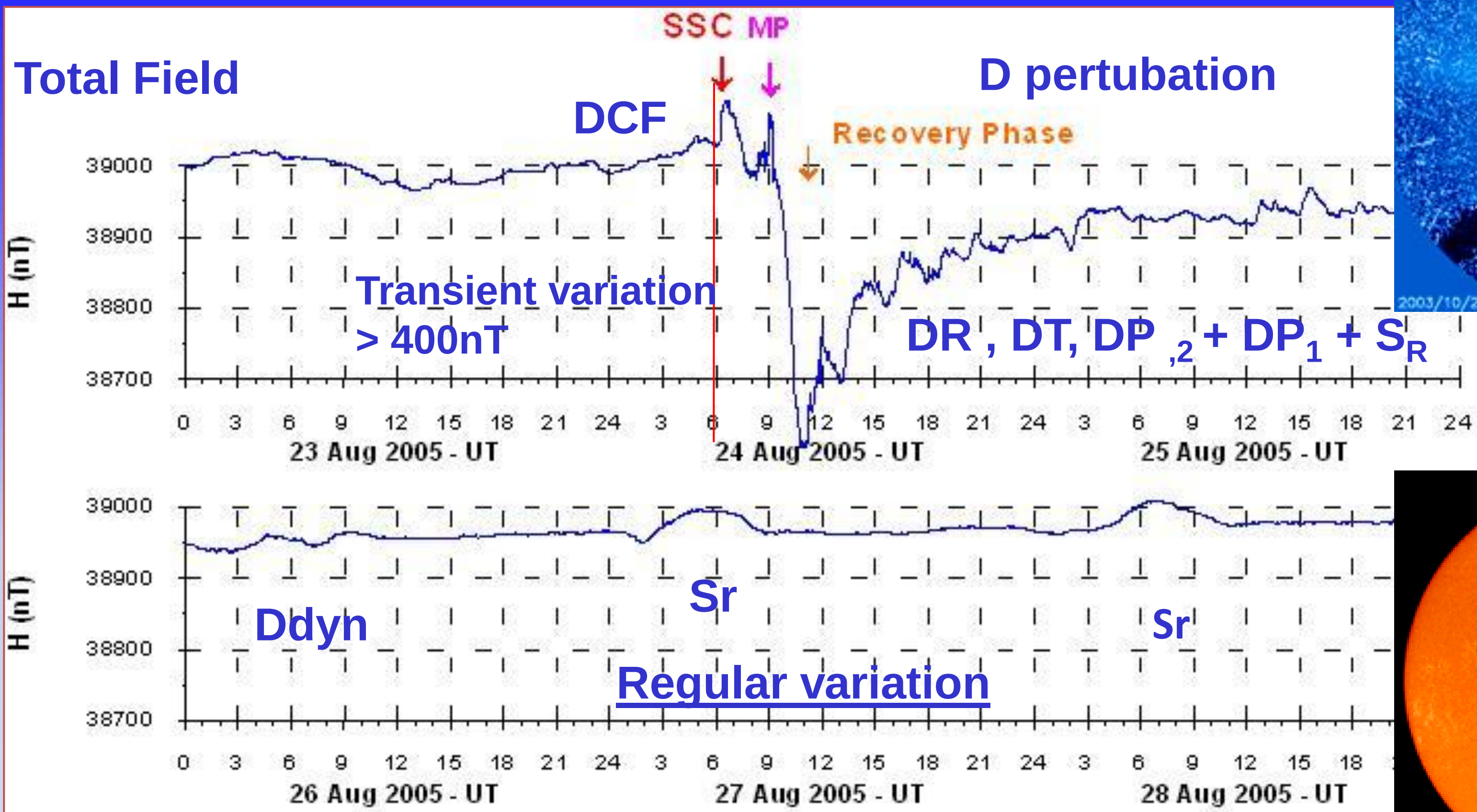
Components of the Earth Magnetic field

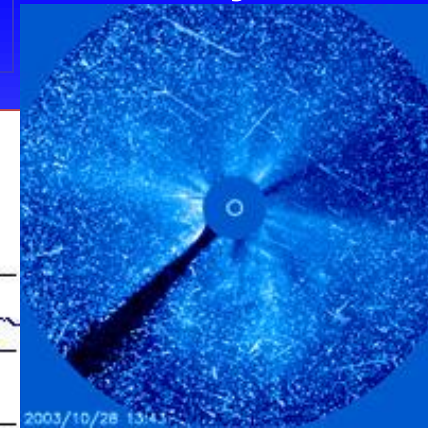
H : horizontal component
D : declination
Z: vertical component
I: inclination

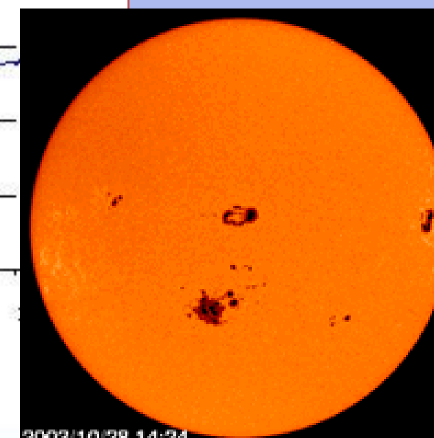
X : Northward component
Y: Eastward component
Z: Vertical component

The earth's magnetic field integrated the effects of all current systems

Day to day variability of the Earth magnetic field







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

Lat = 20N, long = 108E

EQUIVALENT CURRENTS

Equivalent current : principle

- We derive from the magnetic data ' an equivalent current system' which approach ' the real current system'
- The equivalent currents system is based on hypothesis concerning the geometry and some properties of the real currents. These hypothesis simplify the reality.
- Nevertheless the equivalent current systems help to organize the magnetic data and give a first rough approximation of the real currents.

EQUIVALENT : Method

- We organize the magnetic data as follow:

- 1) **latitude**
- Polar, auroral, middle and low latitudes

- 2) **physical process**
- Events related to regular sun radiation or
- High speed solar wind streams
- CME etc….

Equivalent currents
Sq and equatorial electrojet
IONOSPHERIC DYNAMO

Transient variations of the earth's magnetic field (time variations :seconde, minute, hour, day, season, year and solar cycle)

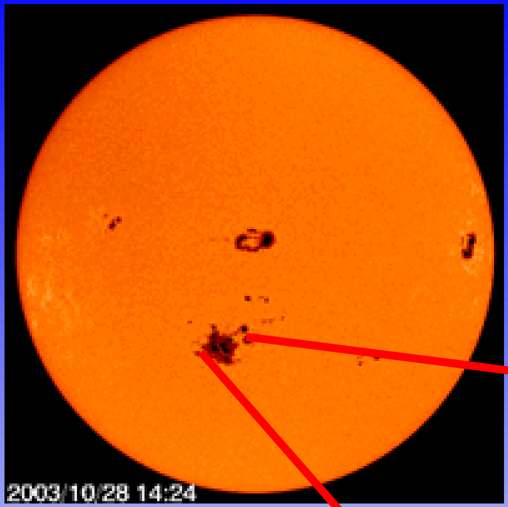
$$\Delta B = S_R + D$$

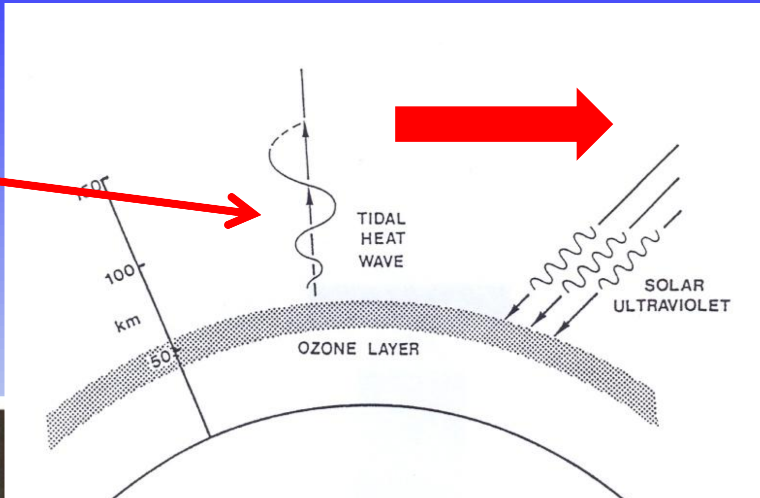
- S_R : regular variation of the Earth's magnetic field
- D : disturbance

- **Sq -> mean of the regular variation of the earth's magnetic field <S_R>**

IONOSPHERIC DYNAMO

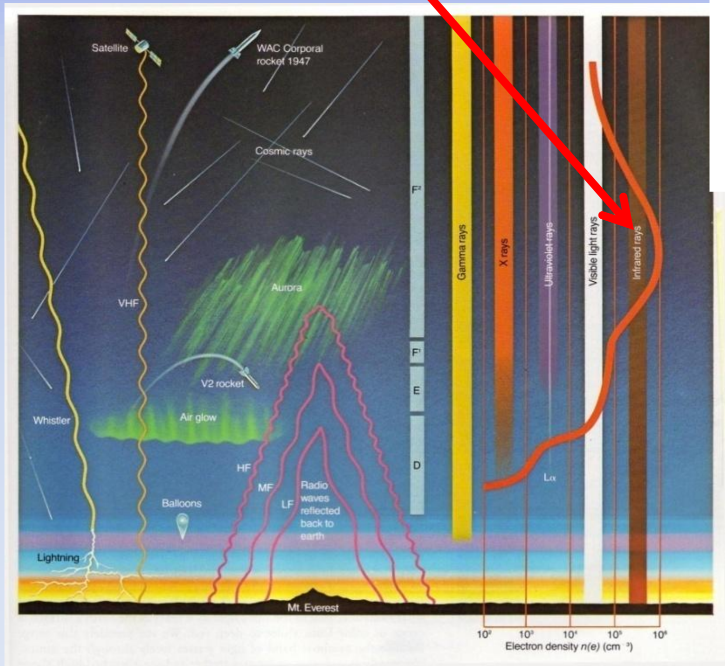
UV et EUV radiations are at the origin of the Regular variation S_R of the earth magnetic field



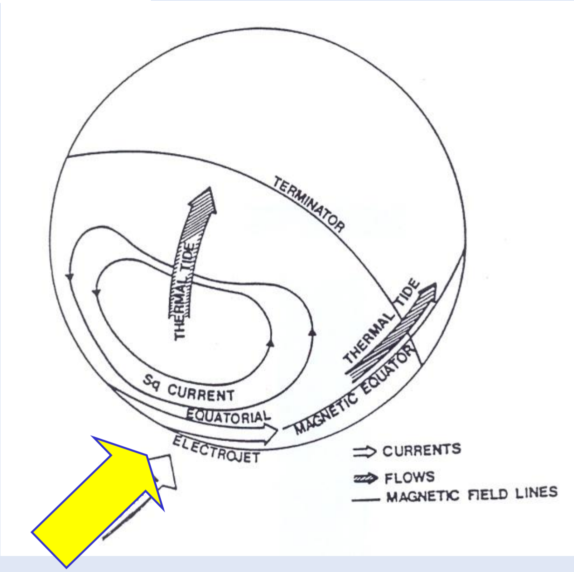


Motions of the atmosphere

Electric currents
Dynamo region
90km<h<150km

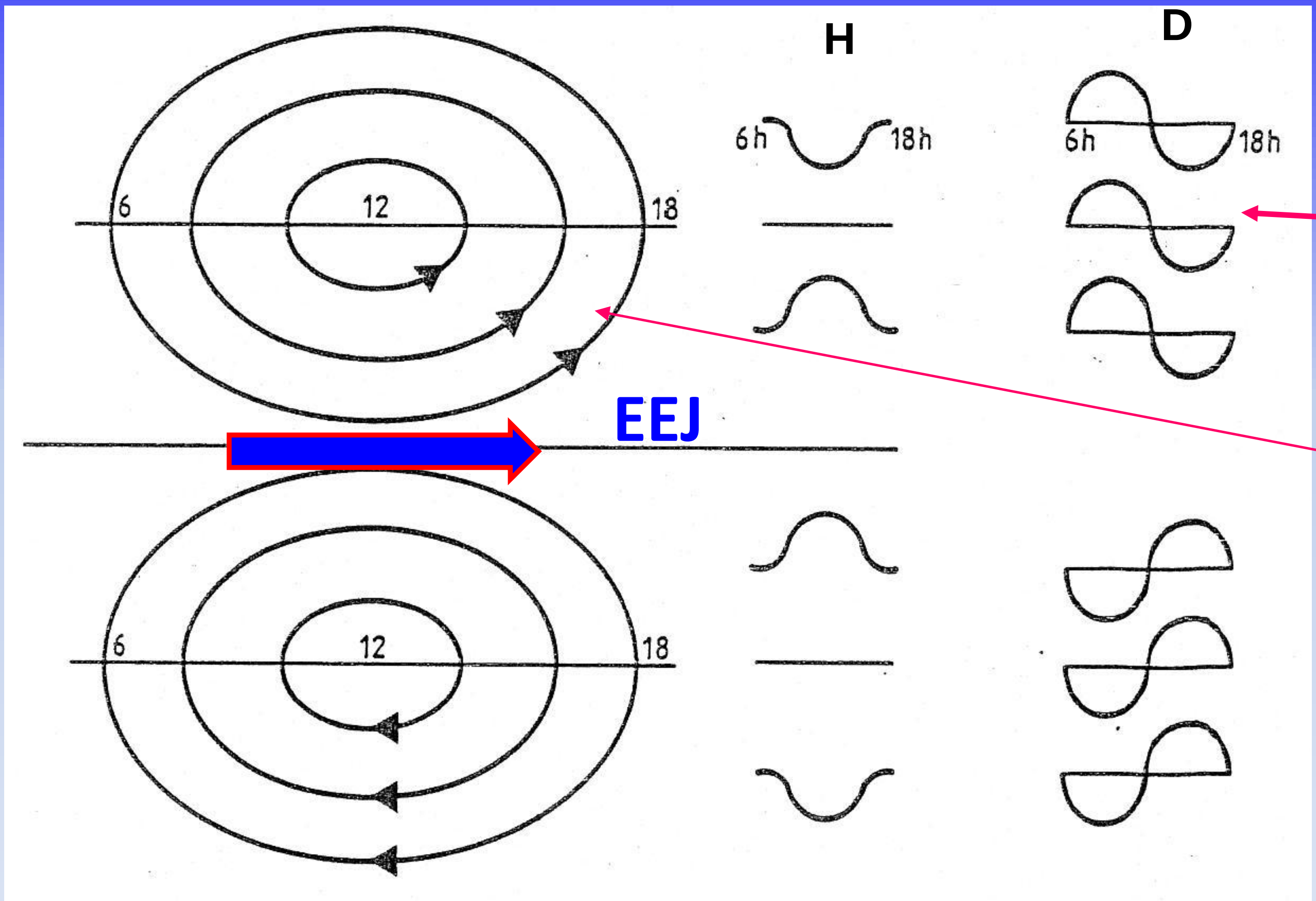


Regular variation of the eart magnetic field Dayside

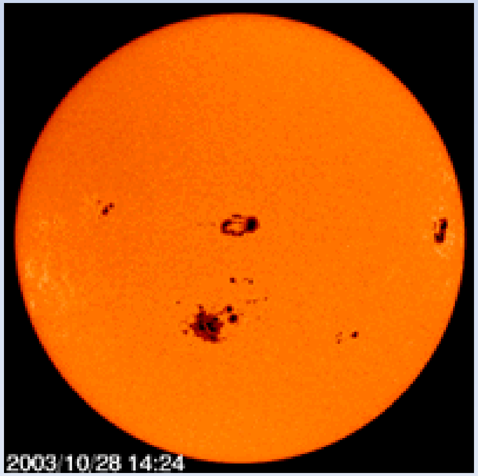


photoionisation create the ionosphere

Infinite plane sheet above a plane earth: The closure of currents is assumed in each hemisphere separately



