Characterization of locations and durations of Ionospheric Scintillation over the equatorial region

Dr. Olwendo Ouko Joseph
Department of Physics.
Pwani University.
P.O Box 195-Kilifi, Kenya.

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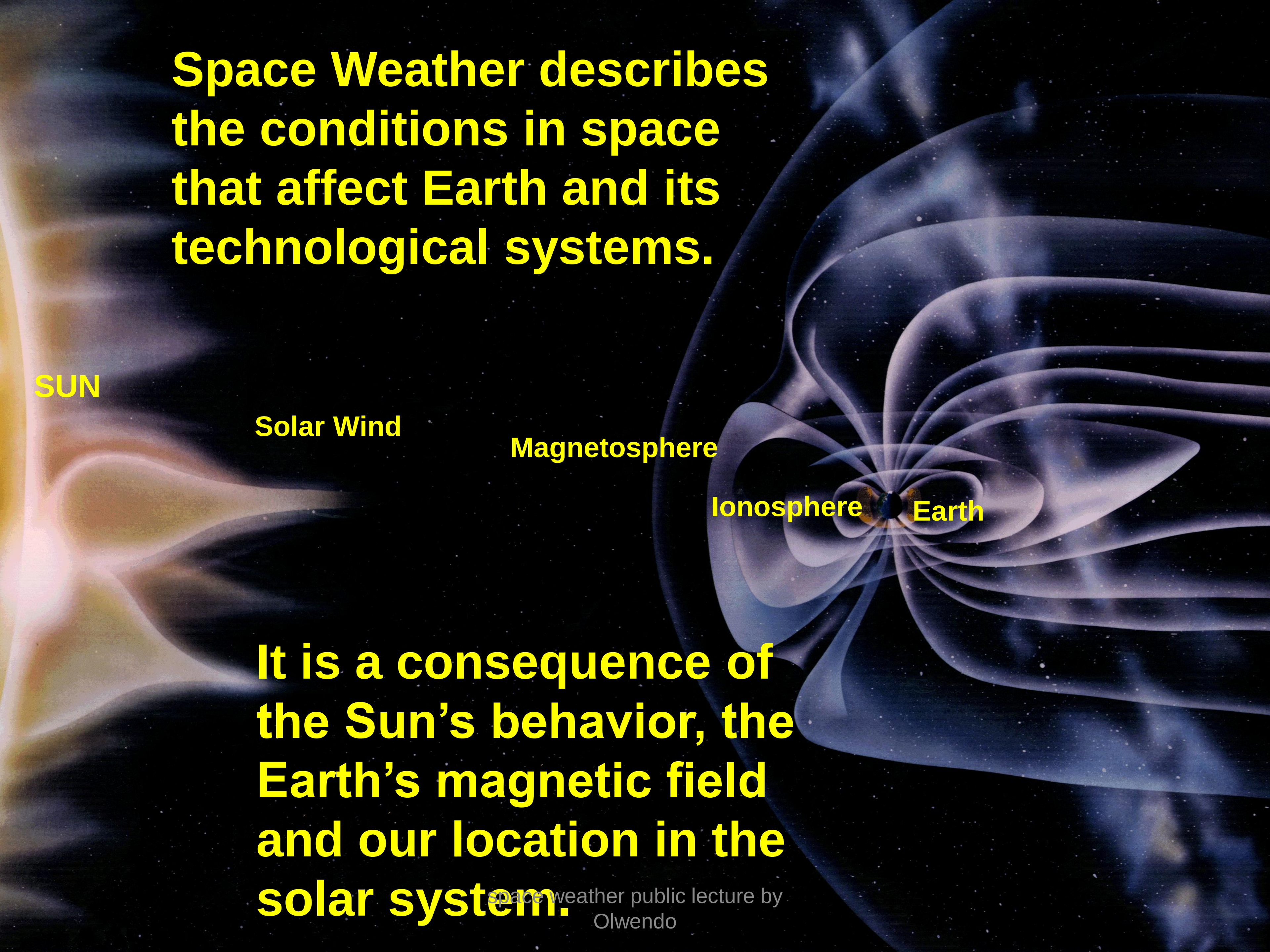
Outline

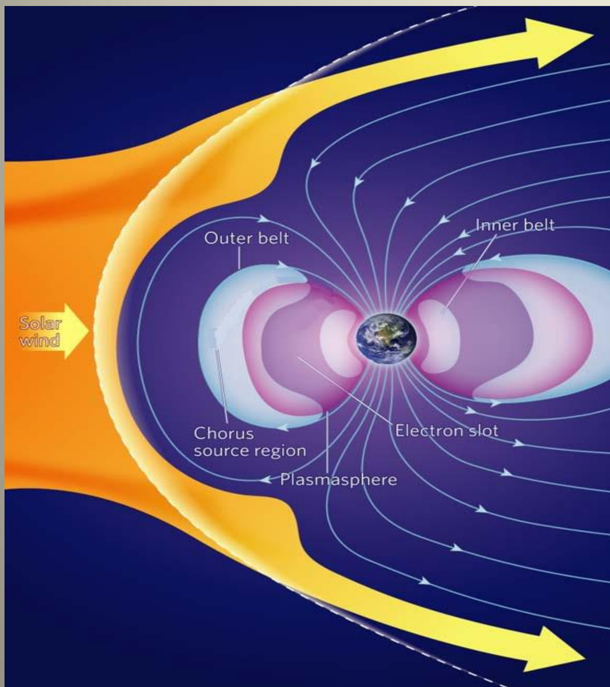
- ✓What is Space Weather? The Sun Earth-Systems
- ✓Global Ionospheric regions & Ionospheric scintillation Phenomena
- ✓Satellite Technology & application in Scientific Research
- ✓ Results in scintillation observation around the Kenya region
- ✓Why bother about ionospheric scintillation?

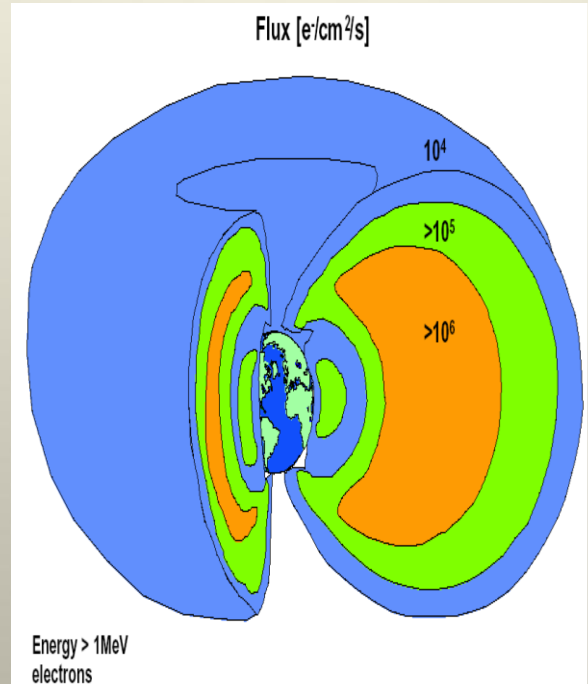
Space Weather describes the conditions in space that affect Earth and its technological systems.

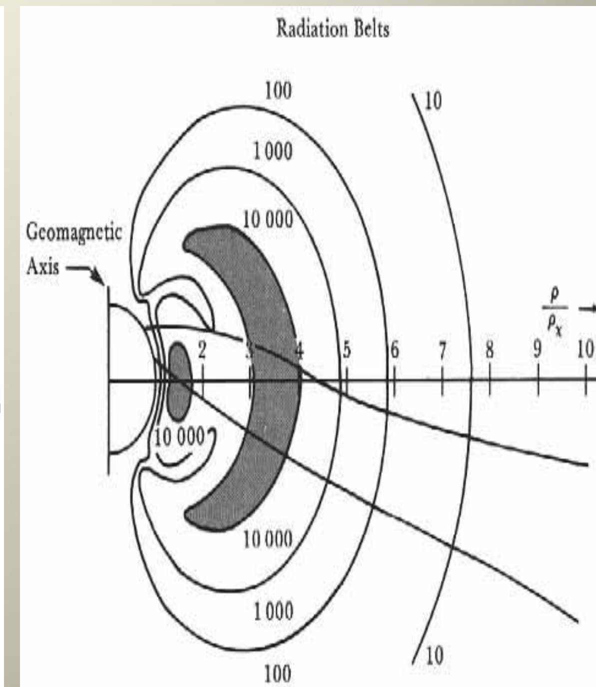


It is a consequence of the Sun’s behavior, the Earth’s magnetic field and our location in the solar system.

Why the concern with Space Weather? Killer Electron (E>1 MeV)







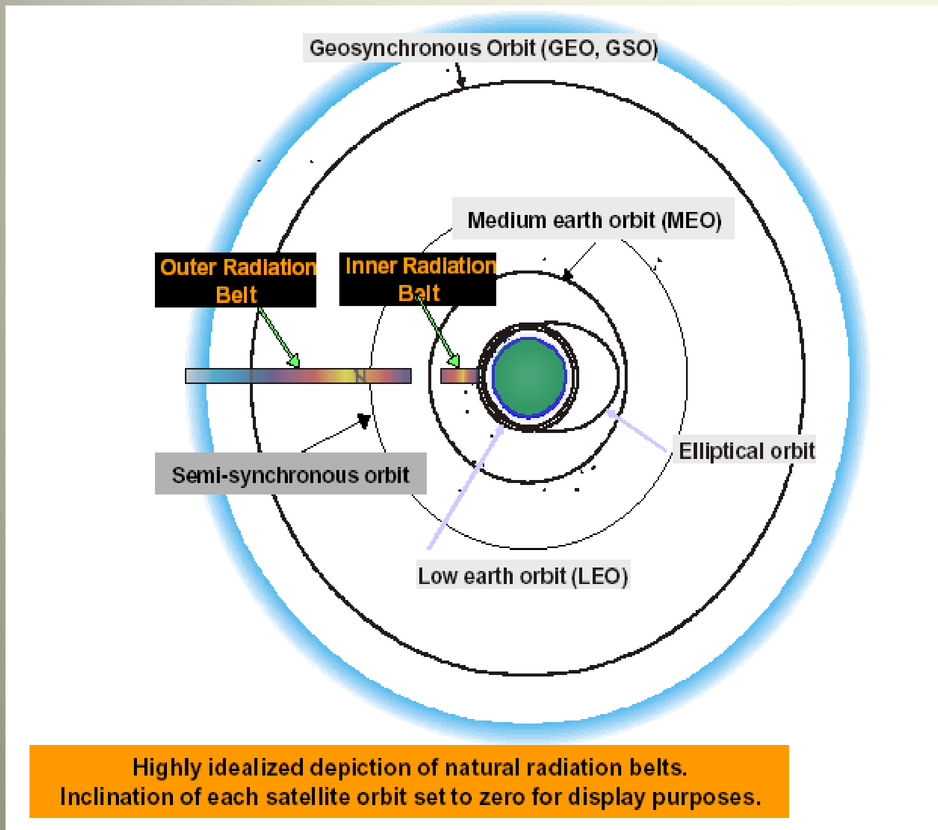
Bill Pickering, James Van Allen, and Werner von Bruan

Explorer 1: press conference

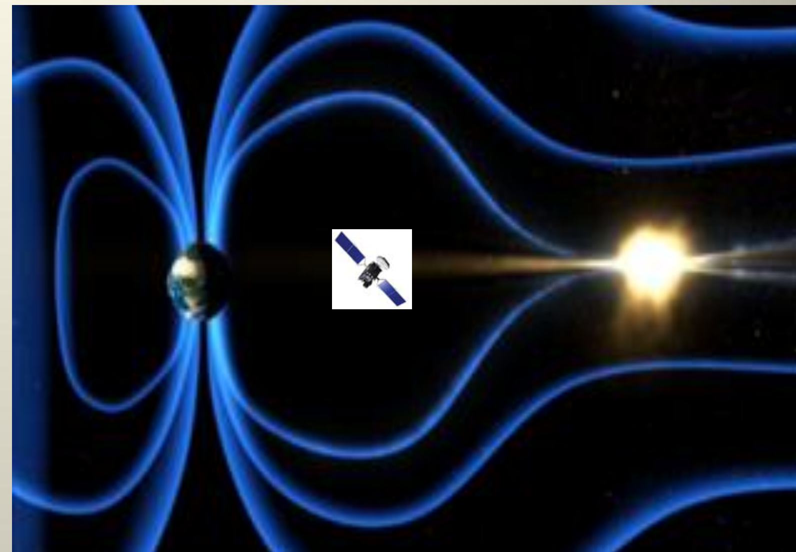
After Van Allen and L.A Frank: J. Geophys. Res. 64,1683, 195

On average the belts are structured with an inner and outer belt,separated by the “slot”.

Satellite motions around the radiation Belts.



Highly idealized depiction of natural radiation belts.
Inclination of each satellite orbit set to zero for display purposes.

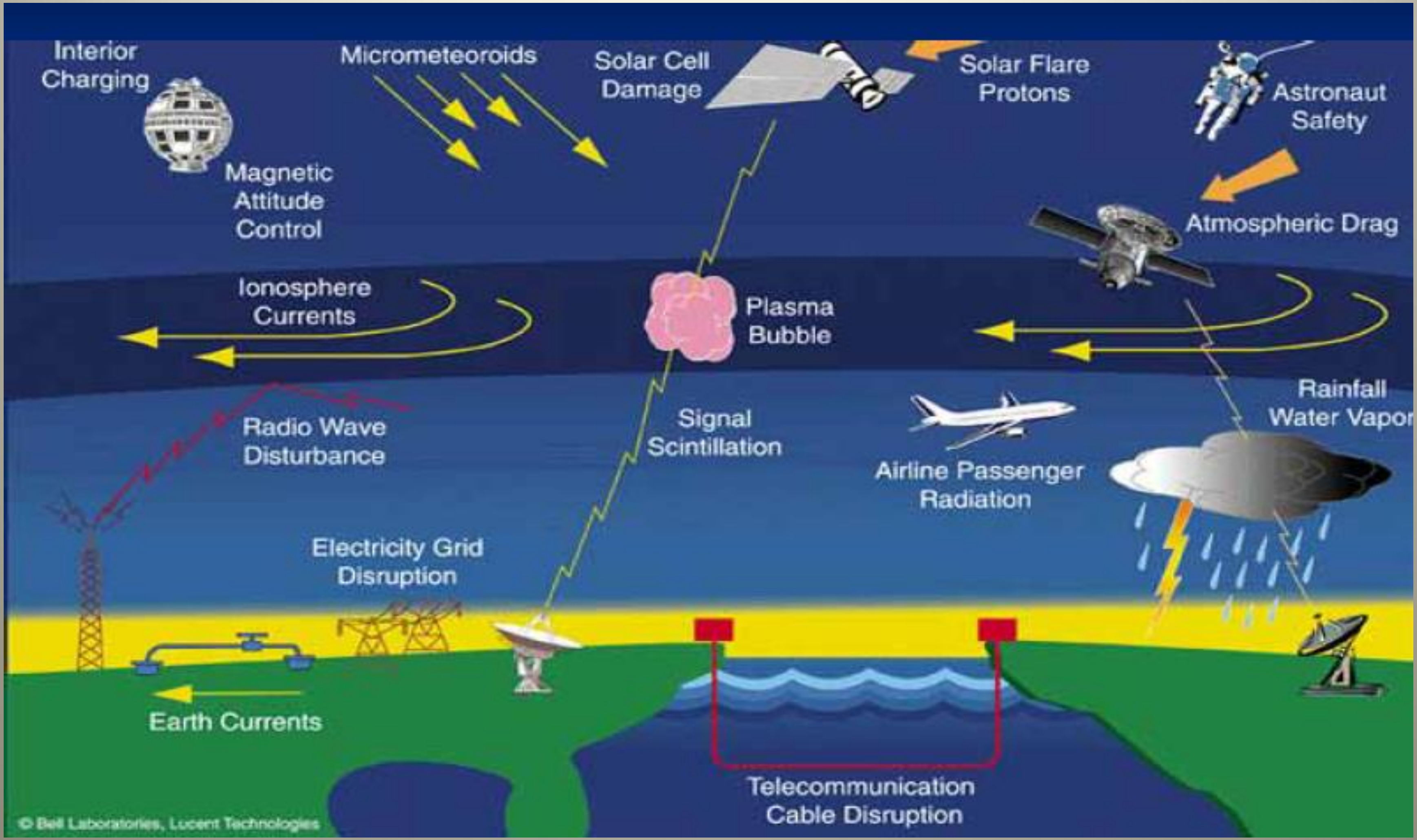


On 5 April 2010 a space weather event caused the Galaxy-15 a geo satellite to malfunction, turning it into an out of contro "*zombie spacecraft*"

Looks like G-15 was in the wrong place at the wrong time (it was right at magnetic midnight, and hence right wher the substorm happened)!
Clilverd et al. (2012), J. Geophys. Res., doi:10.1029/2012JA018175.

