Space Weather at Low-Latitudes: Considerations to Improve its Forecasting

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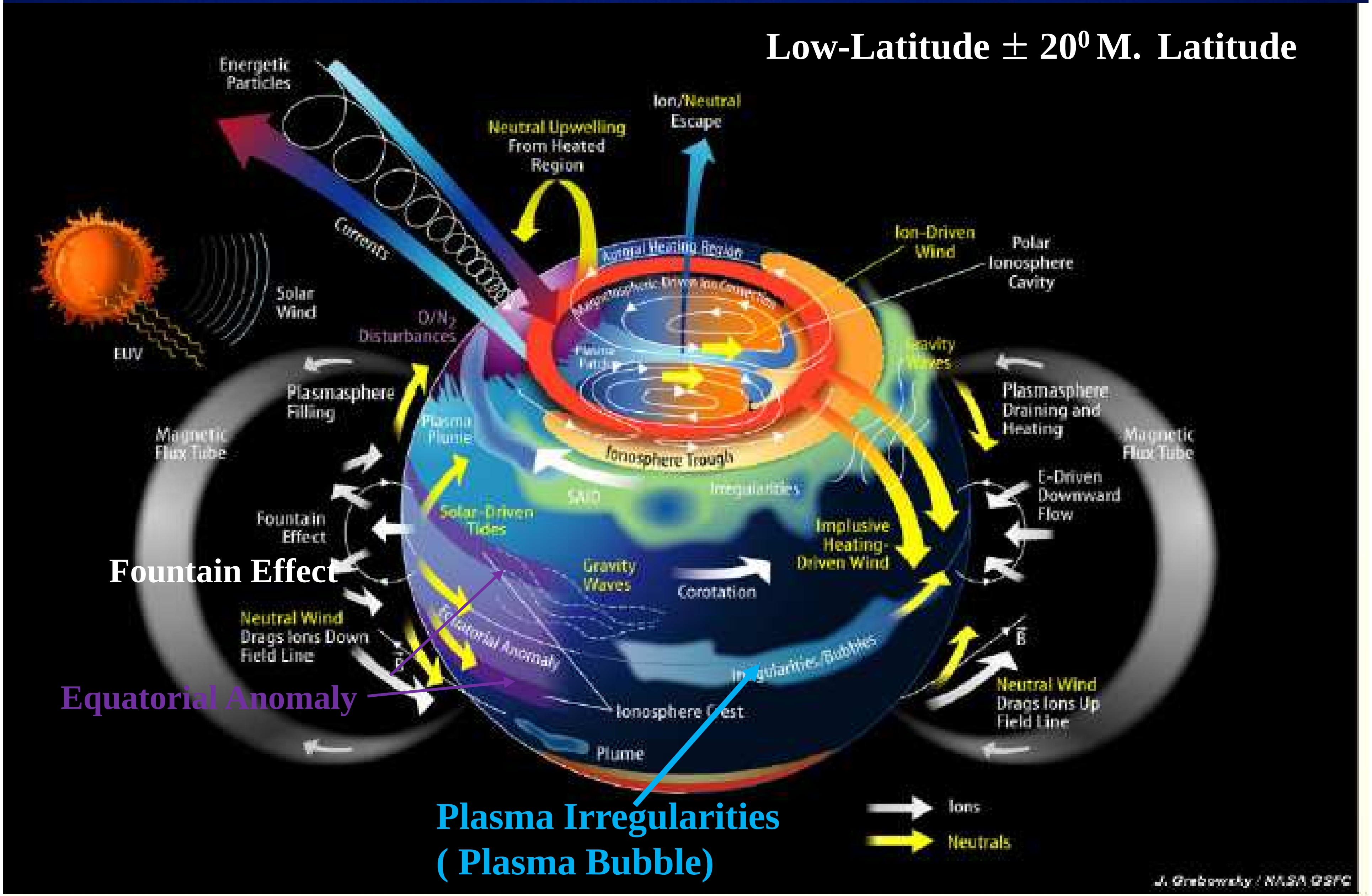
Overview

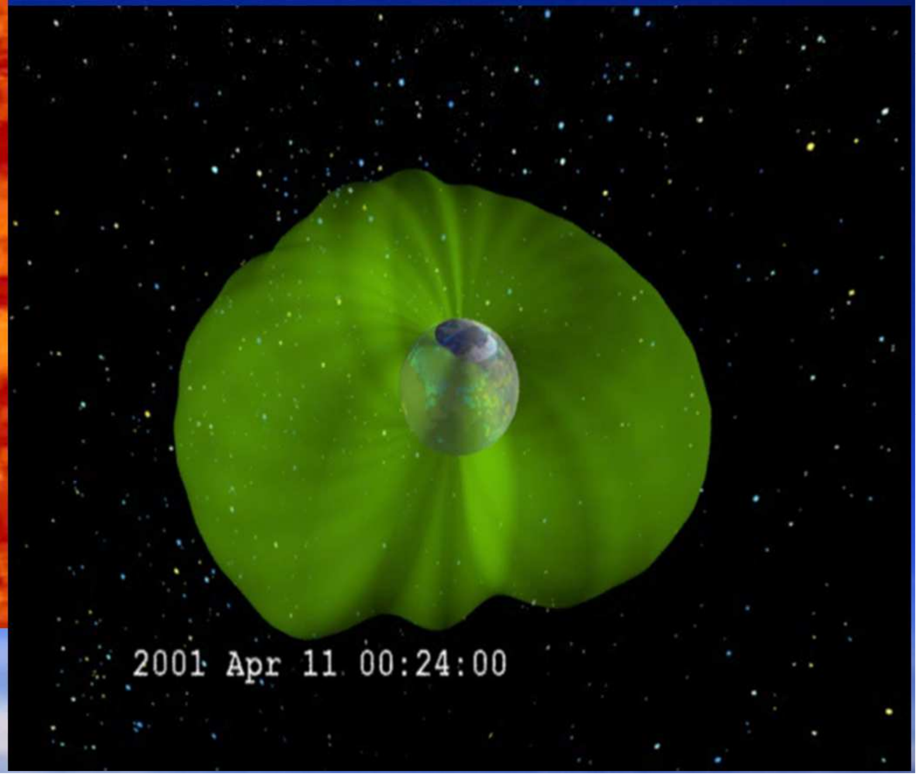
- Space Weather Forecasting: Overview
- Ionosphere/Airglow layer
- Theory, Measurements and Results
  - Plasma Bubble Propagation
  - Total Electron Content (TEC)
  - Coupling between neutral and Electrodynamics
- Summary

Dynamics/Space Weather Activities



Space Weather

- Mainly a consequence of the behaviour of the Sun such as Solar flares/winds and CMEs that make the change in Magnetic Field, ionosphere unstable, resulting in rapid changes and strong spatial gradients that effects on space-based technological systems (GPS and WAAS).



Space Weather: Forecasting

Space Weather Forecasts:

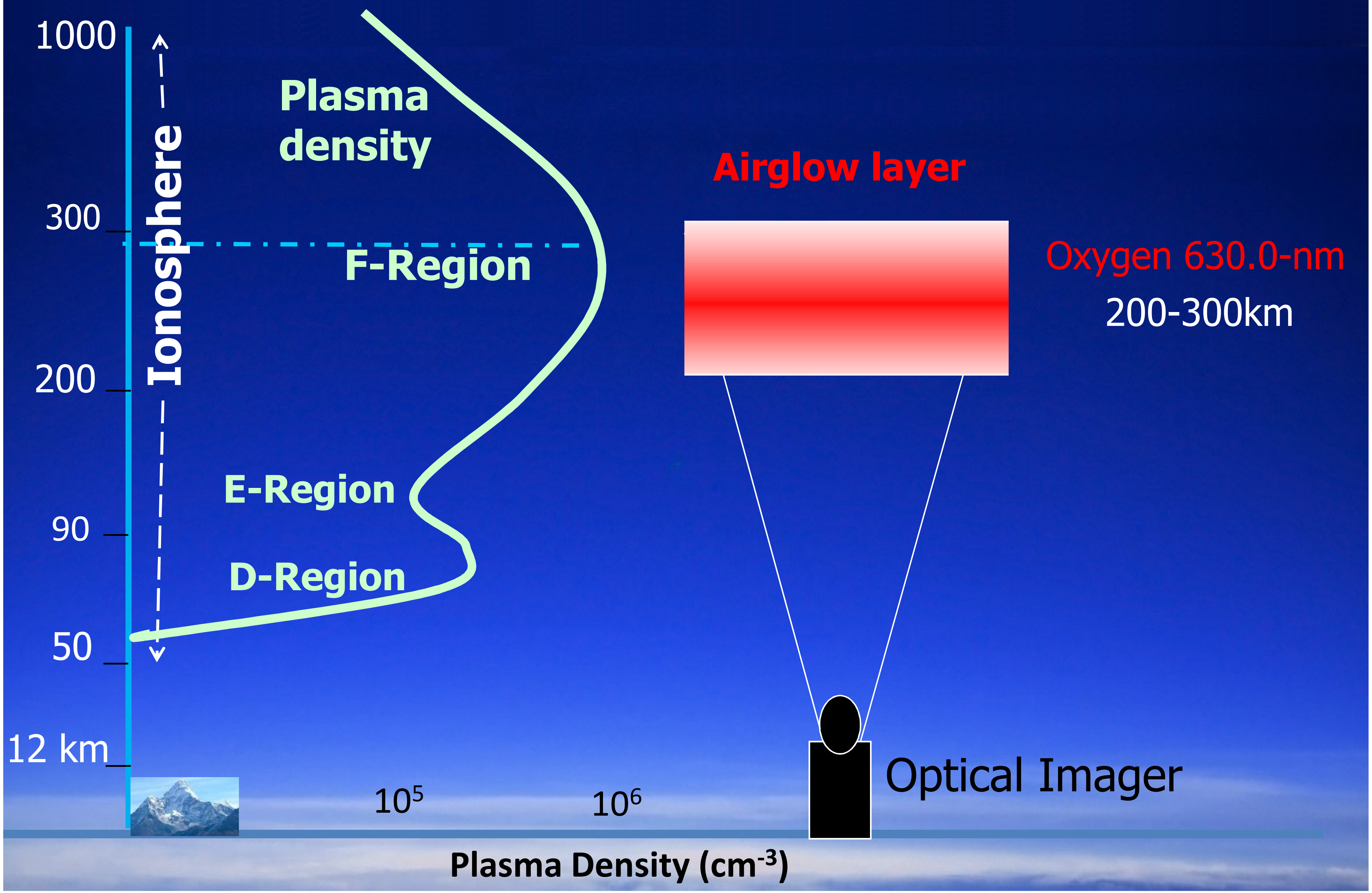
- Predictions of space environment around the GEO
- Predictions of equatorial ionospheric disturbances
- For Low-latitude, Forecast deals with the occurrence of the ionospheric plasma irregularities that can interfere with radio wave propagation and affect communication and navigation systems
- Space-weather forecasts is much like the process of forecasting terrestrial weather using observations, measurements and modelling

Space Weather: Forecasting

- To forecast development of this irregularity, the conditions within the Earth's magnetosphere/ionosphere/thermosphere system have to be examined by tracking the development and dynamics of this structure.

