Electrodynamics coupling between high and low latitudes

Recent advances in the framework of ISWI network

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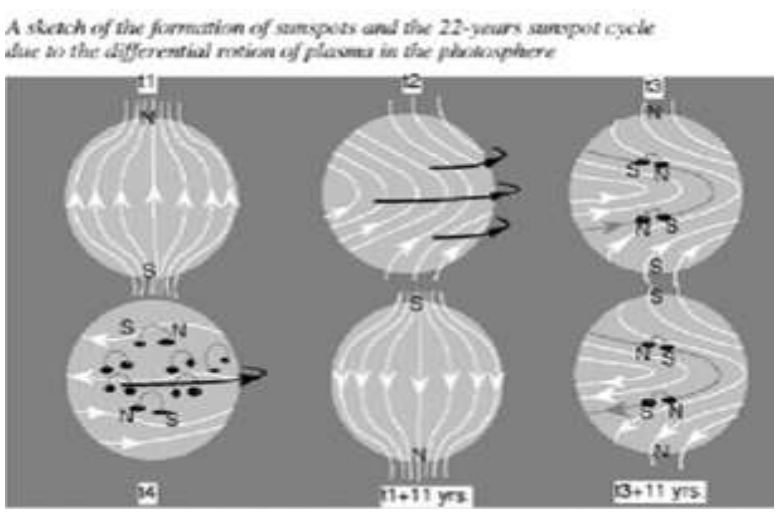
SUMMARY

- **Part I. Introduction :** What we learned for ionosphere studies (large scale)
  - a better knowledge of the sun and its disturbances
  - the need for systemic study of the Sun Earth system using data from multiple instruments (particularly GNSS) and models
  - a better knowledge of the equatorial ionosphere in Africa

- **Part II. Particularities of the Equatorial Ionosphere**
  - Equatorial Fountain, Equatorial Electrojet EEJ
  - Pre reversal enhancement of the zonal electric field and Plasma irregularities
  - Necessity to connect high and low latitudes

- **Part III. on PPEF and DDEF**
  - Impact of PPEF and DDEF on GPS and magnetic data
  - Impact of PPEF and DDEF on PRE

- **Part IV. Conclusion**

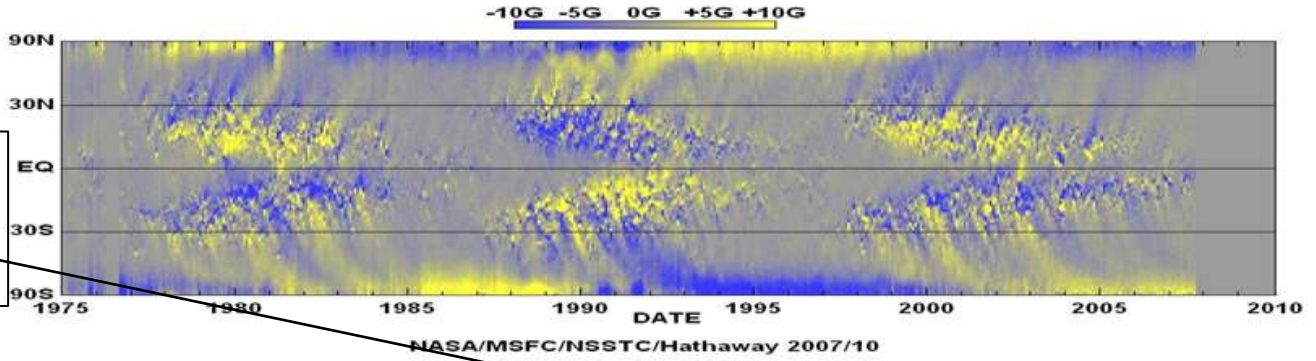


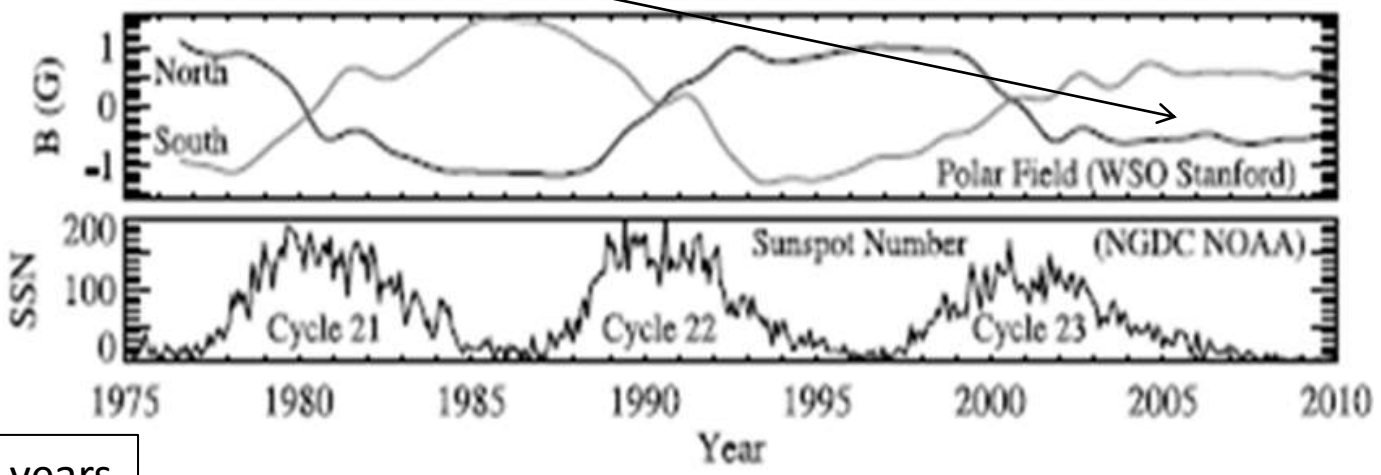
Solar Dynamo

the true solar cycle

by solar physicists

decrease of the component of the poloidal solar magnetic field



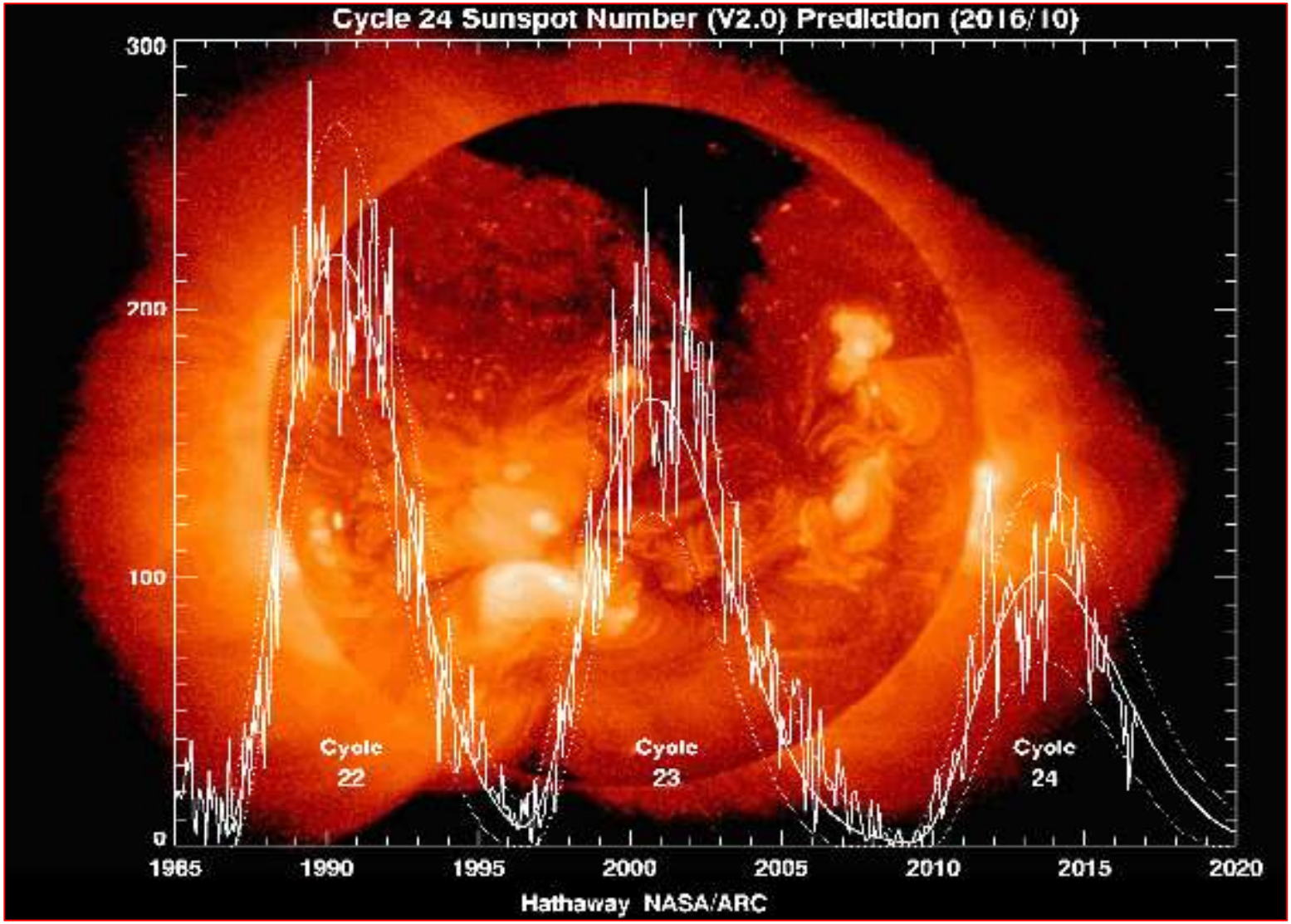


Liu et al., 2011

Variability ~ 11 and 22 years

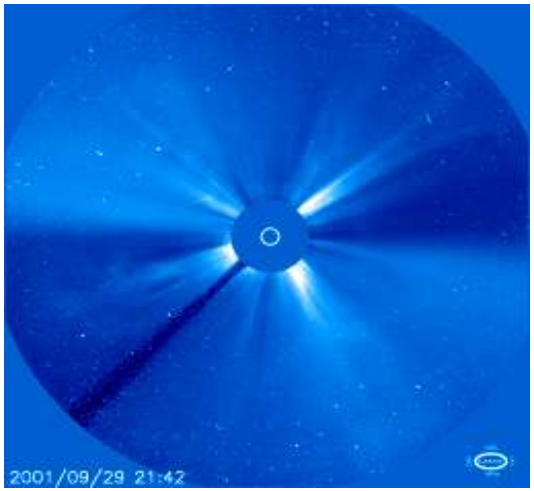
http://solarscience.msf.nasa.gov/dynamo.shtml *

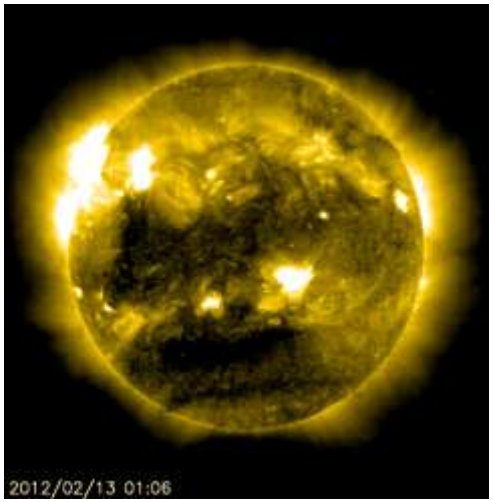
We have to consider all the phases of the sunspot cycle and not only the phases of the minimum and the maximum