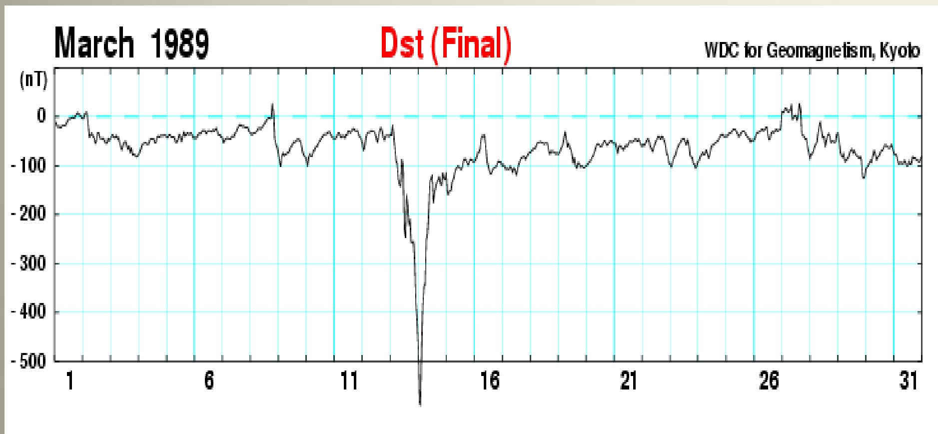
In terms of cost: Geosynchronous Will cost approximately. 200-300 million Dollars (satellite and launch)