Equivalent current Sq/S_R [(Amory-Mazaudier ,1983]



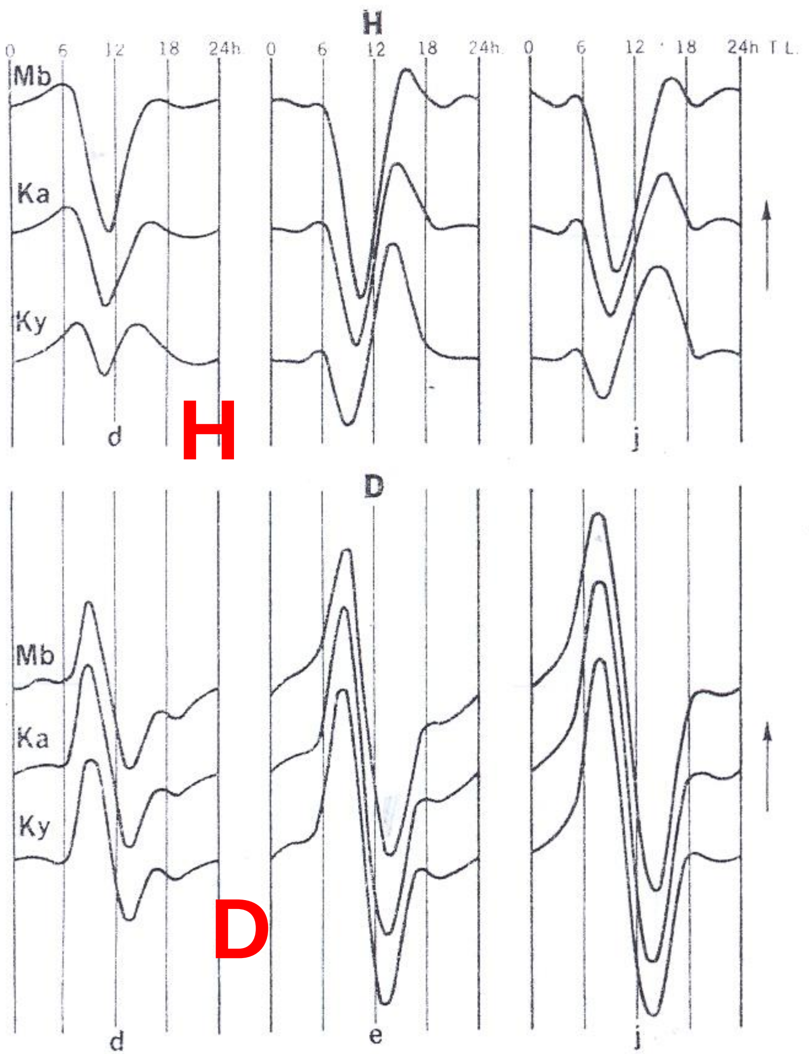


Fig. 20. — Courbes Sq de H et D pour les 3 saisons (*d* : solstice de décembre ; *e* : équinoxe ; *j* : solstice de juin) des années 1958-1959 à Memambetsu (Mb), Kakioka (Ka) et Kanoya (Ky). Échelle de 2 gammas/heure.

Mayaud, 1965

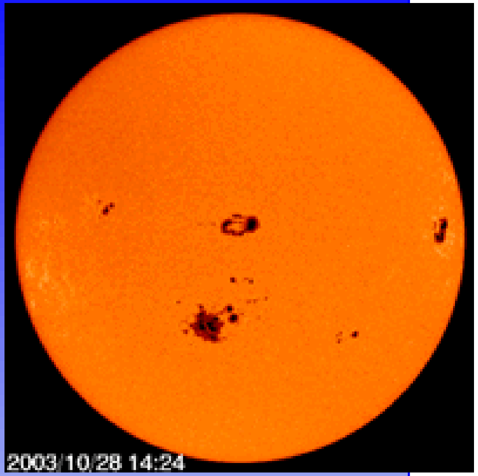
Sq variations of the H and D component

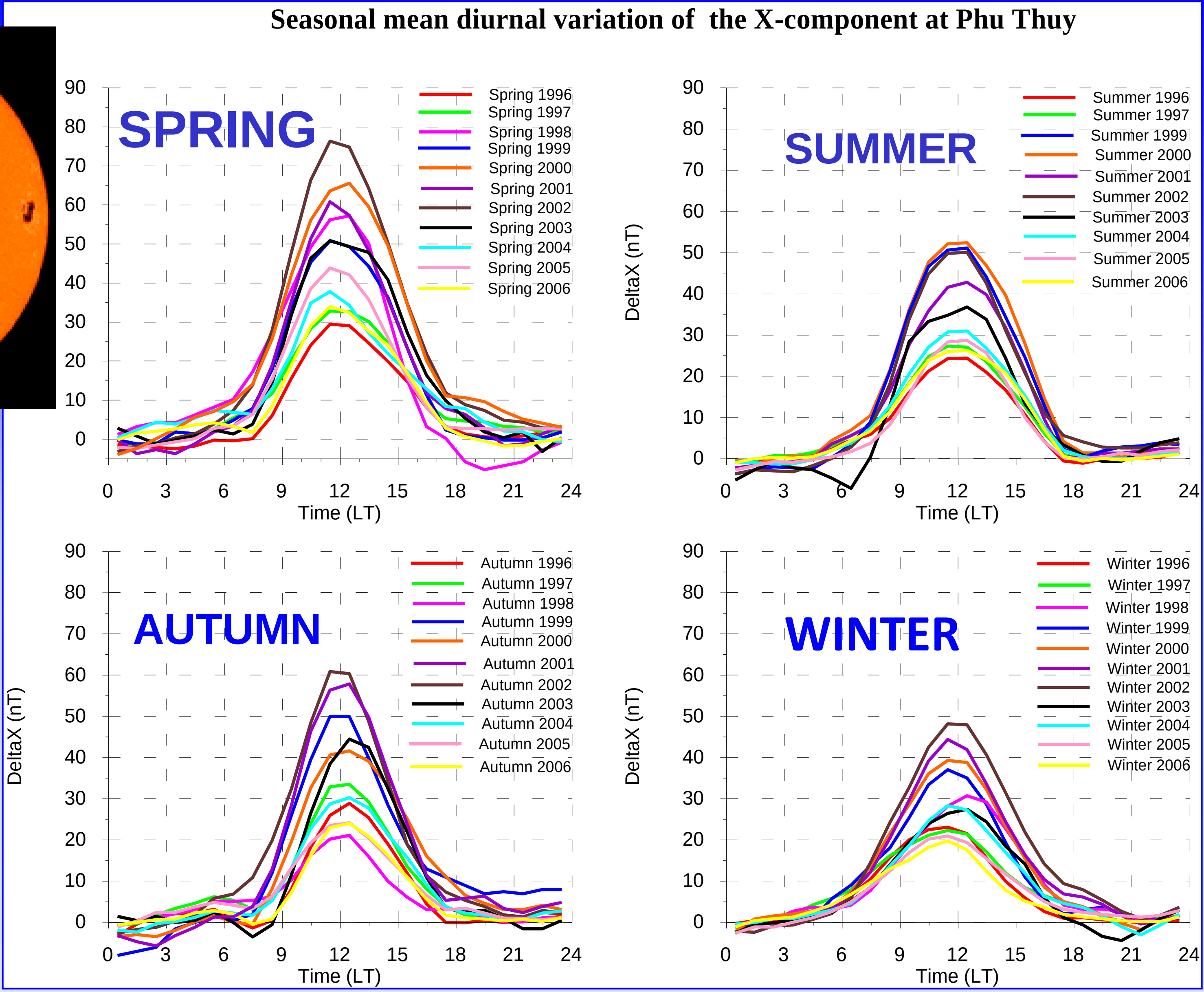
3 stations in the Northern Hemisphere
Memambetsu (Mb),
Kanoya (Ky),
Kakioka (Ka)).

By the past
–> 3 magnetic seasons
Winter : d,
Equinox : e
Spring : j

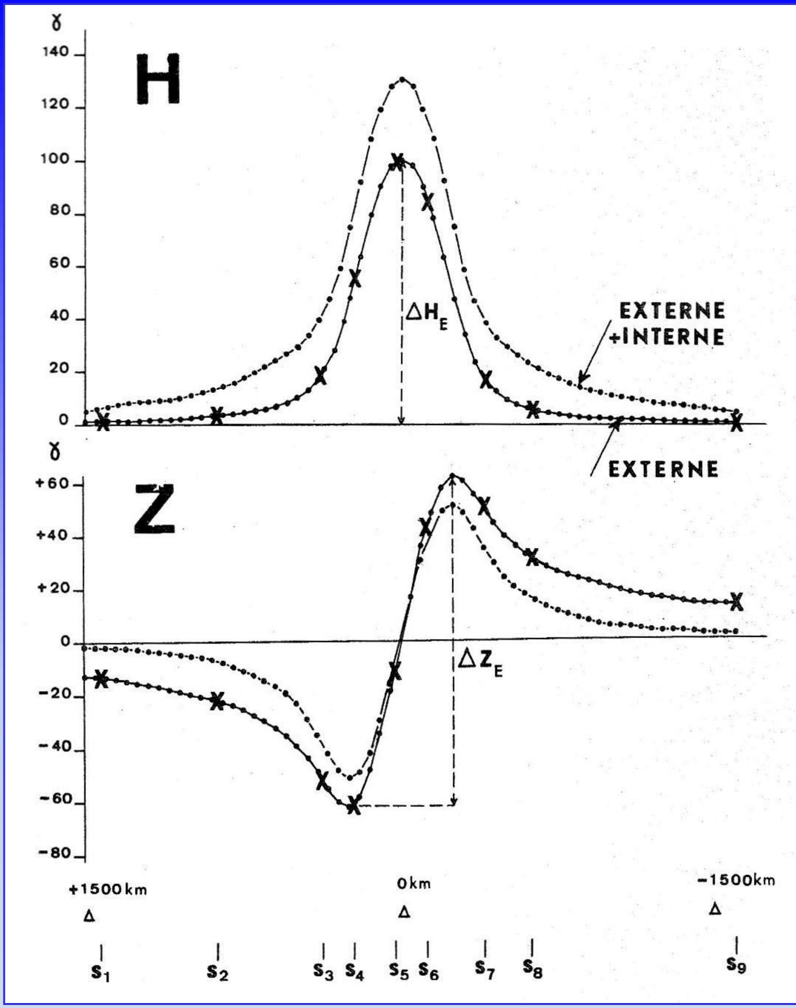
TO CHANGE

Diurnal variation Sq/S_R
Seasonal variation Sq/S_R
Annual variation : Sq/S_R
Solar cycle variation Sq/S_R
Disturbance D





Pham et al., Annales Geophysicae 2011



This figure from Fambitakoye (1973) present the latitudinal variations of the H et Z components under a ribbon of current.
The H component is maximum at the equator and diminish with the distance to the equator.
The Z component is zero at the equator and presents two maximum corresponding to the half height of the H component.
The induced current is very weak.

$$B_e + (B_i \sim 0)$$

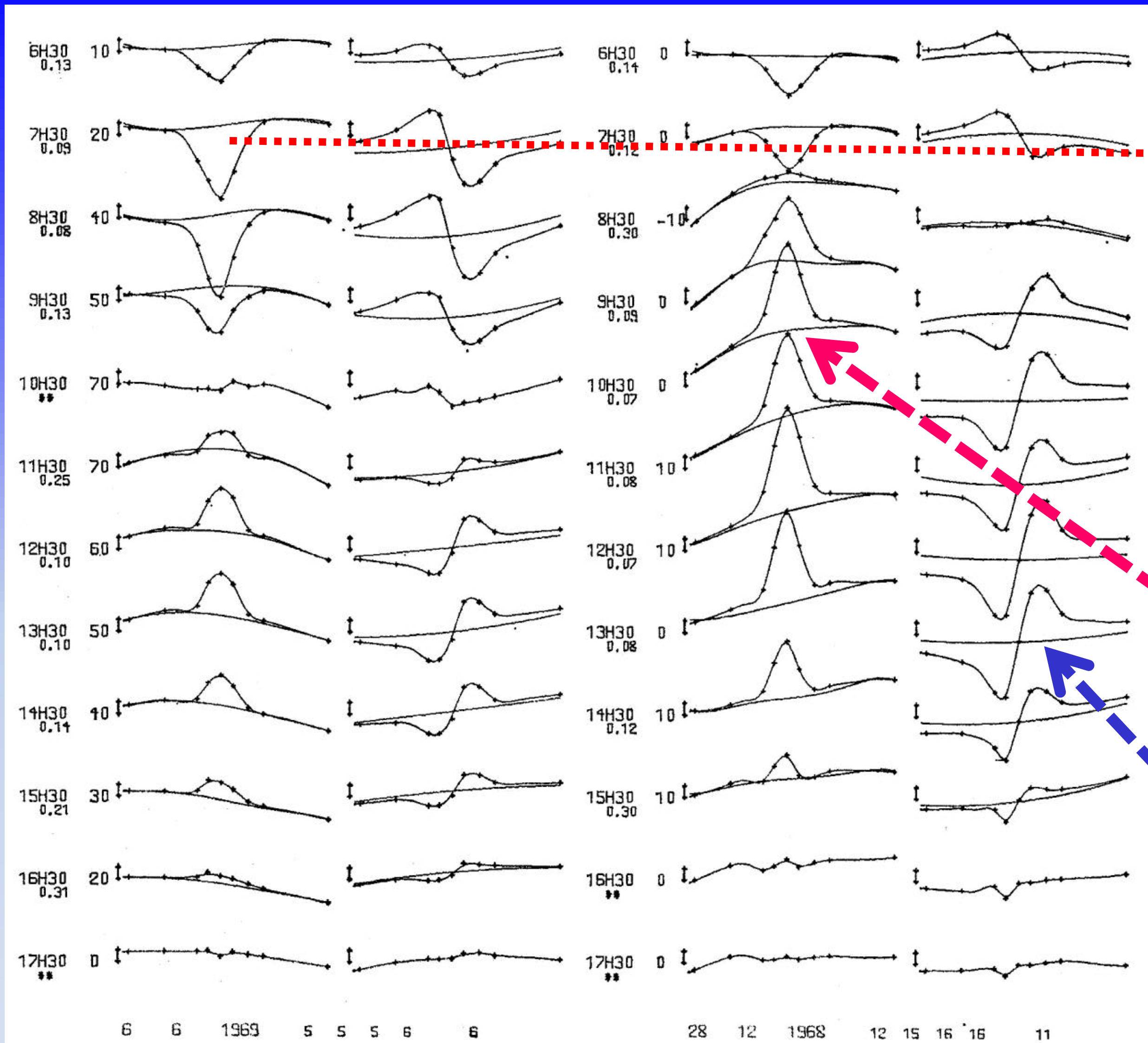
induction

External source

$$I(x) = I_o[1 - \frac{(x-c)^2}{a^2}]^2$$

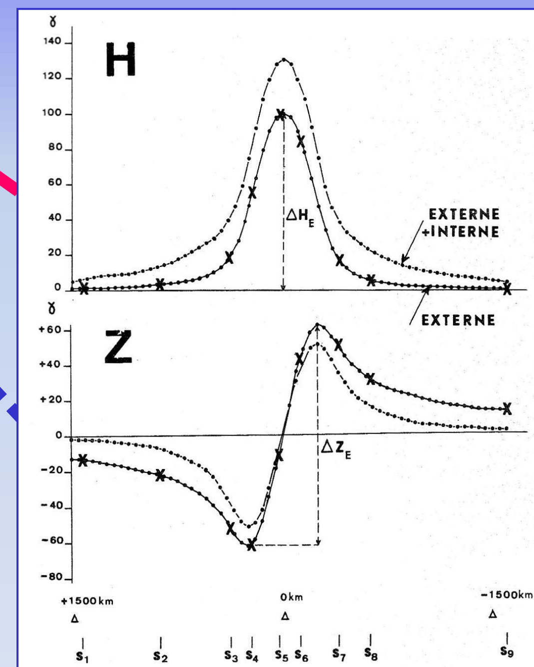
Model of a ribbon of current

Where I_0 is the current intensity at the centre c of the ribbon whose halfwidth is a and length is infinite. The ribbon is assumed to be infinitely thin, and located at a height of 105 km.