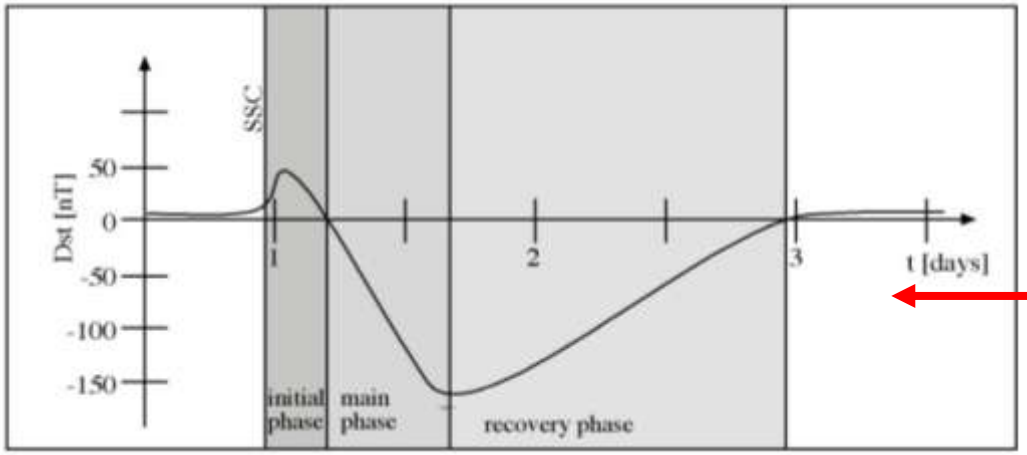


smallest sunpot cycle since the Space era

Coronal Mass Ejection -CME
High speed solar wind flowing from solar coronal hole







Criteria for selection of events

Bz component of IMF toward the south during several hours

Dst

We mainly selected CME

UNIVERSAL PHYSICAL PROCESS : DYNAMO

Permanent dynamos	**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

During storm other non permanent dynamos are acting

4 PERMANENT DYNAMOS

SUN

poloidal /toroidal

MAGNETOSPHERE

Solar wind

IMF

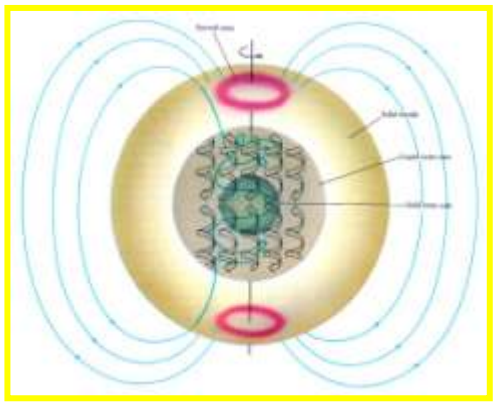
IONOSPHERE

Earth's magnetic field

Neutral wind

EARTH

Motions of the core



CURRENT SYSTEMS

MAGNETOSPHERE

Chapman Ferraro

Ring current

Tail current

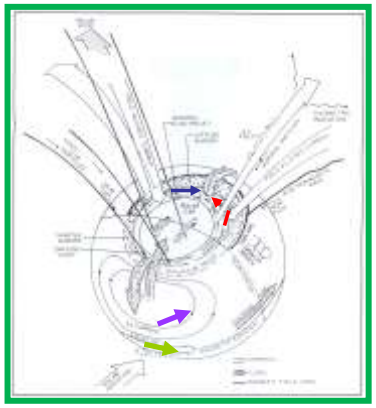
FIELD ALIGNED

IONOSPHERE

Auroral electrojets

Midlatitude currents

Equatorial electrojet



EARTH's MAGNETIC FIELD

Transient variations

Indices -> disturbances

Dst,

Aa, Kp, Ap

Km, Am

AU, AL

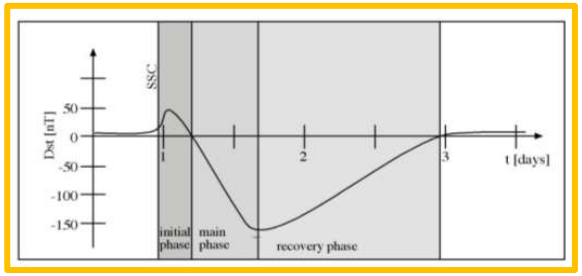
PCN,PCS

Equivalent current

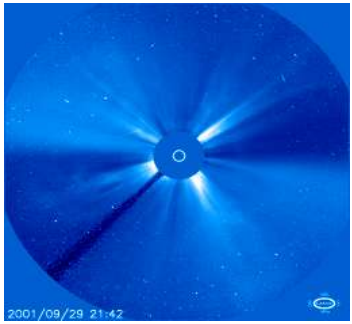
DP1, DP2,Ddyn

[due to PPEF, DDEF]

S_R <Sq>, Sq^P

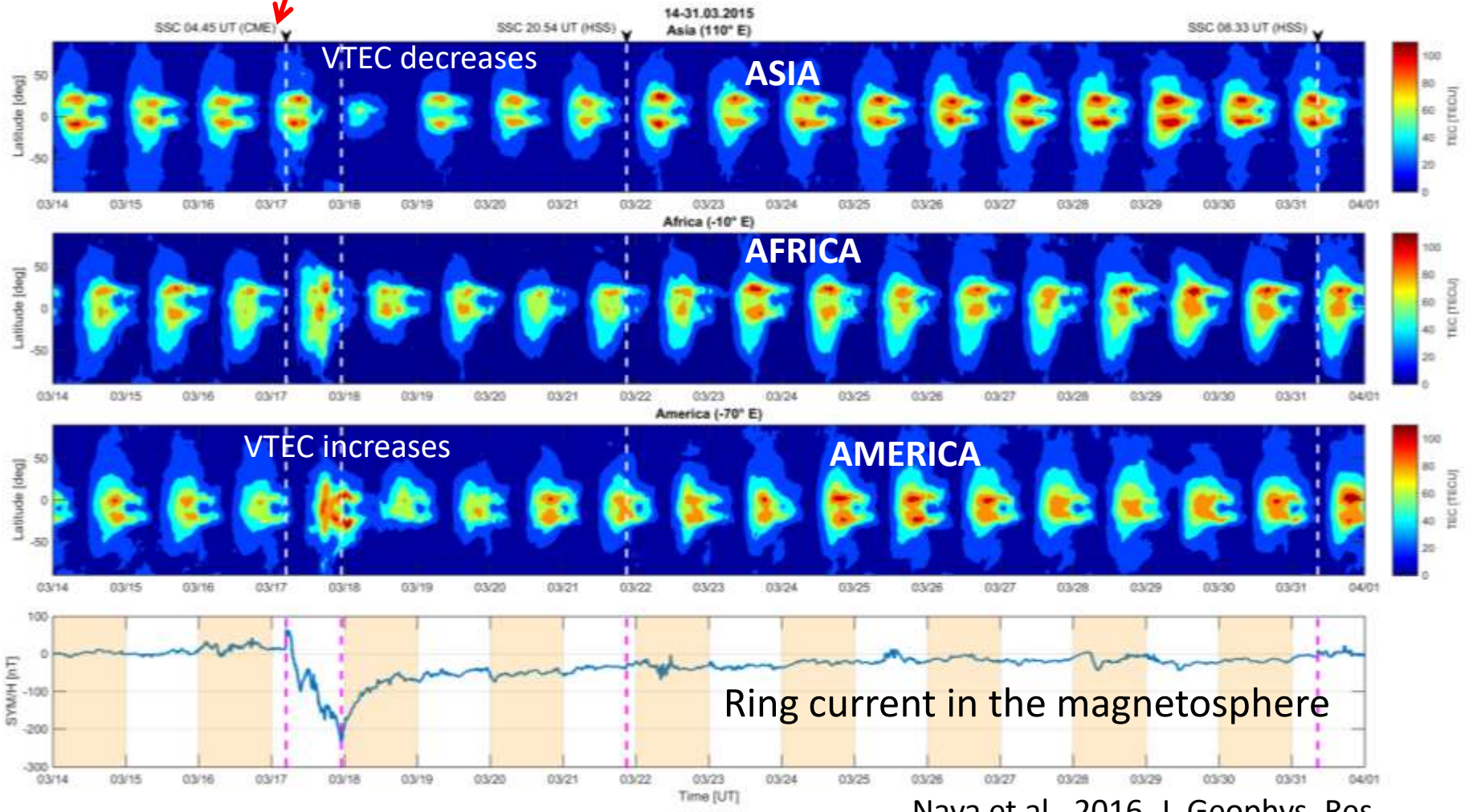


MAGNETIC STORM of St PATRICK's DAY : MAPS of VTEC



Variations near the magnetic Equator due to a CME (~200 GPS stations)

Impact of a CME (solar event, on March 15 ~ 04.45 - 02.00UT)



Nava et al., 2016, J. Geophys. Res.

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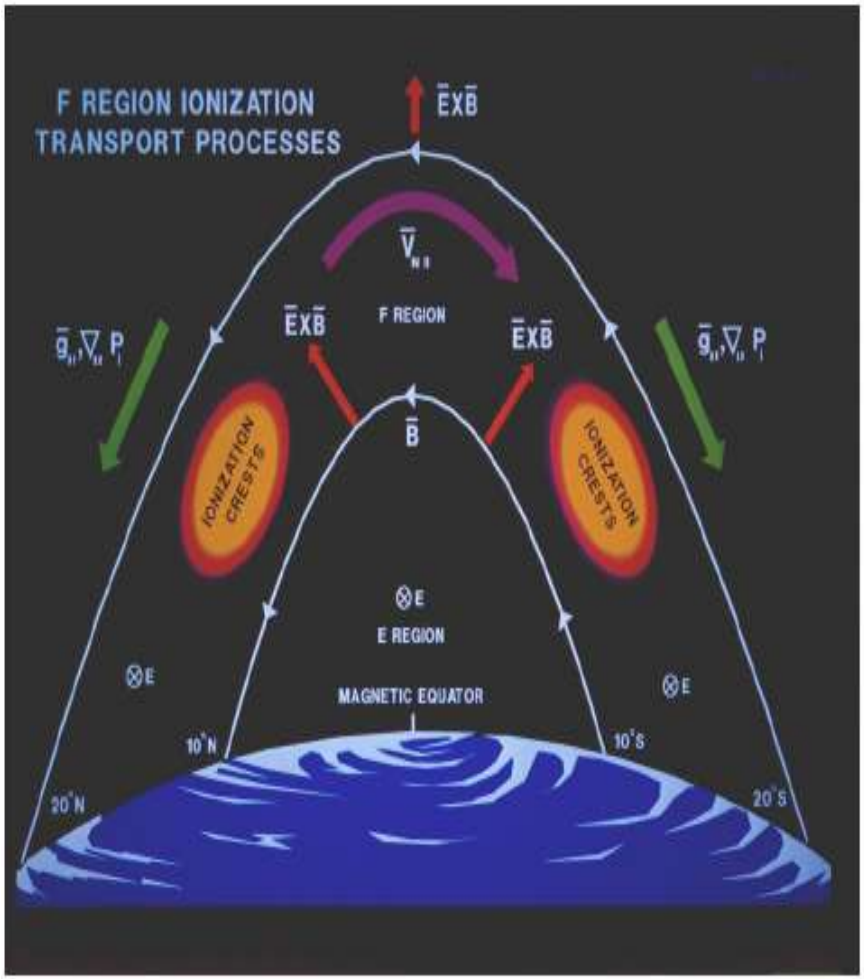
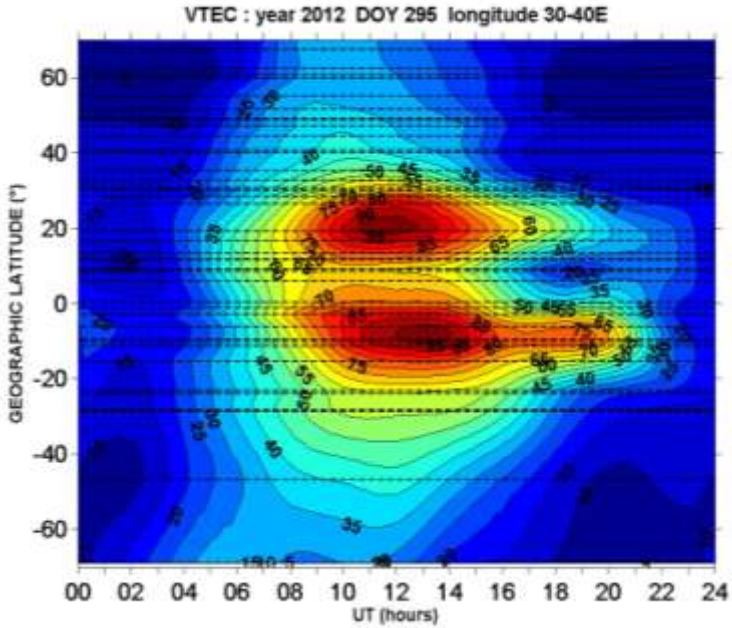
SUN EARTH CONNECTIONS