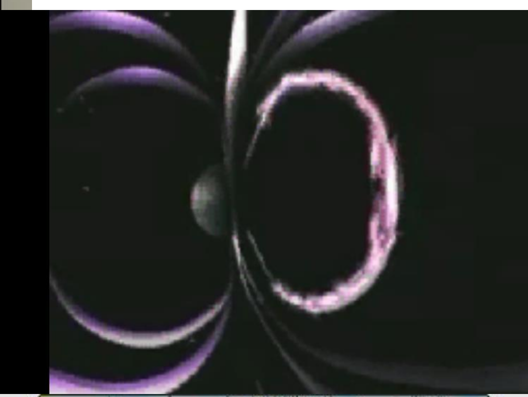
Near earth space weather events

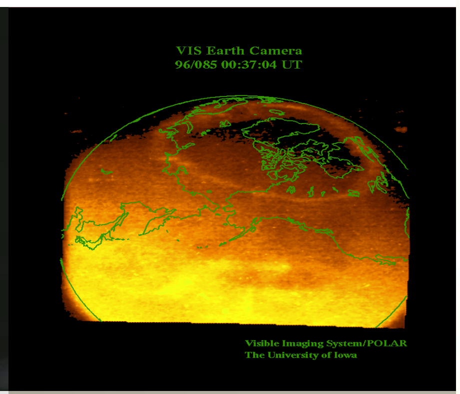


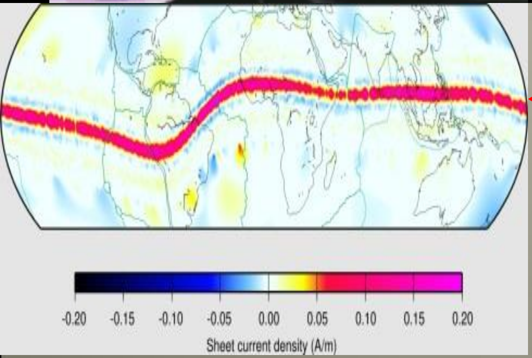
- Courtesy of Prof. Patricia Doherty

Castastrophy from space weather

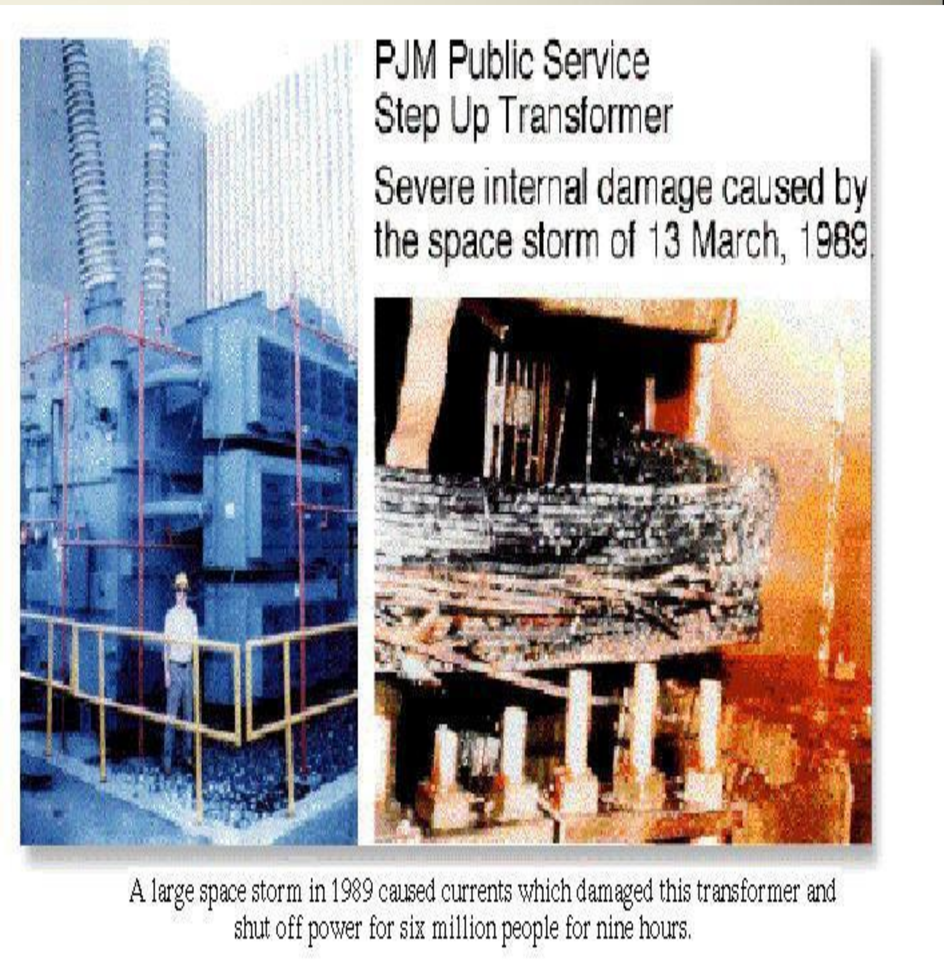






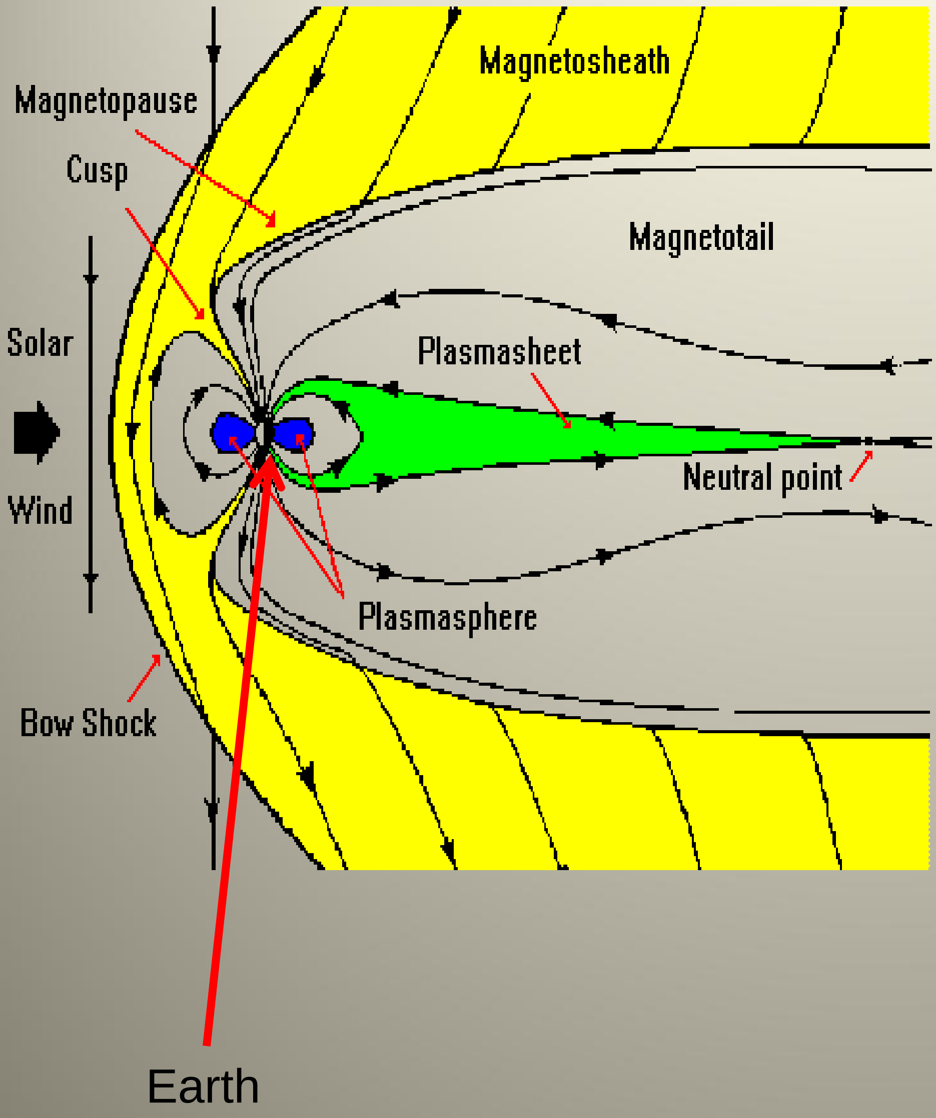


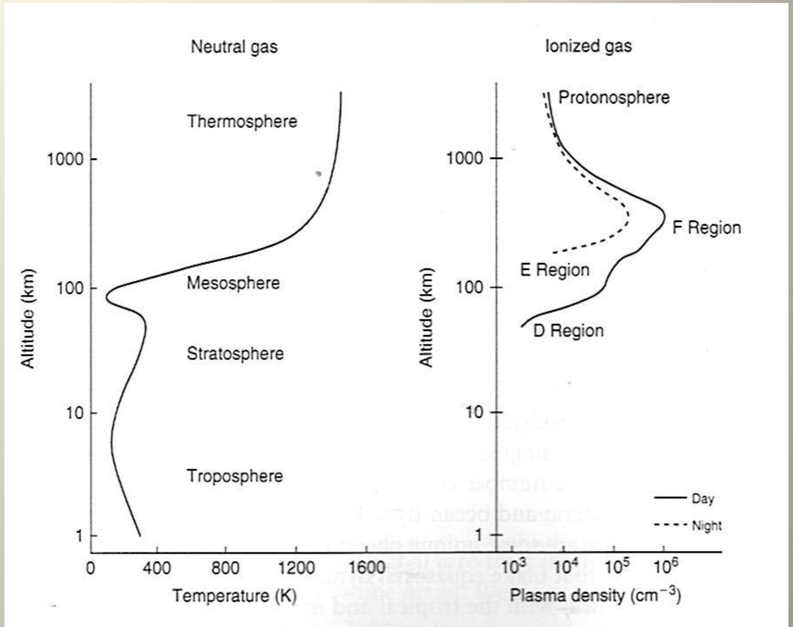
EEJ-eastward
Electric field

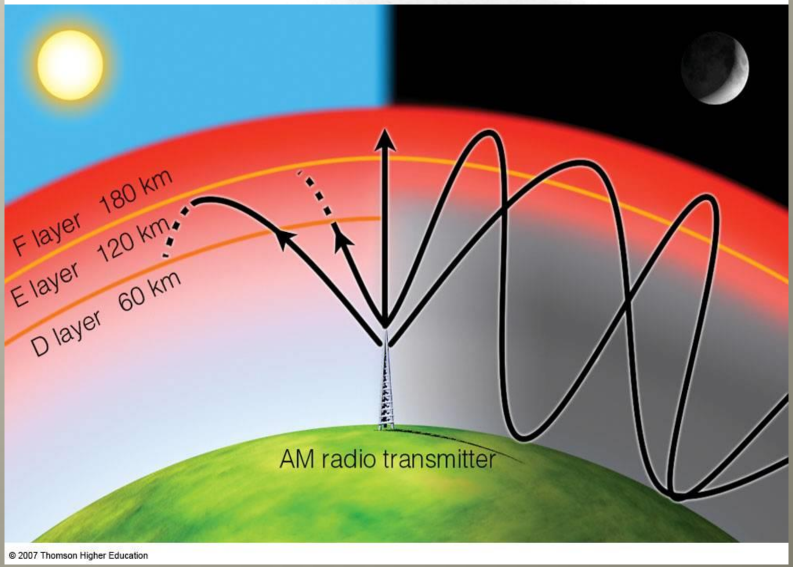


In terms of current flowing:
1 nT=1 mA/m
500nT= 500 mA/m

Sun-Magnetosphere-Ionosphere System

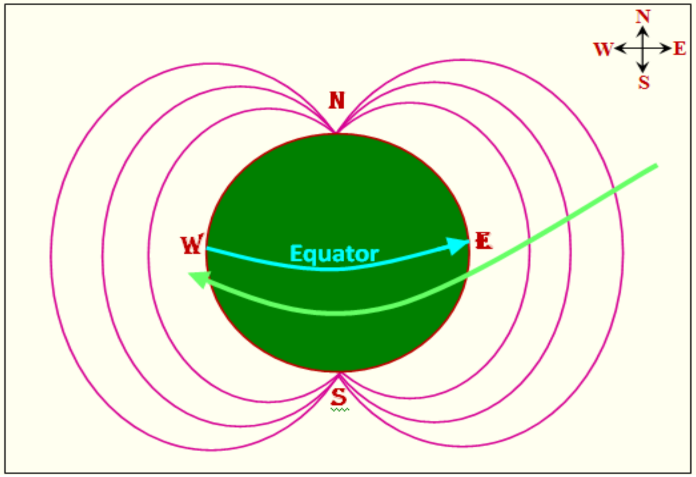


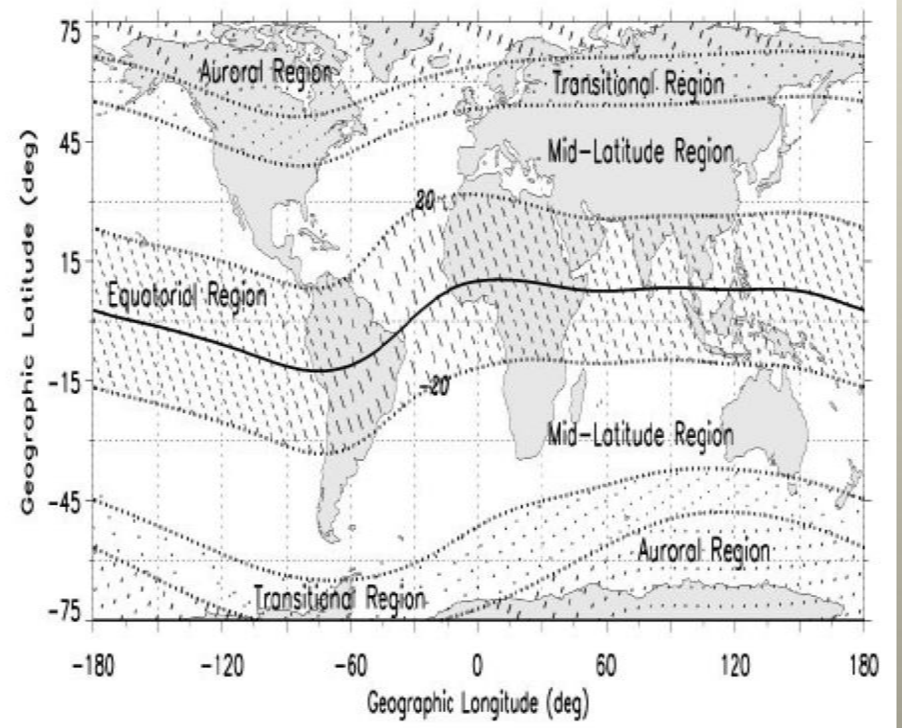




Source: www.spaceweather.com

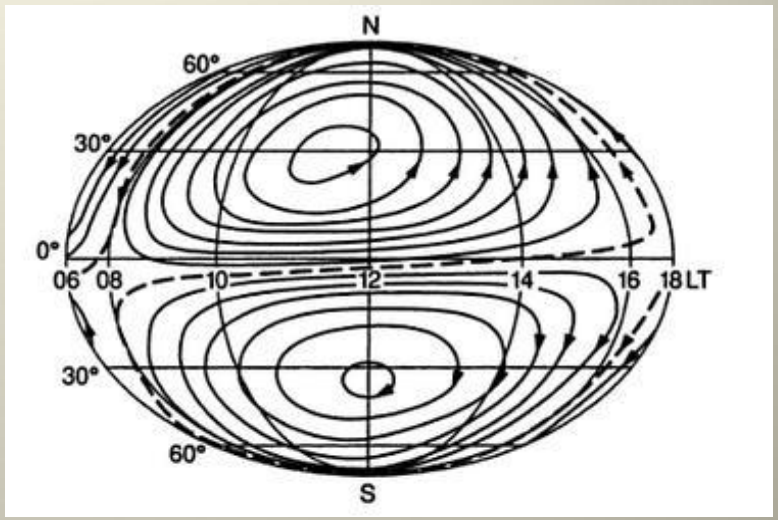
Global Ionosphere

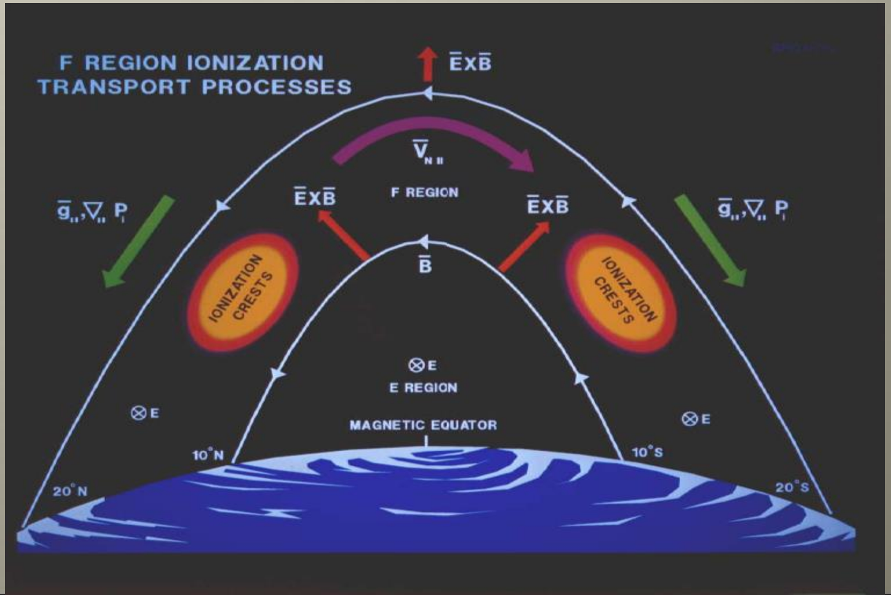




Equatorial Ionosphere

The ionosphere is permeated in the earths magnetic field lines which influence the ectrodynamics leading to 3 geographical regions

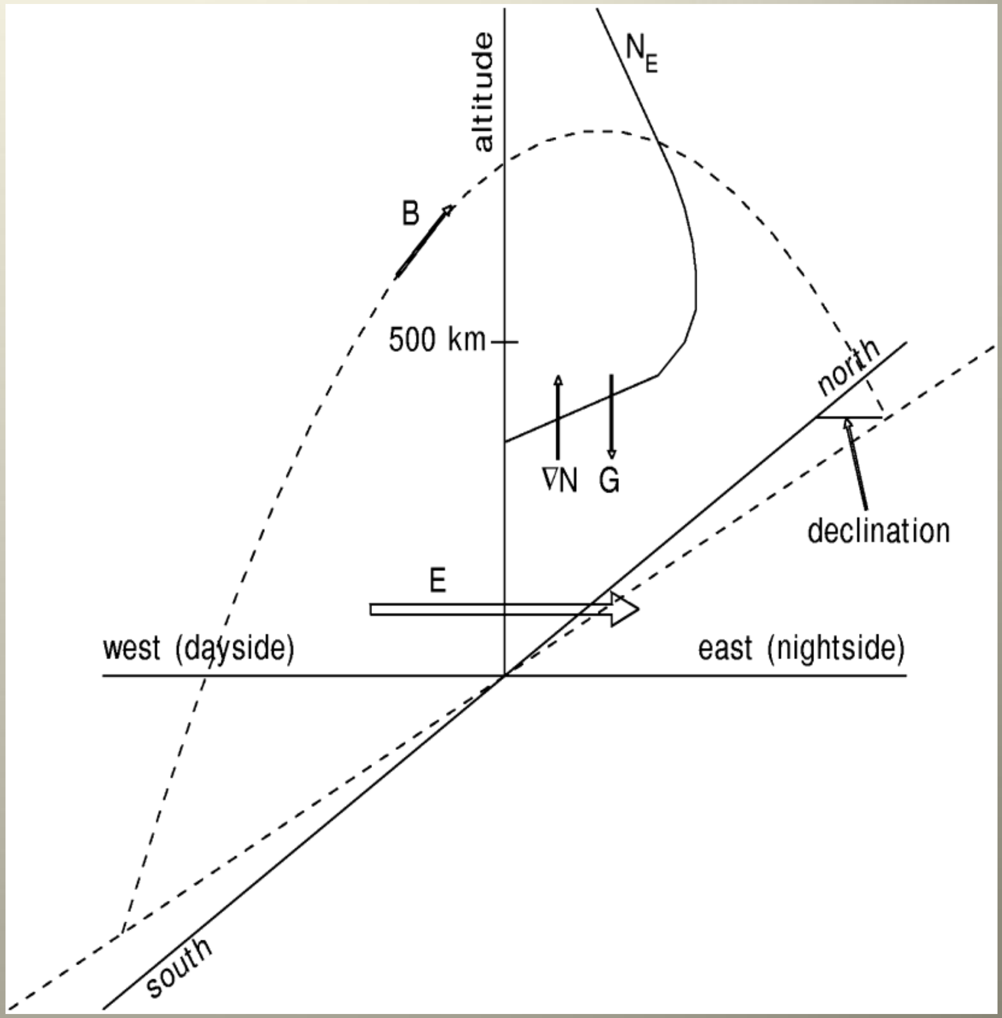




Equatorial Ionospheric dynamics at the local sunset hours: plasma bubbles formation

•Towards dusk the enhanced zonal E is established to keep divergence J = 0 from a sharp east-west (day-night) conductivity (density) gradient: Zonal E leads to prereversal enhancement in the eastward electric field.

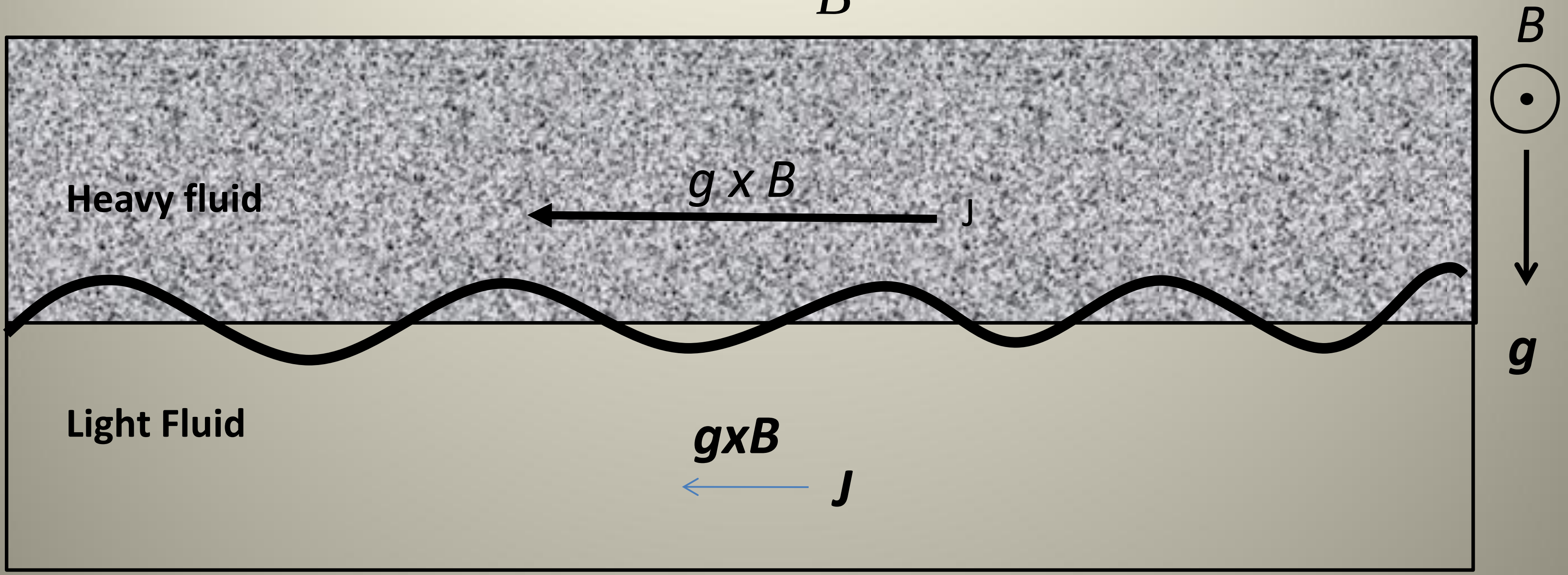
•The F- layer thus rises as the ionosphere co-rotates into darkness. The lower part rapidly decays and a steep vertical density gradient develops leading to a classical Rayleigh-Taylor (R-T) instability.



Schunk and Nagy, 2009, Figure 11.29

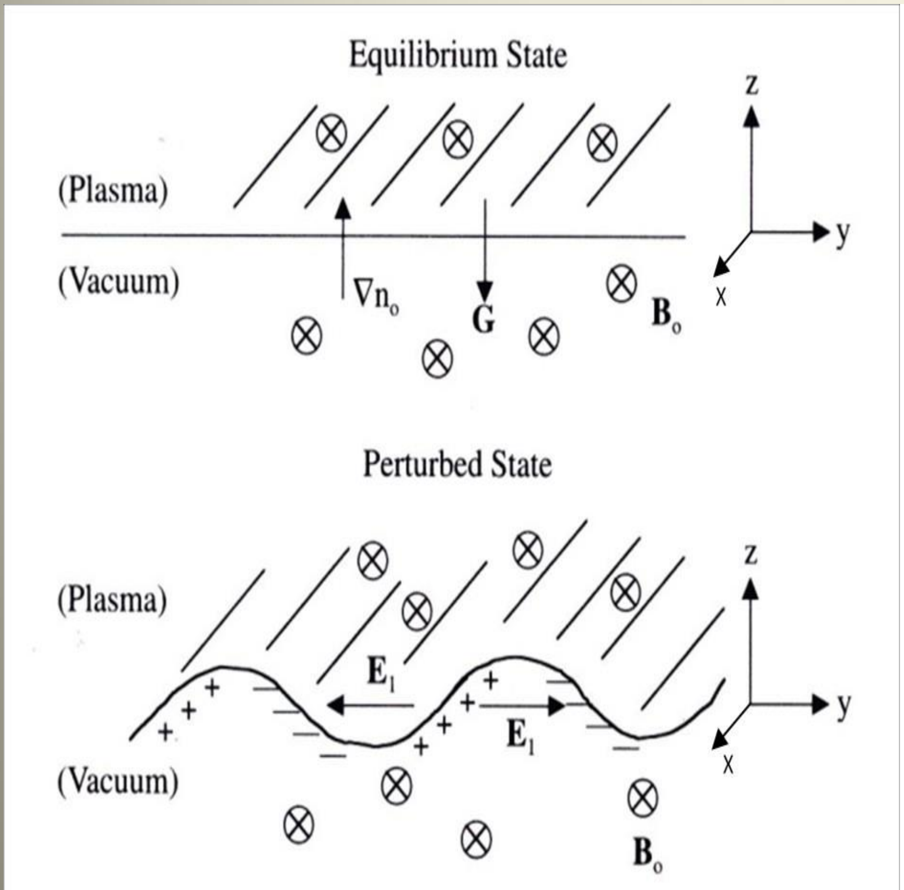
The earth's magnetic field supports the ionospheric plasma against gravity; a current flows along the bottom of the ionosphere which is perpendicular to both *g* and *B*.