Contre-electrojet
Gouin and Mayaud, 1967

IONOSHERIC DYNAMO

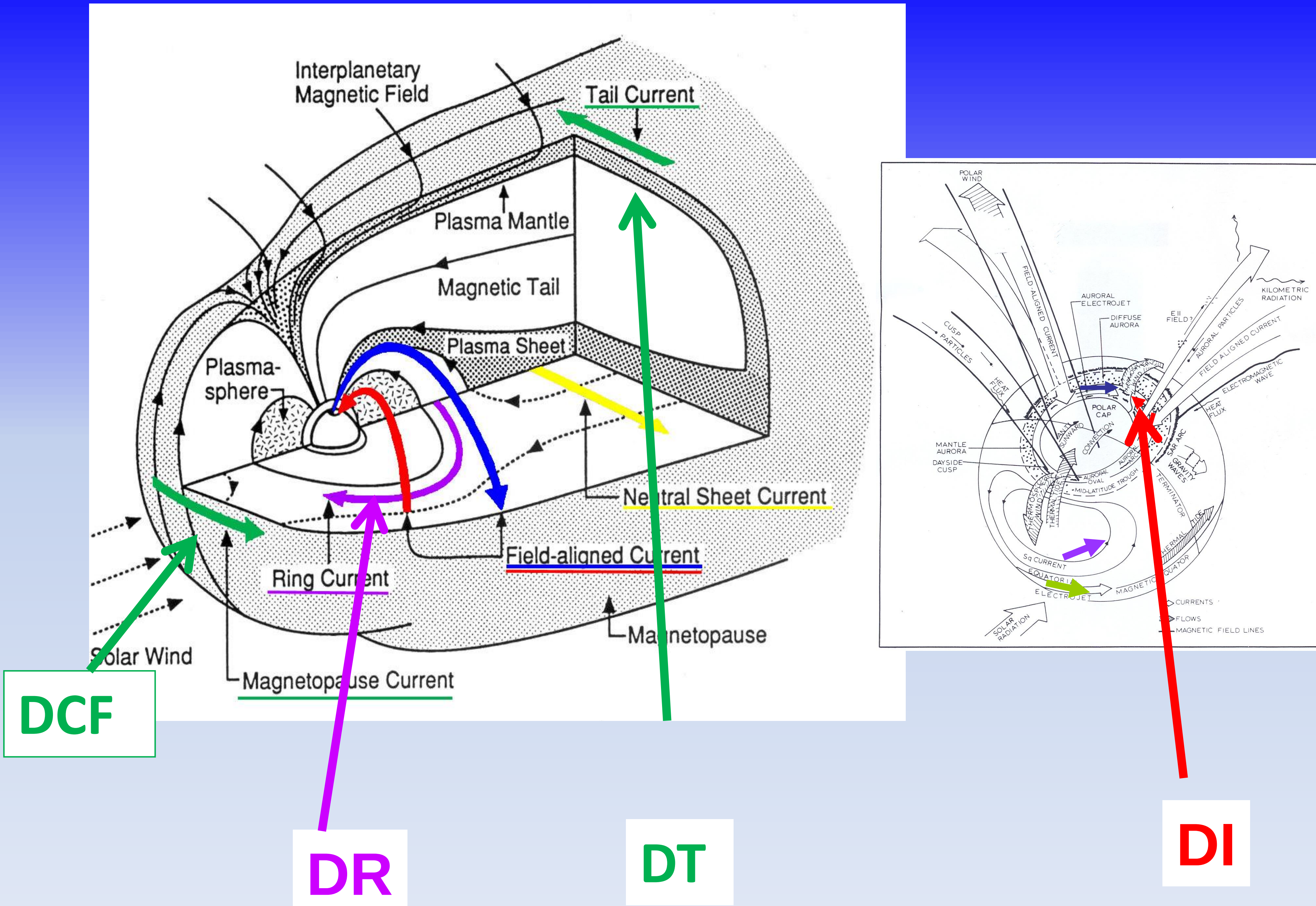


6 juin 1966 **12 décembre 1968**

Latitudinal variation of the earth’s magnetic field at equator
[after Fambitakoye, 1975]

$$\Delta B = S_R + D$$

- S_R : regular variation of the Earth's magnetic field
- **D : Disturbance**


Interplanetary Magnetic Field
Tail Current
Plasma Mantle
Magnetic Tail
Plasma Sheet
Plasma-sphere
Neutral Sheet Current
Field-aligned Current
Ring Current
Magnetopause
Solar Wind
Magnetopause Current
POLAR WIND
FIELD-ALIGNED CURRENT
AURORAL ELECTROJET
DIFFUSE AURORA
E II FIELD?
KILOMETRIC RADIATION
AURORAL PARTICLES
FIELD ALIGNED CURRENT
ELECTROMAGNETIC WAVE
HEAT FLUX
CUSP PARTICLES
HEAT FLUX
POLAR CAP
ANTI SUNWARD
CONVECTION
MANTLE AURORA
DAYSIDE CUSP
AURORAL OVAL
AURORAL ARC
MID-LATITUDE TROUGH
SAR ARC
GRAVITY WAVES
TERMINATOR
THERMOSPHERIC WIND
THERMAL TIDE
Sq CURRENT
EQUATORIAL ELECTROJET
MAGNETIC EQUATOR
THERMAL TIDE
SOLAR RADIATION
CURRENTS
FLOWS
MAGNETIC FIELD LINES
DCF
DR
DT
DI

Magnetic Disturbance due to Electric current disturbance in the Ionosphere

- The disturbance is composed of different parts associated to different physical process

- **DI = DP1 +DP2 + Ddyn**

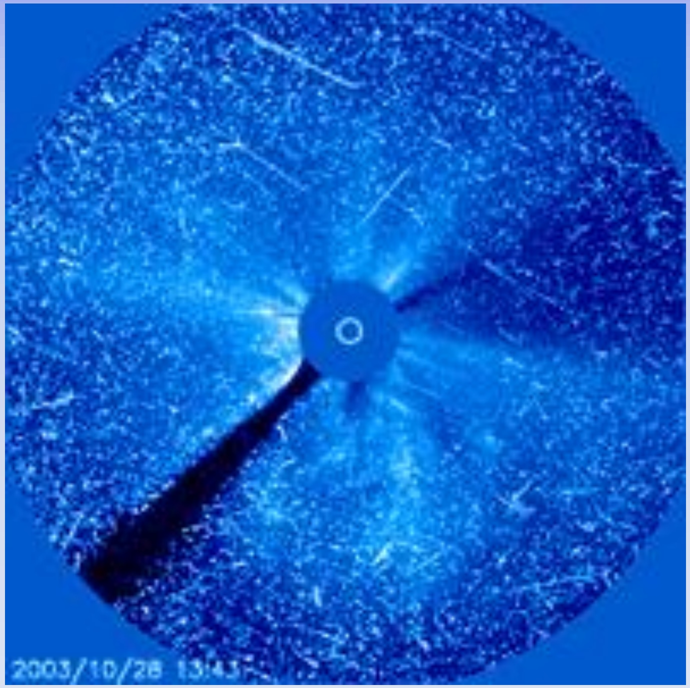
- DP1 : polar magnetic disturbance associated to substorm (Rostoker 1967)

- DP2 : magnetic disturbance associated to the magnetospheric convection electric field (Nishida1968)

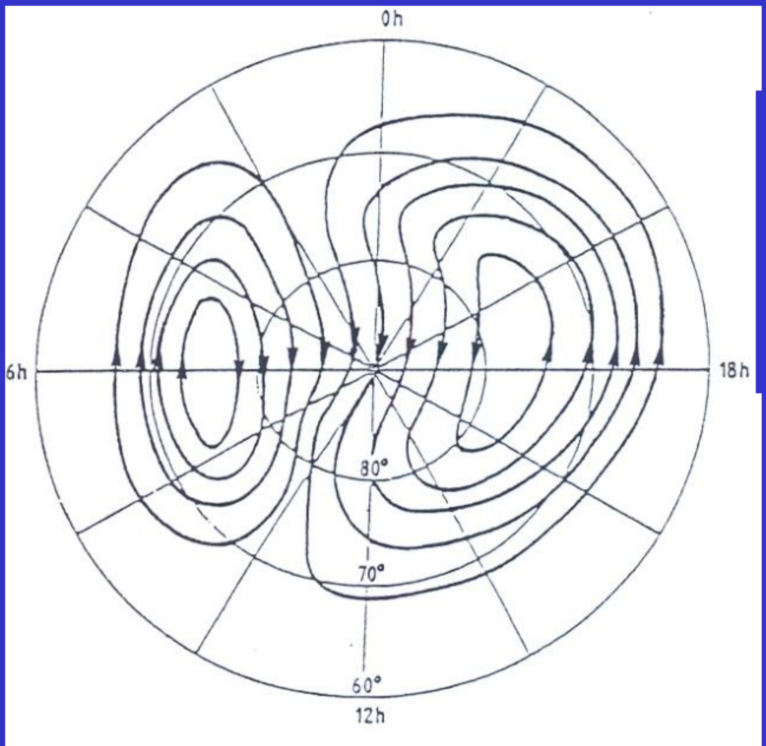
- Ddyn : magnetic disturbance associated to Joule heating (Blanc and Richmond, 1980; Le Huy and Amory-Mazaudier, 2005).

Equivalent current: DP2

see lecture of Prof. Kikuchi

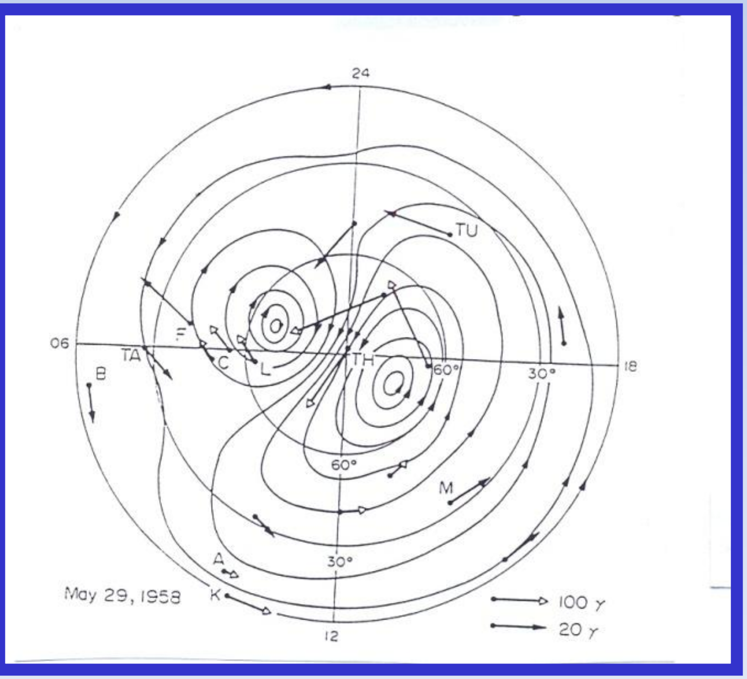


EQUIVALENT CURRENT SYSTEM DP2

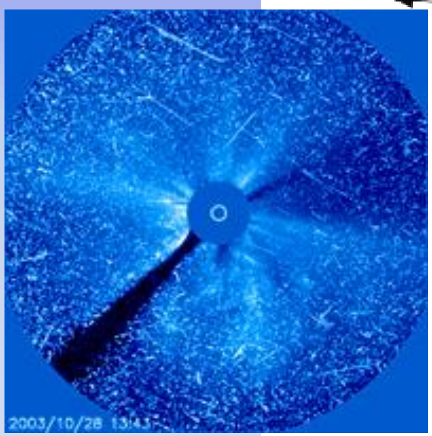


S_q^p Nagata and Kokubun, 1962
Rep. Ionoph Space Japan, 16, 150
This current system is confined at high latitudes during quiet magnetic periods

DP_2, Nishida, 1968, JGR, 73, 5549
Current system extending toward latitudes during magnetic disturbed periods
[Nishida et al., 1966]



Penetration of the magnetospheric convection electric field to low latitudes, Kikuchi et al., 2000, JGR, Vol 105, N° A10, 23251-23261



23,258 KIKUCHI ET AL.: PENETRATION OF ELECTRIC FIELDS DURING A SUBSTORM

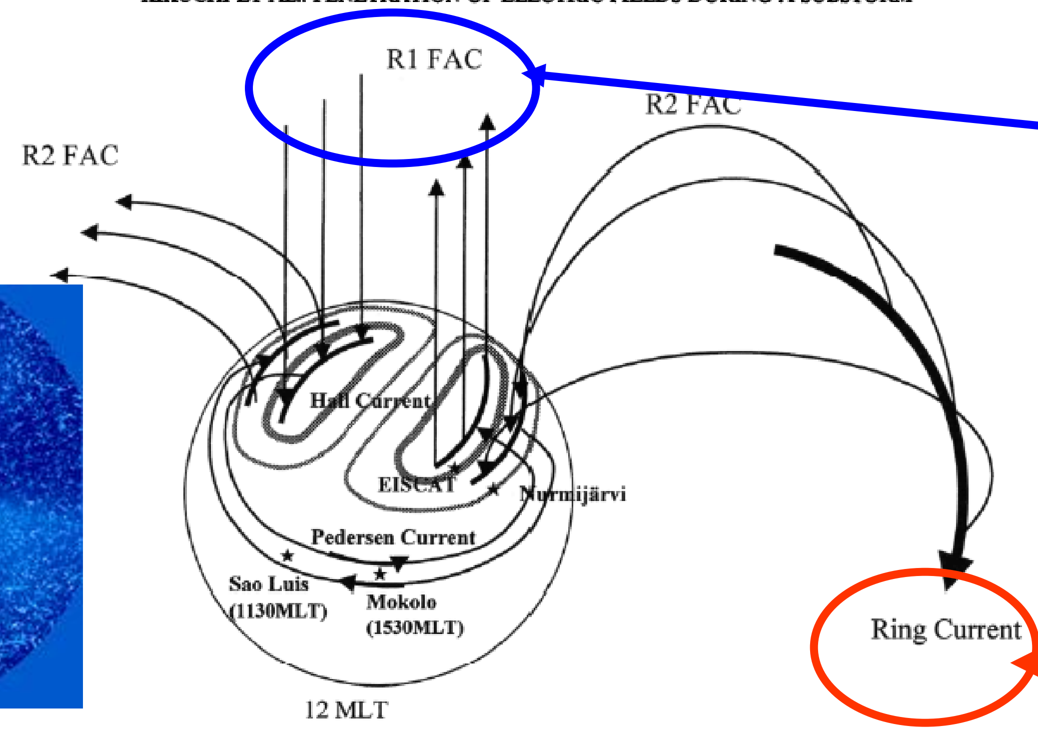


Figure 7. Schematic picture of Region 1 (R1) and Region 2 (R2) field-aligned currents (FACs) with locations of EISCAT, Nurmijärvi, and equatorial (Sao Luis and Mokolo) stations. The dominant electric field associated with R1 FACs is northward in the high-latitude afternoon sector and eastward at the daytime dip equator. The R2 FACs enhance the northward electric field at EISCAT but reduce this component at the Nurmijärvi and equatorial stations. The electric fields drive ionospheric Hall currents at high latitudes and Pedersen currents at the dip equator. The Hall currents are closed circuits in the ionosphere, while the Pedersen currents are connected to the R1 and R2 FACs. The magnetic local time of the equatorial stations corresponds to the peak of the negative bay at 1440 UT.