The Equatorial Ionosphere

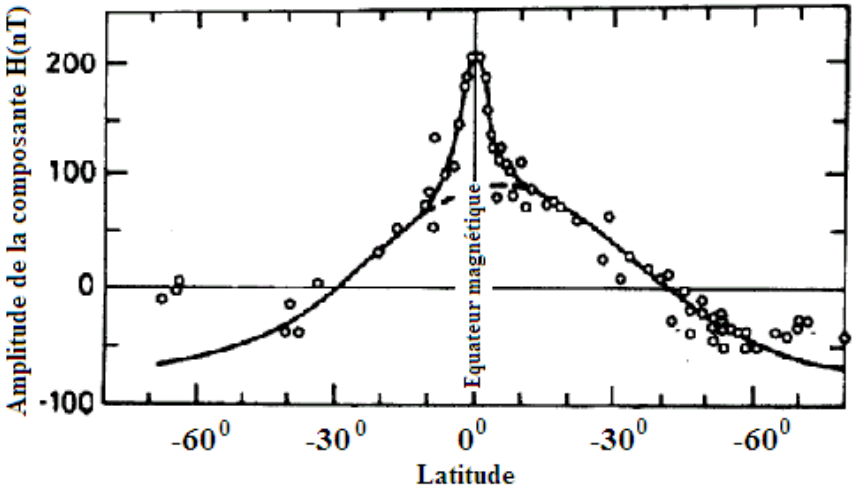


Equatorial Fountain



First VTEC map in East AFRICA

Amory-Mazaudier et Fleury, 2013

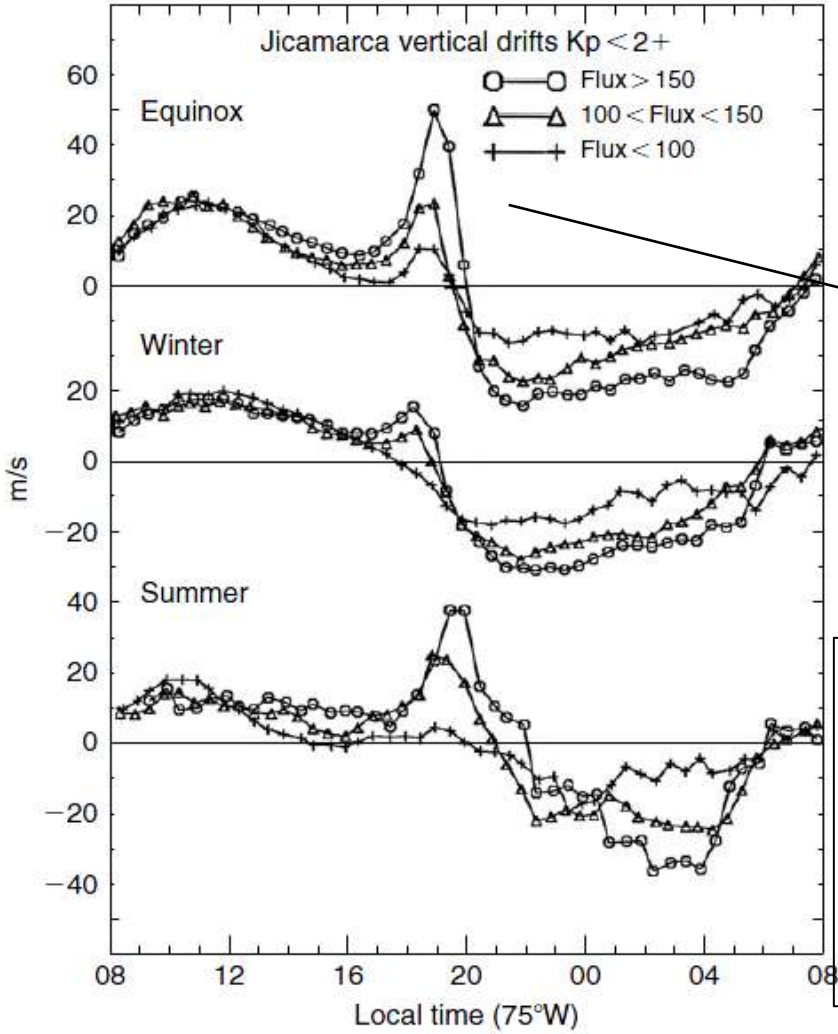


The Equatorial Electrojet (Jacobs, 1990)

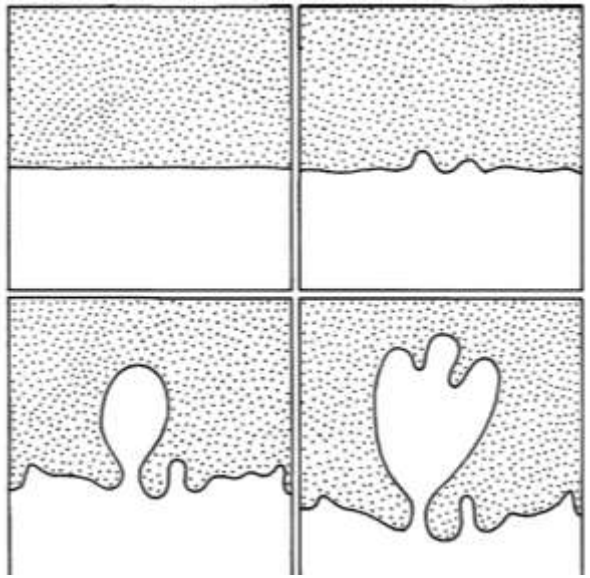
Eastward electric field => moves up

Westward electric field => moves down

PRE : Pre Reversal Enhancement



Equatorial Plasma Bubbles



Sequential diagram, from photos, of the development of a Rayleigh Taylor instability. The heaviest fluid [... ..], over a lighter and more transparent fluid (Kelley, 2009)

Upward vertical drift ⇔ Eastward electric field

Downward vertical drift ⇔ Westward electric field

Average vertical plasma velocities at Jicamarca during the equinox (March-April, September-October), winter (May-August), summer (November-February) for 3 solar flux values (Fejer et al., 1991)

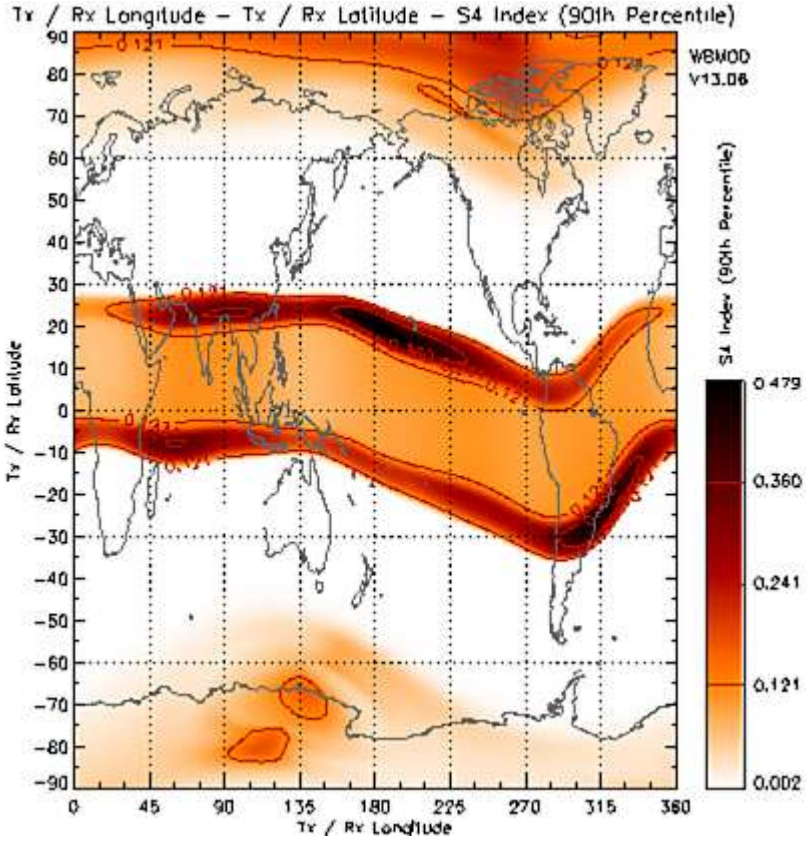
Scintillations : a regular phenomenon

Ionospheric scintillation is the rapid modification of radio waves caused by small scale structures in the ionosphere

<u>Physical Process :</u> Instabilities in Plasma

Indice of scintillation

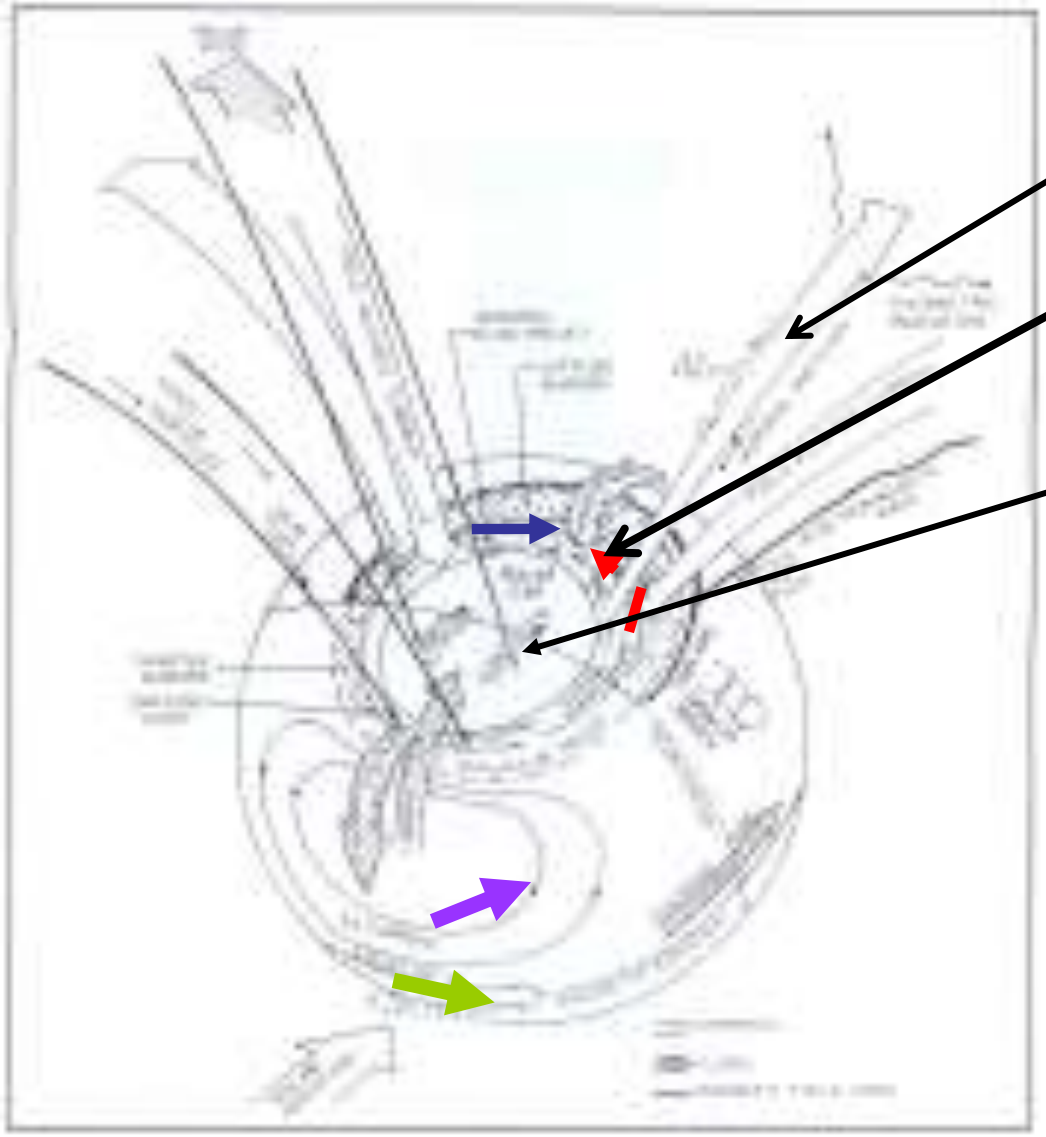
$$s4 = \sqrt{\frac{< I^2 > - < I >^2}{< I >^2}}$$