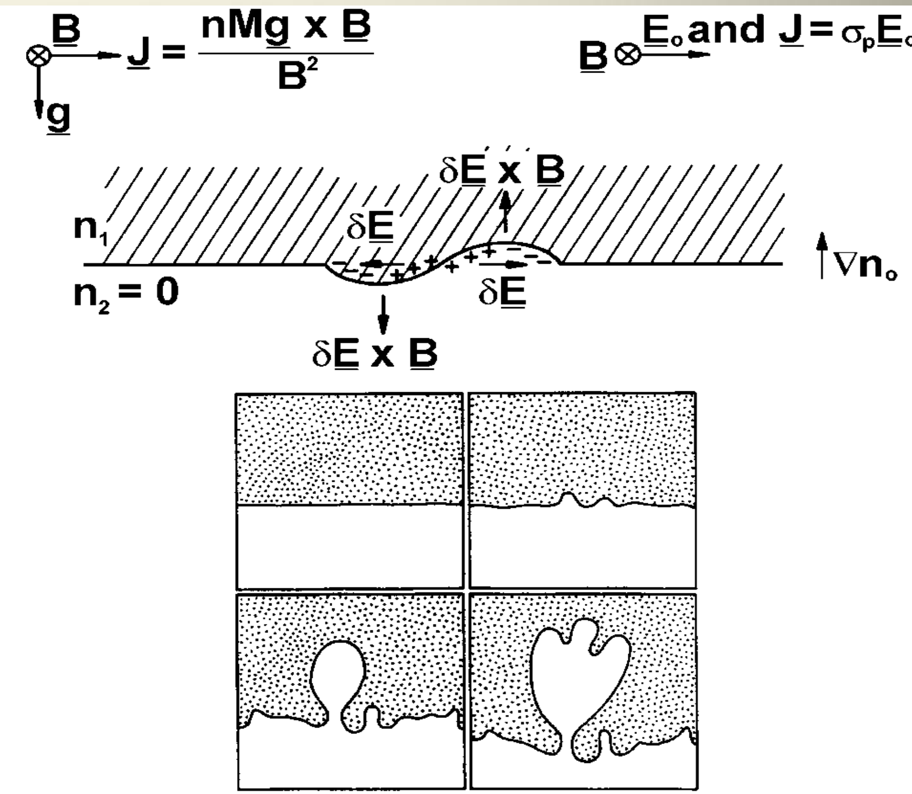
$$J = ne(V_i)_\perp = nM_i \vec{g} \times \frac{\vec{B}}{B^2}$$



If the bottom of the ionosphere is vertically perturbed, the perturbation tends to block the current flow and a charge builds up on either side. The resulting electric fields combined with the background *B* tends to drive the plasma further upward where it initially went up and downward where it initially went down

Linear Theory of Rayleigh-Taylor instability [Schunk and Nagy, 2009, Figure 11.30

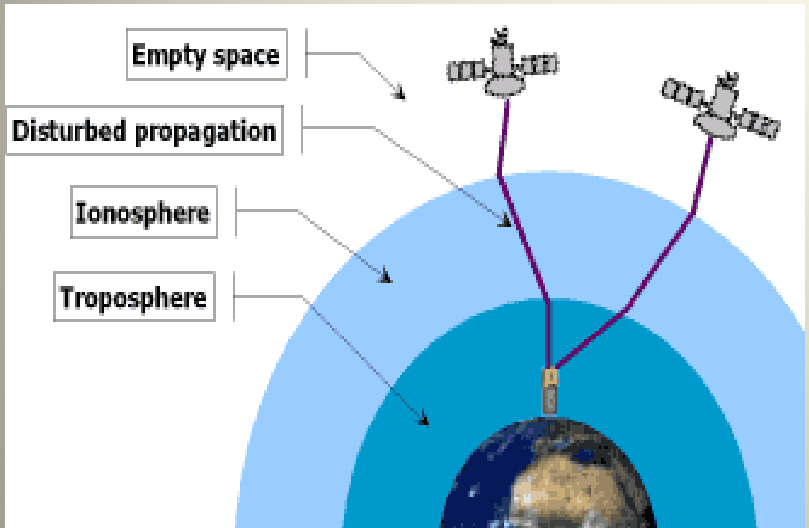


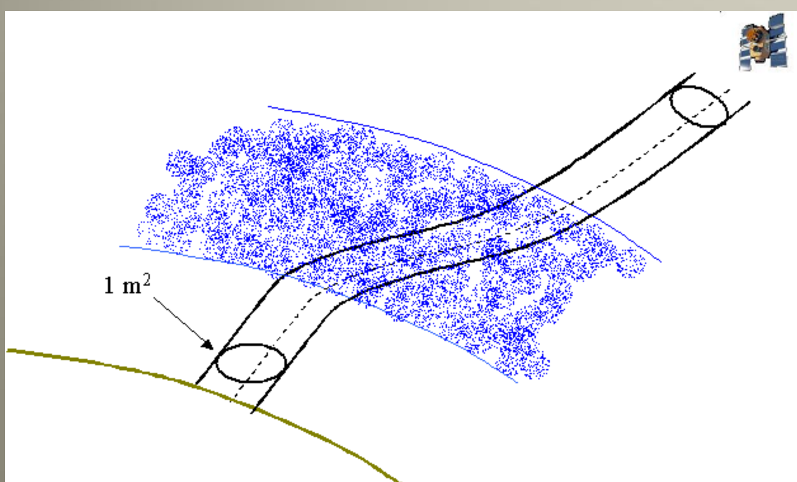


$$A = A_0 e^{\gamma t}$$

$$\gamma \approx \frac{\sum_F}{\sum_F + \sum_E}\left[\frac{\boldsymbol{E}\times\boldsymbol{B}}{B^2} + U_n + \frac{g}{\nu^{eff}}\right]\frac{1}{N}\frac{\partial N}{\partial h}$$

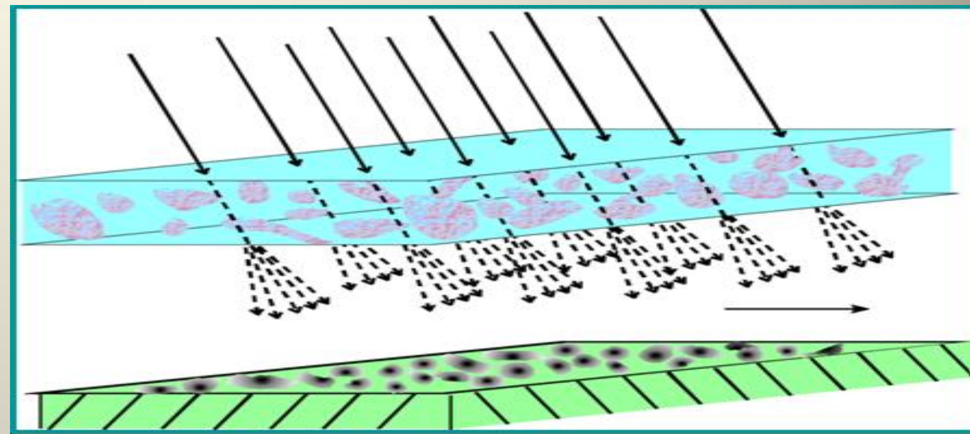
Ionospheric Measurements from GNSS Observables

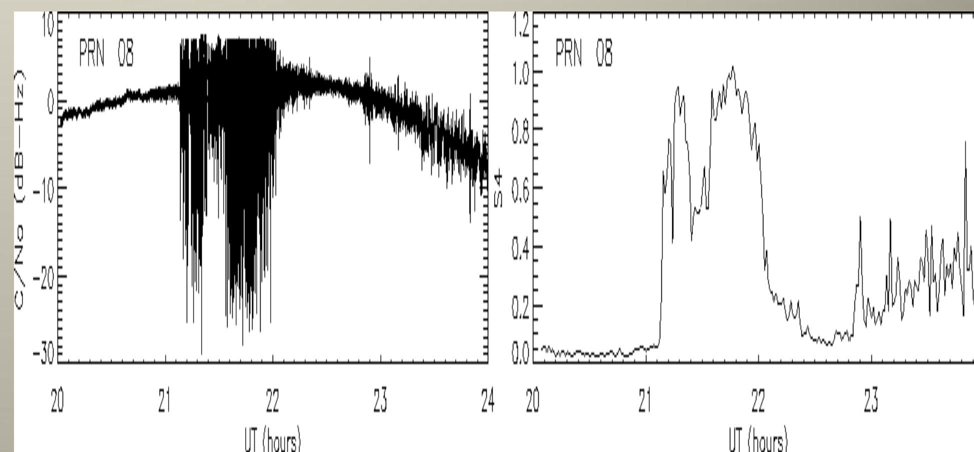




$$\Delta t = 40.30\frac{TEC}{cf^{2}}$$

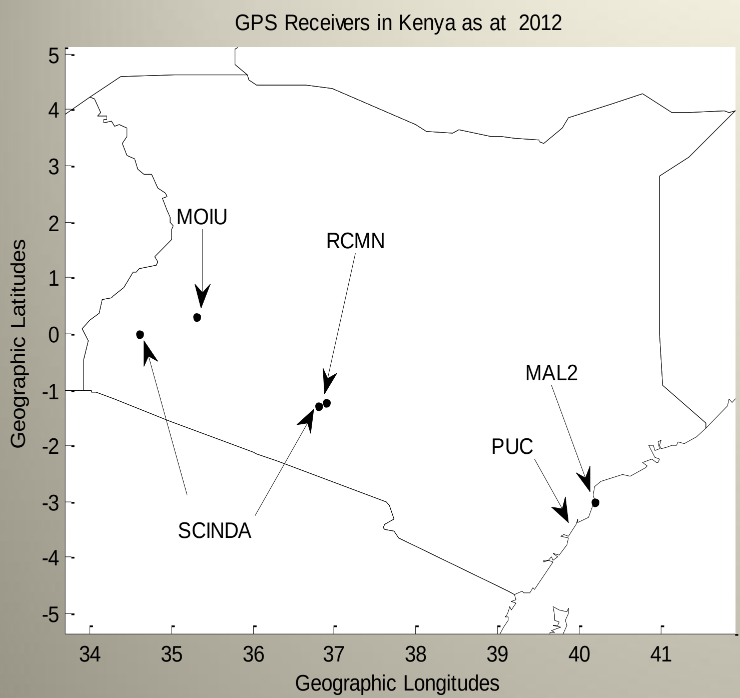
Ionospheric Irregularities

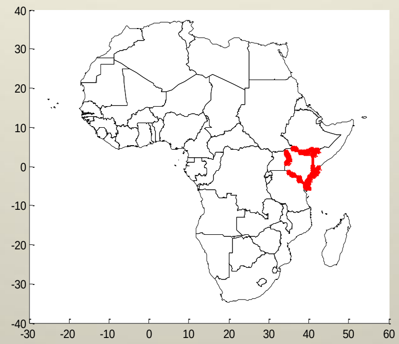




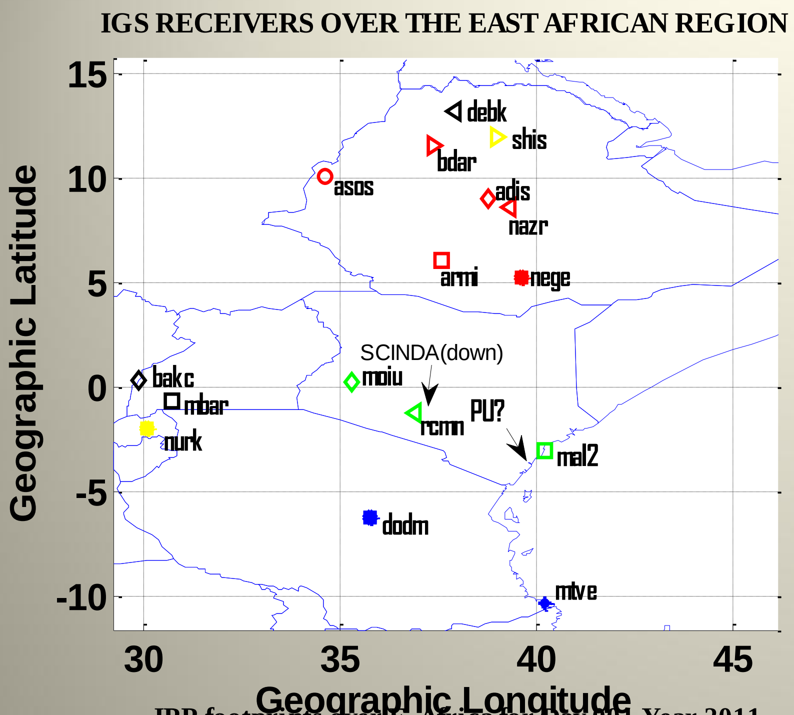
$$S_4 = \sqrt{\frac{\langle I^2\rangle - \langle I\rangle^2}{\langle I\rangle^2}}$$

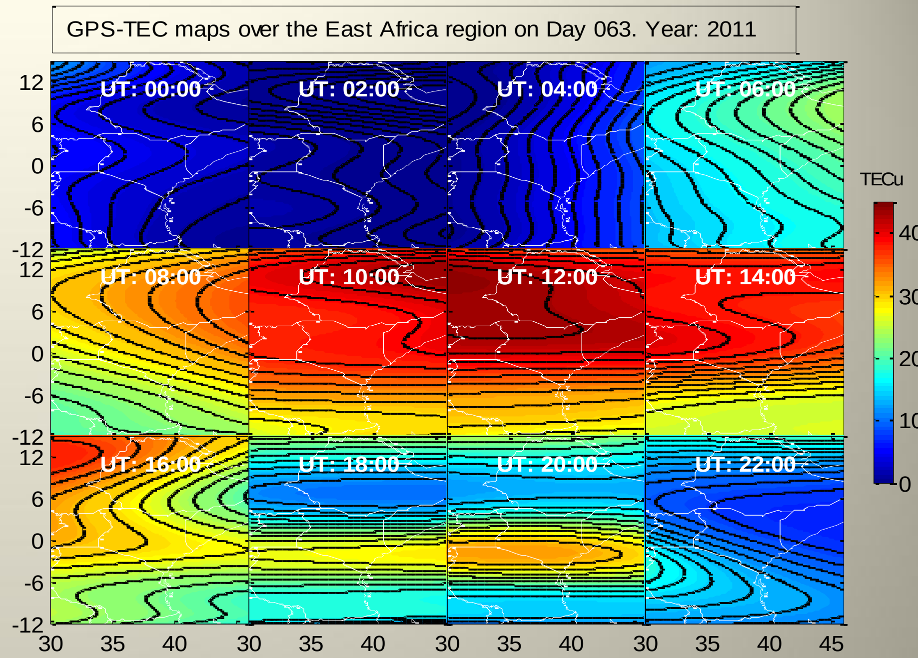
Infrastructure in Kenya: Observation stations.