Direct process
DDP

Loaded driven process/RC

Shield effect
Shielding
Overshielding

Electrodynamic coupling between high and low latitudes on May, 27, 1993 Kobéa et al. 2000, JGR, Vol 105, A10, 22979-22989

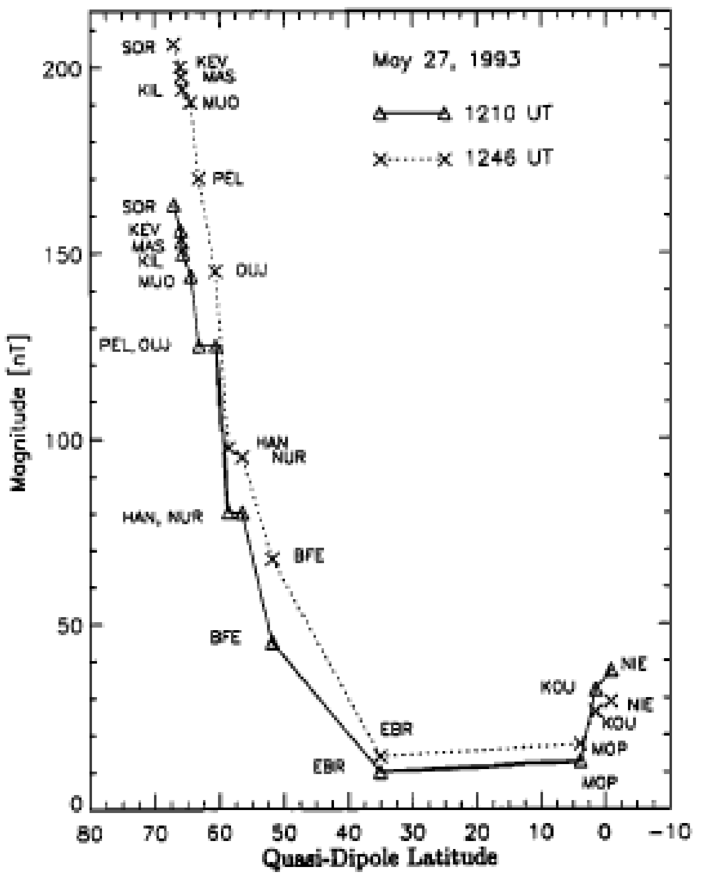


Figure 4. Latitudinal profile of the fluctuations at 1210 and 1246 UT extending to the equator, in the longitudinal sector ranging from 65° to 120° magnetic longitude including IMAGE and the West African network.

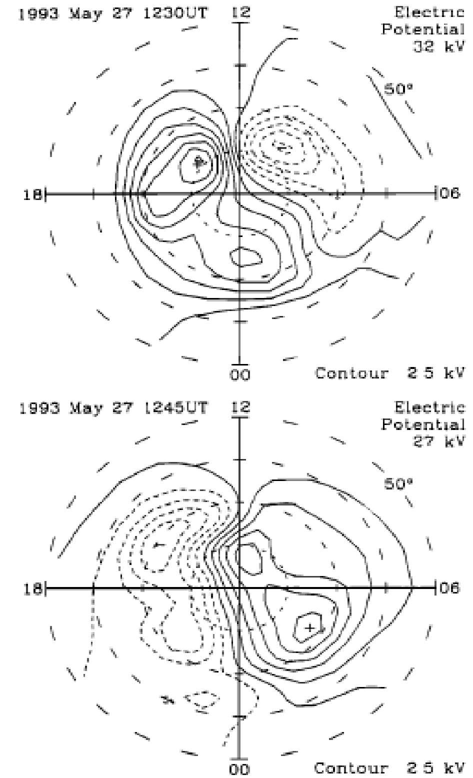


Figure 6. Electric potentials at 1230 and 1245 UT on May 27, 1993, with a 2-hour running mean subtracted to emphasize the fluctuations. The contour interval is 2.5 kV.

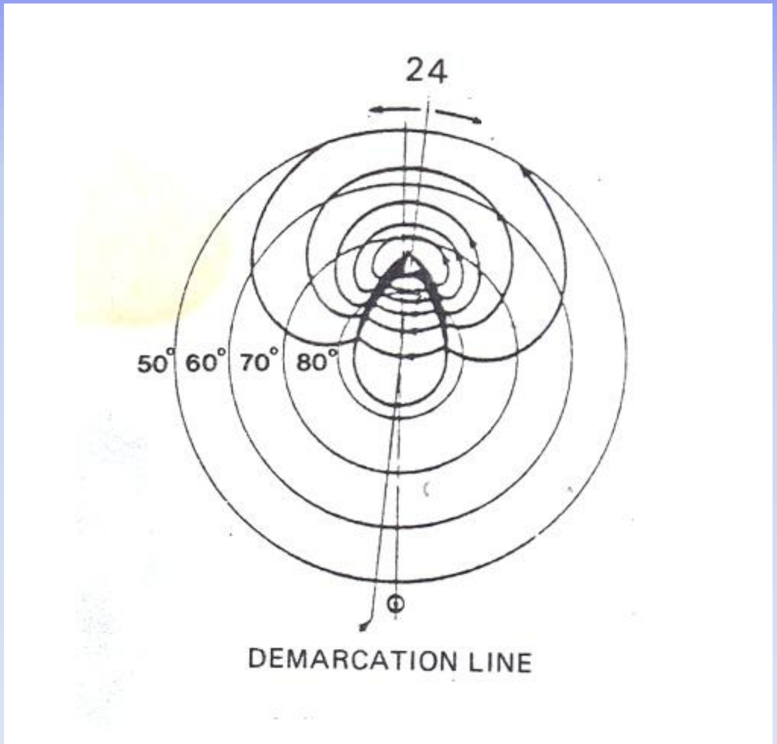
Richmond and Kamide, 1988 AMIE
JGR vol 83 n°A6, 5741-5759

EQUIVALENT CURRENT DP1 - SUBSTORM

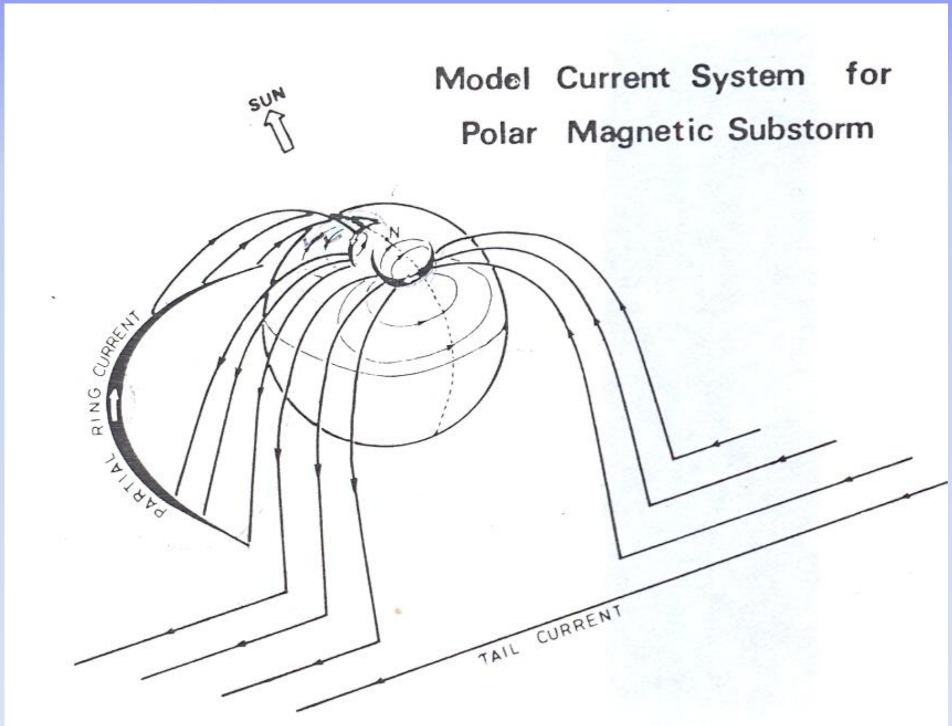
Equivalent current DP_1

On current cell on the nightside

Substorm model
Fukushima and Kamide, 1973



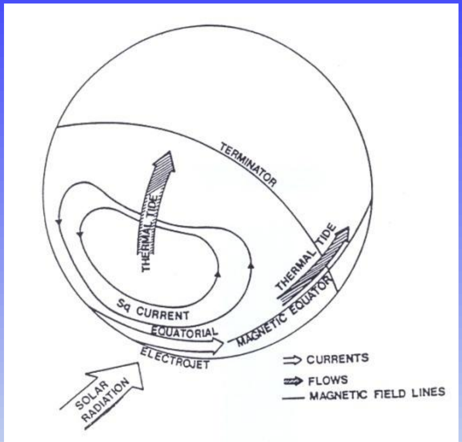
Rostoker, 1967



Equivalent current : Ddyn

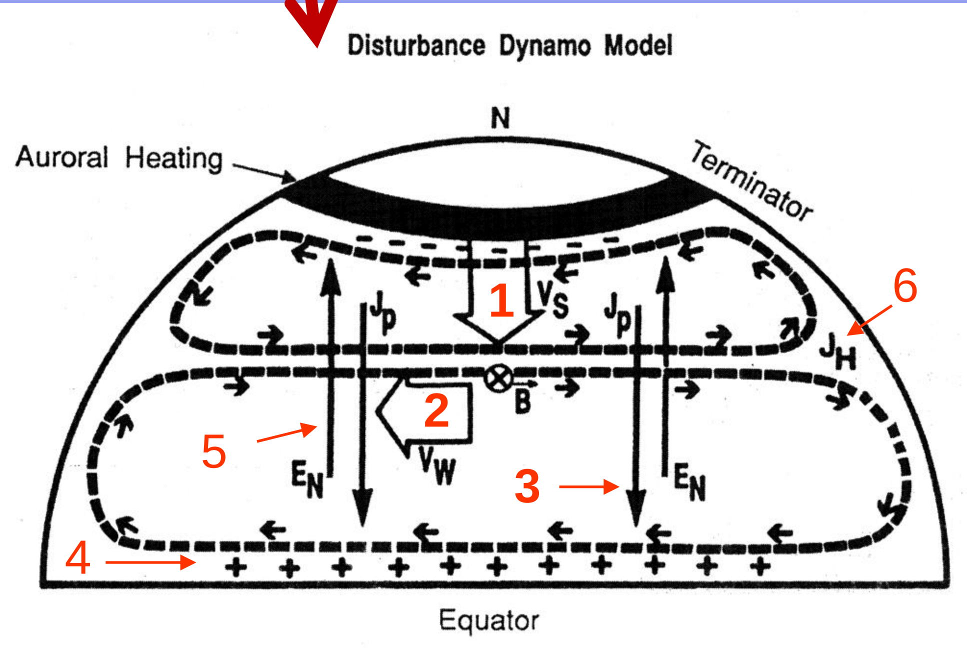
Ionospheric disturbance dynamo/secondary dynamo

JGR,85, 1669-1686, 1980 Blanc and Richmond

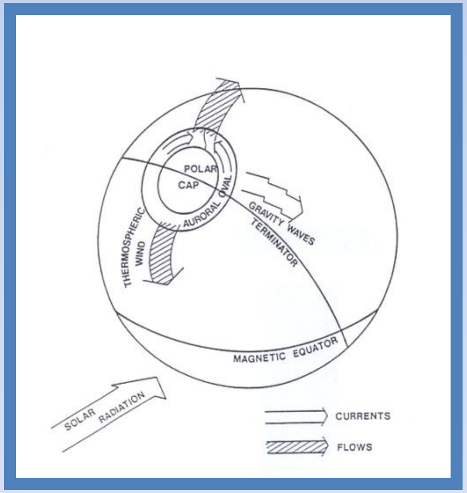


Regular wind

Mazaudier and Venkateswaran, 1990
Annales Geophysicae, 8, (7-8), 511-518



Storm wind



Richmond and Matshushita, JGR, 1975 vol 80, N°19, 2839-2850
Thermospheric response to a magnetic storm

Ddyn

Signature of the ionospheric disturbance dynamo: Ddyn
Le Huy and Amory-Mazaudier, JGR, **2005**

Blanc and Richmond, 1980

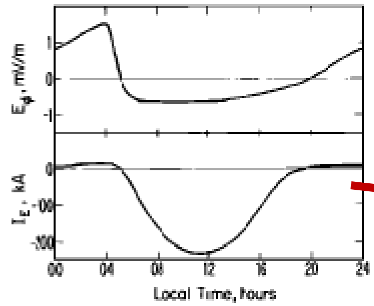


Fig. 9. Local time distributions of the equatorial electrojet parameters E_ϕ, eastward electrostatic field, and I_E, total eastward current flow between +10° and -10° magnetic latitude. Both are basically reversed from their observed normal quiet-day variation.

2. Criteria for the Selection of Cases and Data Analysis

2.1. Criteria

[10] Our purpose being to study the sole ionospheric disturbance dynamo process, we must point out that only daytime signatures can be inferred from the data. Here are the criteria for the selection of the period of observation: (1) daytime period => to study the dynamo action in the E region, (2) period immediately after a storm => there is Joule heating in auroral regions during the period preceding our selected period, (3) no auroral electrojet => there is no penetration of the magnetospheric convection electric field during our selected period.