- From the predictions, system operators can make preparations to minimize damage from strong impacts that might happen on Technological system - Satellites, power grids, communications and navigations systems .

Ionosphere



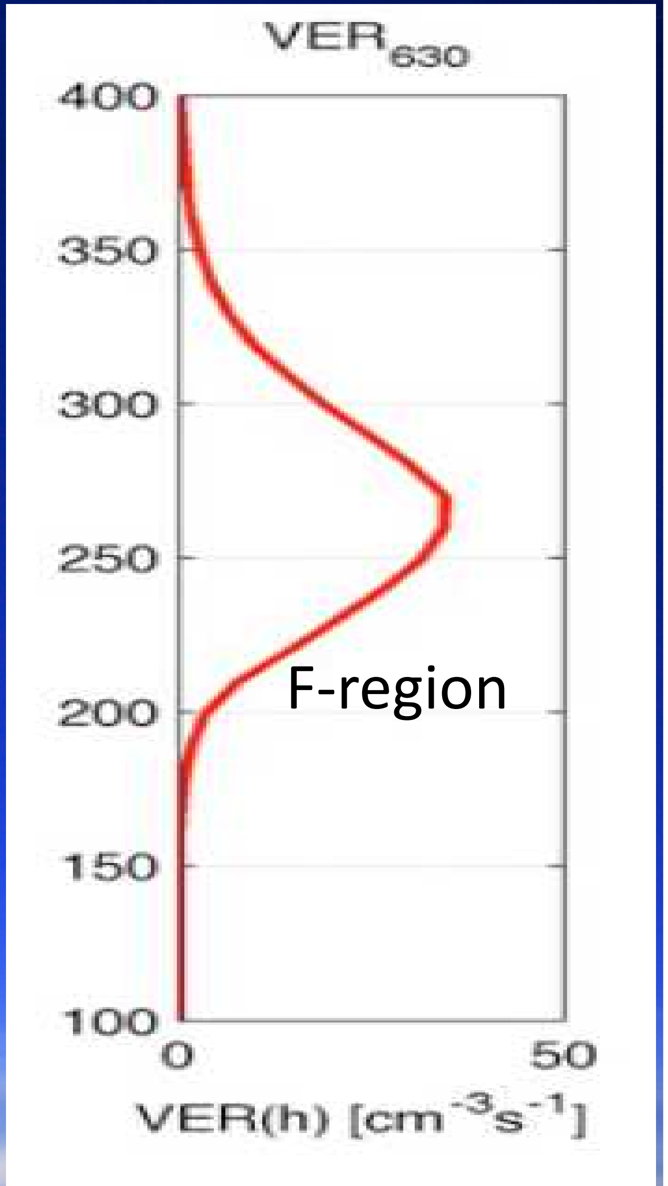
1000
300
200
90
50
12 km
Ionosphere
Plasma density
F-Region
E-Region
D-Region
Airglow layer
Oxygen 630.0-nm
200-300km
Optical Imager
10^5
10^6
Plasma Density (cm^-3)

630.0-nm Airglow Emissions

$O^+ + O_2 \longrightarrow O_2^+ + O$

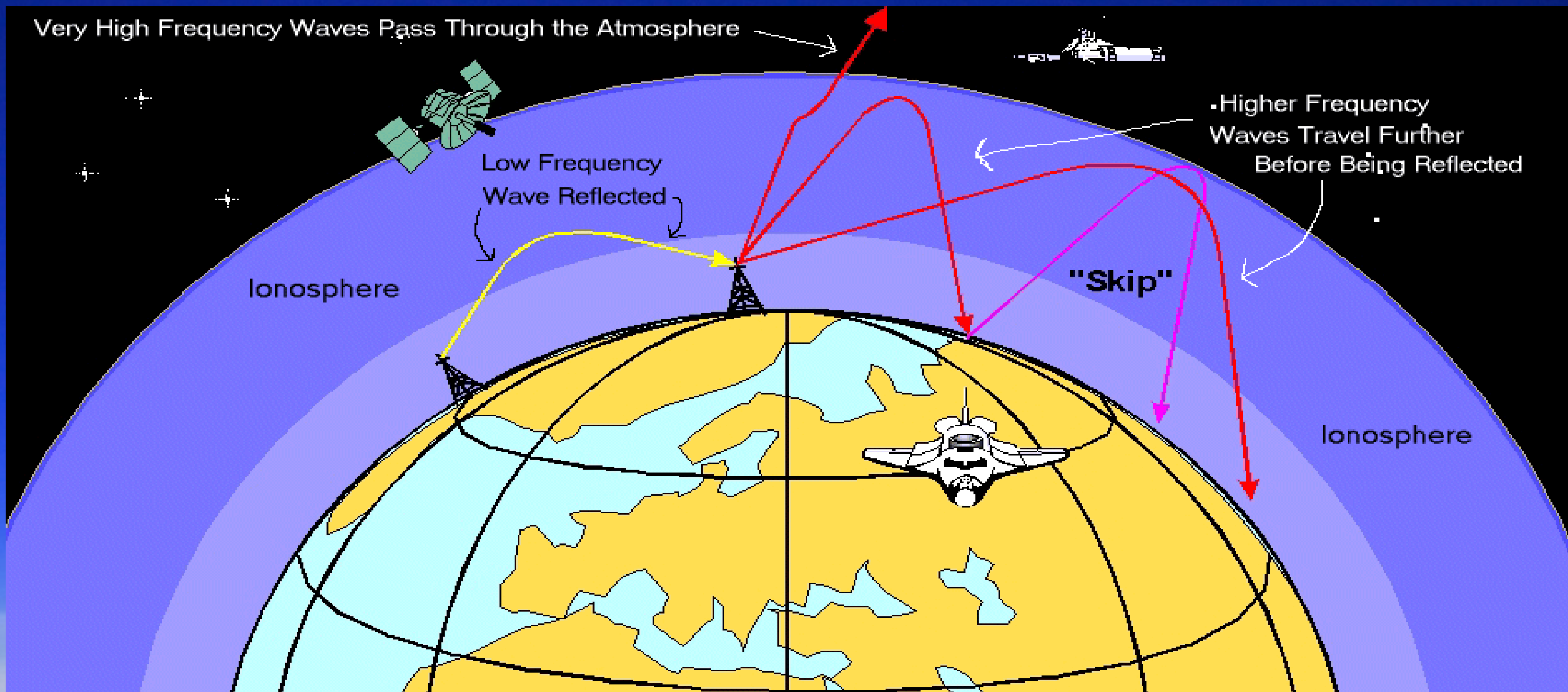
$O_2^+ + e \longrightarrow O(^1D) + O(^3P)$

$O(^1D) \longrightarrow O(^3P) + h\nu$ (630 nm)

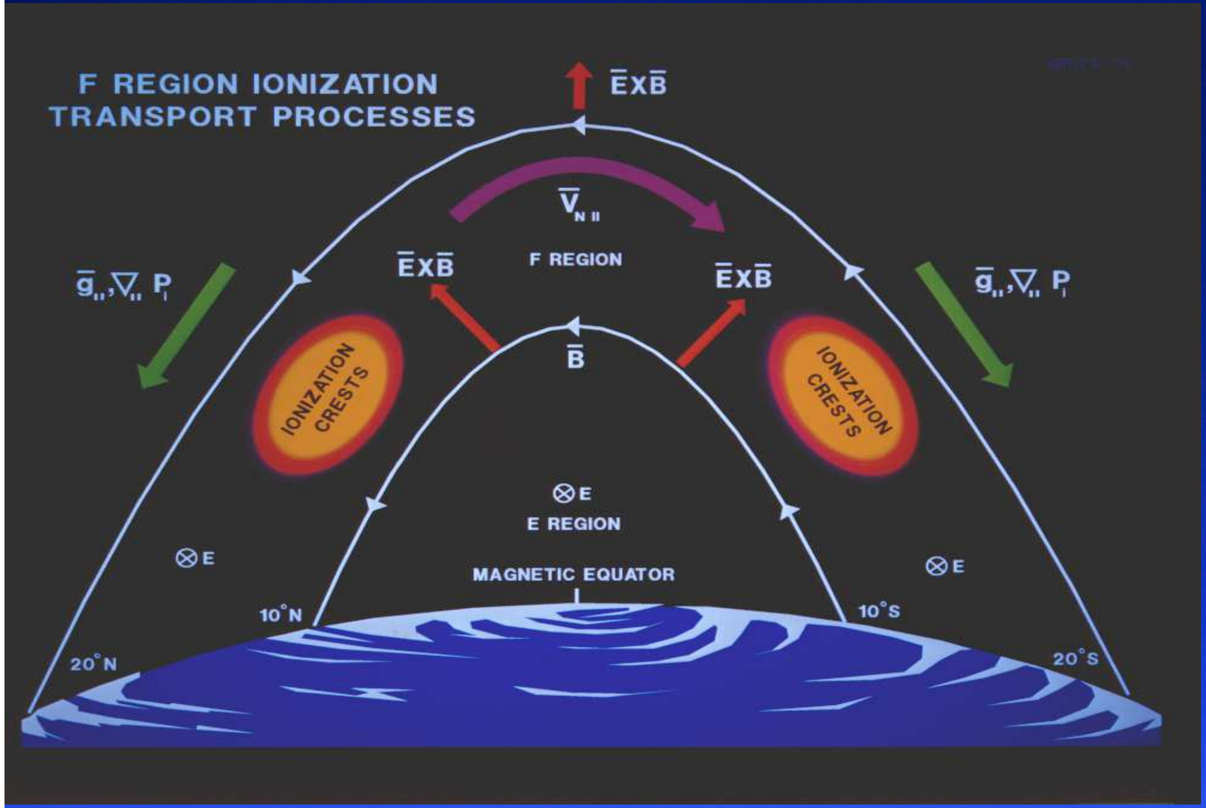


Ionosphere and Radio Wave Communication

- F-region is mainly responsible for the radio, television and satellite communication systems
- Ionospheric irregularity causes scintillation that can degrade and disrupt : Communication, Surveillance and GPS Navigation Systems