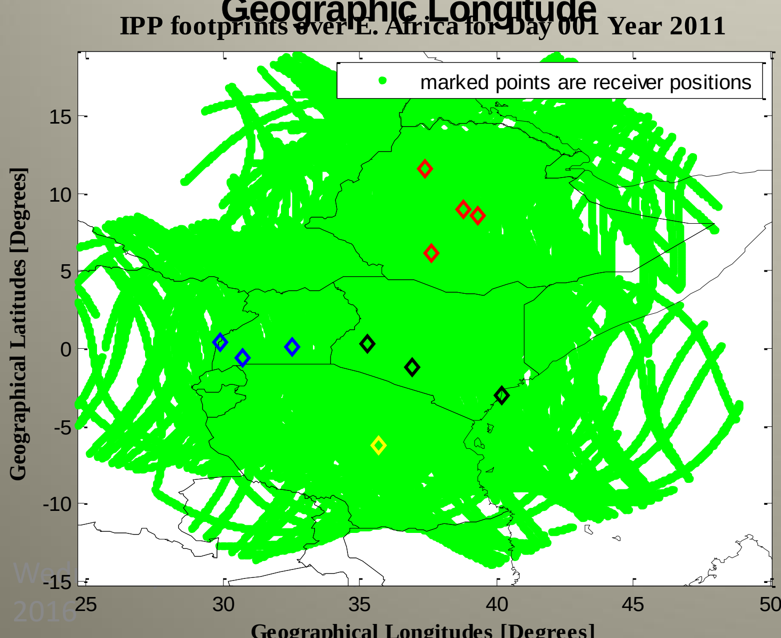


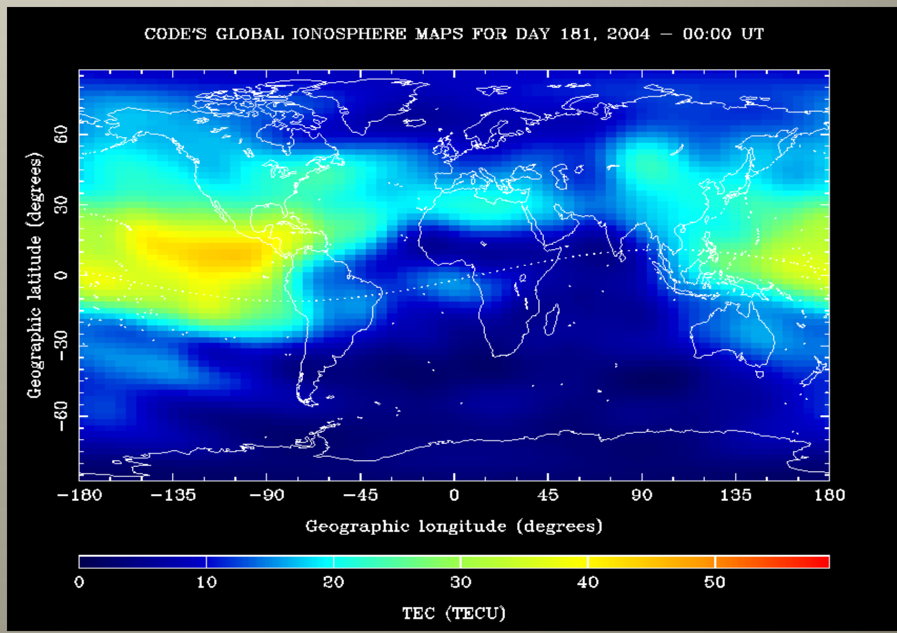


Research group as at 2010


IGS RECEIVERS OVER THE EAST AFRICAN REGION
Geographic Latitude
Geographic Longitude
debk
shis
bdar
asos
adis
nazr
armi
nege
SCINDA(down)
bakc
moiu
mbar
rcmn
PU?
nurk
mal2
dodm
mtve


GPS-TEC maps over the East Africa region on Day 063. Year: 2011
UT: 00:00
UT: 02:00
UT: 04:00
UT: 06:00
UT: 08:00
UT: 10:00
UT: 12:00
UT: 14:00
UT: 16:00
UT: 18:00
UT: 20:00
UT: 22:00
TECu


IPP footprints over E. Africa for Day 001 Year 2011
marked points are receiver positions
Geographical Latitudes [Degrees]
Geographical Longitudes [Degrees]

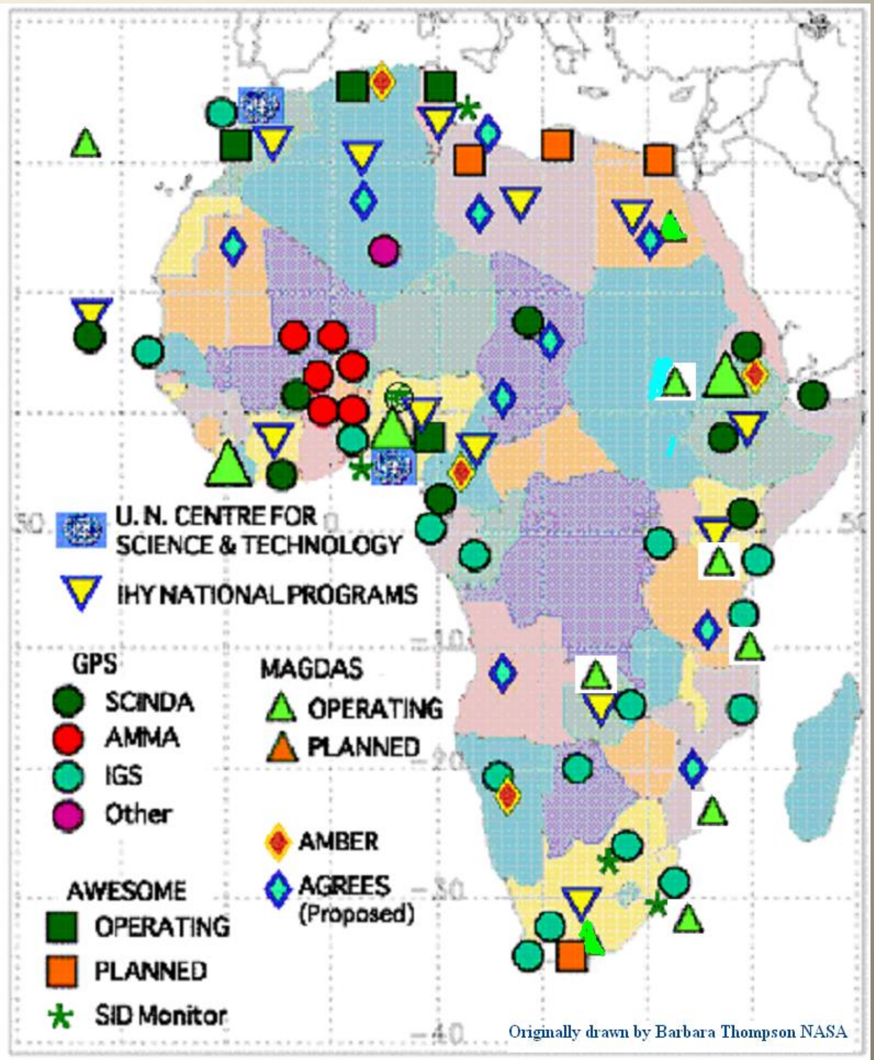

CODE'S GLOBAL IONOSPHERE MAPS FOR DAY 181, 2004 — 00:00 UT
Geographic latitude (degrees)
Geographic longitude (degrees)
TEC (TECU)

International Support in infrastructure in Africa

- 13 units of MAGDAS
- 7 units of GPS including SCINDA,
- 4 units of AWESOME
- 20 units of SID monitors

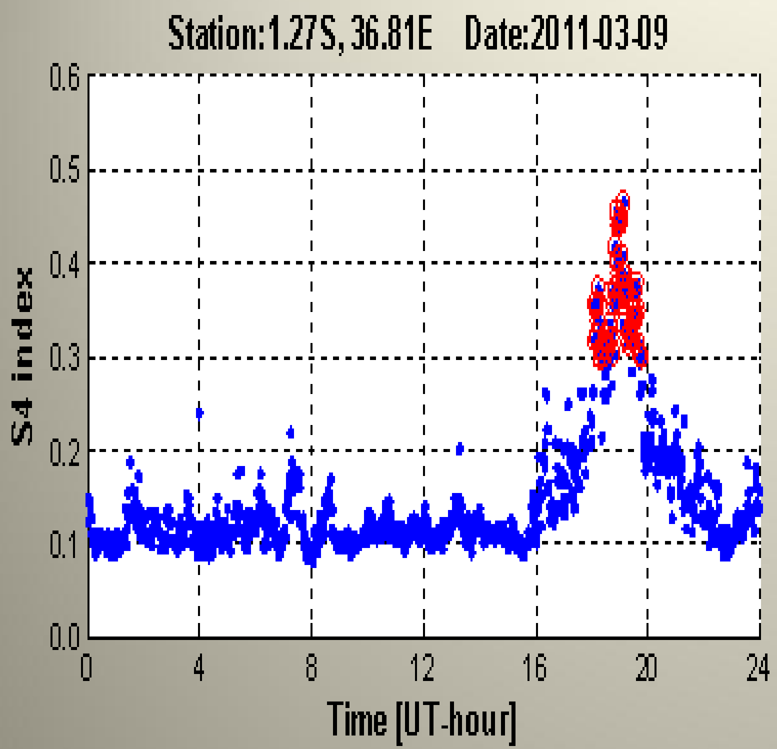
data obtained from these facilities are being used to improve our understanding of space weather as it affects the performance of GNSS

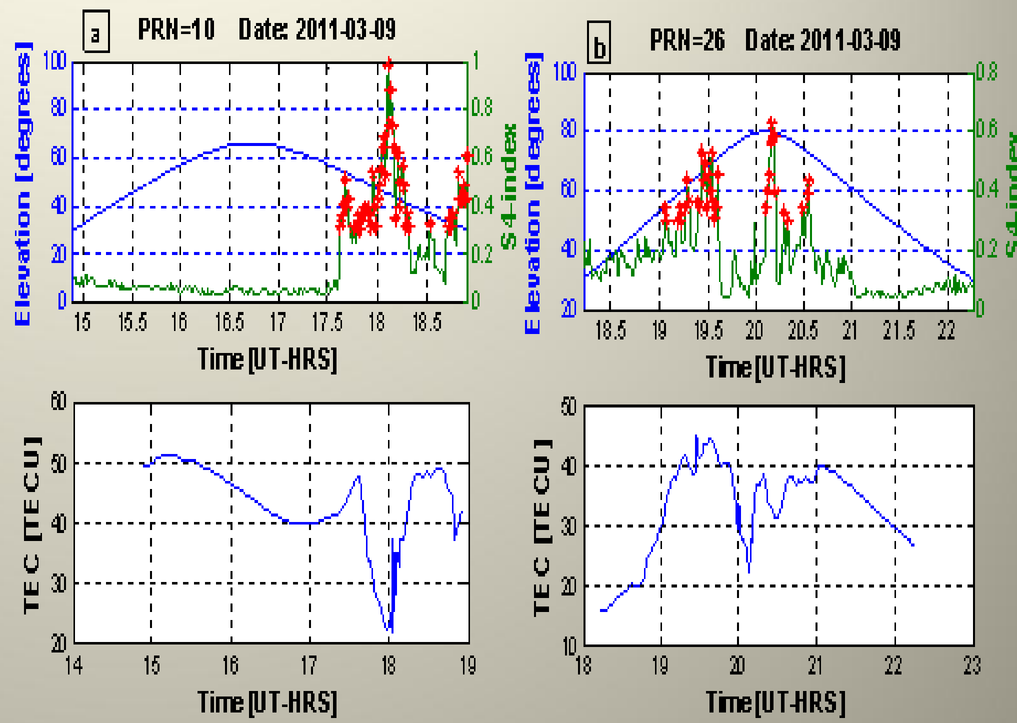
Additional monitors:
3 units GPS from BC/ICTP
More planned under ICTP/BC partnership
Ionosondes planned



Based on presentation by Dr. Rabiu Babatunde

Diurnal Variations of S4 and what it means

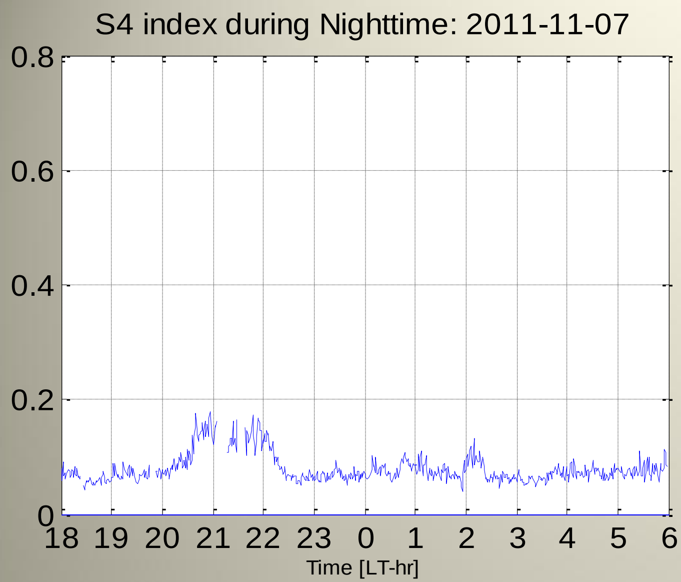


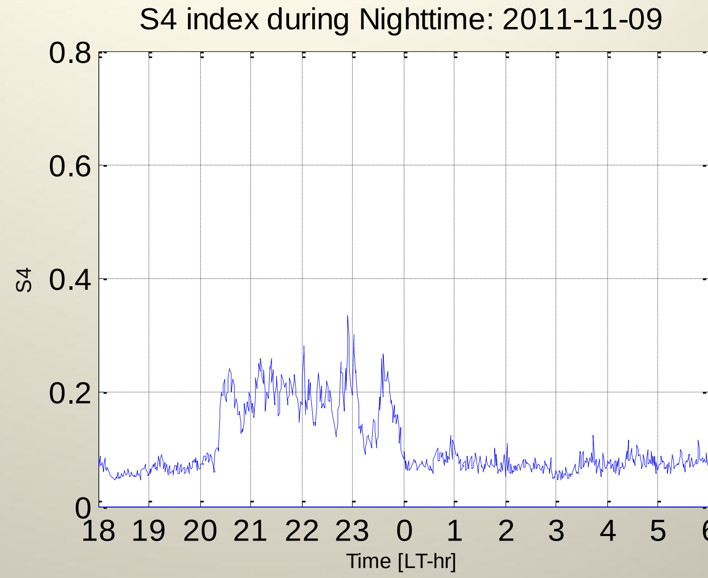


Depletion in TEC are signatures
of plasma density irregularities
in the ionosphere- Plasma Pubbles

Olwendo et al. 51(2013), 1715-1726, ASR

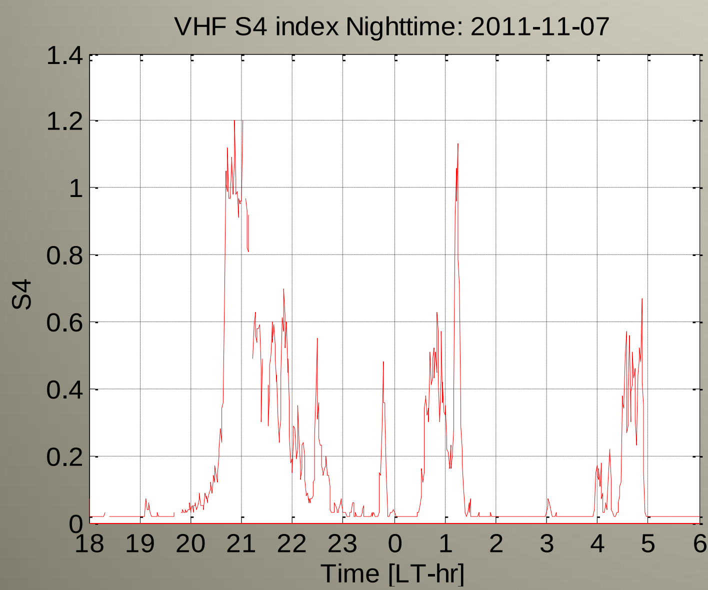
L-band scintillation and VHF scintillation observations