Ddyn

$$D_{dyn} = \Delta H - S_R - DR$$

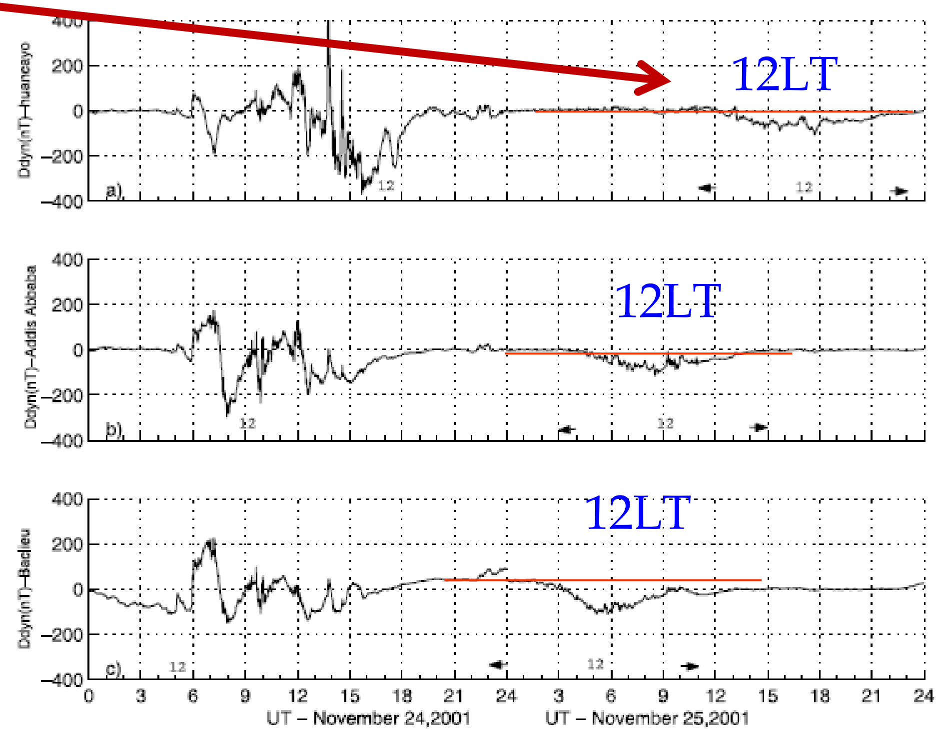


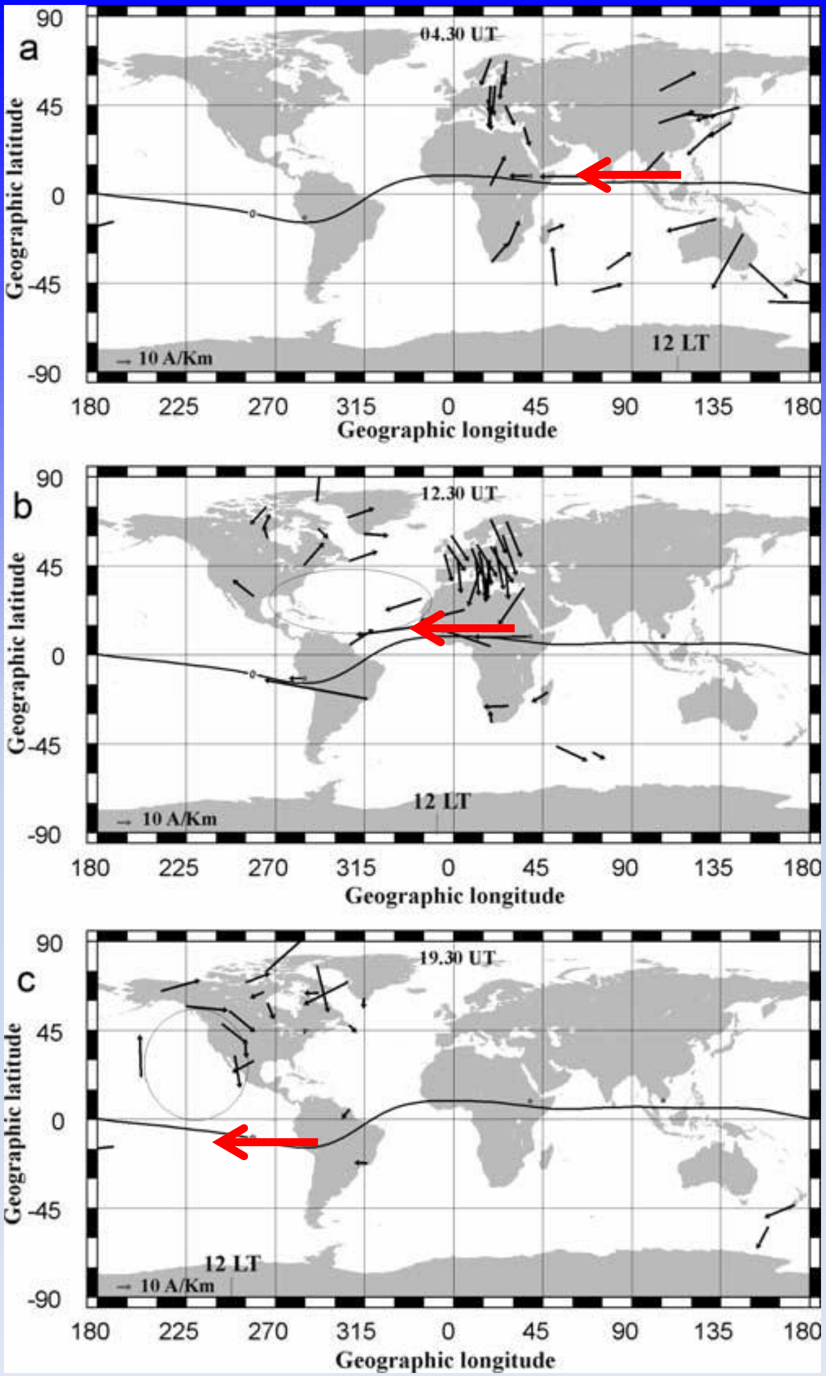
Figure 9. Same as Figure 4 for the sixth storm event on 24 and 25 November 2001.

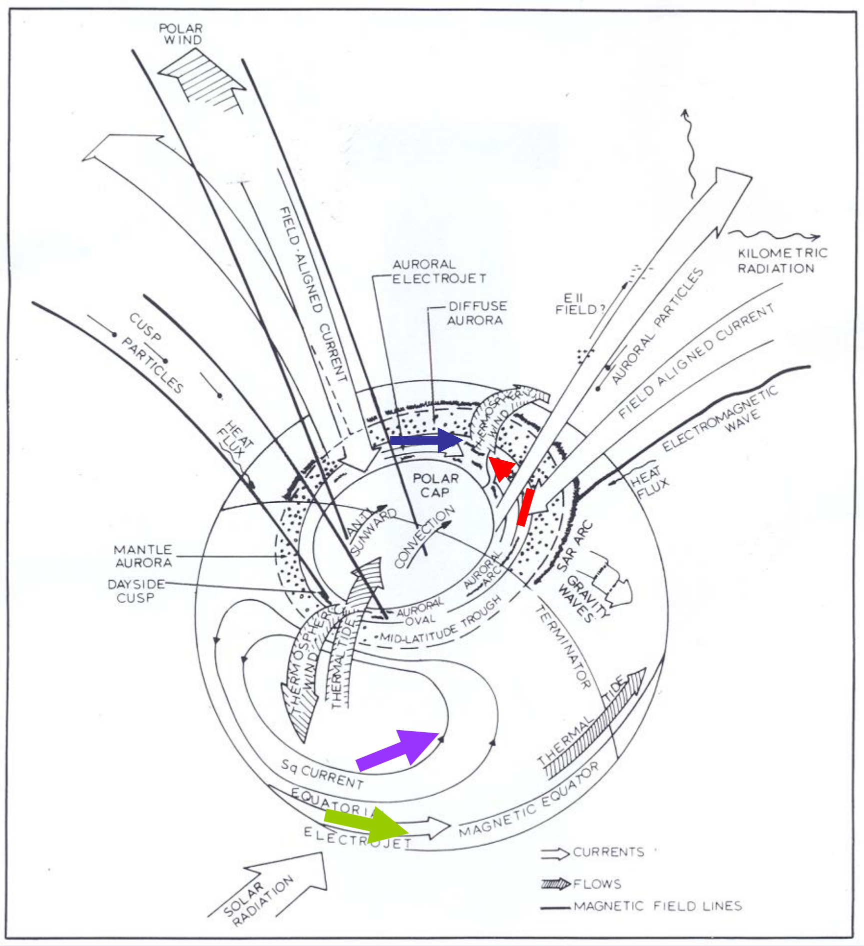
PICS

Dynamo Ionosphérique Perturbée

Le Huy et Amory-Mazaudier

JGR, 2005 et JGR, 2008





BASSES ET HAUTES LATITUDES

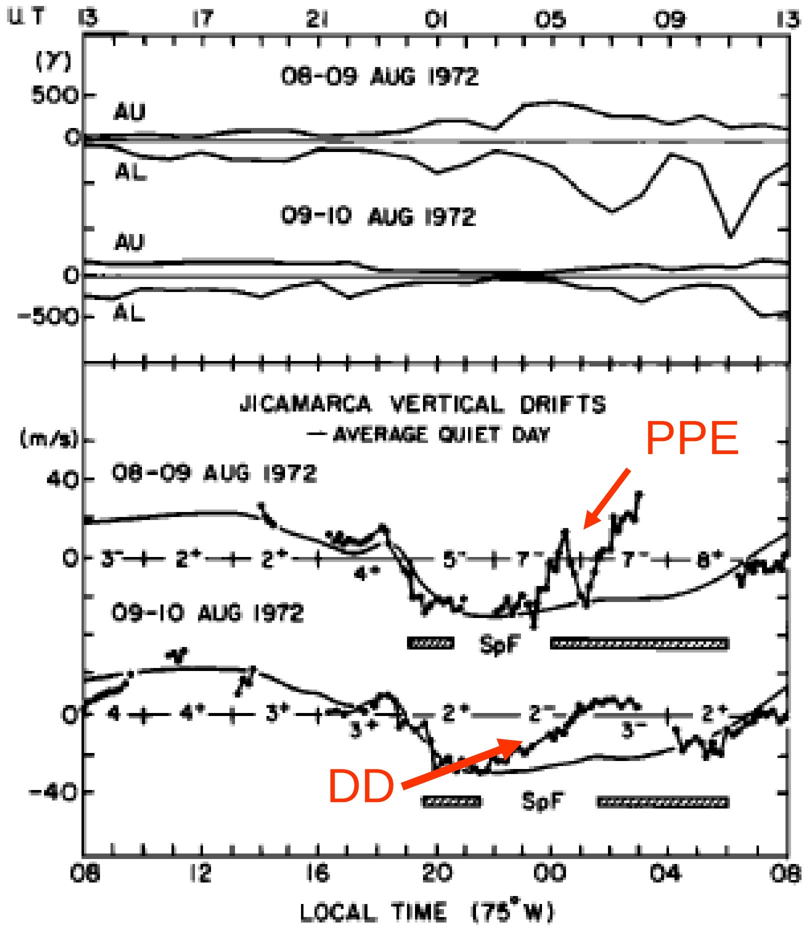


Figure 1. Auroral electrojet indices and F-region vertical drifts at Jicamarca on August 8-10, 1972. The solid curves in the lower panel show the average quiet time diurnal variation. Deviations from this pattern beginning at 2300 LT on August 8 are due to direct penetration effects, whereas the slower deviations starting at 2200 LT on August 9 are due to the disturbance dynamo.

Equatorial Disturbance Dynamo Electric Fields
Fejer et al., 1983
GRL, Vol 10, N°7, 537-540

Mayaud, JGR 1980
Comment on the Ionospheric Disturbance dynamo

Blanc JGR 1983
Magnetospheric convection Effects at midlatitudes
1. Saint-Santin Observations
Vol 88, P. 211

Outlines

- **Sun Earth System : a global electromagnetic complex system**
- **Dynamo process and large scale dynamos**
- **Electric currents associated to the different dynamos**
- **Magnetic field to approach electric currents**
- **Magnetic indices**

MAGNETIC indices

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

WHY MAGNETIC INDICES ?

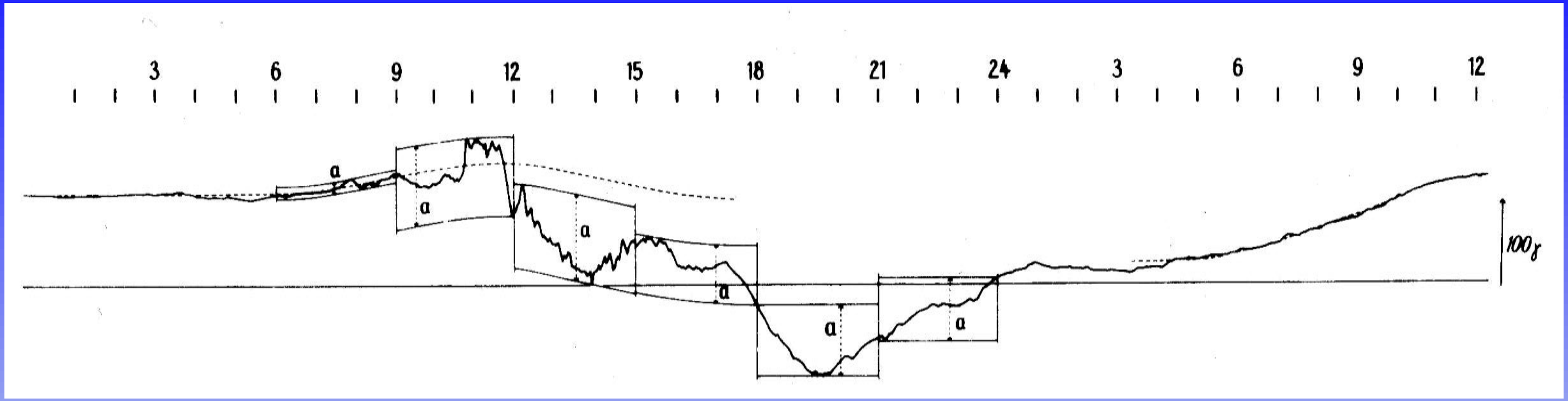
TO APPROACH A COMPLEX REALITY

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

FIRST USE OF MAGNETIC INDICES

TO SELECT MAGNETIC QUIET DAYS

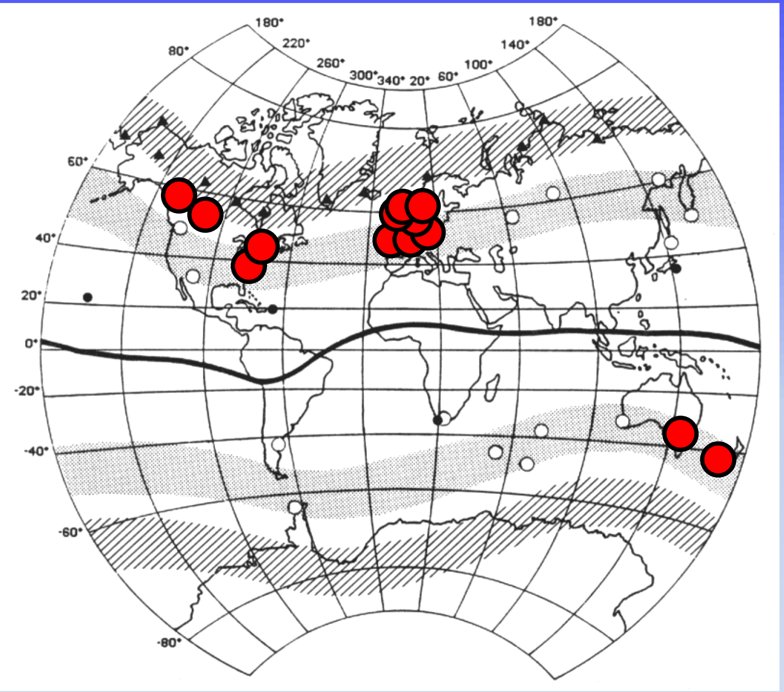
= > physical processes related to solar radiations are dominant

