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The Ionosphere: Basic Characteristics and Low-Latitude Structure

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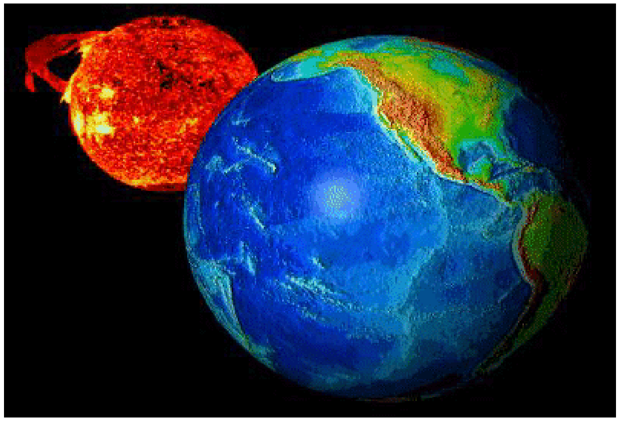
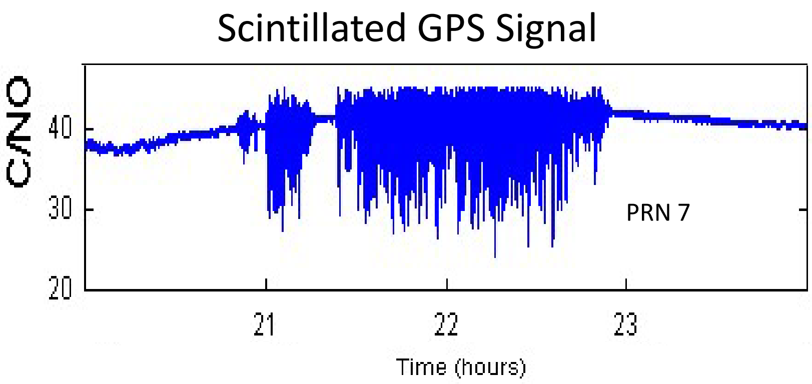
ICTP

Outline

- The importance of the ionosphere for systems depending on radio signals
- The atmospheric system
- Formation of the ionosphere
- Ionospheric variability
- Ionospheric irregularities & scintillations





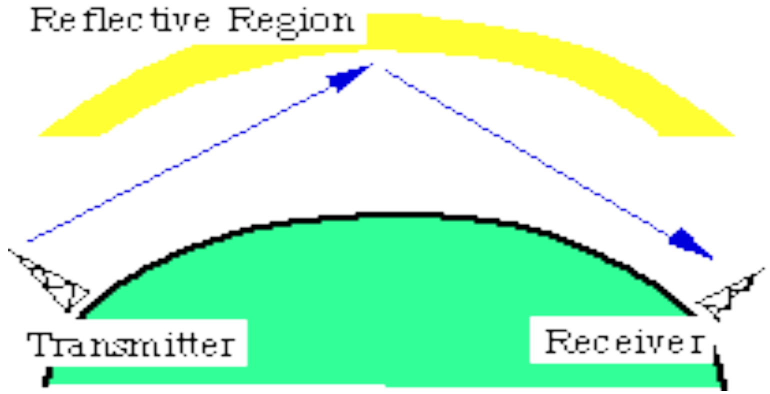
The importance of the Ionosphere for systems depending on radio signals

The beginning

- In 1864 James Clerk Maxwell published a theory of electromagnetic waves.
- In 1899 Guglielmo Marconi invented the first practical radio telegraph system sending signals across the English Channel.
- In 1901 he demonstrated transatlantic radio communications. He was awarded the Noble Prize in Physics in 1909.

The question raised by Marconi's experiment

- How can the radio signals reach a distant receiver if radio waves should travel along straight lines?
- In 1902 Oliver Heaviside and Arthur Kennely came out with the explanation:



Implications to the radio communications (1)

For the most of the 20 century radio communications relied on HF frequencies (3-30 MHz) that used the ionosphere as reflector.

The applications included:

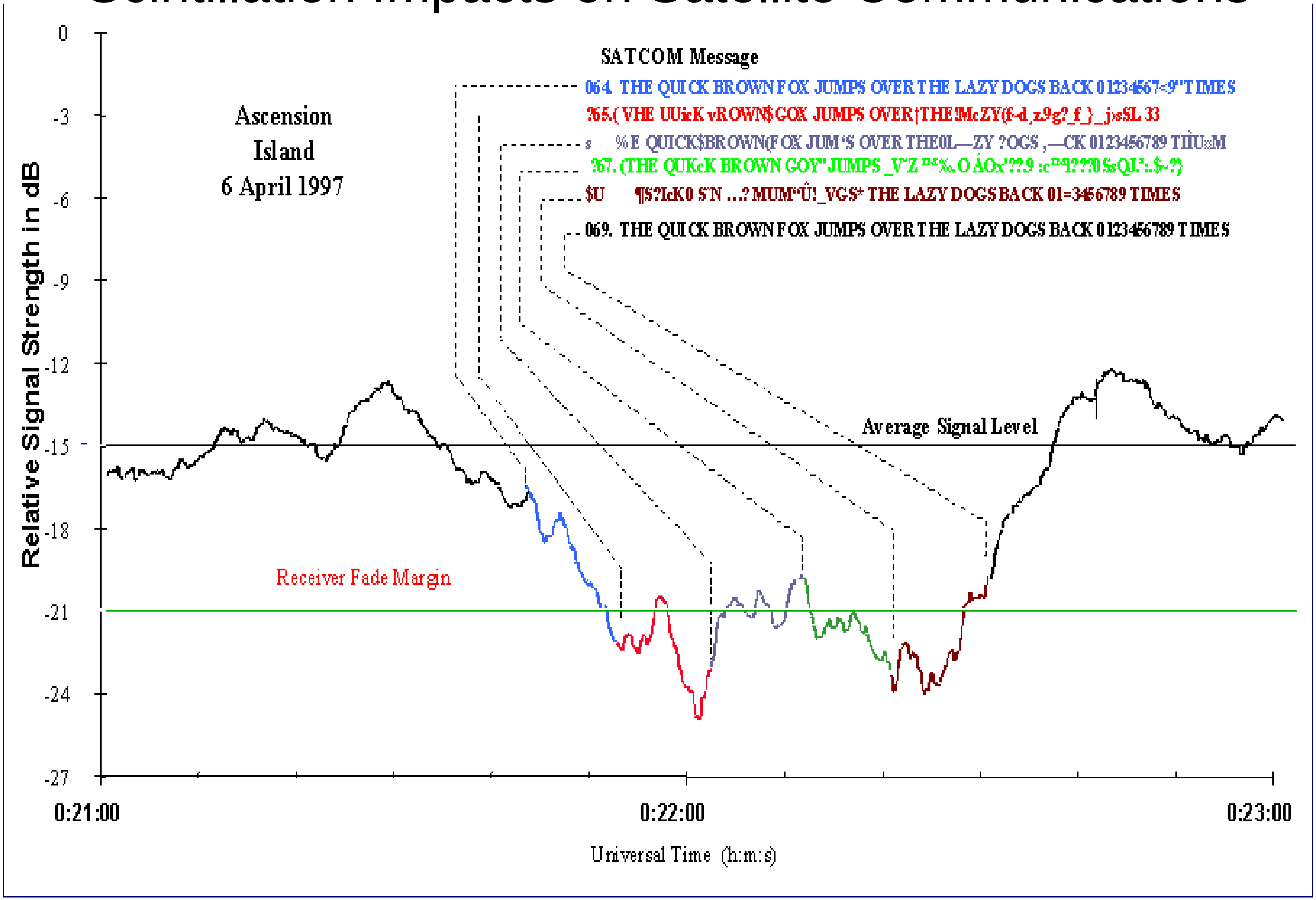
- Radio Broadcasting
- Civilian point-to-point communications
- Military communications and surveillance
- Ship-to-shore communications
- Trans-oceanic aircraft links
- Jamming

Implications to the radio communications (2)

In the 21 century:

The applications are mostly related to trans-ionospheric radio links including civilian and military satellite communications and satellite navigation systems.

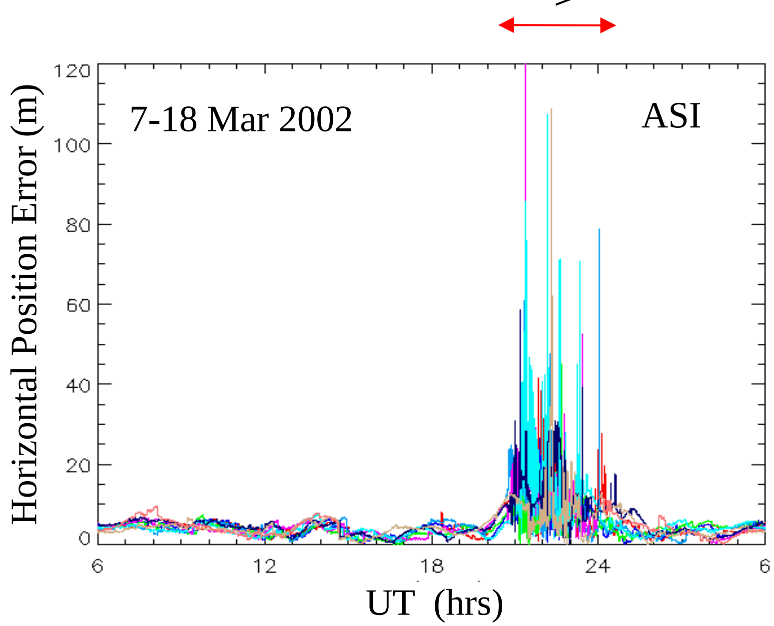
Scintillation Impacts on Satellite Communications