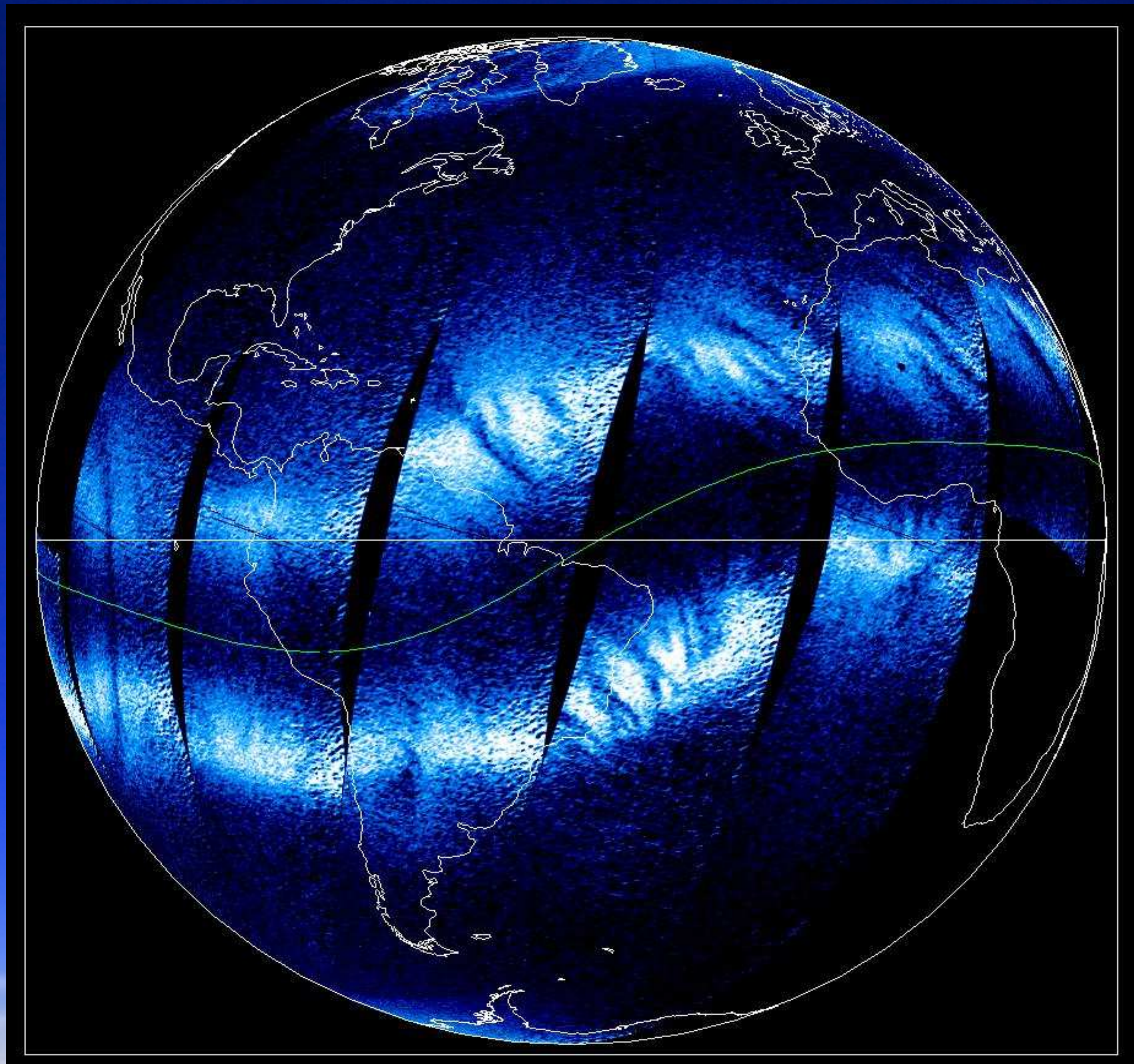


Equatorial Ionosphere

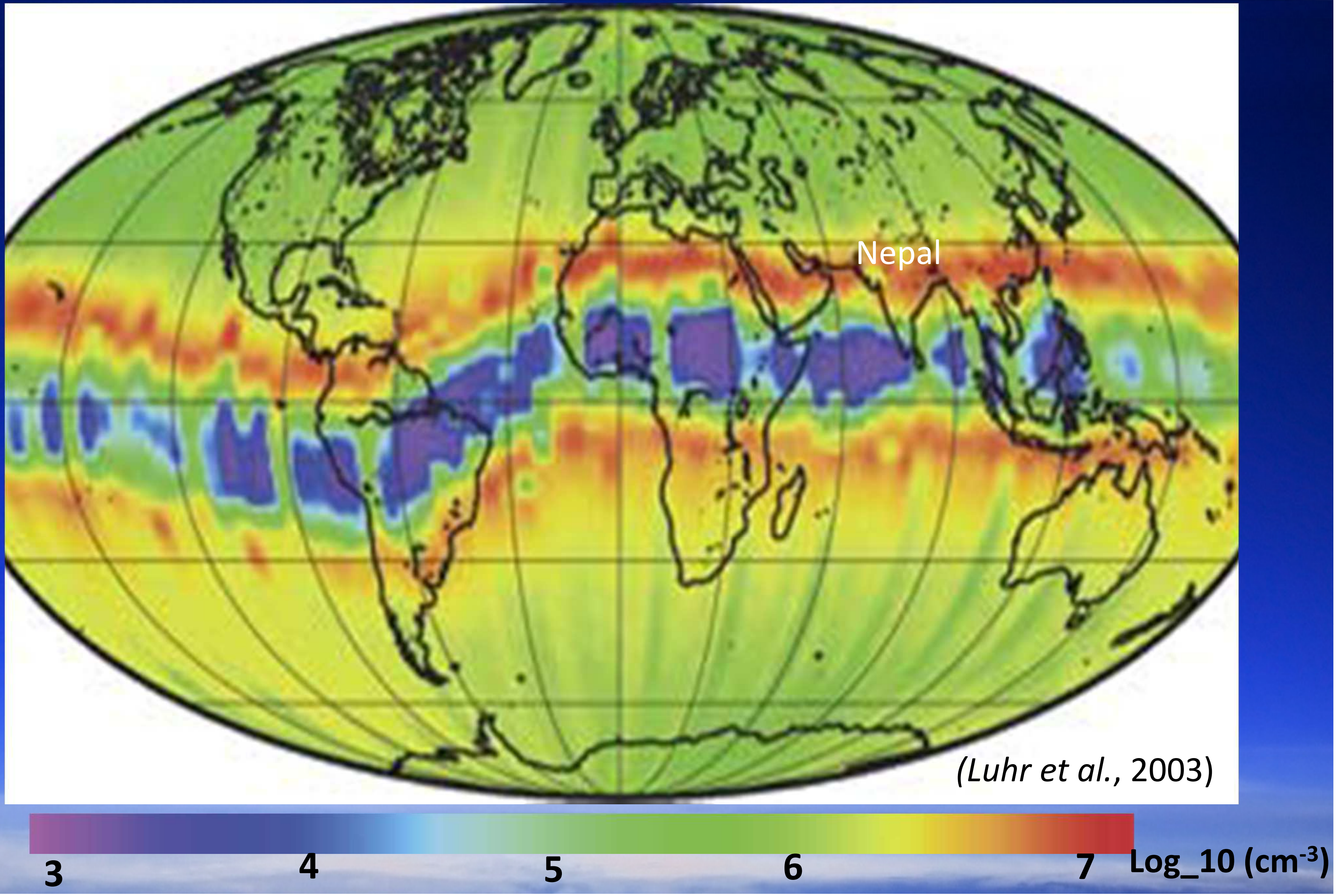


- **B** field is nearly horizontal
- Daytime:
  - *E*-region E is eastward
  - Off-equatorial E maps to F above mag. Equator -> Upward ExB
  - Formation of Appleton Anomaly

Anomaly Region Imaged in UV- Emissions by GUVI Instrument on the NASA TIMED Satellite



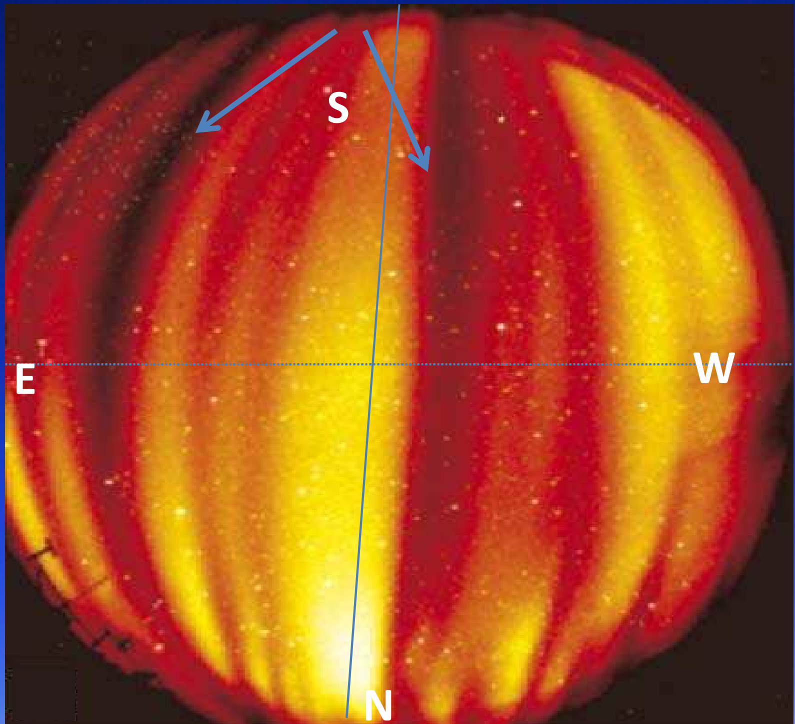
Longitudinal Variations of Electron Density in 20 Longitude Sector



Equatorial Plasma Bubble (EPB)