Scintillation index at GPS L1 (1575.42 MHz) assuming constant local time 23.00 at all longitudes (from http://www.sws.bom.gov.au)

"Ionospheric scintillation is primarily an equatorial and high-latitude ionospheric phenomenon, although it can (and does) occur at lower intensity at all latitudes. Ionospheric scintillation generally peaks in the sub-equatorial anomaly regions, located on average ~15° either side of the geomagnetic equator."

AURORAL and EQUATORIAL IONOSPHERE ARE STRONGLY CONNECTED



Field aligned current

Precipitation of particles

Auroral electrojets

Electric field

Auroral latitudes

Middle latitudes

Equatorial latitudes

Coupling between high and low latitudes

- 1. Transmission of an electric field **PPEF** related to the magnetospheric convection

  [theory-Vasyliunas 1970,1972]

- 2.a Thermal expansion of the atmosphere due to Joule heating in the auroral zone : changes in pressure, temperature, motions and composition of the Atmosphere

  [theory-Fuller-Rowell et al., 1994,1996]

- 2.b Transmission of a disturbance electric field dynamo **DDEF**, by the disturbed atmospheric motions in the dynamo layer also due to Joule heating in the auroral zone

  [theory – Blanc and Richmond, 1980]

FIRST EVIDENCE OF PPEF – magnetic data

S_q^p Nagata and Kokubun, 1962
Rep. Ionoph Space Japan, 16, 150
This current system is confined at High latitudes (magnetic quiet time), now DP_0

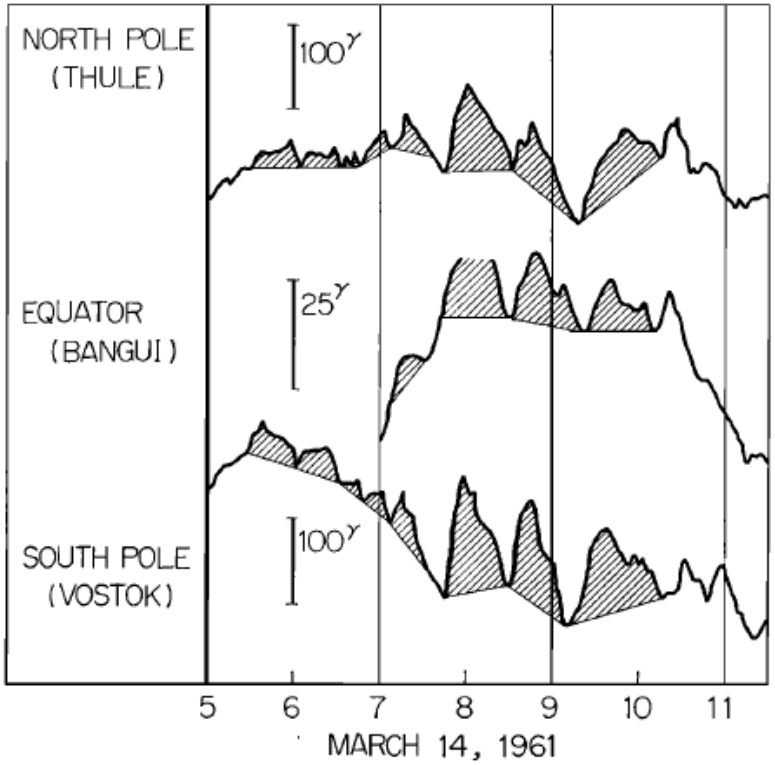
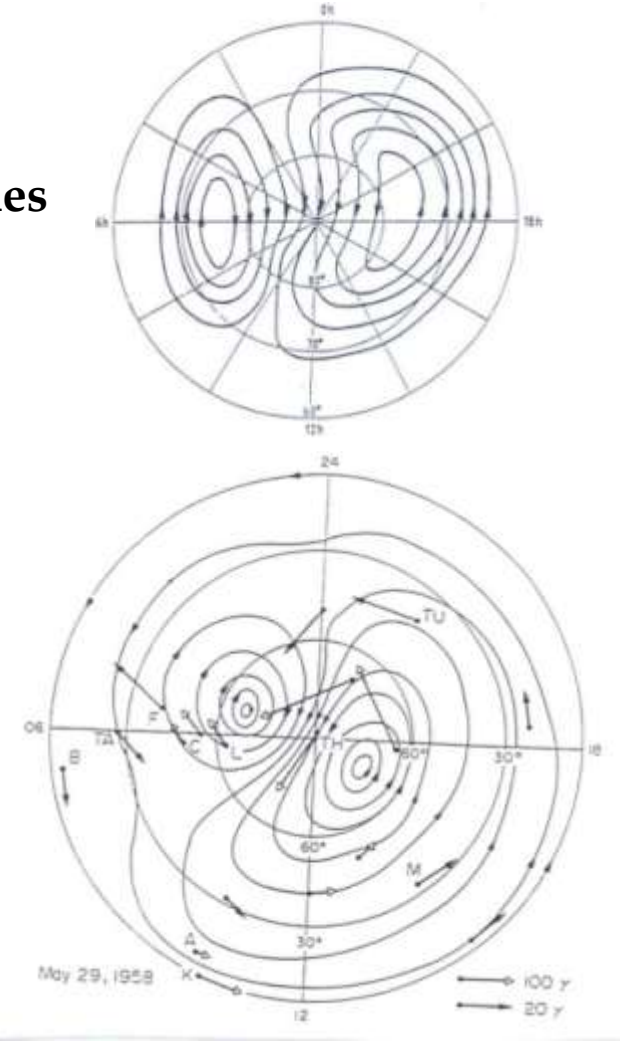


Fig. 1. Train of D_P 2 fluctuations (shaded). Geomagnetic latitudes of these stations are 88.9 (Thule), 05.0 (Bangui), and —89.1 (Vostok).

Transmission of an electric field



DP_2, Nishida, 1968, JGR, 73, 5549
This current system extends towardLow latitudes (magnetic disturbed time) [Nishida et al., 1966]

COUPLING between HIGH and LOW LATITUDES
Storm winds and ionospheric disturbance dynamo
=> delay between the auroral and equatorial regions DDEF

Auroral electrojets

↓

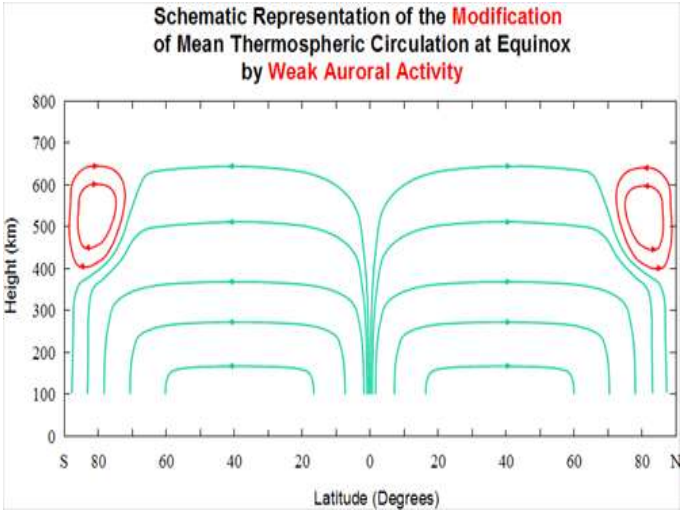
Joule heating most effective

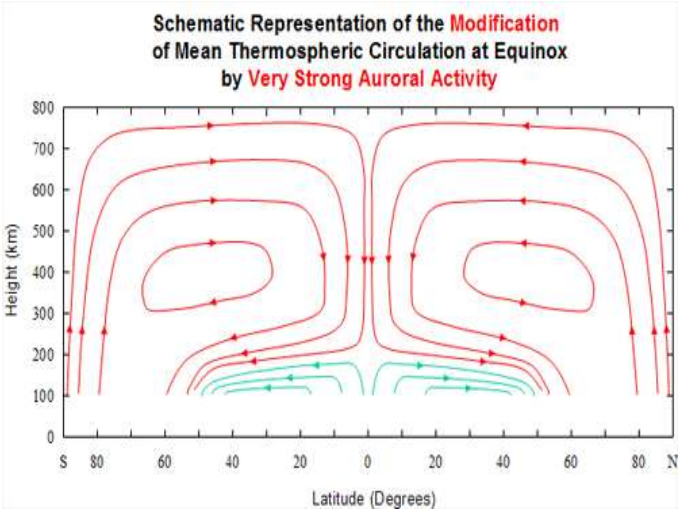
↓

$+ \Delta Vn \longrightarrow \Delta E_{dyn} \longrightarrow \Delta J \longrightarrow \Delta B$

Gravity waves, HADLEY convection cell etc…

Review Fejer et al., 2016, Space Sci Rev

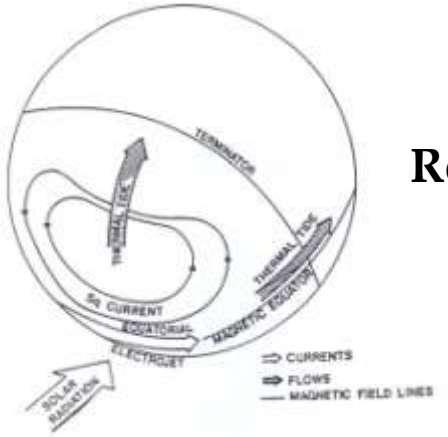




FIRST EVIDENCE OF DDEF

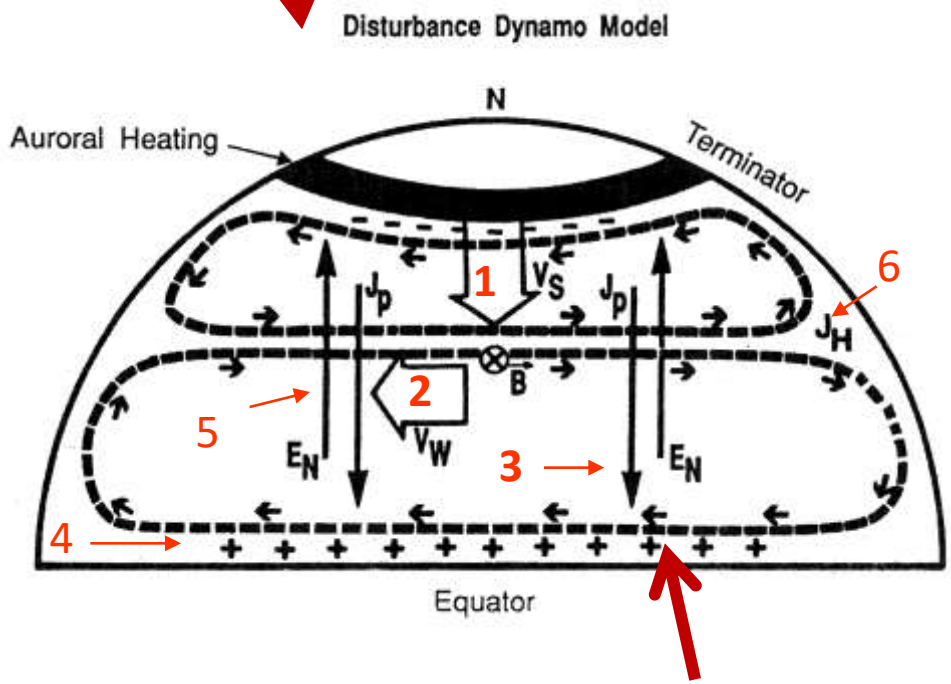
MODEL of Blanc and Richmond, JGR,85, 1669-1686, 1980