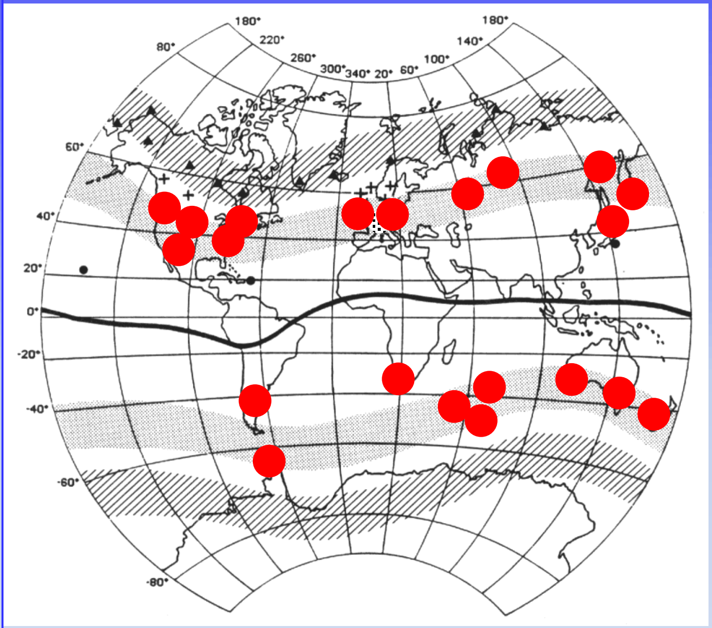
except for quiet days after big storms ionospheric disturbance dynamo

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

magnetic activity

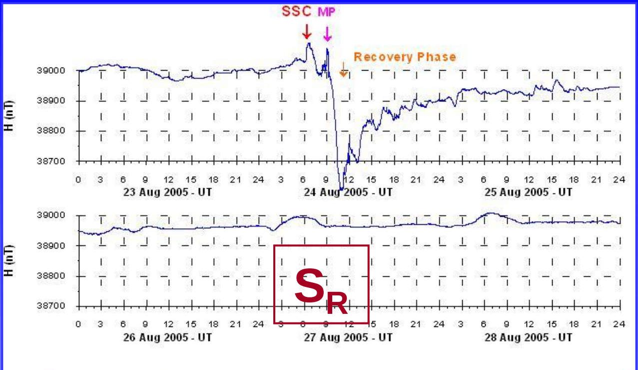
am< 20nT=> quiet day ; am< 13 nT => very quiet day





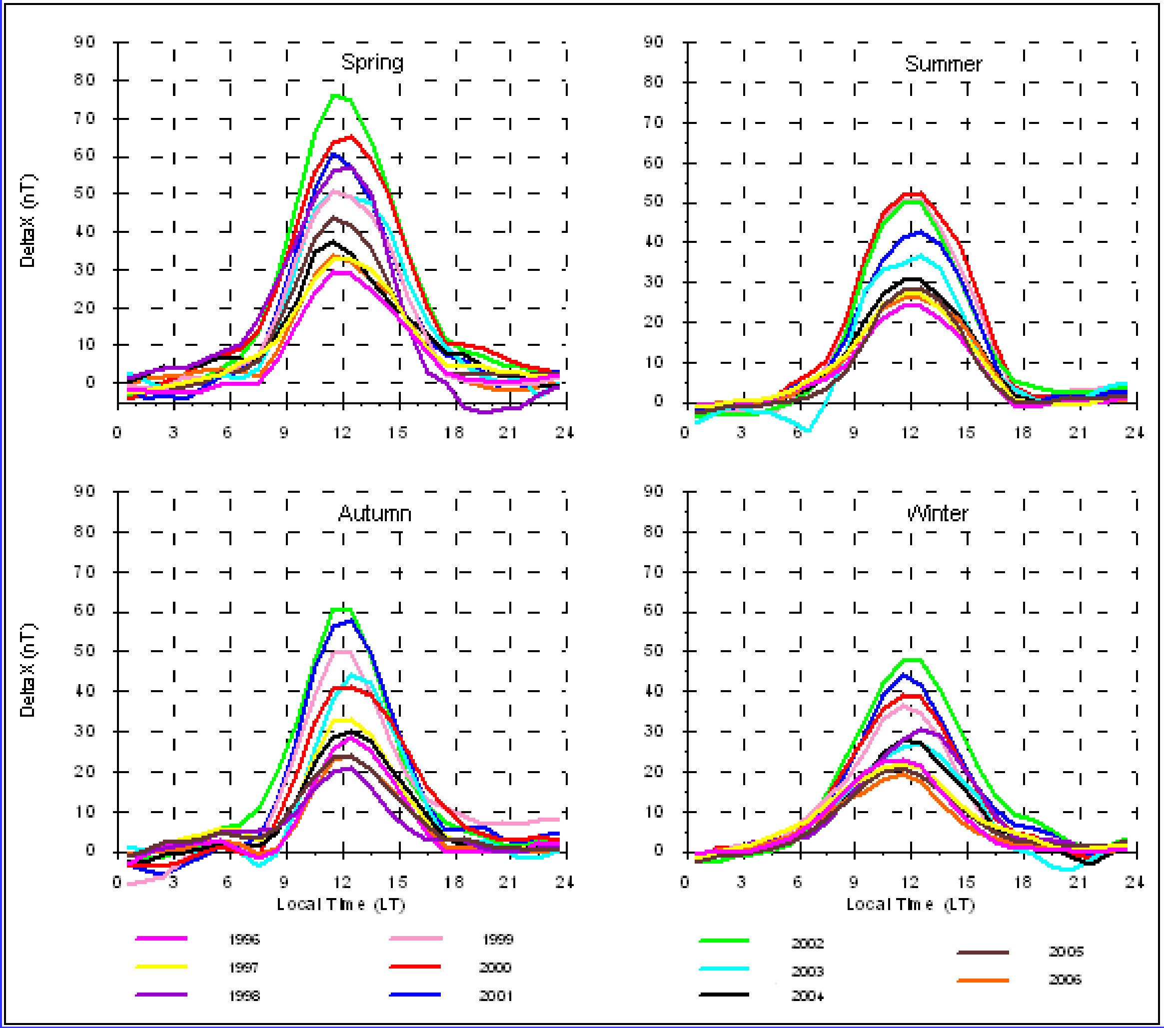
12 observatories
9 in the northern hemisphere
2 in the southern hemisphere

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



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

Daily am < 20 nT



Study on the regular ionospheric dynamo at the origin of the Sq/ S_R

The selection of days is essential for all Studies in GEOPHYSICS

Pham Thi Thu et al., 2011 Annales geophysicae

H component observed at Phu Thuy/Vietnam Solar cycle variations

SECOND USE OF MAGNETIC INDICES

TO APPROACH SOLAR WIND COMPONENTS (B, V)

for example

Use of magnetic index as proxy of solar wind parameters

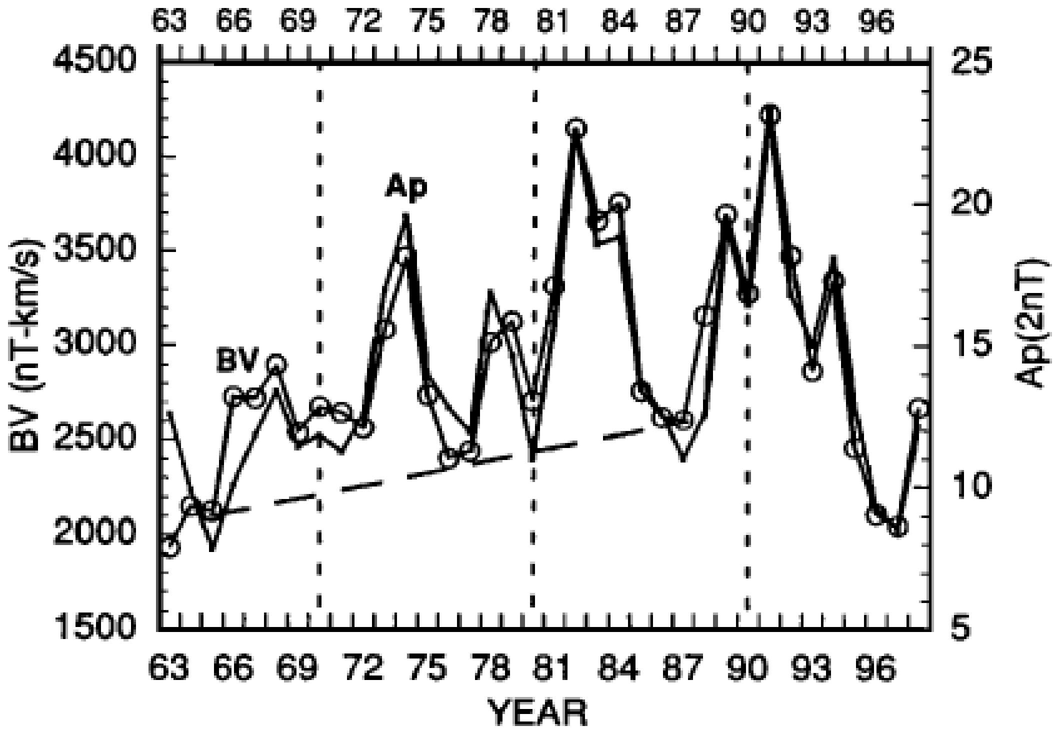


Figure 4. Annual mean values of *Ap* and the product *BV* are plotted for the period 1963 to 1998. Vertical dashed lines represent the solar polar field reversal epochs. The long-term trend in the *BV* data is highlighted by the dashed line.

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

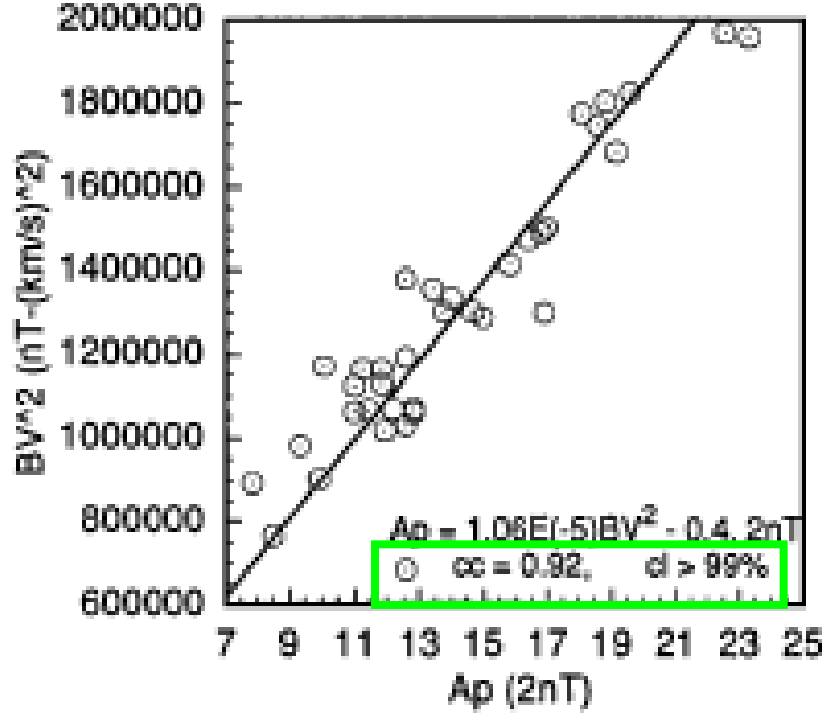


Figure 3. Linear correlation between BV^2 and Ap data is depicted for the 1963 to 1998 period. It represents the best fit between Ap and interplanetary parameters (V, B).

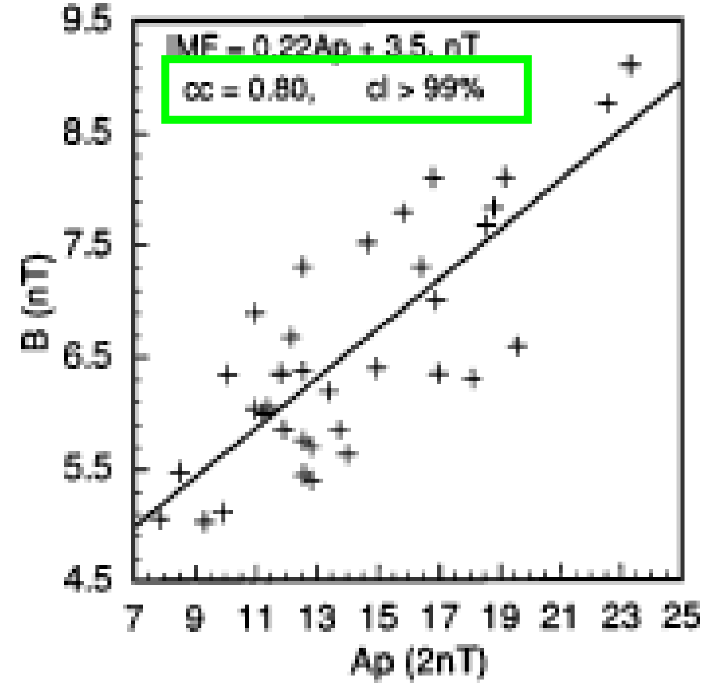


Figure 2. Linear correlation between B and Ap annual mean values is shown for the 1963 to 1998 period.