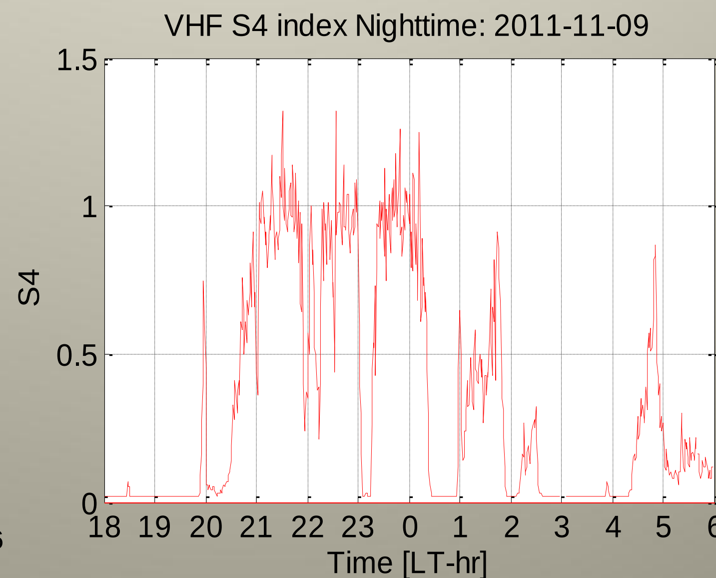




Amplitude scintillation are caused by Irregularities with size of the order of 1st FZ

$$d_F = \sqrt{\lambda\left(z - L/2\right)}$$



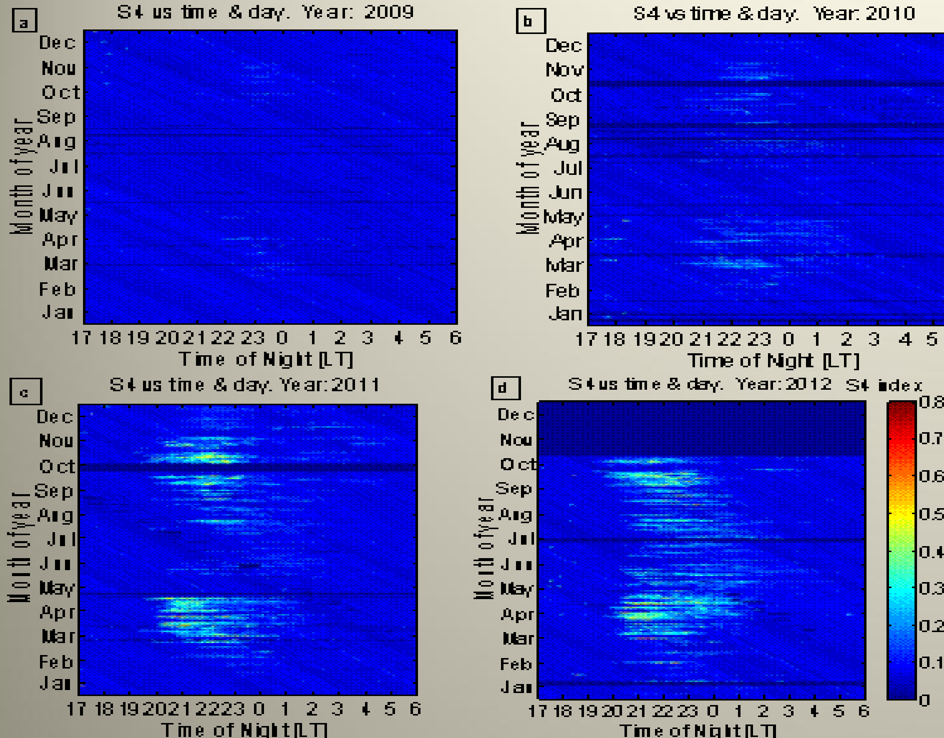


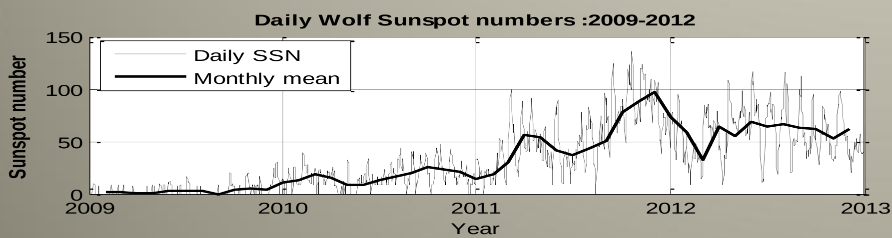
Thin layer

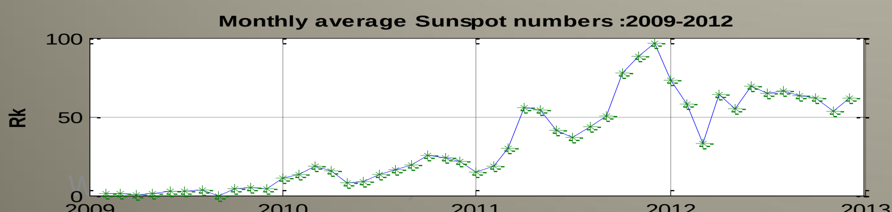
$$d_F = \sqrt{L\lambda}$$

Climatology: Diurnal and Seasonal Variation of S4 index

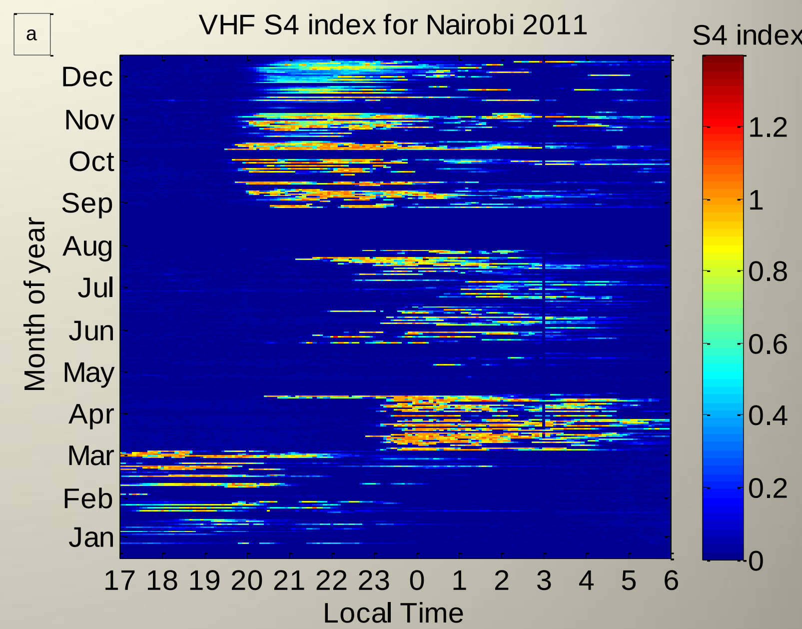
L-band Scintillation







VHF Scintillation

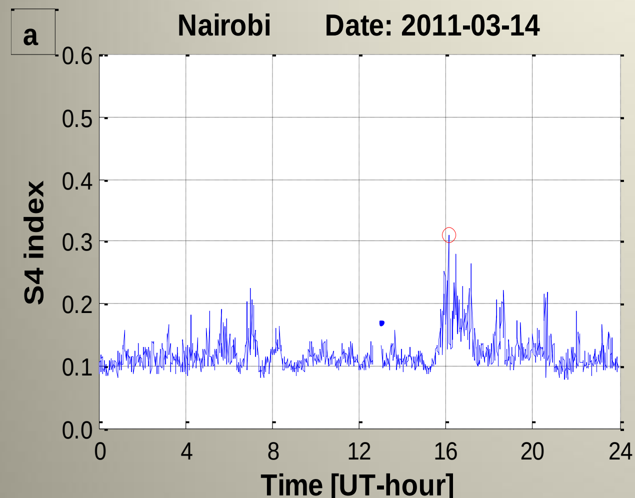


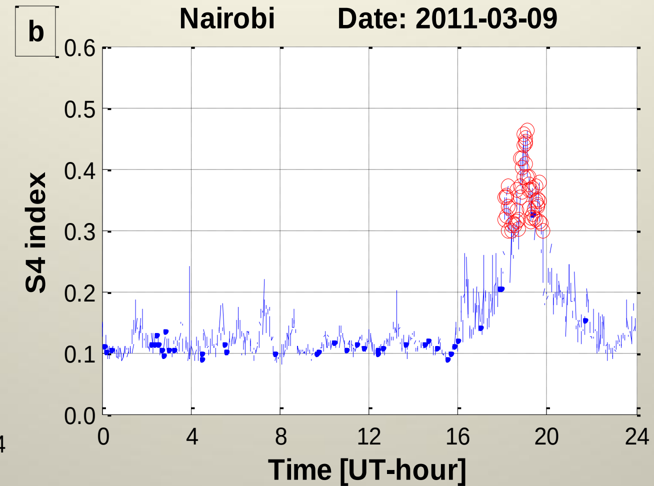
Occur all year round and persist till morning hours

Olwendo et al. 51(2013), 1715-1726, ASR

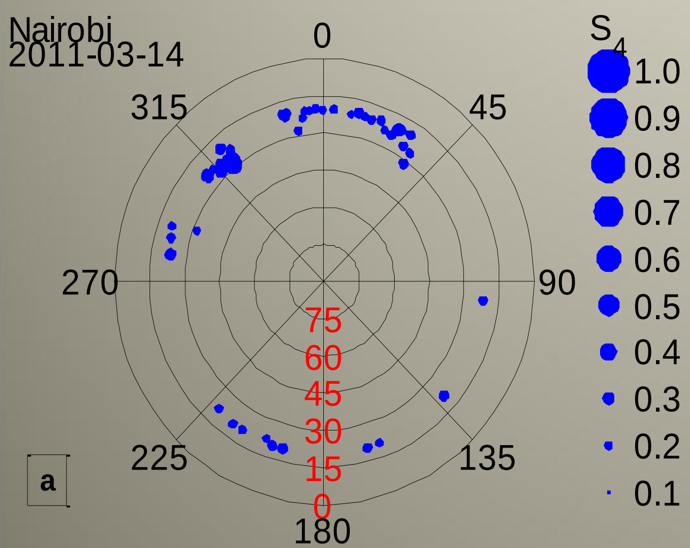
Olwendo et al., 138-139(2016), 9-22, JASTP

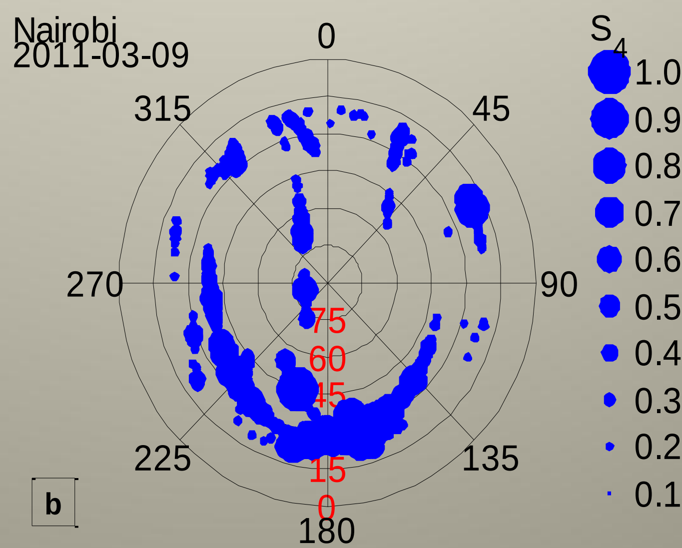
Climatology on directional Analysis : Spatial Distribution of irregularities





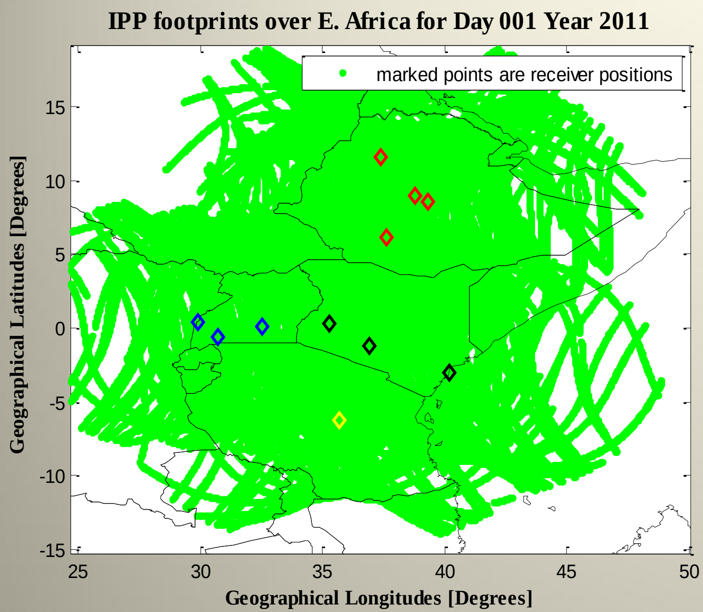
Temporal variation of S4 is already well known to some level



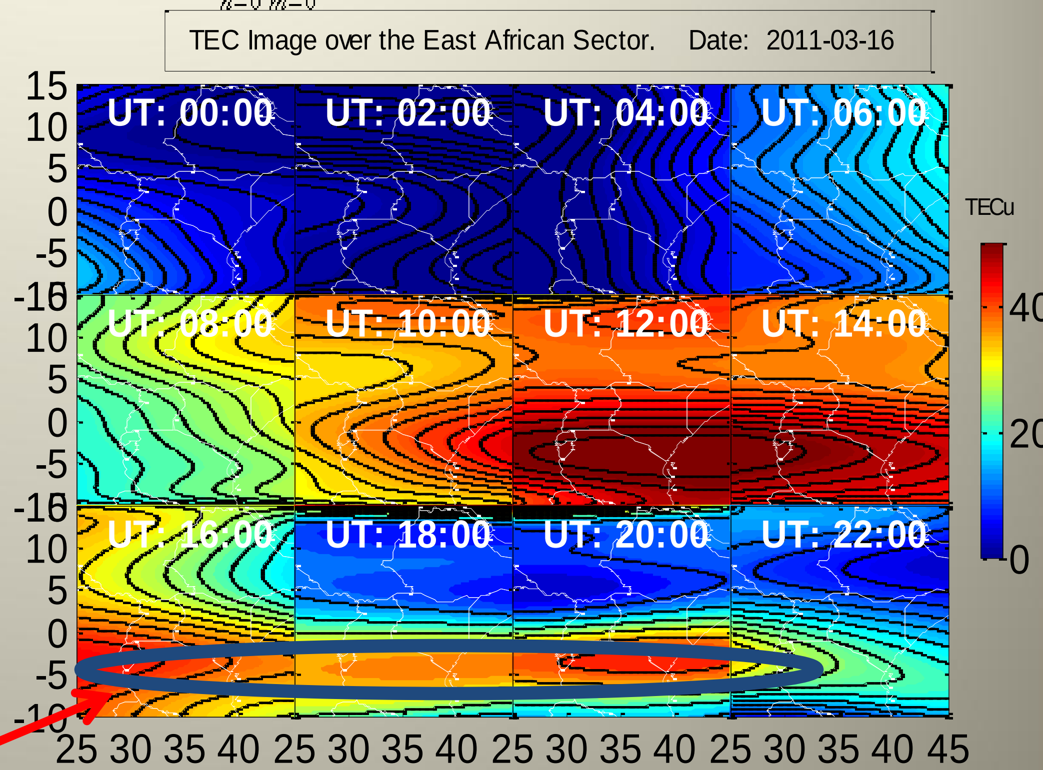


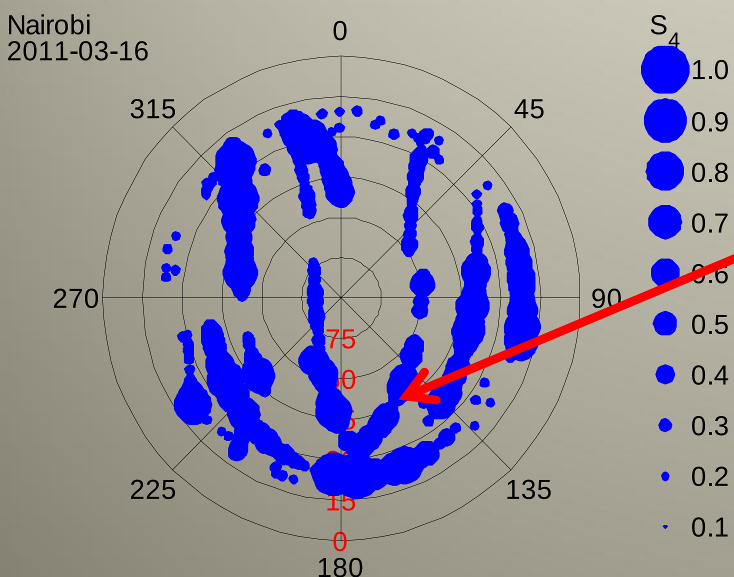
Spatial distribution of irregularities causing scintillation