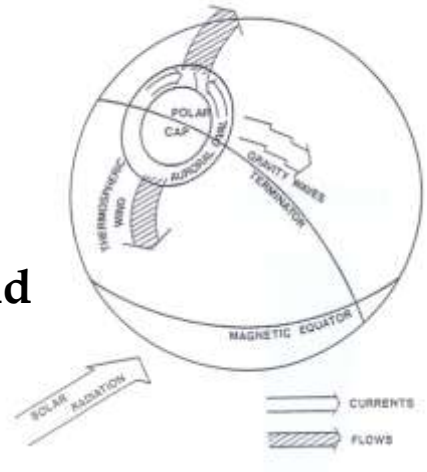
OBSERVATION Le Huy and Amory-Mazaudier, JGR 2005 Ddyn



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

Reversed current flow
Westward direction

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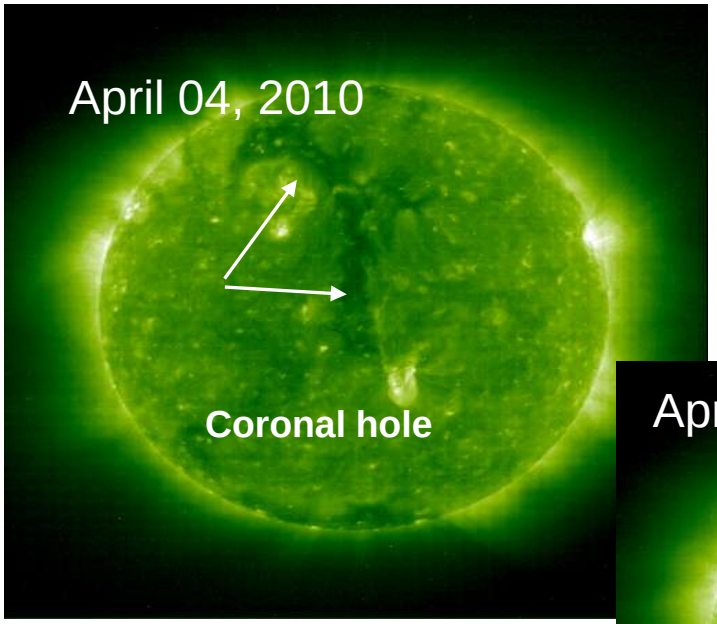
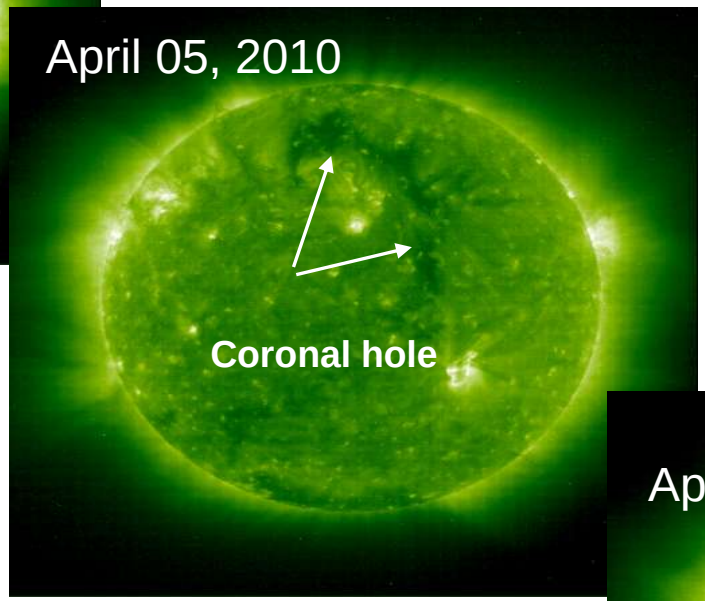
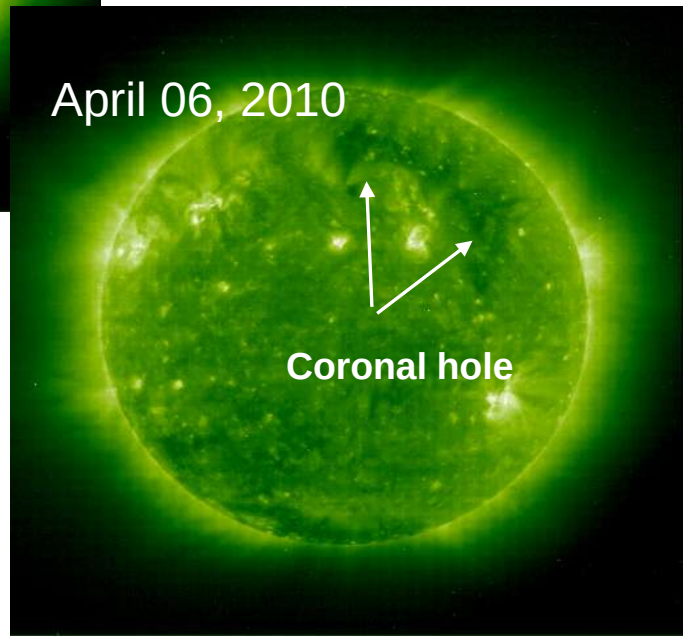
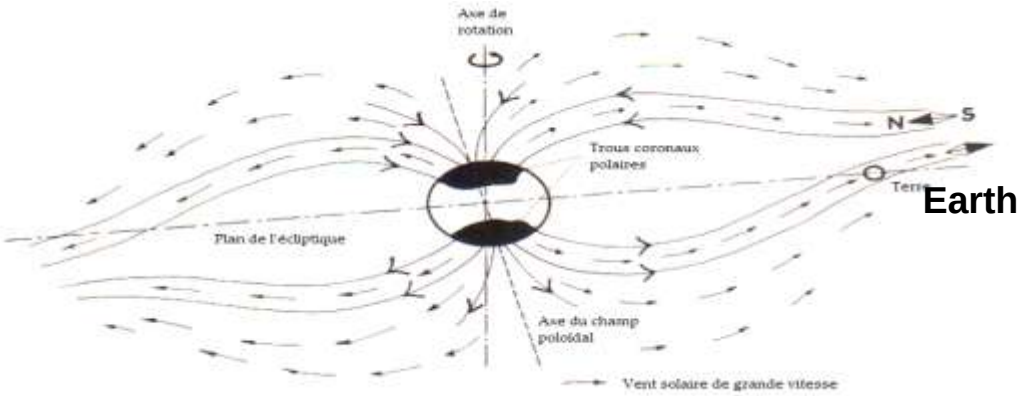
Solar event :
CME + coronal hole -> April 2010