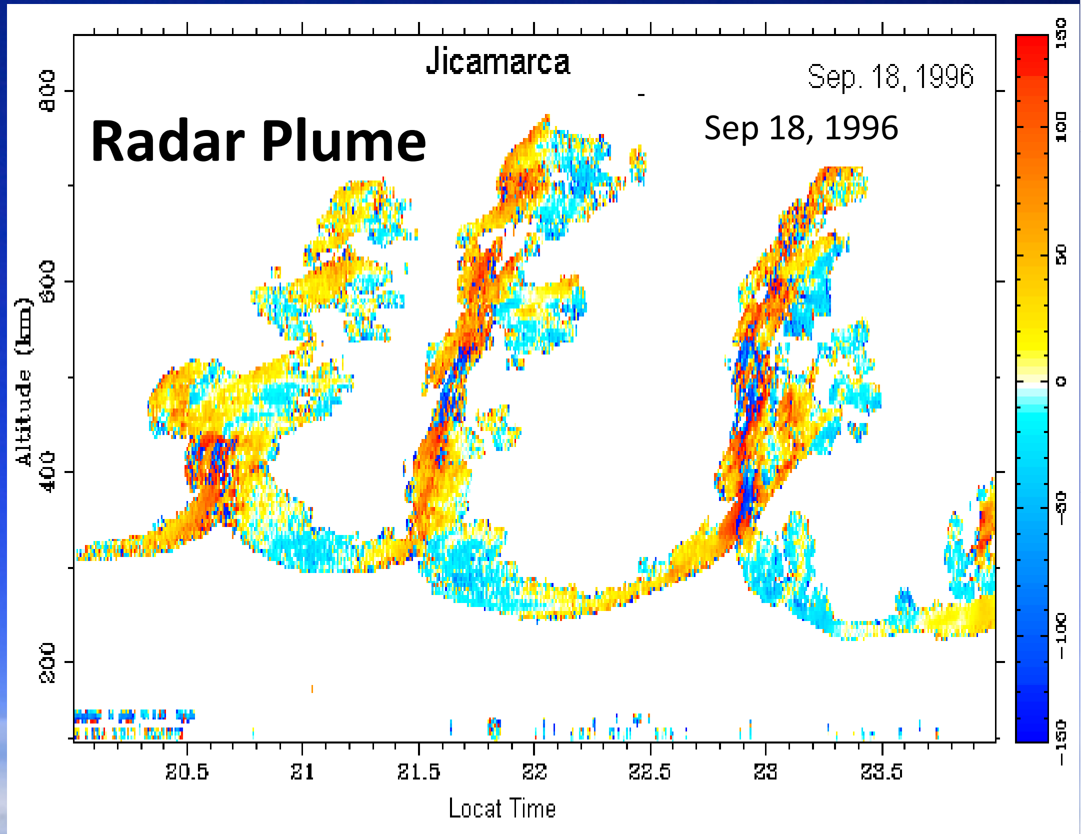
- Development of ionospheric irregularities in nighttime equatorial ionosphere (±20º Mlat) – Equatorial Plasma Bubble (EPB/ESF)

Plasma Bubbles



Optical image measured by USU CCD camera, Christmas Island

Jicamarca, Peru (12°S, 77°W)



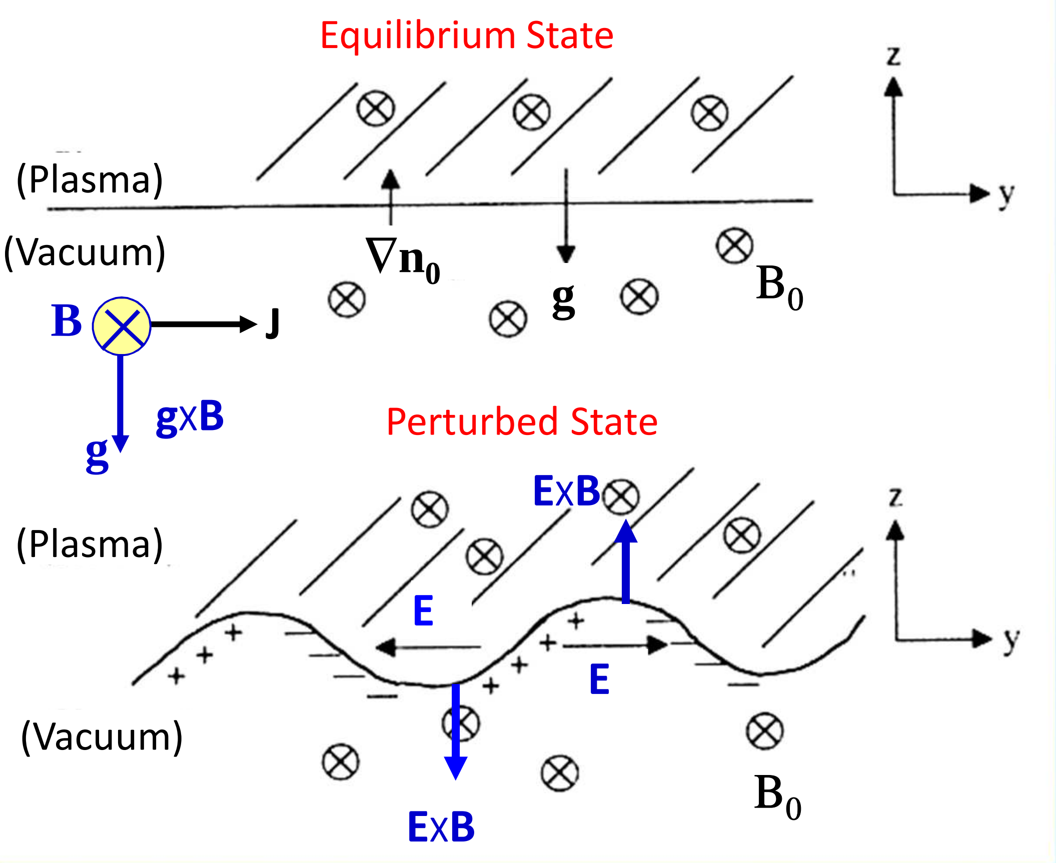
F-region ionospheric irregularities studied for more than 70 years … there is very good understanding of the physics … BUT its day-to-day variability is still not predicted.

Theory: Rayleigh-Taylor Instability

- Imagine a system with two liquids that are immiscible
- If the heavier fluid is on top of the lighter fluid, we have a dynamically unstable system
- A perturbation will cause the two liquids to switch places



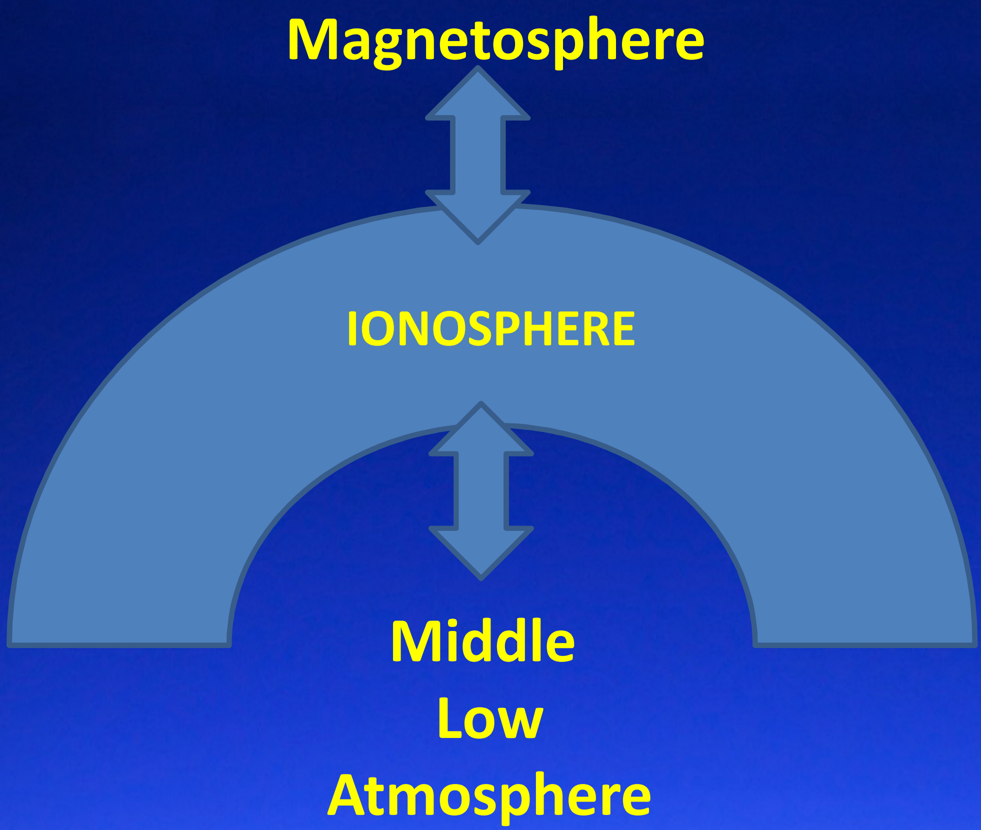
Theory: Rayleigh-Taylor Instability



[*Schunk and Nagy*, 2000]

- gxB drift is the R-T driver
- Perturbation electric fields
- ExB plasma drifts and perturbation grow
- Triggered in the bottomside of the F-region by **seed perturbation** (e.g. gravity wave, wind shear)

Coupling from Above and Below



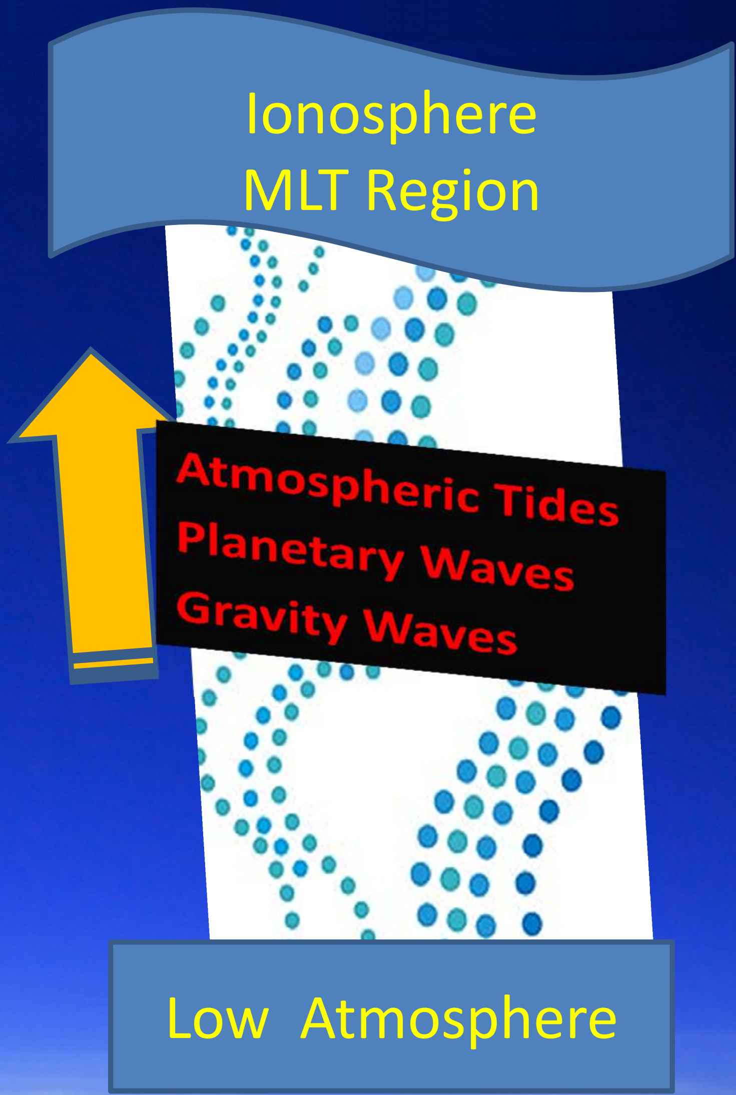
The possible causes of the ionospheric variability includes:

- Solar ionizing radiation
- Solar wind
- Geomagnetic activity
- Neutral atmosphere and electrodynamics.