Spatial distribution of irregularities and the ionization anomaly crests



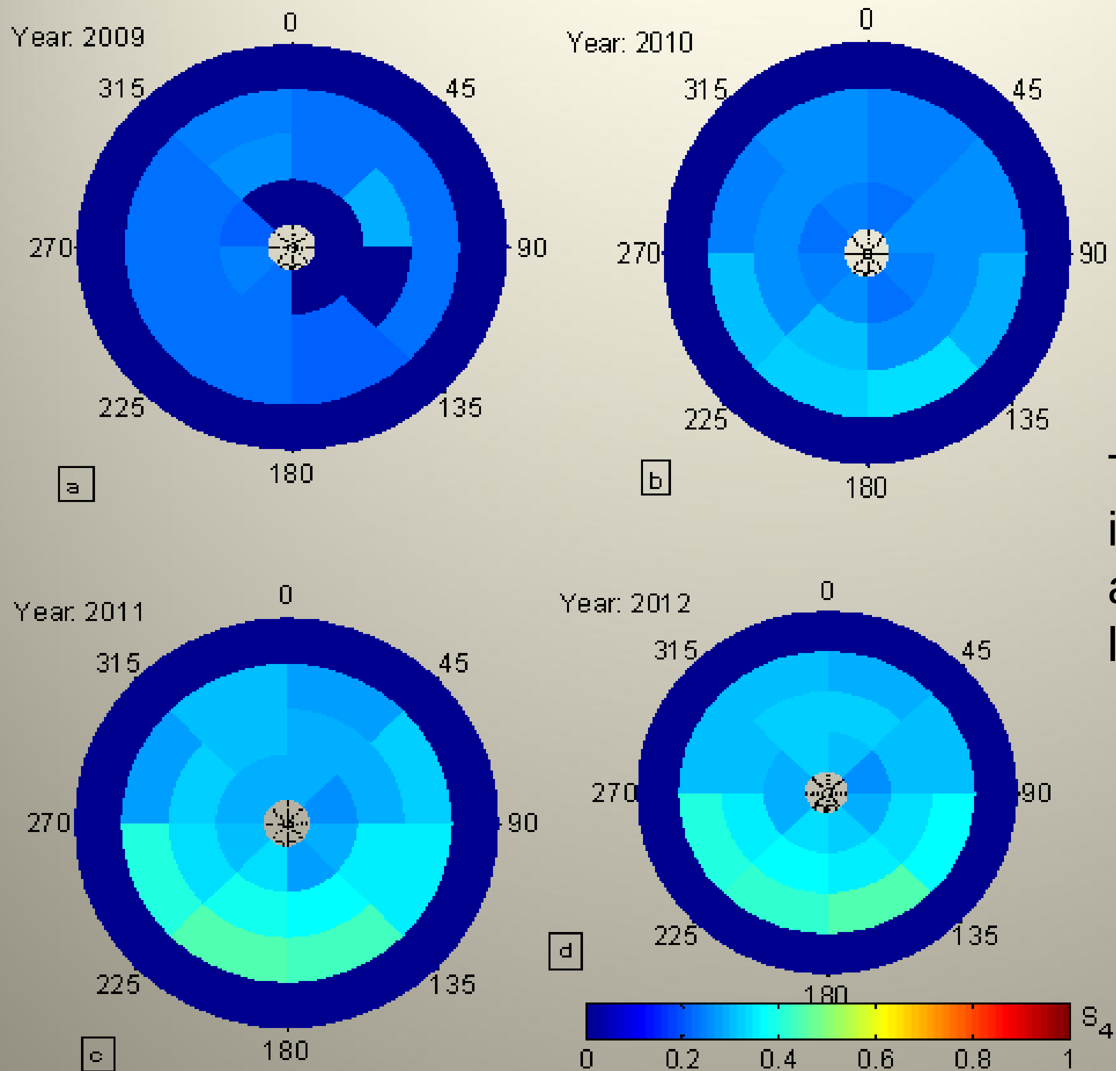
$$TEC(\lambda, \phi) = \sum_{n=0}^{N} \sum_{m=0}^{a} \overline{P_{nm}} [\cos(\phi)] \{ a_{nm} \sin(m\lambda) + b_{nm} \cos(m\lambda) \}$$





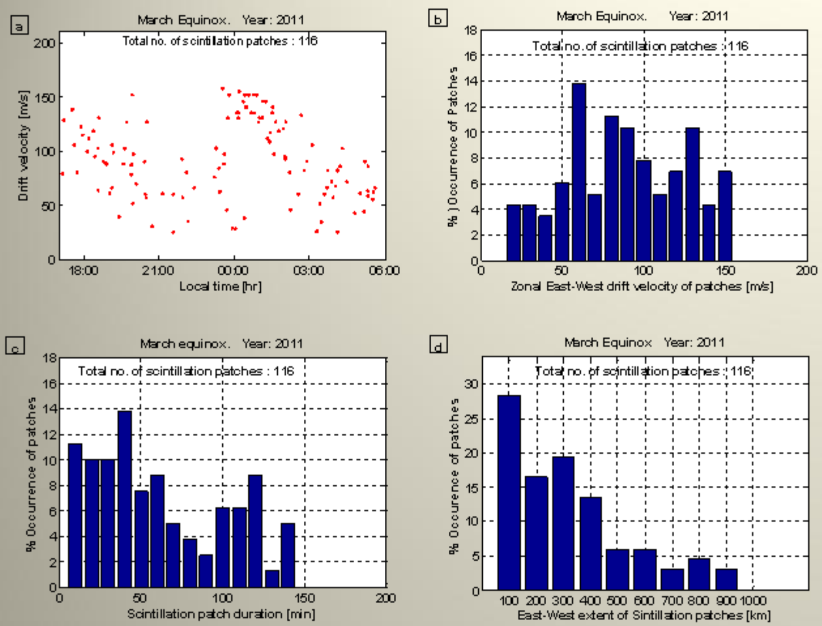
Ionospheric irregularities are within the region with high background electron density –Equatorial Ionization Anomaly

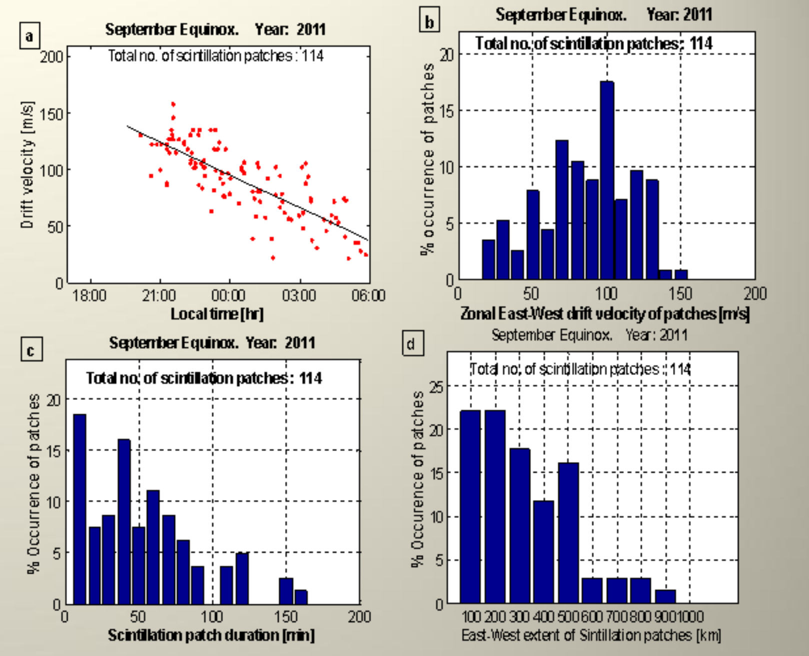
Spatial distribution of irregularities: A climatology

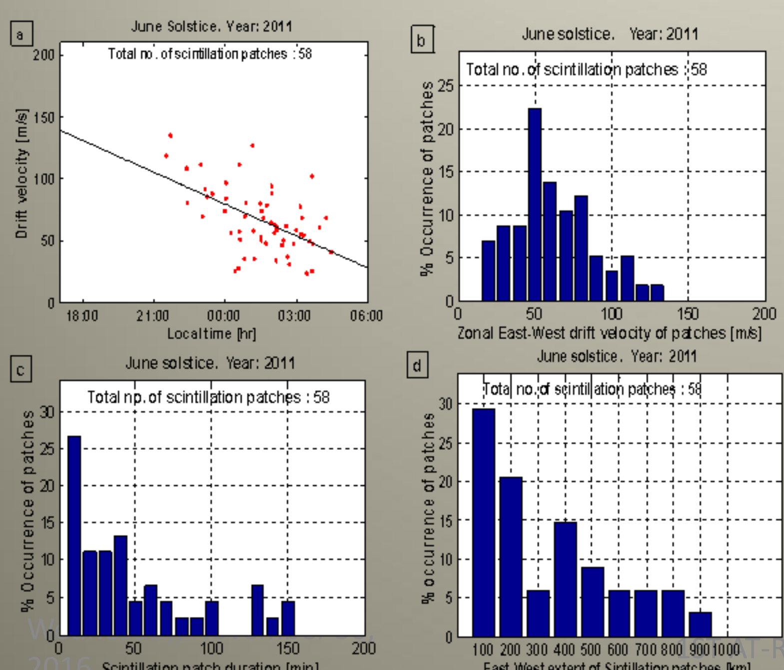


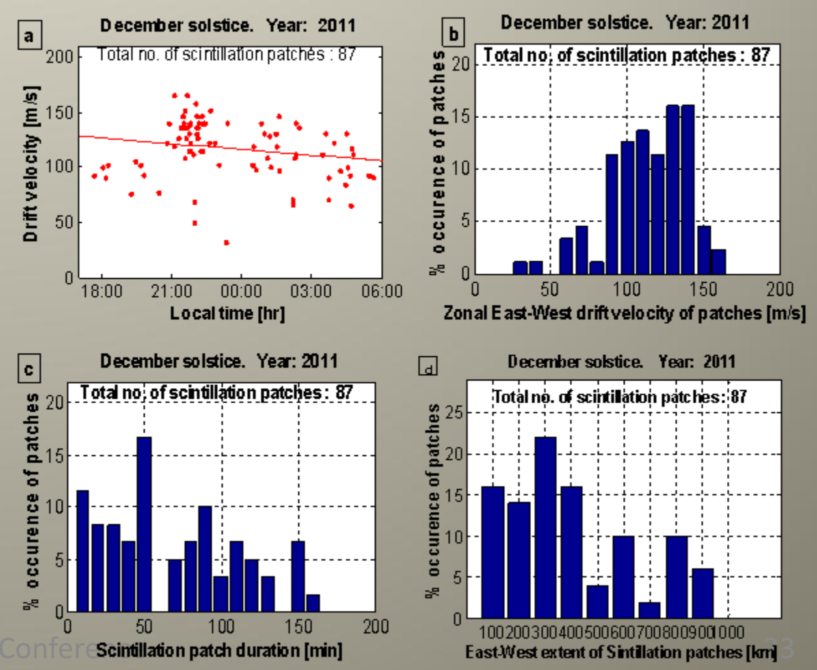
The S4 values are stronger in Southern parts of the sky as viewed from the Receiver location in Nairobi (Kenya)

Olwendo et al., 138-139 (2016), 9-22, JASTP

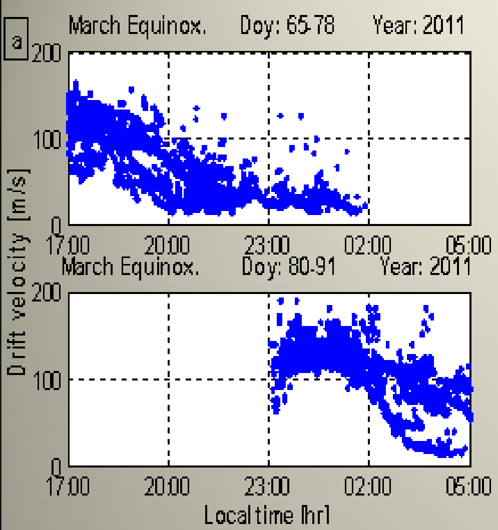

a
March Equinox. Year: 2011
Total no. of scintillation patches : 116
Drift velocity [m/s]
Local time [hr]
b
March Equinox. Year: 2011
Total no. of scintillation patches : 116
%) Occurrence of Patches
Zonal East-West drift velocity of patches [m/s]
c
March equinox. Year: 2011
Total no. of scintillation patches : 116
% Occurrence of patches
Scintillation patch duration [min]
d
March Equinox Year: 2011
Total no. of scintillation patches : 116
% Occurence of patches
East-West extent of Sintillation patches [km]

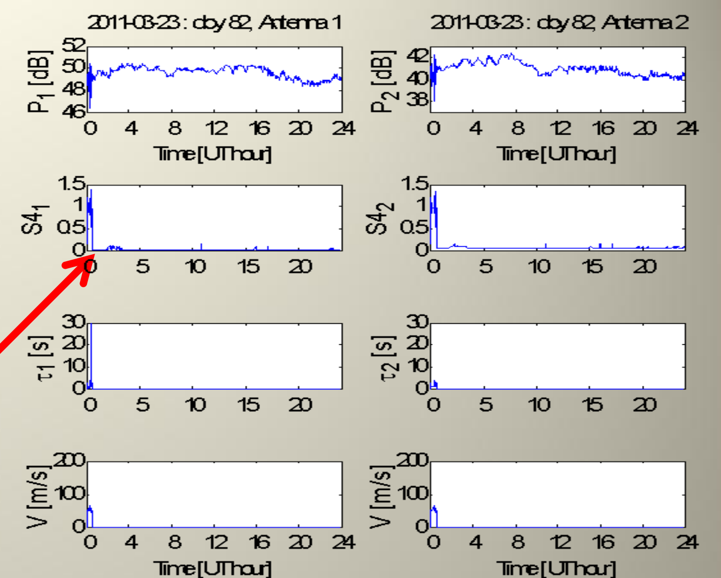

a
September Equinox. Year: 2011
Total no. of scintillation patches : 114
Drift velocity [m/s]
Local time [hr]
b
September Equinox. Year: 2011
Total no. of scintillation patches: 114
% occurrence of patches
Zonal East-West drift velocity of patches [m/s]
c
September Equinox. Year: 2011
Total no. of scintillation patches: 114
% Occurrence of patches
Scintillation patch duration [min]
d
September Equinox. Year: 2011
Total no. of scintillation patches : 114
% Occurence of patches
East-West extent of Sintillation patches [km]


a
June Solstice. Year: 2011
Total no. of scintillation patches : 58
Drift velocity [m/s]
Local time [hr]
b
June solstice. Year: 2011
Total no. of scintillation patches : 58
% Occurrence of patches
Zonal East-West drift velocity of patches [m/s]
c
June solstice. Year: 2011
Total no. of scintillation patches : 58
% Occurrence of patches
Scintillation patch duration [min]
d
June solstice. Year: 2011
Total no. of scintillation patches : 58
% occurrence of patches
East-West extent of Sintillation patches [km]