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

Kp (ap)/Km (am)/aa

THIRD USE O F MAGNETIC INDICES

to study

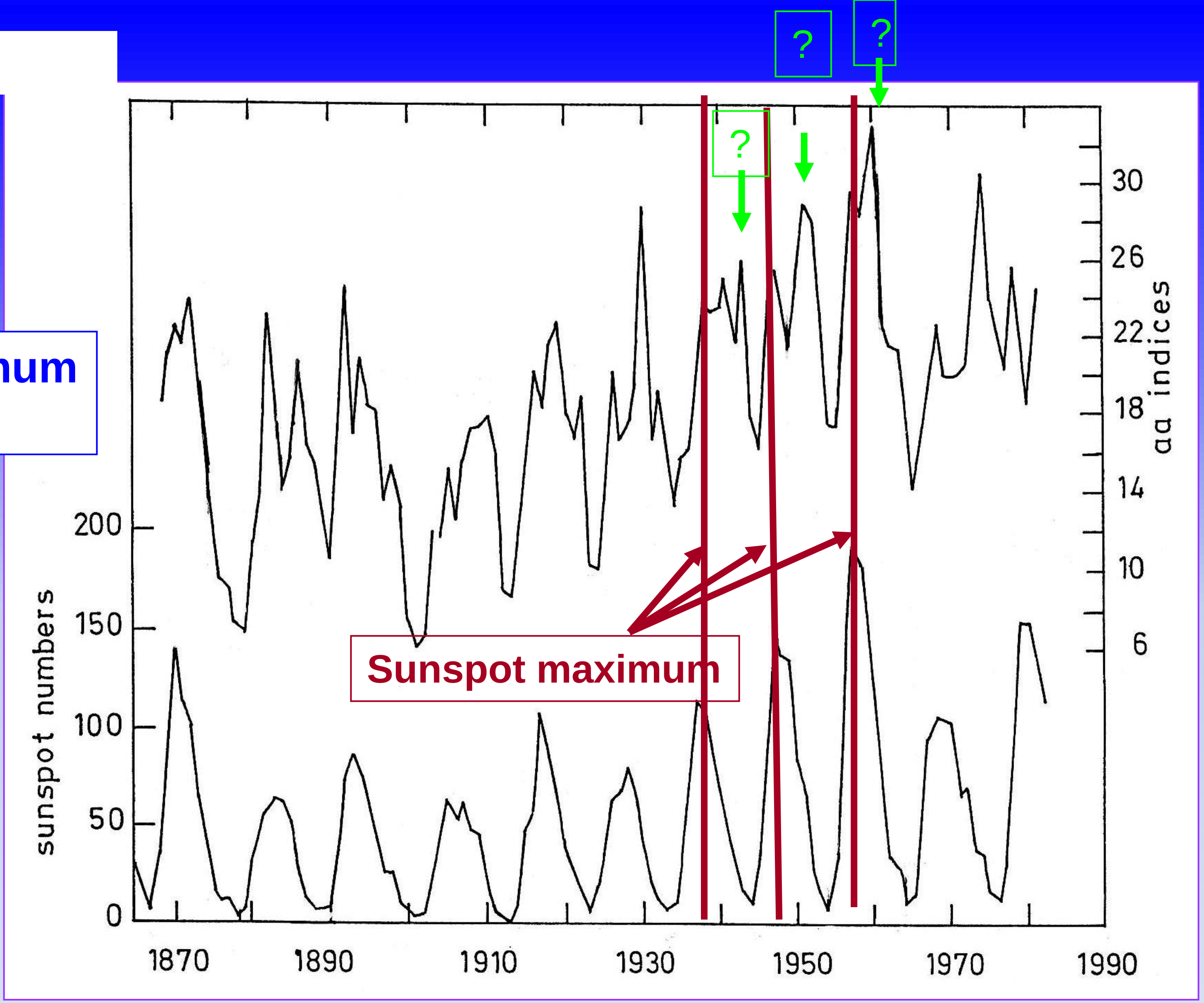
-SOLAR ACTIVITY and GEOMAGNETISM

- LONG TERM VARIATION OF THE SUN

Solar activity

aa index

First Maximum CME

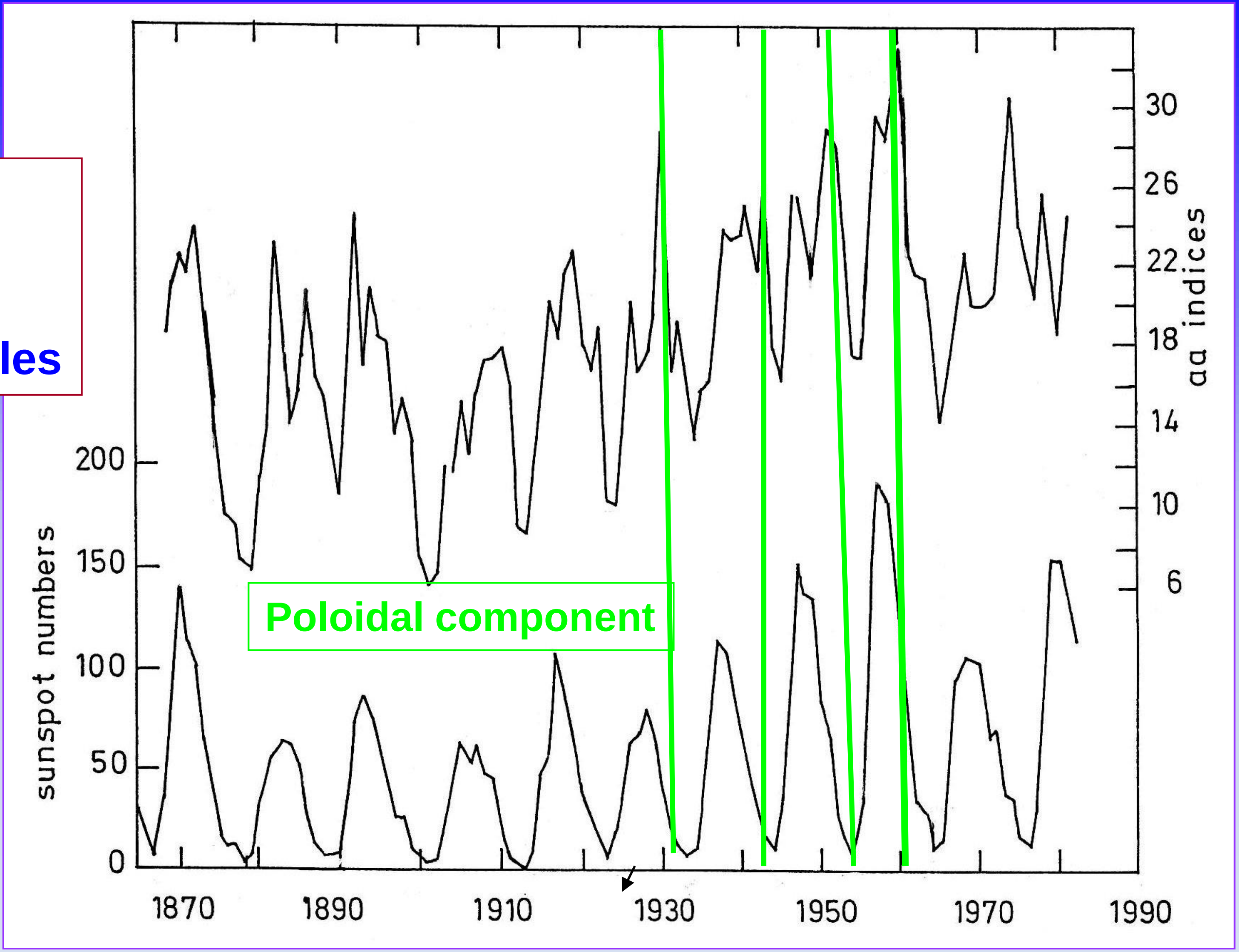


Used for many studies in medecine, climate change, solar wind parameters etc

aa index

Second Maximum

Coronal holes

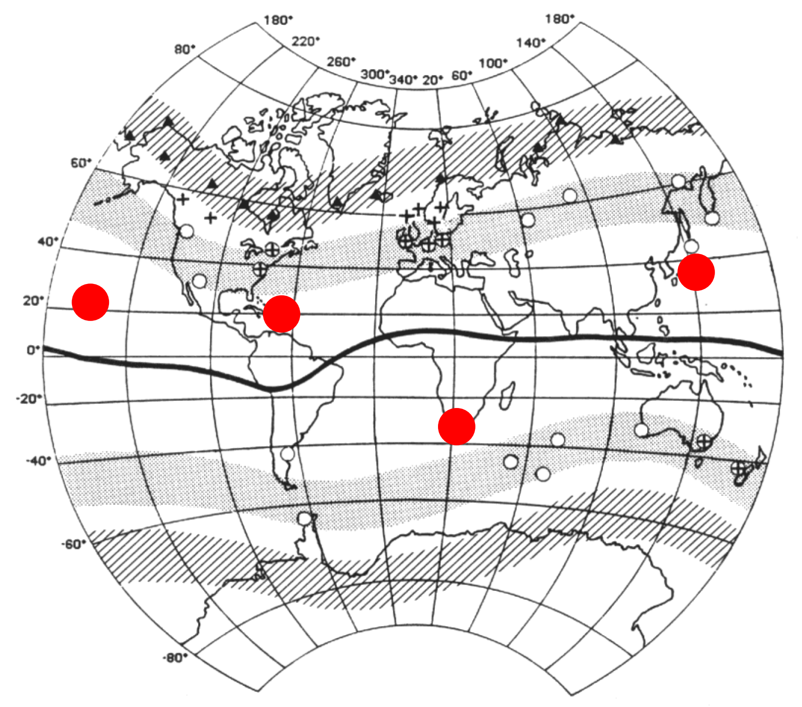


Used for many studies in medecine, climate change, solar wind parameters etc

Dst AU and AL

FOURTH USE O F MAGNETIC INDICES

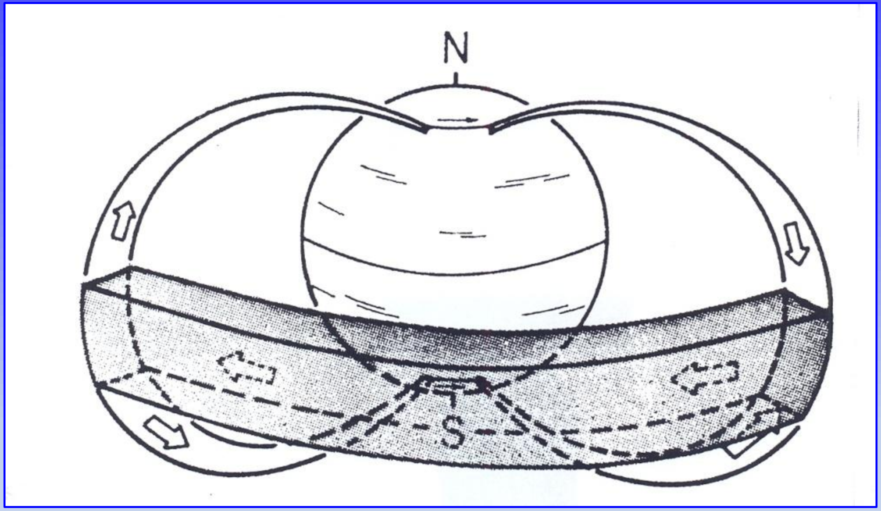
to study magnetic storms



Dst index
symmetric part of the ring current

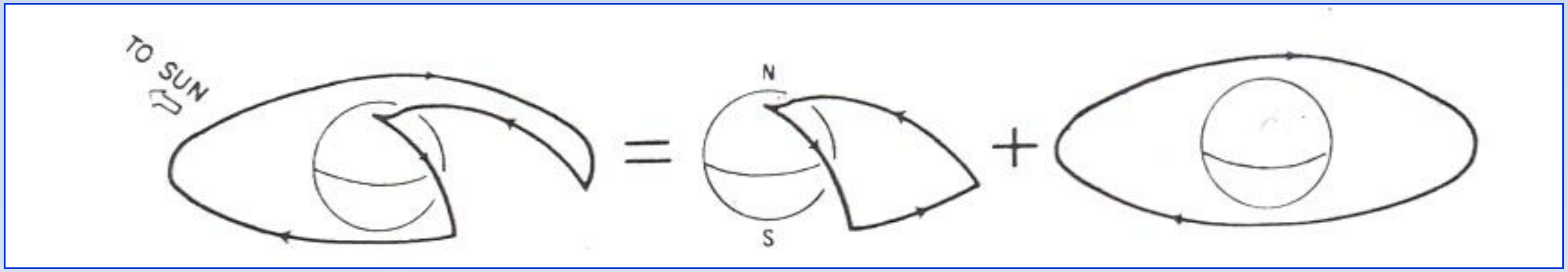
"*Dst is computed using 1-minute values from four low latitude observatories The locations of which are sufficiently distant from the auroral and equatorial electrojets to inhibit noise from these two sources.*
Local Dst values are computed at each "Dst" observatory at one instant in time. Contributions 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).

Partial ring current



Cummings, JGR, 1966

Fukushima and Kamide, 1973

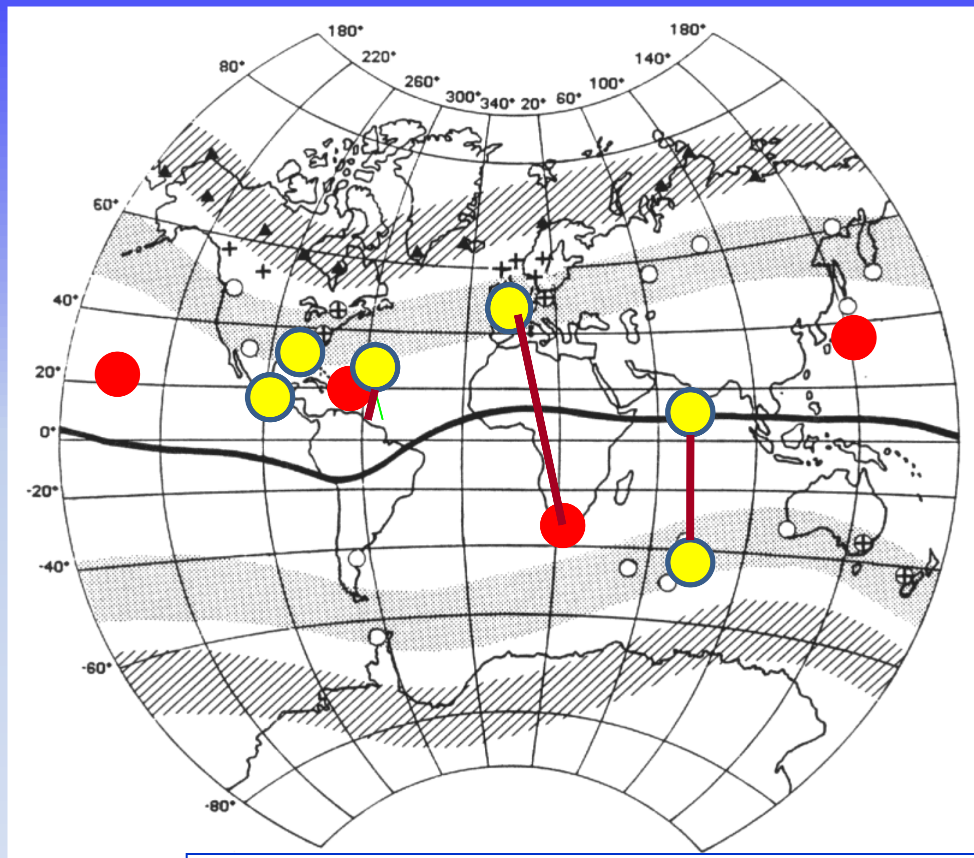


SYM + ASY

Dst

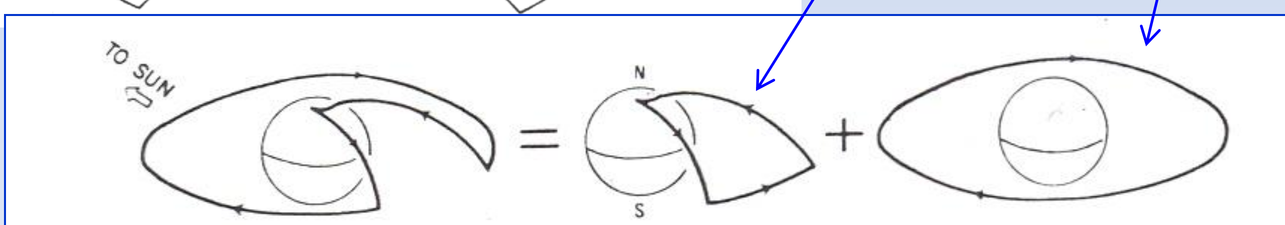
New indices SYM and ASY

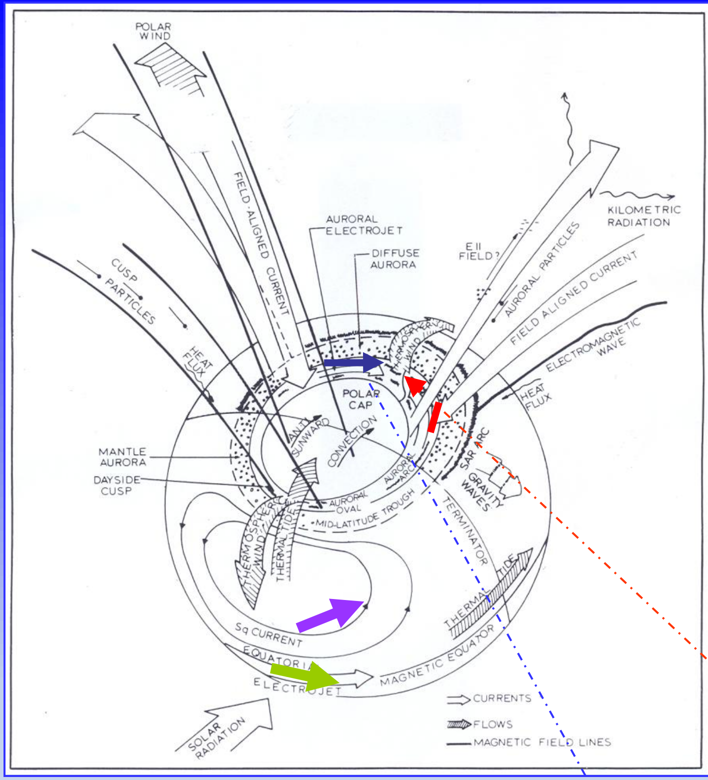
SYM (1') ⇔ Dst (1h)