Atmosphere -Ionosphere Coupling

- When global-scale waves propagate from lower atmosphere to ionosphere it is possible to cause disturbances

- Day to day ionospheric variations due to planetary and gravity wave propagation upward to dynamo region

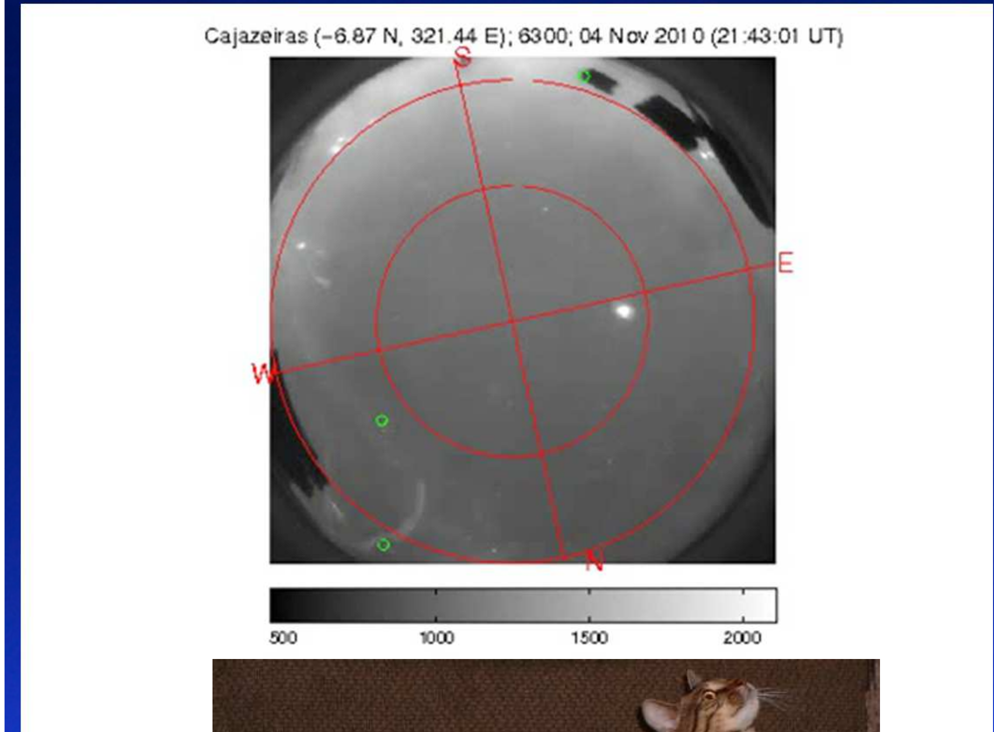


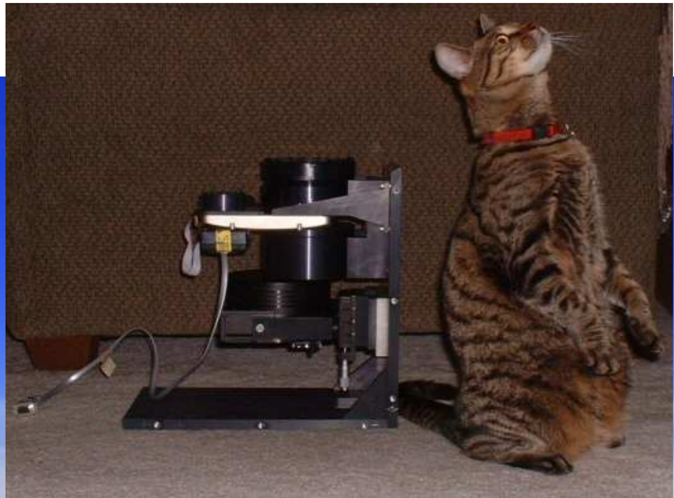
Instrumentations

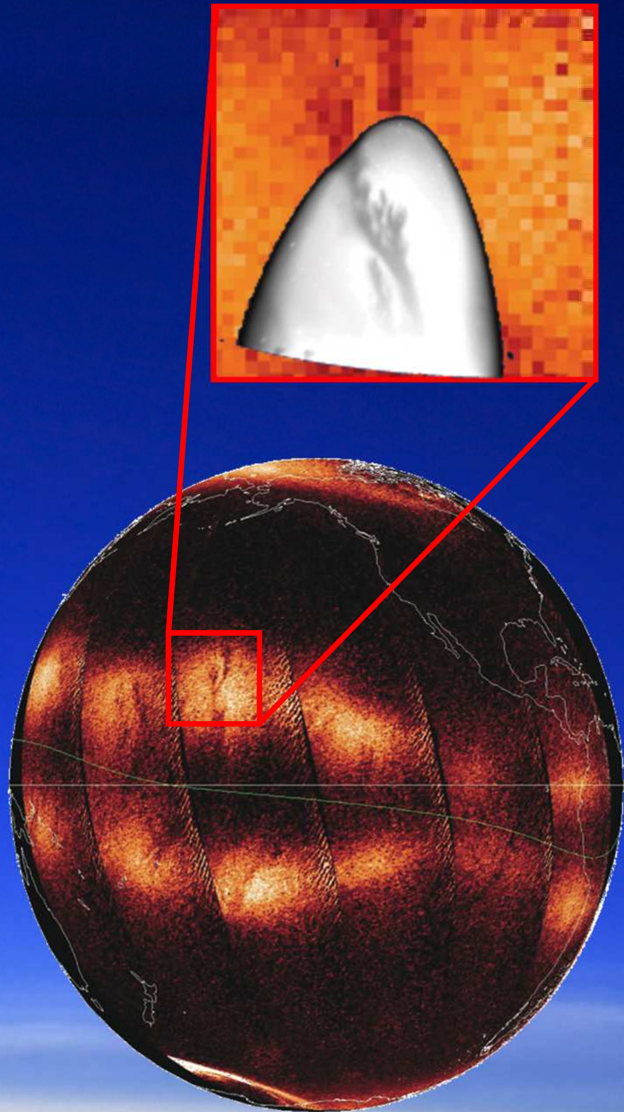
- Optical imaging system: Plasma depletion or bubbles/gravity waves
- RF receiver: Scintillations
- Satellite observations - GPS receivers: Total Electron Content (TEC), Solar activities
- Fabry-Perot Interferometer: Neutral winds