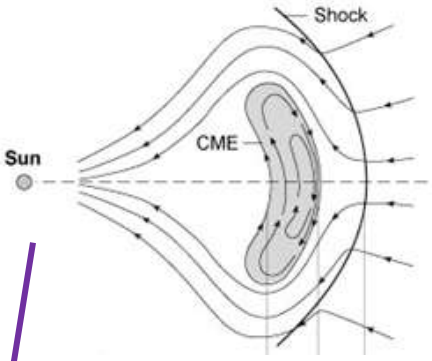


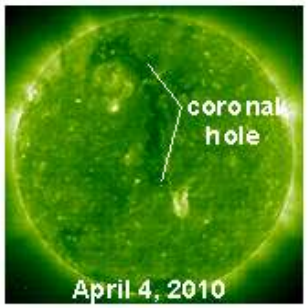


Earth

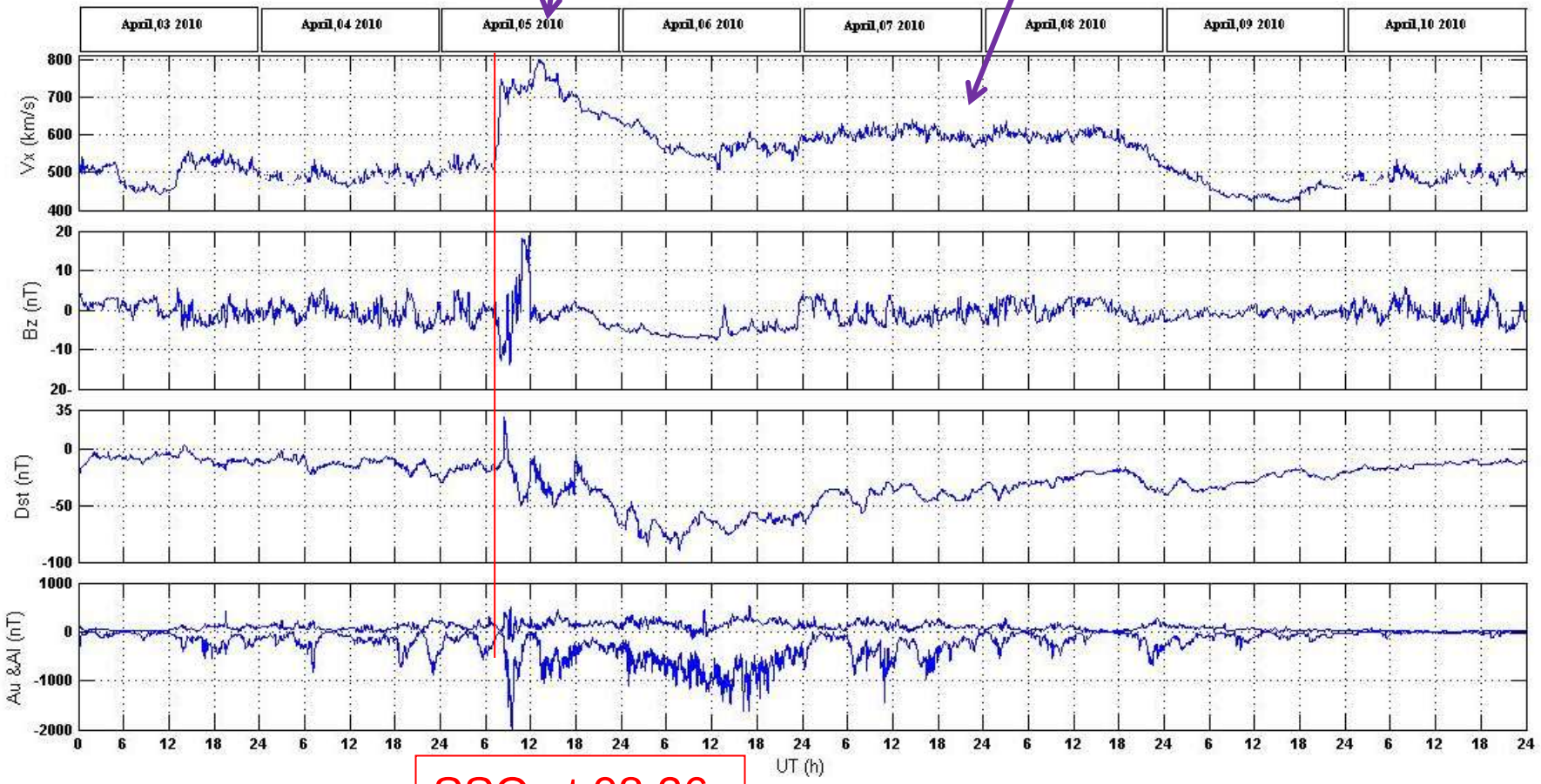
High speed solar wind streams

Shimeis et al., JGR 2012





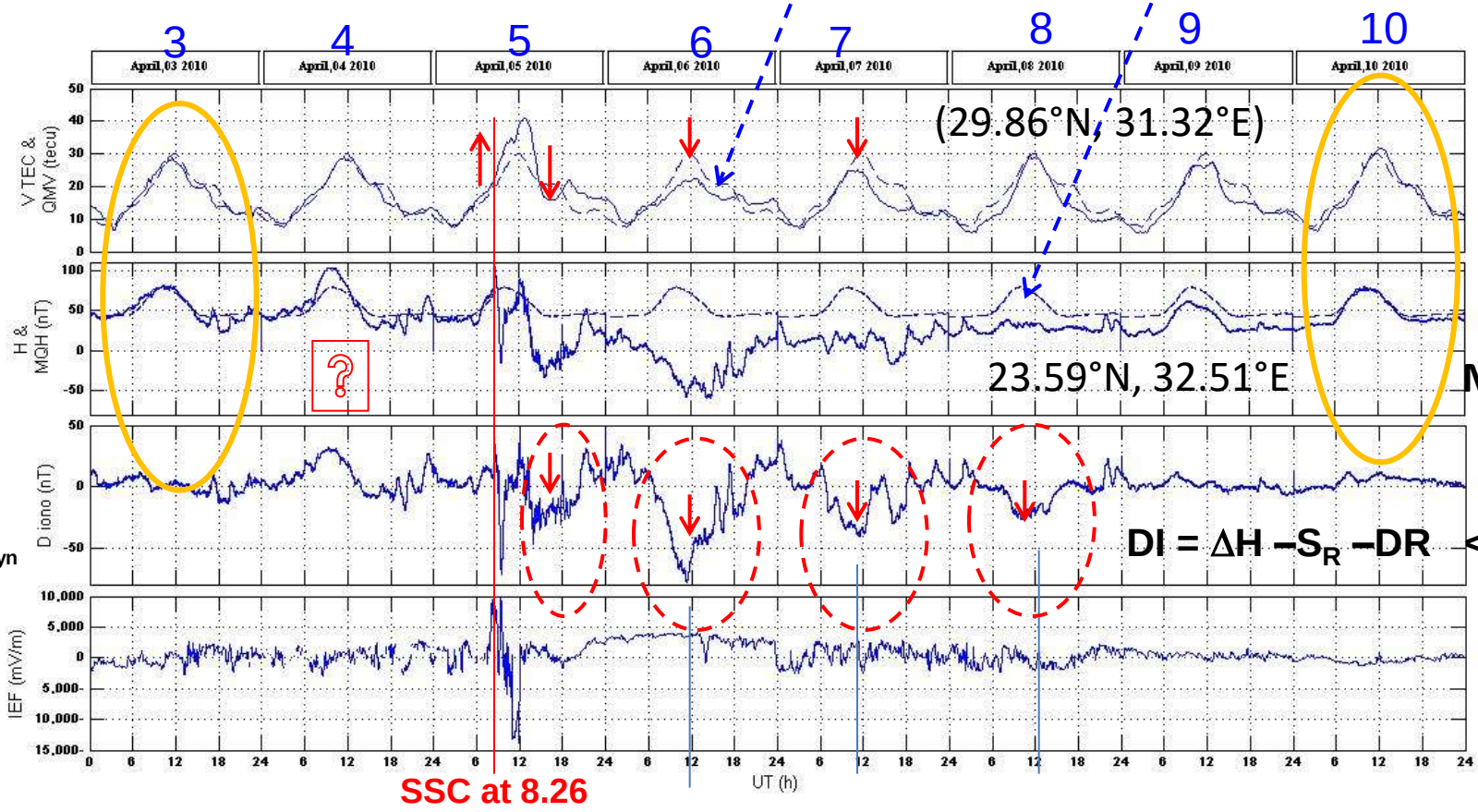
A solar wind stream flowing from the indicated coronal hole should reach Earth on April 6th or 7th. Credit: SOHO Extreme UV Telescope



SSC at 08:26

dashed lines : the quiet time variations

April 2010



TEC — **SCINDA**

ΔH — **MAGDAS**

DI
$DP_2 + D_{dyn}$

$DI = \Delta H - S_R - DR$ <=Dst

IEF

At the beginning of the storm
-> Prompt penetration of the magnetospheric electric field, (Vasyliunas, 1970)
DP2 (Nishida, 1968)

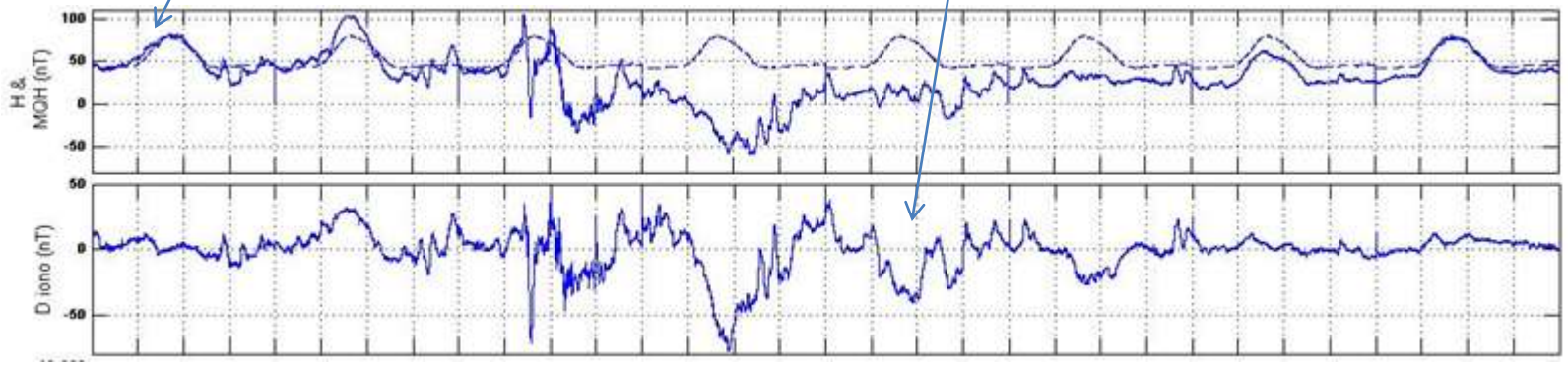
Three hours after the beginning of the storm
-> ionospheric disturbance dynamo (Blanc and Richmond, 1980) is acting at low latitudesDdyn (Le Huy Minh and Amory-Mazaudier, 2005, 2008)

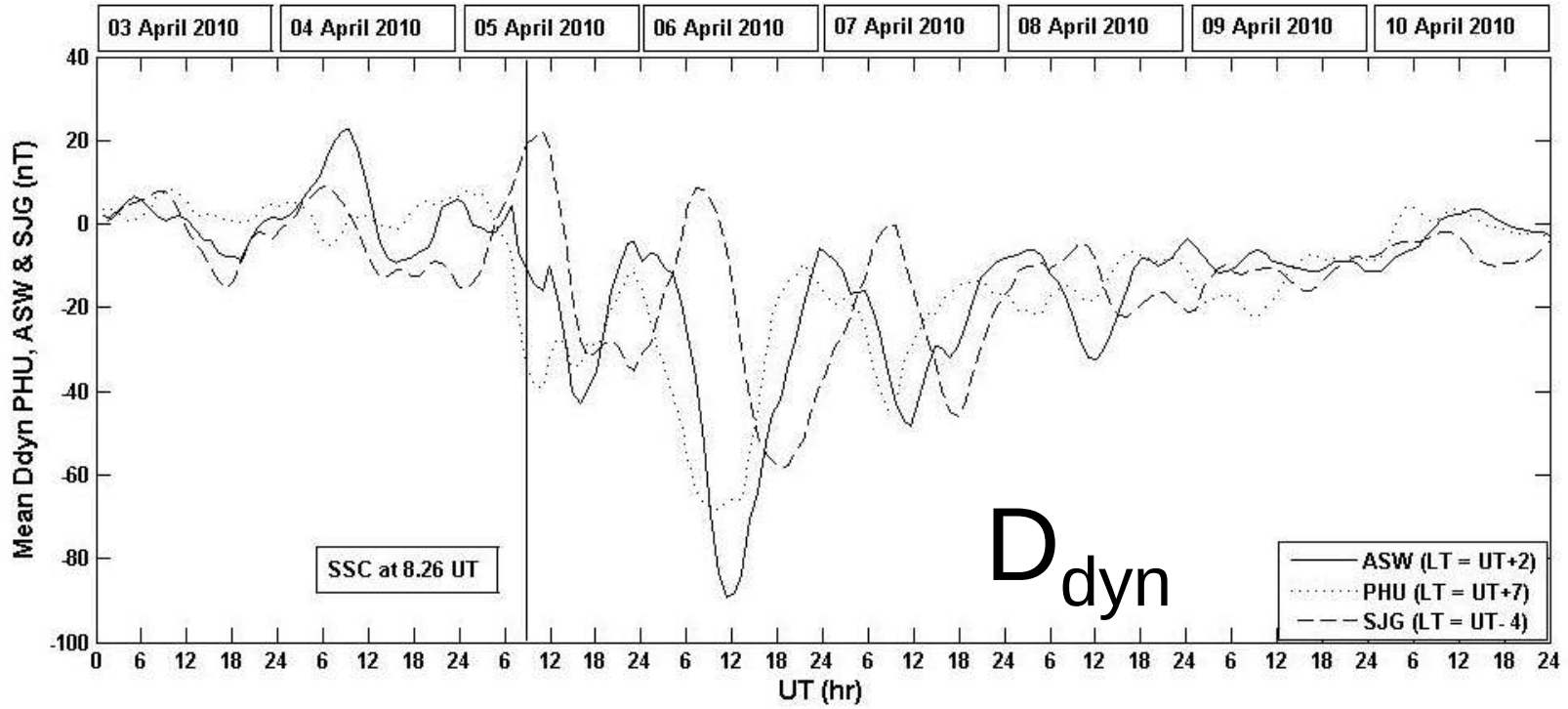
Law of and Savart $D_{iono} = \Delta H - S_R - DR$

(DR ring current magnetic disturbance)