SYM ~ Dst

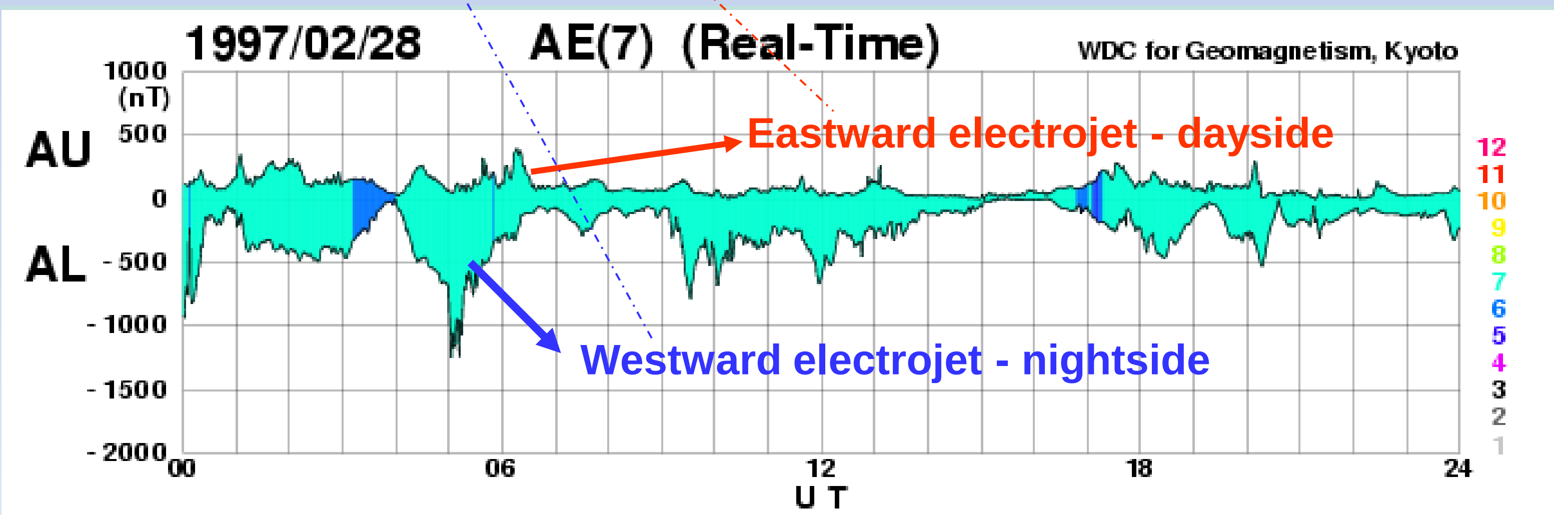
ASY



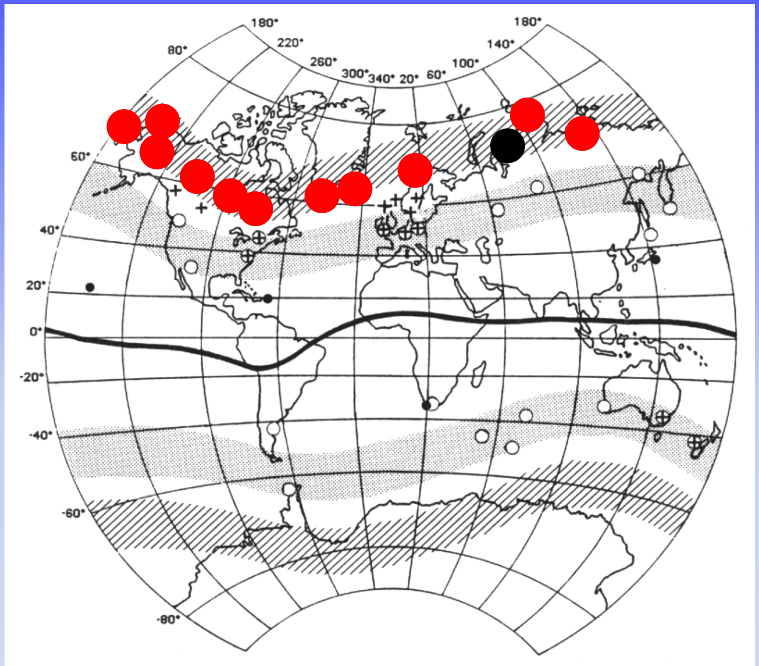


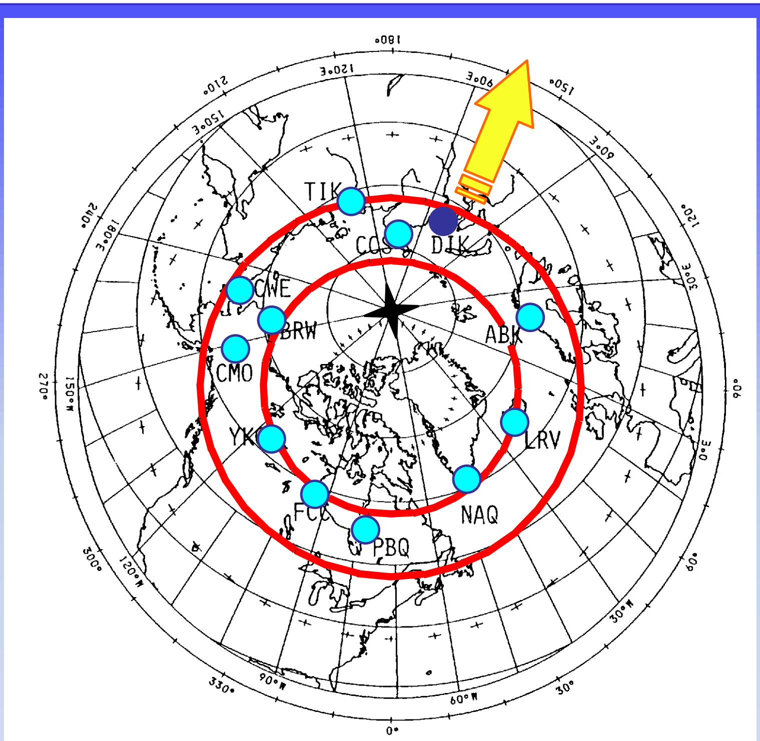
Auroral indices

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)

- 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

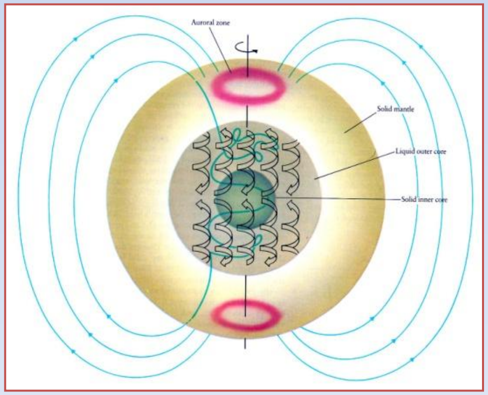
4 DYNAMOS IN

SUN
poloidal /toroidal

MAGNETOSPHERE
Solar wind
IMF

IONOSPHERE
Earth's magnetic field
Neutral wind

EARTH
Motions of the core

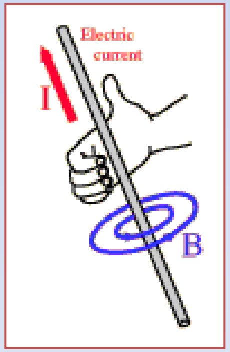


CURRENT SYSTEMS

MAGNETOSPHERE
Chapman Ferraro
Ring current
Tail current

FIELD ALIGNED

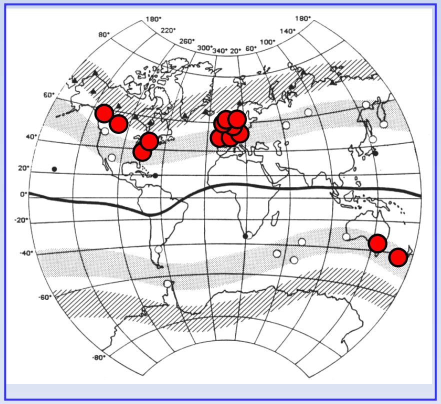
IONOSPHERE
Auroral electrojets
Midlatitude currents
Equatorial electrojet



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



Geophysical studies : the initial work
all the data are available on the web

- Sun
  - Sunspot cycle, poloidal cycle
  - Solar event
- Solar wind parameters V,B (E)
  - Solar wind magnetosphere dynamo
- AU and AL
  - Auroral electrojets
- Dst -> [Hsym and H asym]
  - Ring current
- Intermagnet magnetograms free
  - Planetary map of the transient variations of the Earth magnetic field

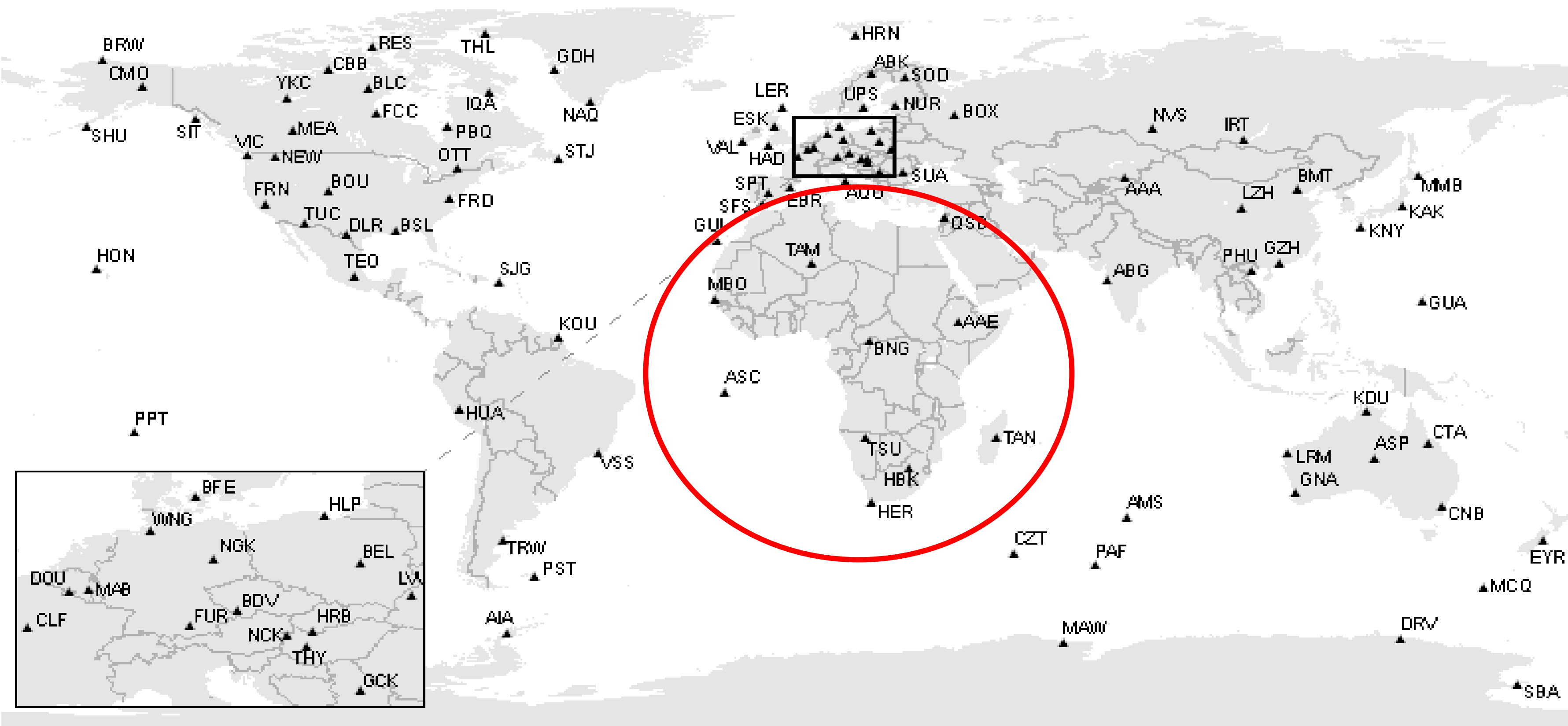
DATA BASE AVAILABLE ON THE WEB

WORLD

INTERMAGNET
Since year 1991
CD-ROM

http://www.intermagnet.bgs.ac.uk

AFRICA : 11 permanent observatories



The data consist of one-minute, hourly and daily mean values for the vector Component X,Y,Z or D,H,Z
The intermagnet CD-ROM/DVDs are available at no charge for academic purposes

- Data bases on the web - FREE

All kind of data

http://spidr.ngdc.noaa.gov/spidr/index.jsp

Magnetic field data (magnetometer)

http://www.intermagnet.bgs.ac.uk

http://www2.bc.edu/~Kassie/AMBER.html

http://ganymede.ipgp.jussieu.fr/jussieu

Magnetic model

http://www.iugg.org/IAGA/iaga_pages/pubs_prods/igrf.htm

Ionospheric data ionosondes

http://www.ukssdc.ak.uk

Solar data

http://solarscience.msf.nasa.gov/dynamo.shtml

SOHO : Solar Heliospheric Observatory under google

MAGNETIC INDICES
http://isgi.cetp.ipsl.fr

- WDC-C2 for Geomagnetism (Dst, Ae; Kyoto, Japan): http://swdcwww.kugi.kyoto-u.ac.jp/
- GFZ (Kp, Ap; Potsdam, Germany): http://www.gfz-potsdam.de/pb2/pb23/GeoMag/niemegk/kp_index/
- Observatori de l' Ebre (rapid variations; Roquetes, Spain): http://www.obsebre.es
- the Danish Meteorological Institute (PC; Copenhagen, Denmark) http://web.dmi.dk/fsweb/projects/wdcc1/pcn/pcn.html
- the Arctic and Antarctic Research Institute (PC; St. Petersburg, Russia) http://www.aari.nw.ru/

GPS networks / On the web for all

IGS

http://sopac.ucsd.edu

http://cddis.gsfc.nasa.gov or http://igs.ensg.ign.fr

NOAA et UNAVCO

http://www.ngs.noaa.gov/CORS

http://www.unvaco.org

AMMA in IGS now

http://www.amma-international.org