Observations Sites

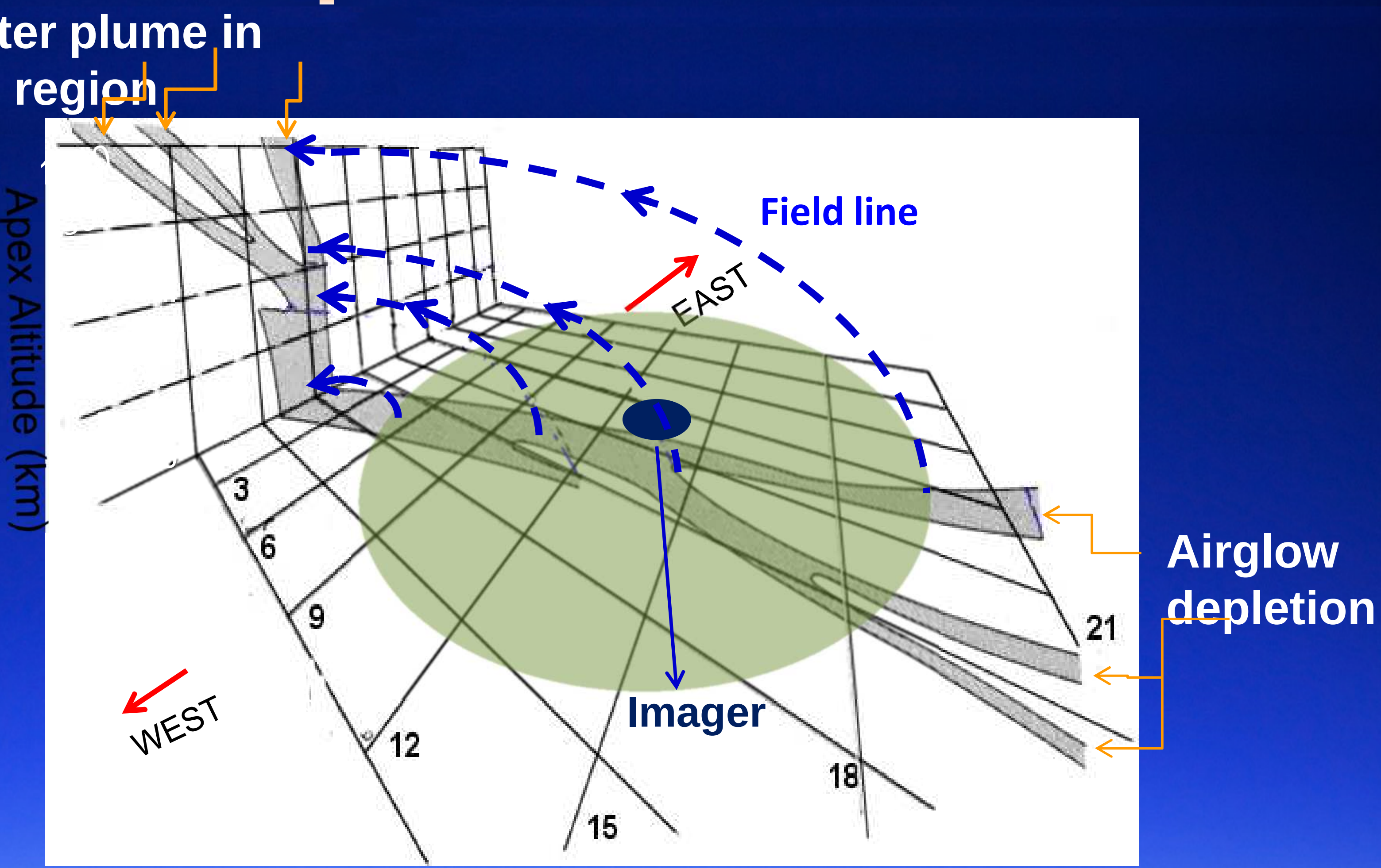
Airglow Imaging







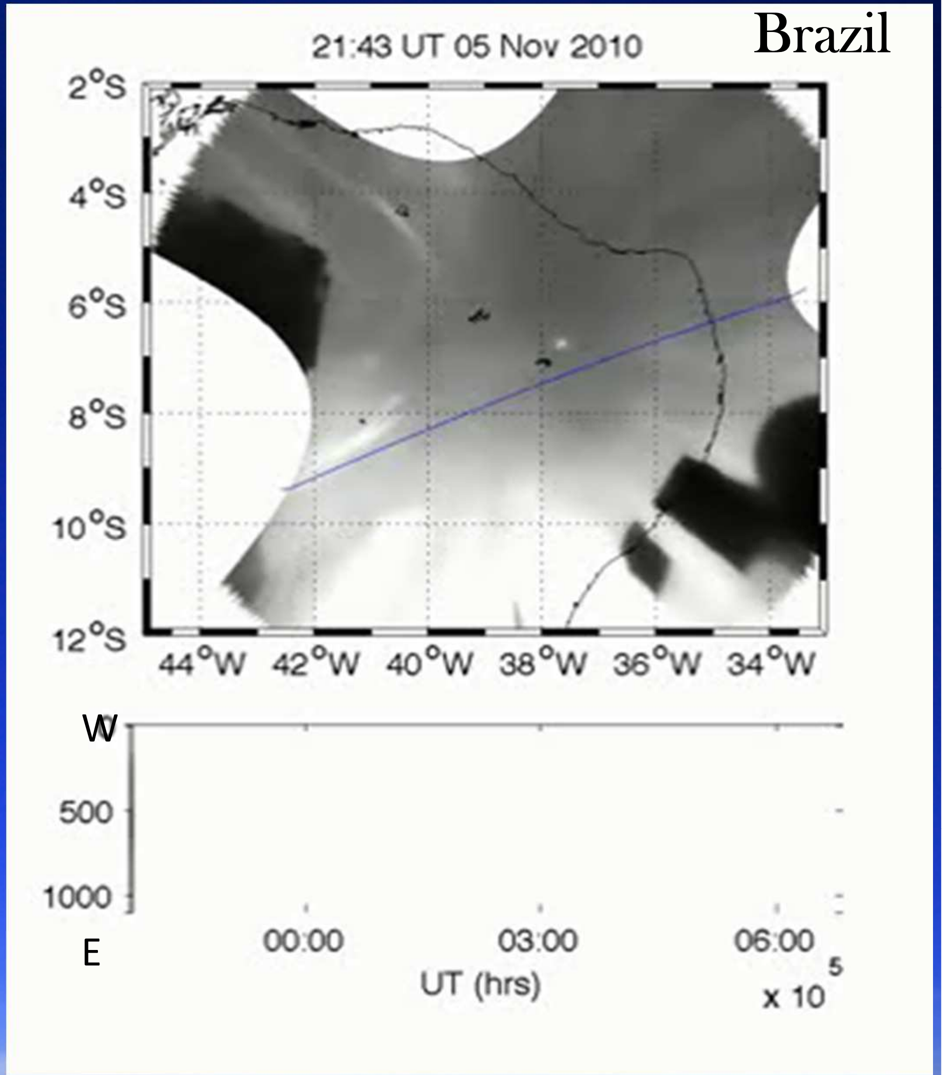
Airglow Apex Mapping to Geomagnetic Equatorial Plane



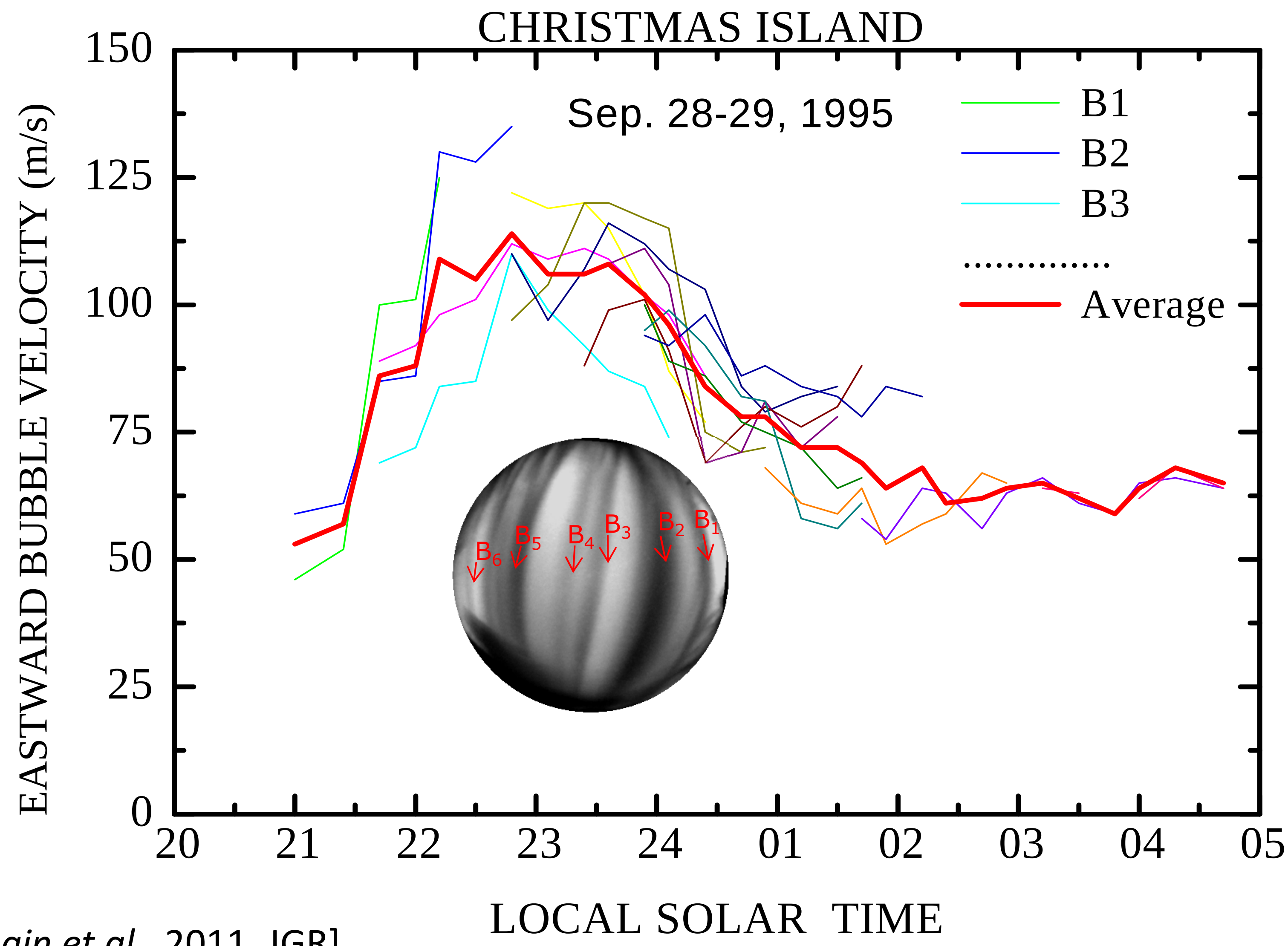
(*Mendillo,* 1982)

EPB Drift Velocity

- Images projected onto geographic coordinates at altitude of 250 km
- Intensity cut through the image along a line of constant magnetic latitude
  - Chosen to correspond to the magnetic latitude of the FPI pierce point used in the comparison
- Data stacked in time to get keogram plot to estimate velocity