Regular variation S_R

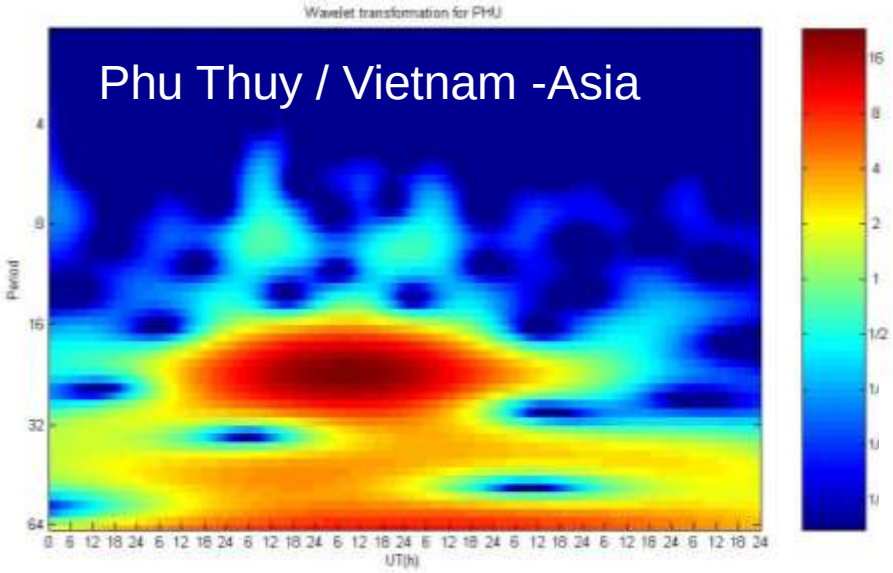
$D_{iono} = DP_2 + D_{dyn}$

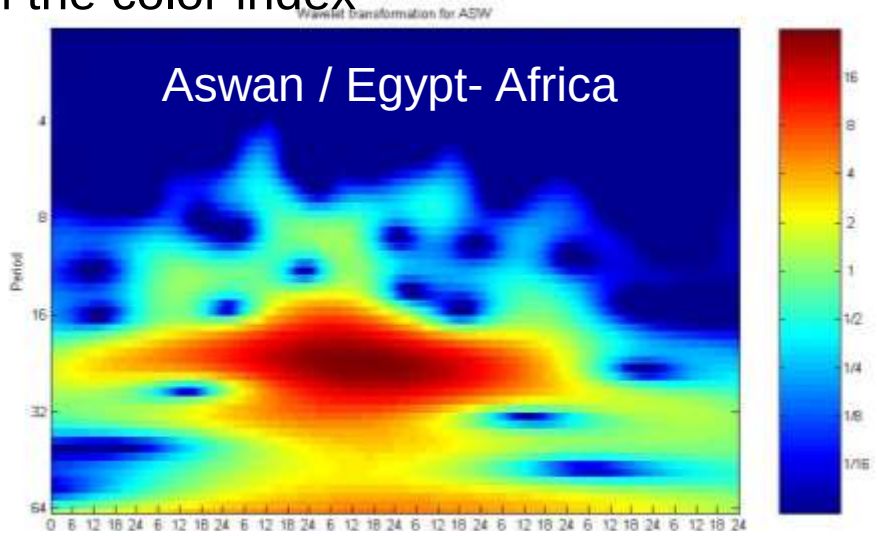


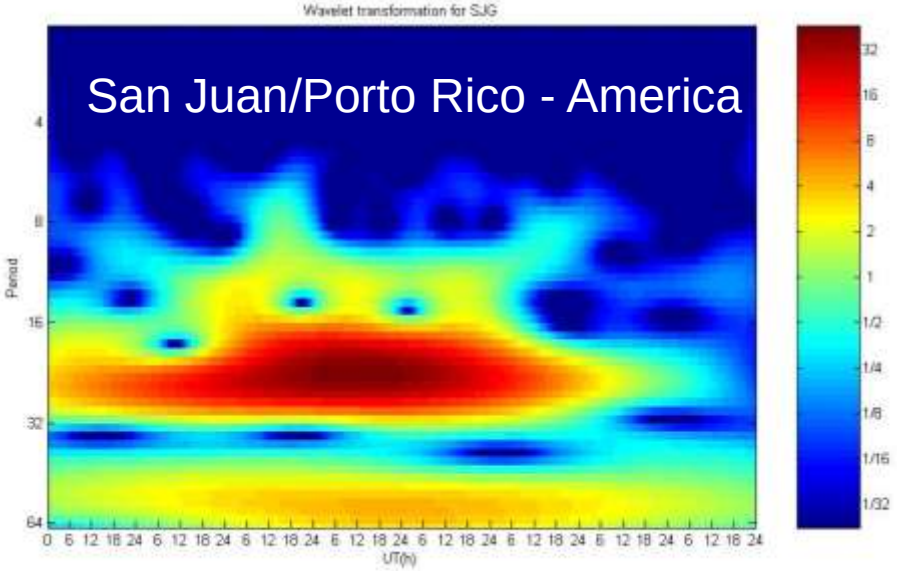


Fathy et al., 2014, JGR

Illustration of the continuous wavelet transformation of PHU station (a), ASW station (b) and SJG (c) . The vertical axis illustrates the period of the signal in hours and the horizontal axis is the universal time in hours. It's clear that the dominant frequency of the signal around the period of 22 hours in the time interval from (45-125hrs) as it is clear from the color index