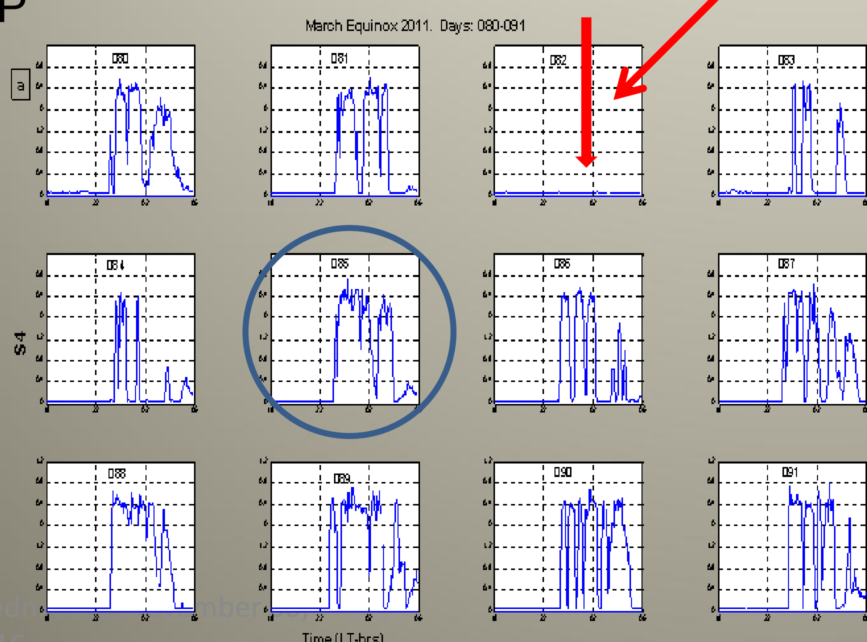

a
December solstice. Year: 2011
Total no. of scintillation patches : 87
Drift velocity [m/s]
Local time [hr]
b
December solstice. Year: 2011
Total no. of scintillation patches : 87
% occurence of patches
Zonal East-West drift velocity of patches [m/s]
c
December solstice. Year: 2011
Total no. of scintillation patches: 87
% occurence of patches
Scintillation patch duration [min]
d
December solstice. Year: 2011
Total no. of scintillation patches: 87
% occurence of patches
East-West extent of Sintillation patches [km]

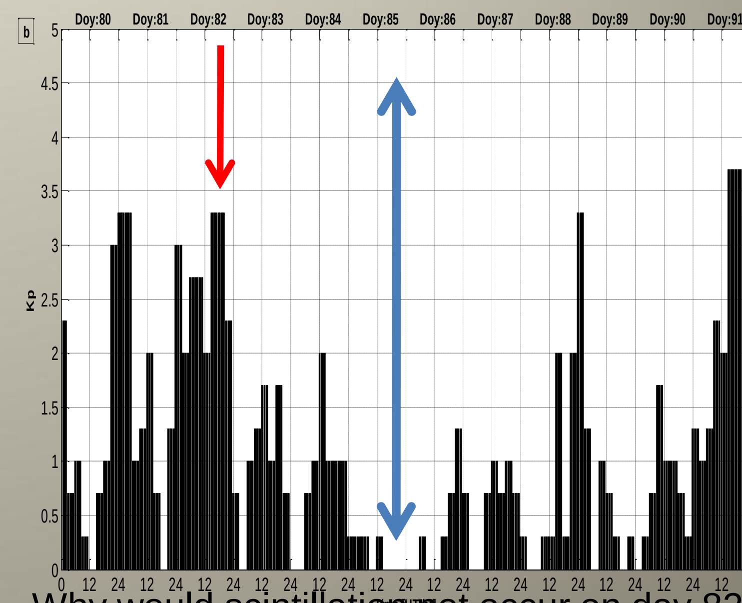
March equinox and December solstice: Post-midnight scintillation occurrence





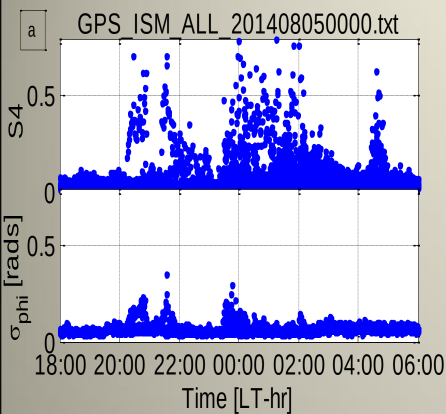
Olwendo et al., 138-139(2016), 9-22, JASTP

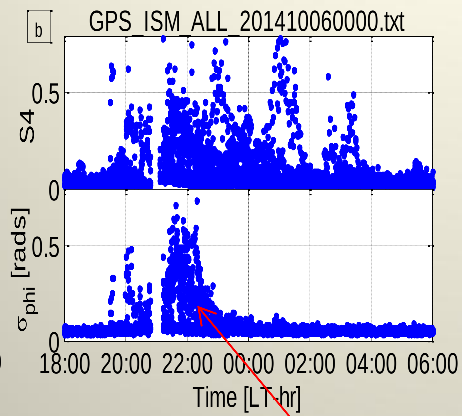


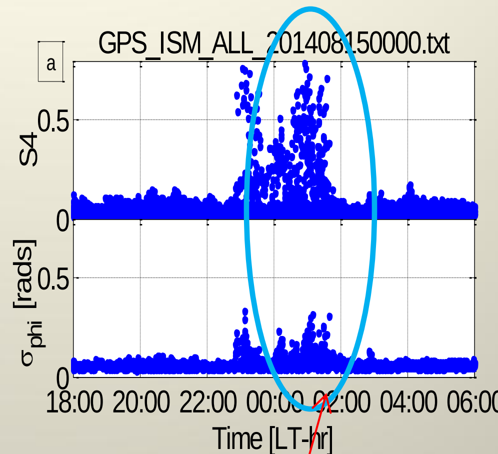


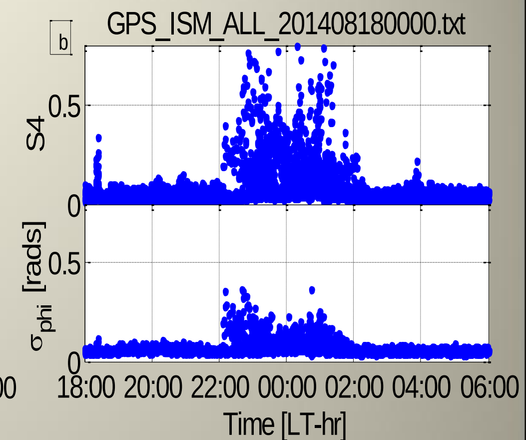
Why would scintillation not occur on day 82 when Kp>3 and again why would it occur on day 85 when Kp is nearly ~0

Post-midnight at L-band frequency: New observations



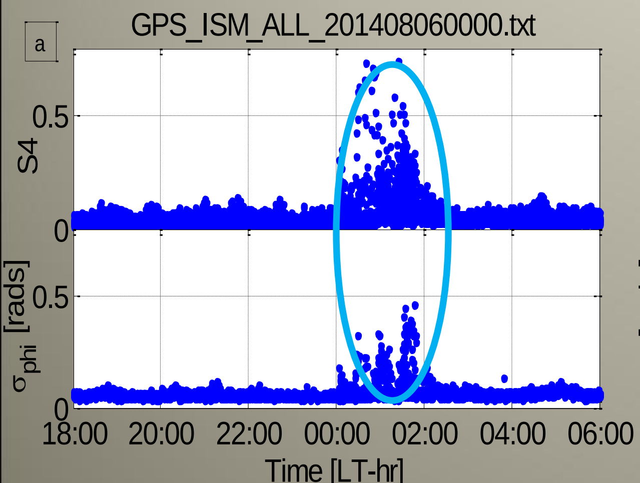


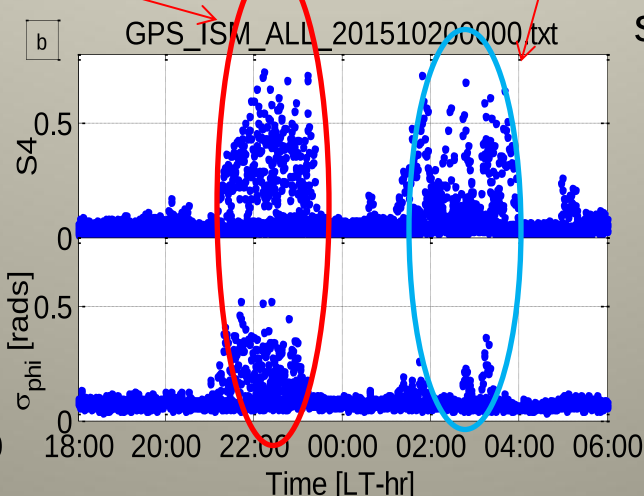


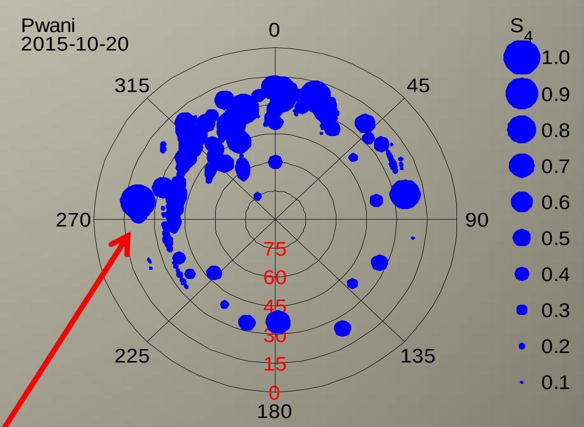


Amplitude and phase scintillation occurring concurrently

Amplitude scintillation Observations without phase scintillation. WHY?



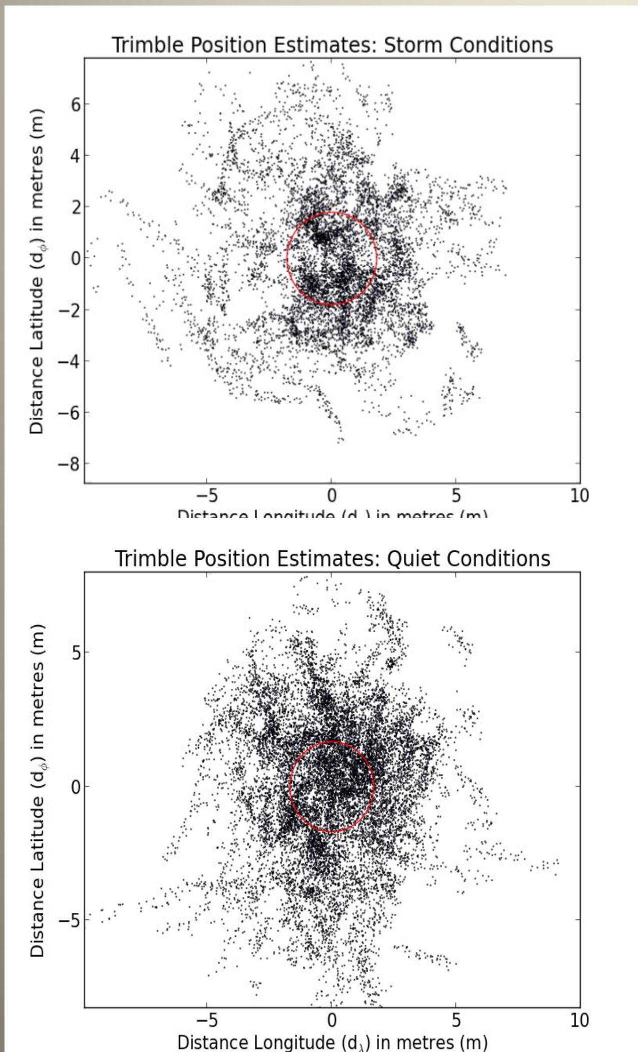




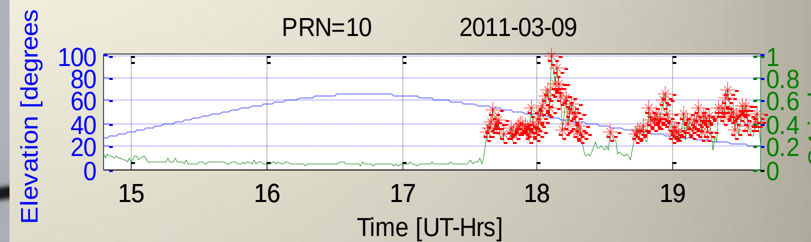
Scintillation Events mainly to the Northern part from receiver location

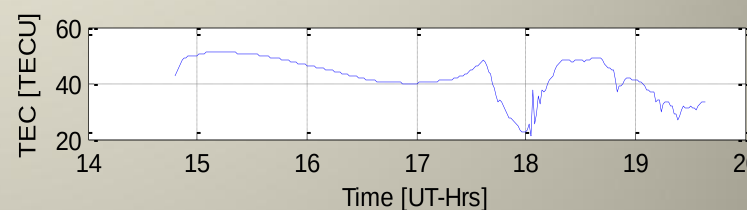
Errors in Precise Positioning due to ionospheric scintillation

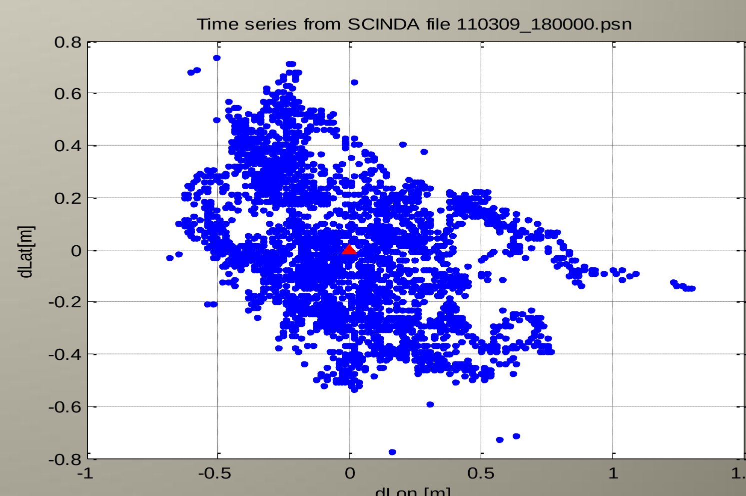
Single Frequency receiver



Positioning errors in Dual Frequency reference receiver

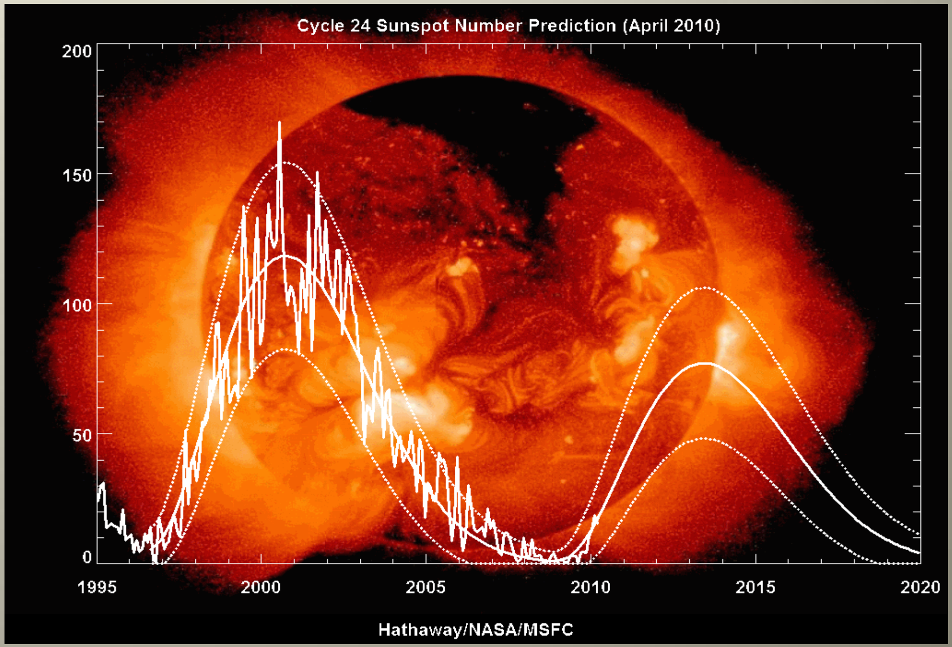






Summary

GNSS is an enabling technology that can make major contributions to economic growth and societal betterment. It is also a key to scientific exploration.



THE END:
THANKS FOR LISTENING