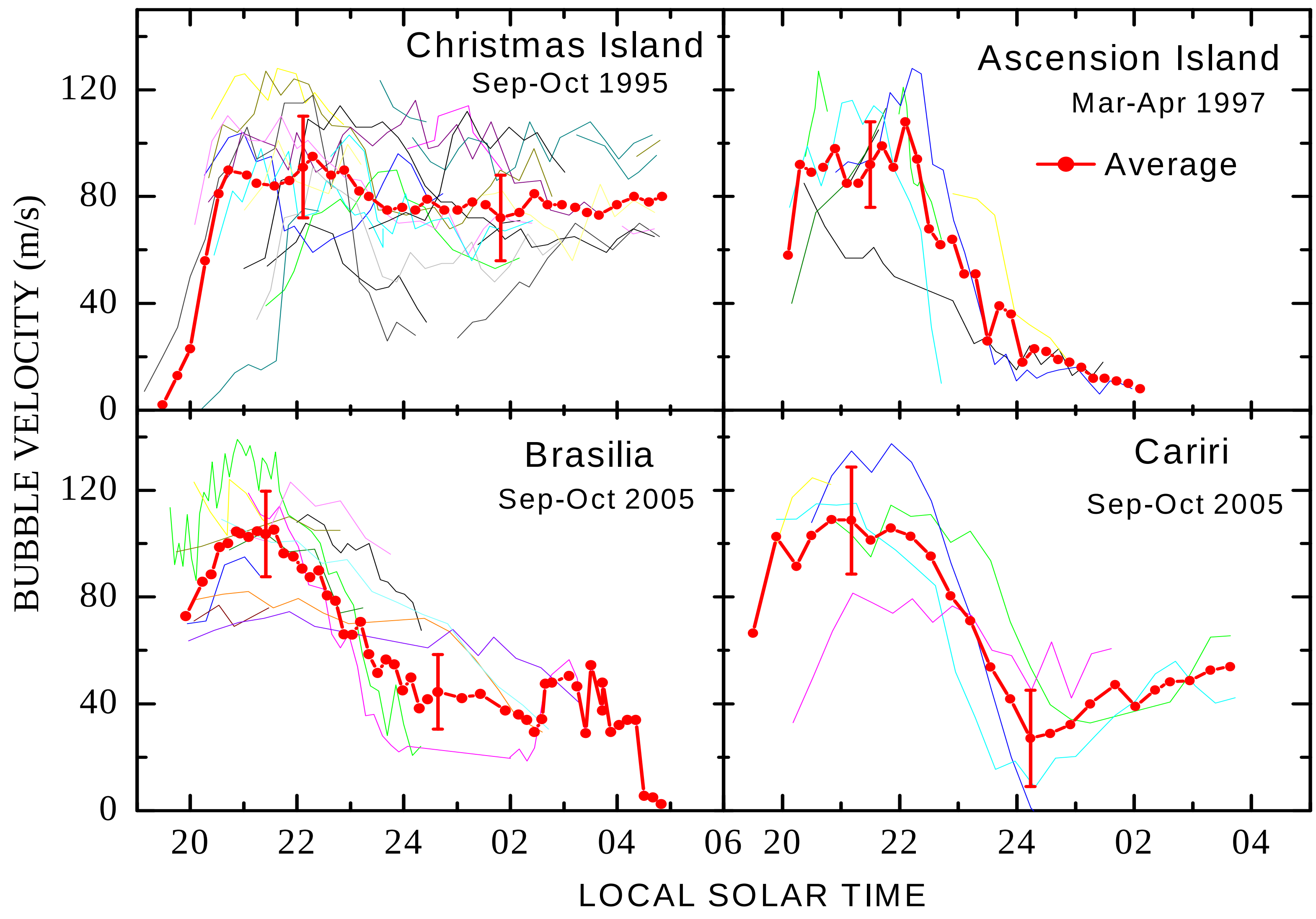


Zonal Drift Velocity of Plasma Bubbles

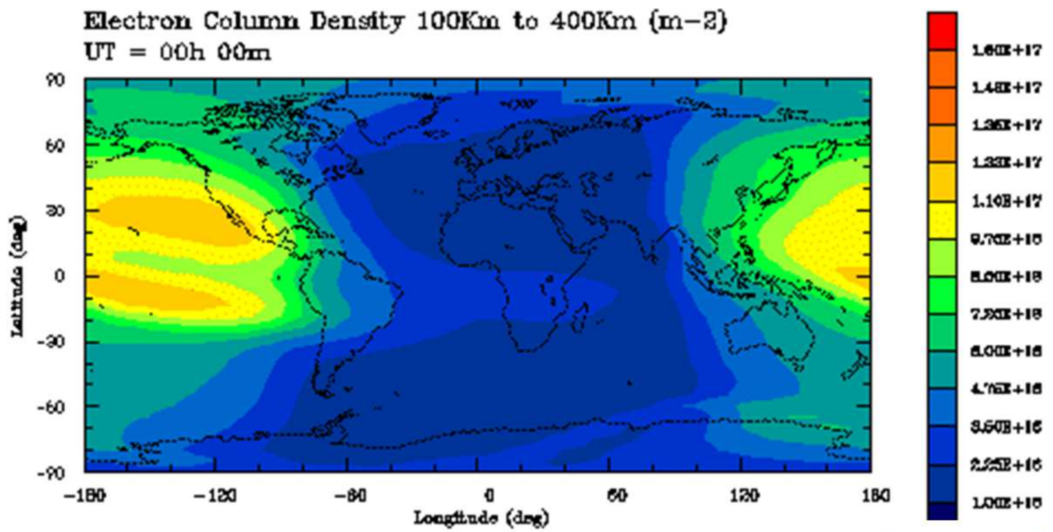


[*Chapagain et al.*, 2011, JGR]

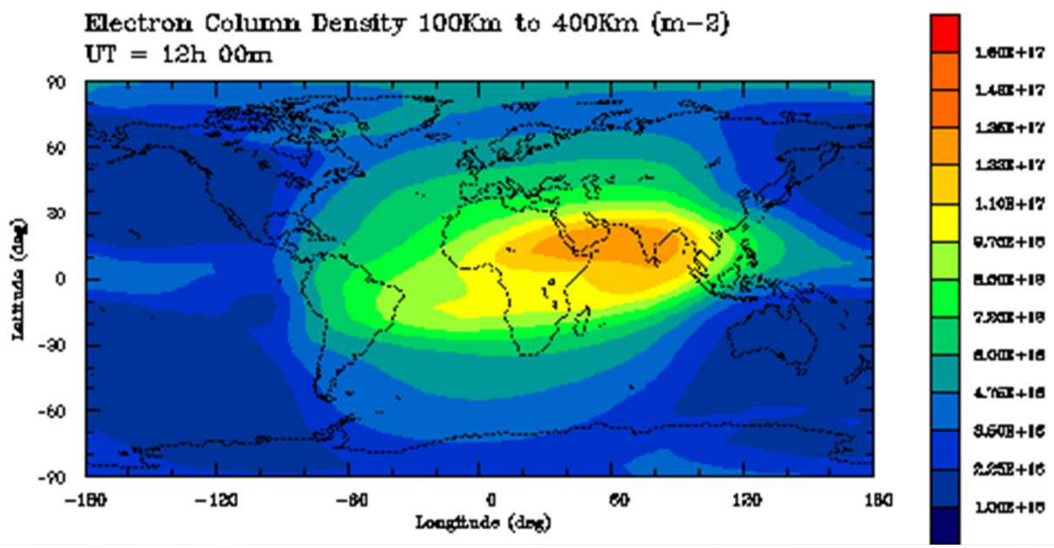
Comparison of EPB Velocities from different sites



Ionosphere Total Electron Content: Quiet Vs. Disturbed Conditions

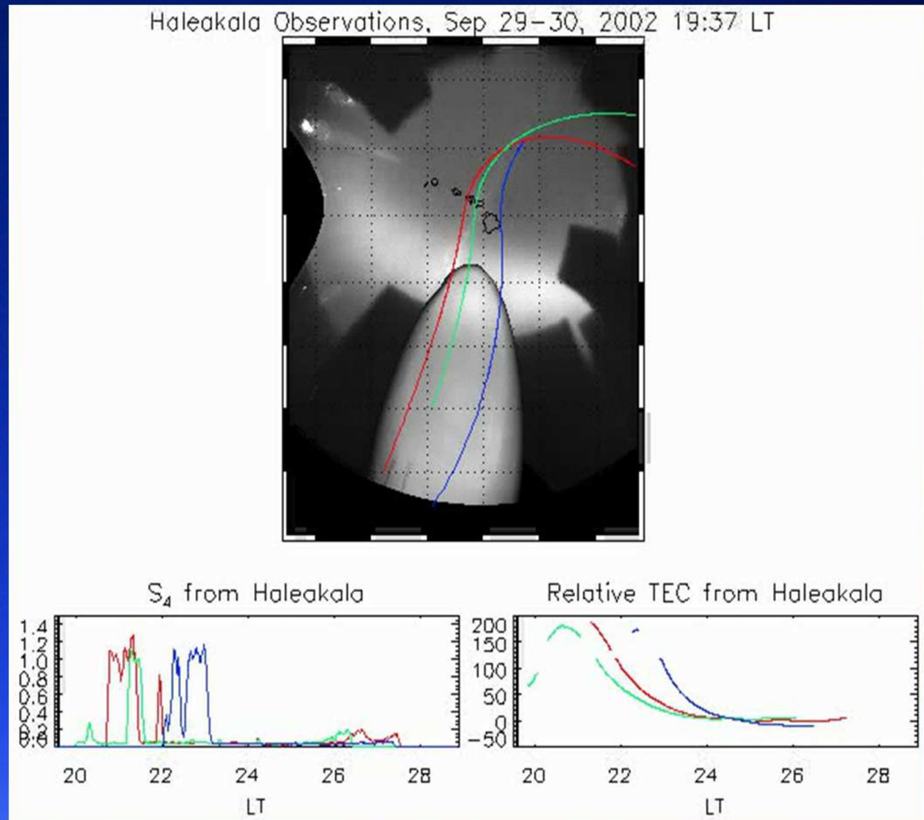


Ionospheric Storm UT = 12h 00m



Courtesy: Chau, JRO, Peru

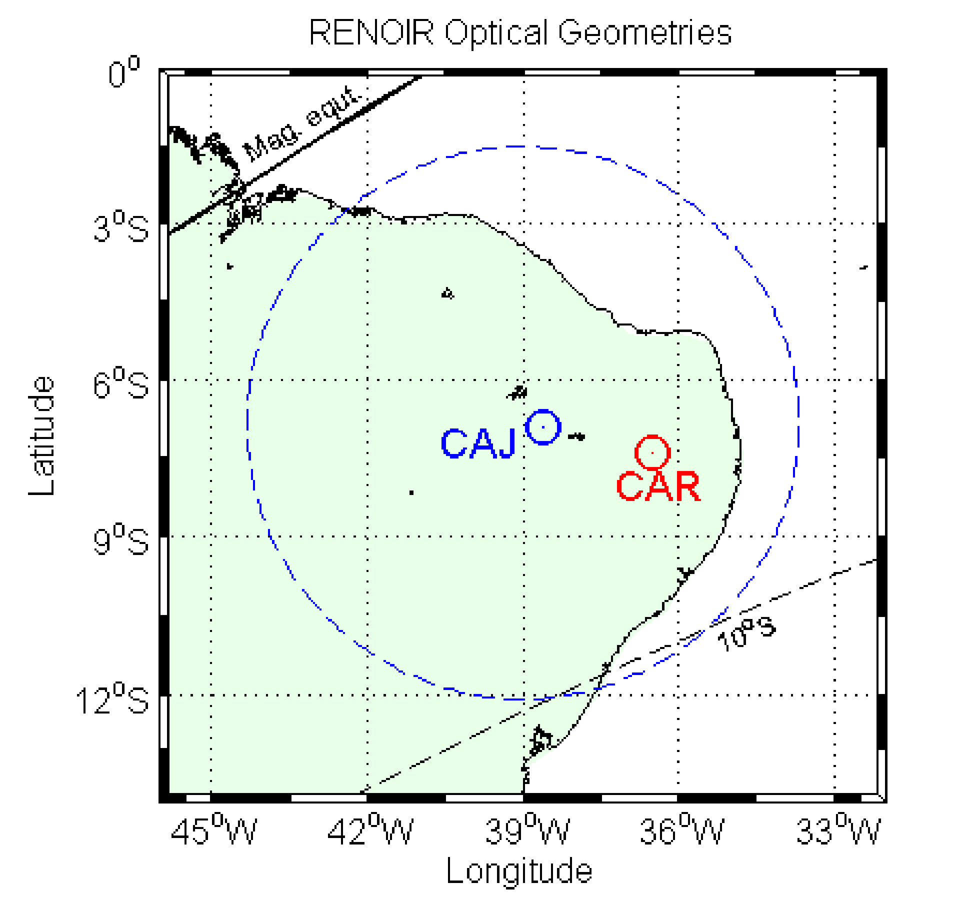
GPS – Scintillations, Total Electron Content



Thermosphere-Ionosphere Coupling (Electrodynamics)

- Simultaneous measurements EPBs drifts and Neutral winds from two sites in Brazil

- Investigate the **F-region dynamo** by comparing zonal neutral winds and EPB speeds