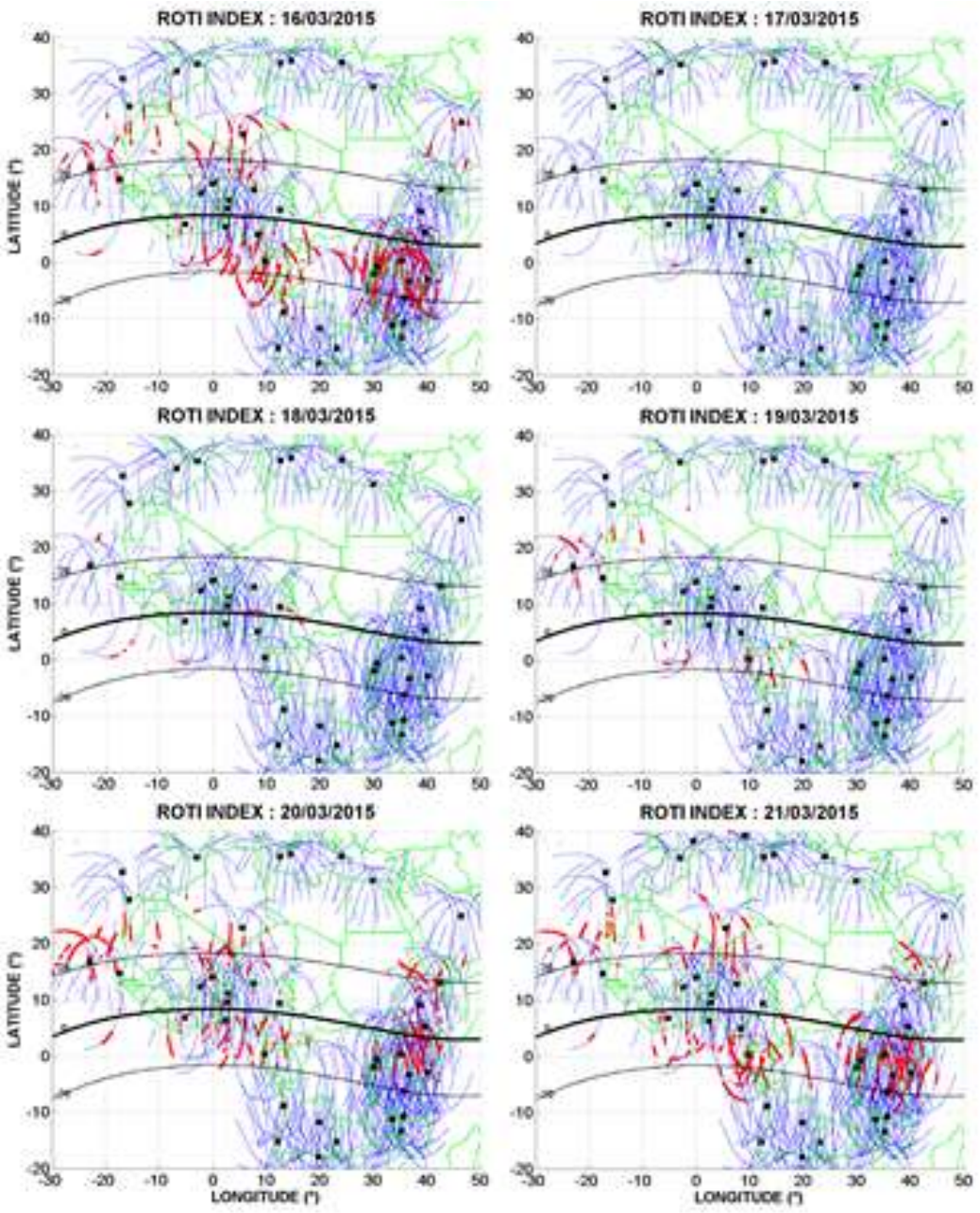






Fathy et al., 2014 - JGR

EFFECT OF **DDEF** on ROTI INDEX



Storm March 17, 2015 equinox

$$\mathbf{rot} = \frac{STEC_{k+1} - STEC_k}{time_{k+1} - time_k} * 60$$

Dst < -200 nT

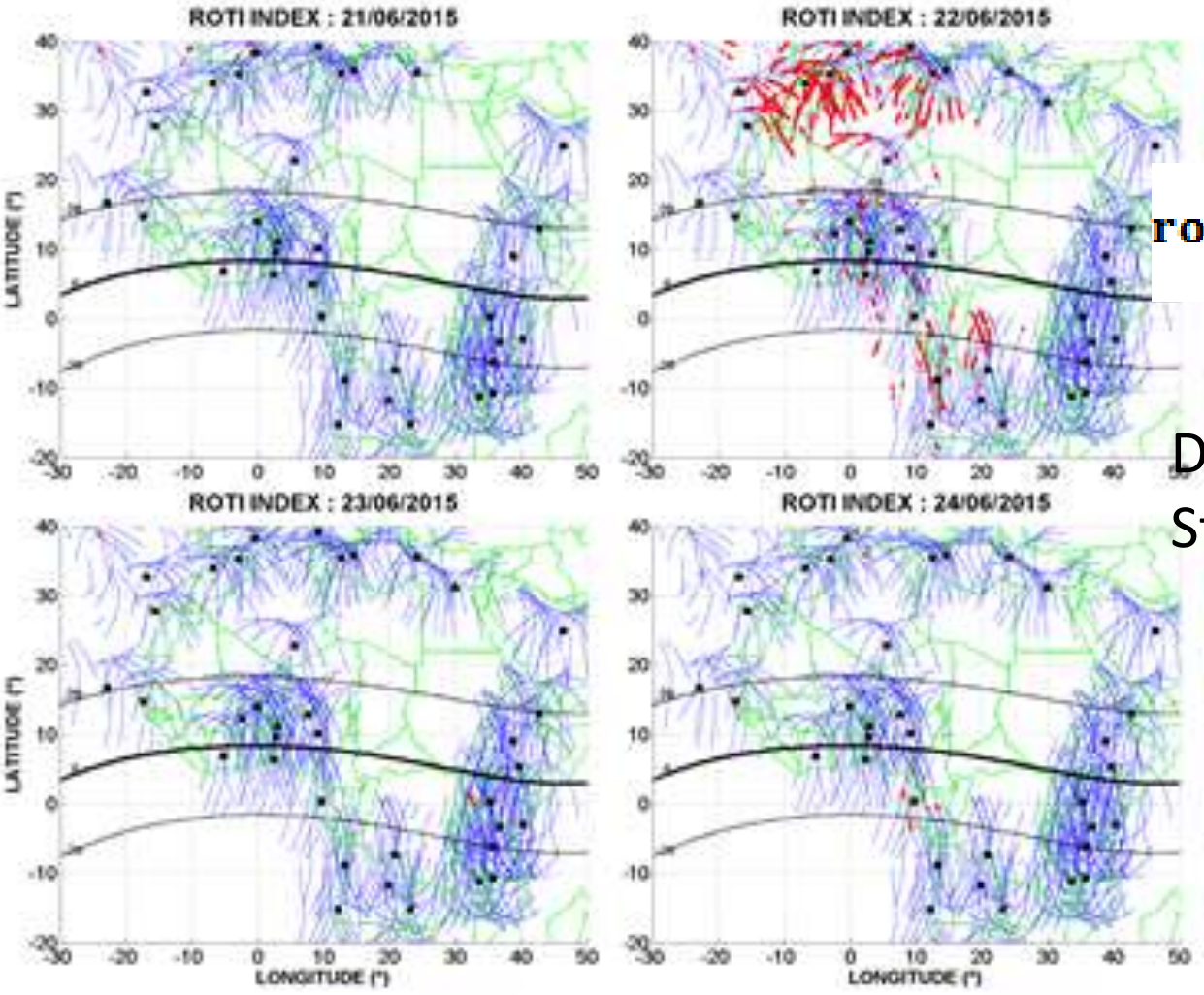
Storm started at 04.45 UT

Inhibition of scintillations over the whole earth during several days

DDEF effect long duration

Kashcheyev, A et al.,2018 in JGR

EFFECT OF **PPEF** ON THE ROTI INDEX



Storm June 22, 2015
solstice

$$\mathbf{rot} = \frac{STEC_{k+1} - STEC_k}{time_{k+1} - time_k} * 60$$

Dst < -200 nT
Storm started at 18.33 UT

Increase of scintillations

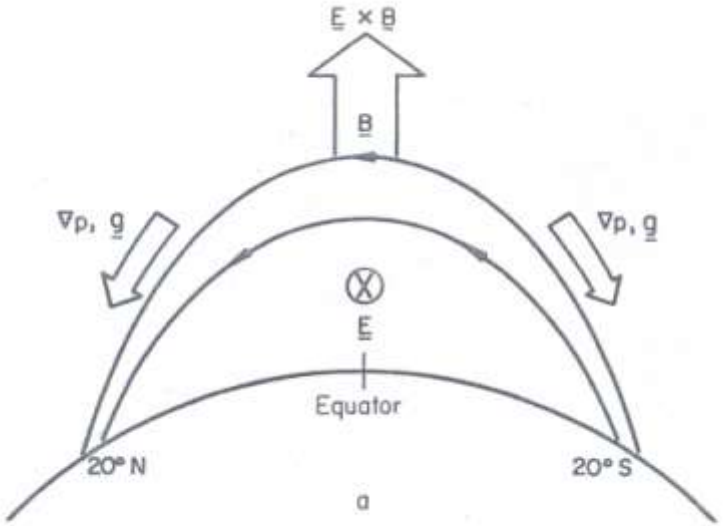
PPEF effect
short duration

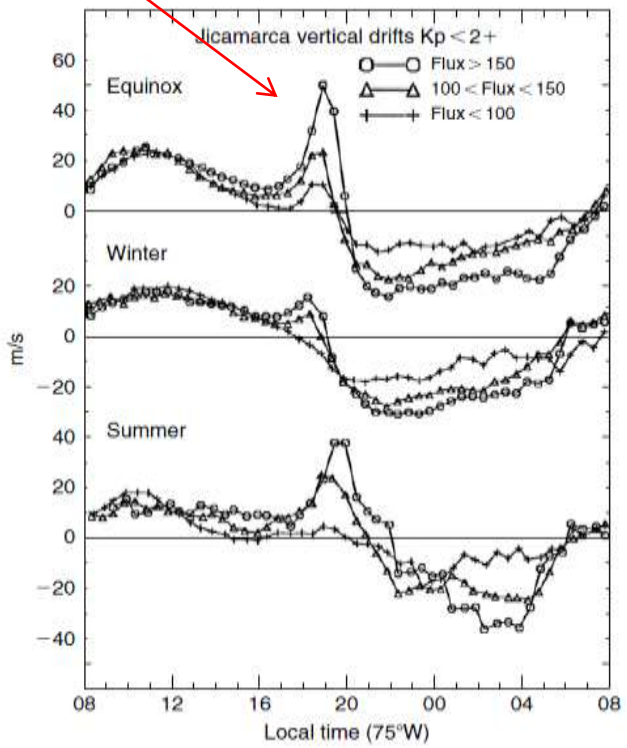
Kashcheyev, A et al.,2018 in JGR

Eastward electric field => moves up

Westward electric field => moves down

PRE : Pre Reversal Enhancement of Ey





Model of Fejer et al.,(2008)

At the time of the PRE
PPEF is an eastward Ey
=> increases the PRE
DDEF is a westward Ey
=> decreases the PRE

PPEF

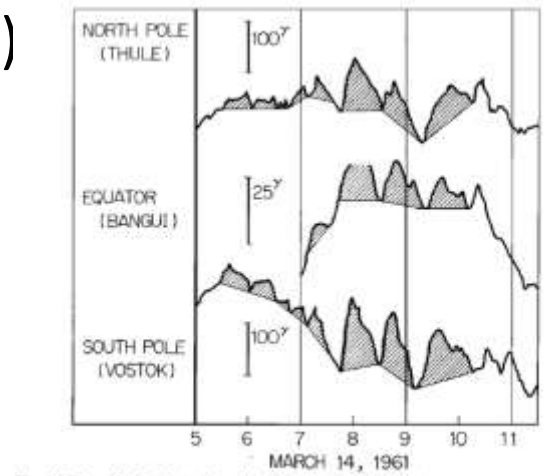
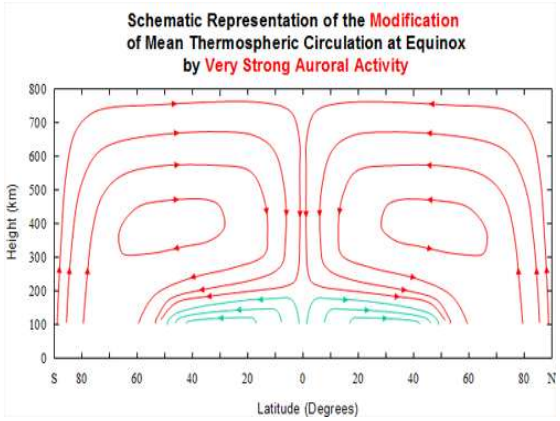
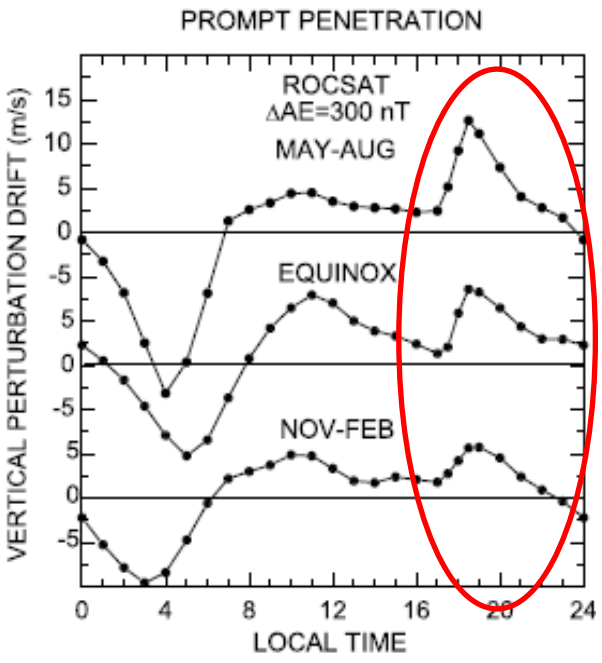


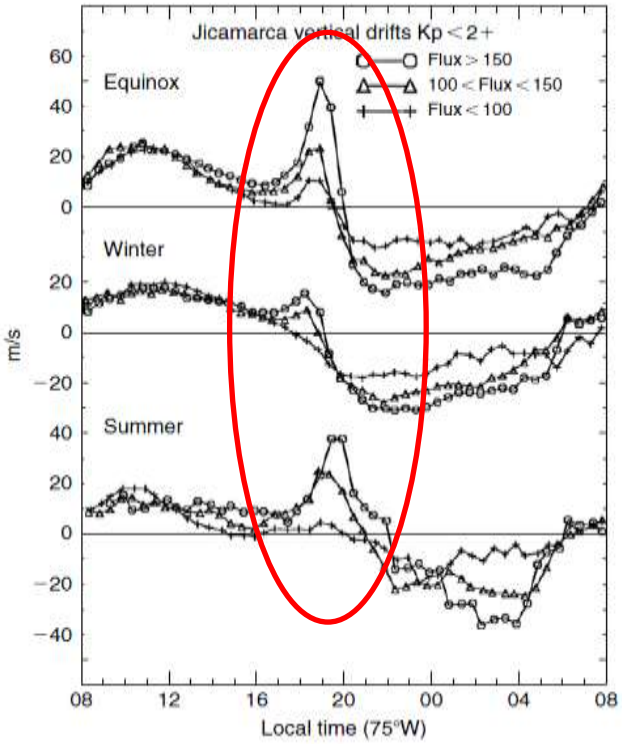
Fig. 1. Train of D_Y 2 fluctuations (shaded). Geomagnetic latitudes of these stations are 88.9 (Thule), 05.0 (Bangui), and −89.1 (Vostok).

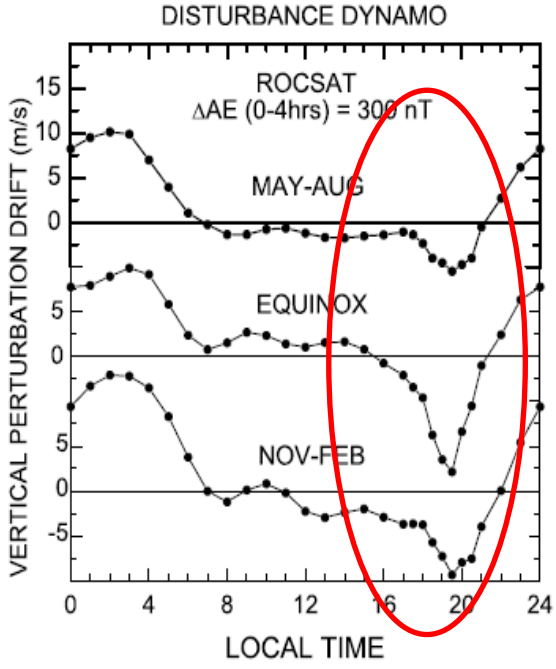
DDEF





PPEF





DDEF

Explanation

Storm of June 22 2015 (Solstice) : The storm started at 18.33 UT , The station whose local time is the time of the PRE is affected by the PPEF at the beginning of the storm

=> increase of the scintillations

Storm of March 17 2015: the storm started at 04.45 UT, at the time of the PRE (post sunset) the stations in Africa are under the effect of the ionospheric disturbance dynamo : DDEF

=> Inhibition of scintillation

Success of the International Cooperation between many institutions during international projects UNBSSI [IEEY-IHY-ISWI] continuing in the ISWI network

- More and more African scientists are participating in international symposia. In this workshop there are researchers from 10 African countries: Algeria, Burkina Faso, Ivory Coast, Egypt, Ethiopia, Kenya, Nigeria, Uganda, Rwanda, Sudan, Zambia. There are more and more publications in excellent journals with as first author a researcher from Africa.
- We have defined a new systemic approach of the Sun-Earth system and Space Weather, including many different data sets and models, and train the new generation of scientists, in many schools over the world.
- We have succeeded in training many scientists particularly in Africa. Now, in Africa national or regional schools and workshops are organized by African scientists.
- Curricula concerning the Sun Earth system and Space weather are now in many Universities over the world.
- In Africa, most instruments of different moderately priced instrument networks are no longer operational: SCINDA [3 GPS receivers are still operational on ~12], CALLISTO [2 on 8], MAGDAS [0 on 12] But all the expensive instruments placed in observatories all work very well.
- => necessity to develop space weather observatories


Thank you