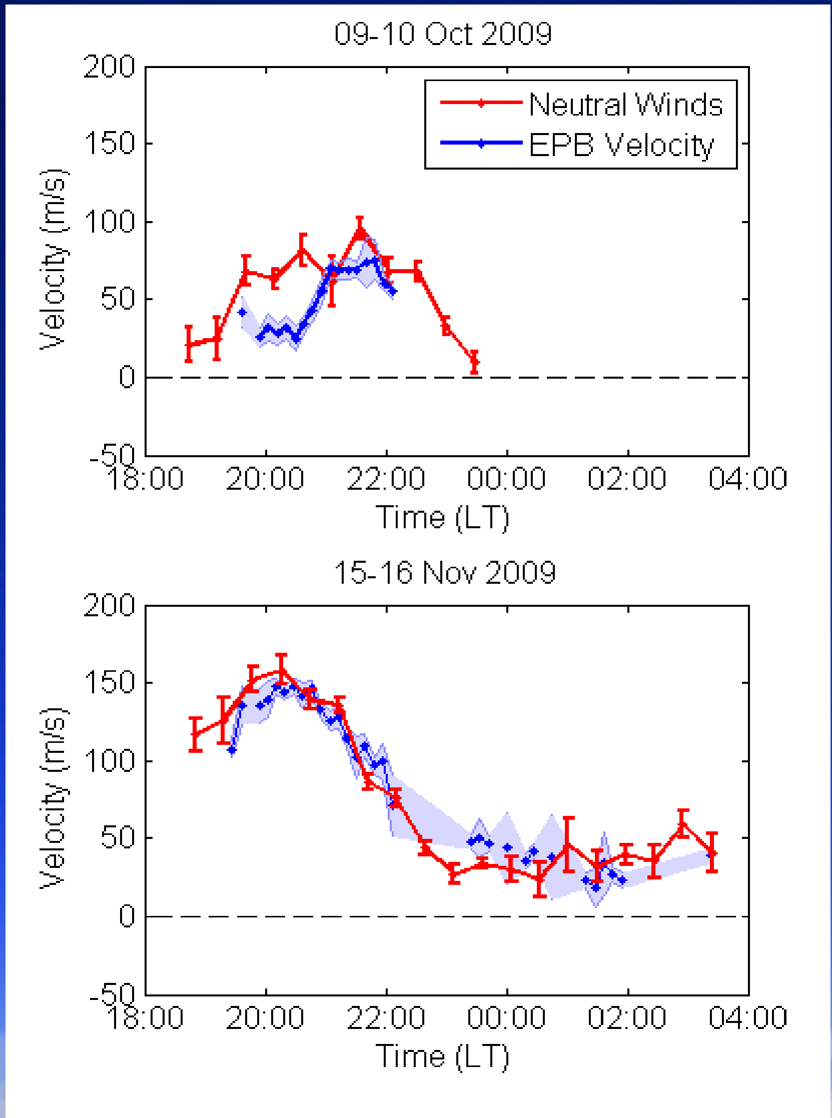
Database: Brazil

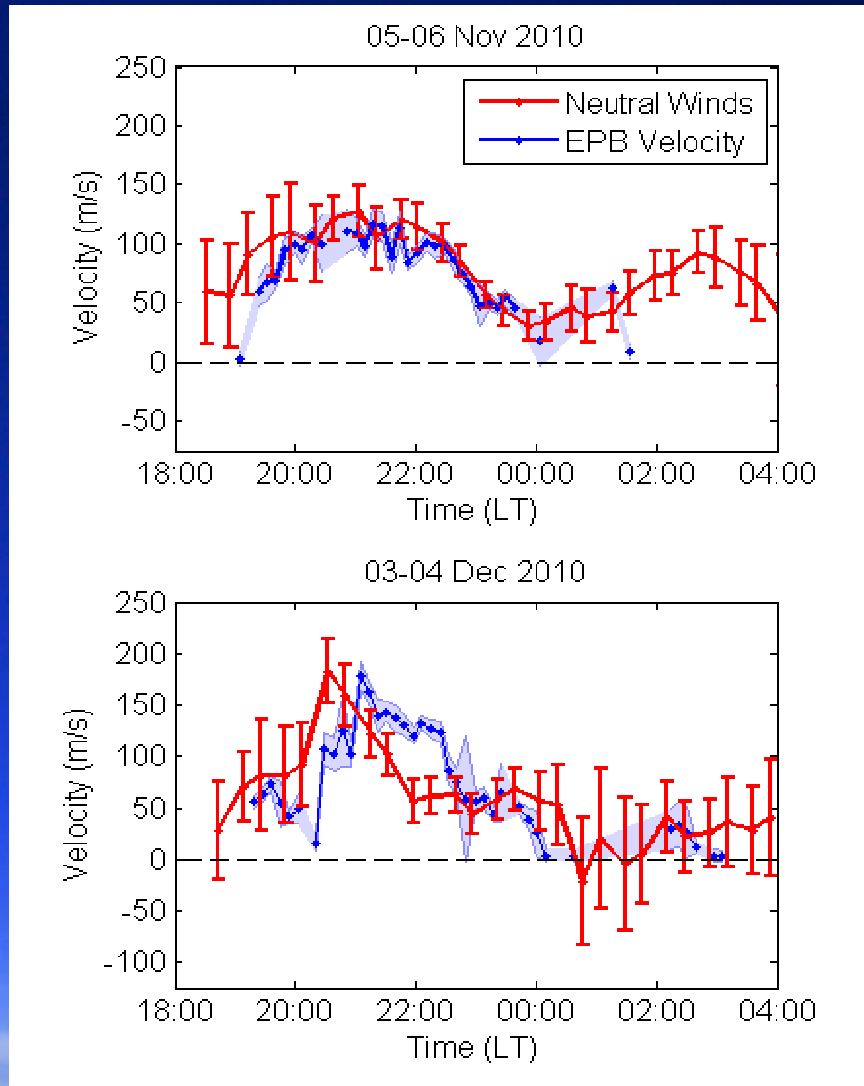
Geomagnetically quiet and solar minimum (Kp<3, 65 <$F_{10.7}$<80)

Month	EPB	EPB-Wind
Oct 2009	16	14
Nov 2009	16	10
Dec 2009	10	9
Nov 2010	18	17
Dec 2010	8	7
Total	70	57

Comparison of Winds and EPB Velocities

Brazil

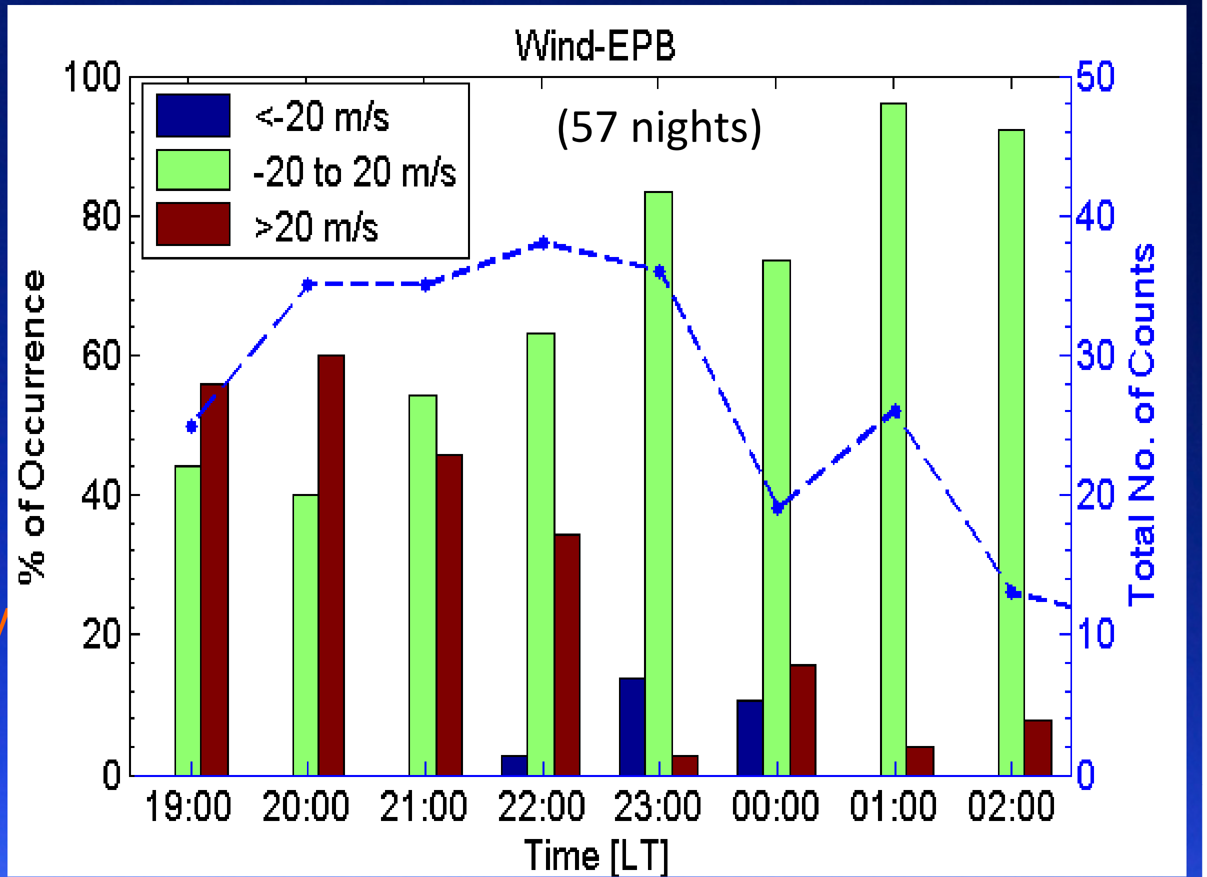




Chapagain et al. (201), JGR

Differences in Winds and EPB Velocities

- Wind≅EPB (40-95%)
  - Excellent agreement after ~23:00 LT
  - F-region dynamo fully developed.



- Wind>EPB (2-60%)
  - Early evening discrepancy
  - F-region dynamo not fully activated.
- Wind<EPB (22:00-00:00 LT)

Chapagain et al. (2012), JGR

Summary

- The Space Weather of the low-latitude ionosphere is also affected during solar/magnetospheric events, BUT … most Space Weather events are not influenced, at least directly, by the Sun/Magnetosphere activity.
- The F-region dynamo is not fully activated in early evening hour, but fully developed around midnight and post midnight hours that reveals the important facts on the development of early night EPBs.
- Understanding the Ionosphere-Atmosphere coupling (Electrodynamics) is important to improve the predictability efforts of most low-latitude Space Weather Events, including EPB/ESF
- Day-to-day variability of F region irregularities/EPBs, important for communications/navigation systems, is not yet understood and challenging measurements are needed to do so.

So….

Extensively monitoring the ionospheric variability and finding its seeding mechanics could be the most important investigations for Low-latitude Space Weather Forecasting

Research Status in Space Physics in Nepal

Space and Atmospheric Research Laboratory (SARL) , PMC, TU

Dr. Narayan P Chapagain – Associate Professor, TU, Kathmandu

Dr. Binod Adhikari (PhD, Brazil)– Postdoctoral Research Associate

Two PhD students & 14 MSc Students

Research Field of Interest

Ionosphere/Thermosphere, Magnetosphere, Atmospheric Physics

Collaboration :

- Utah State University, Logan, UT, USA
- Jicamarca Radar Observatory, Peru
- Proposed Project: Optical Imaging System (UVU, USA)

  GPS/GNSS, Ionosonde and Magnetometer


Thank you