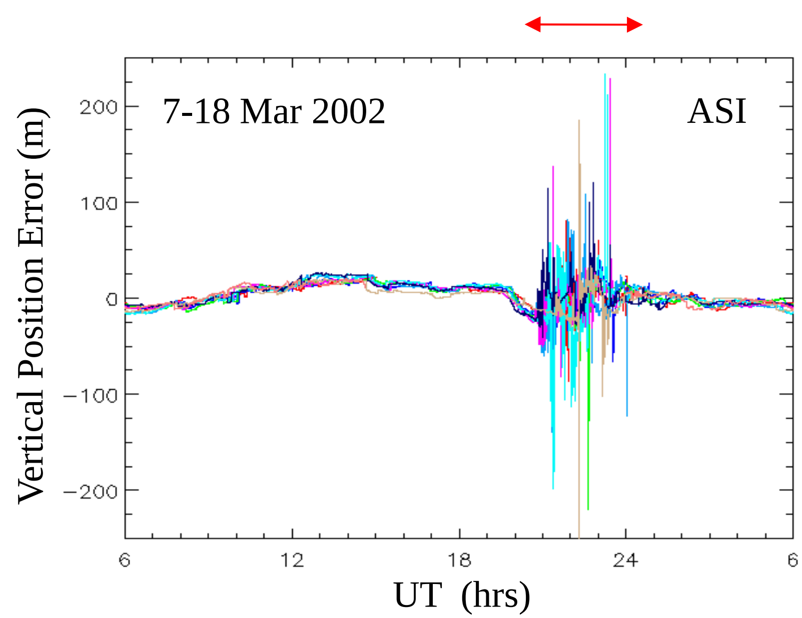
Representative GPS Positioning Errors from Scintillation Near Solar Maximum

Position from dual frequency receiver

Active Ionosphere
21:00-23:30 UT



Horizontal Errors >100 m



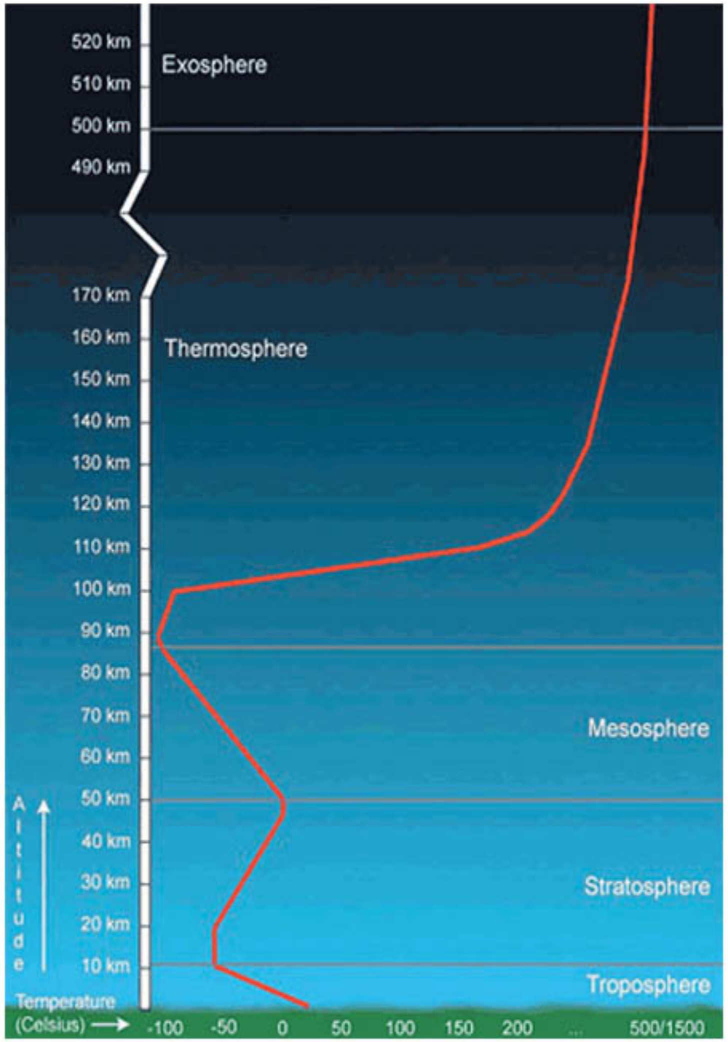
Vertical Errors > +/- 200 m

The atmospheric system

The study of the atmospheric system: a word of warning

- **The atmospheric system is not normally studied as a *system* but taking only into account one particular element of the system as its temperature or ionization.**
- ***This approach reduces the possibilities of a full understanding of the atmospheric system behavior as a whole*.**

Atmospheric structure: temperature



The *termal structure* is described as a number of layers (-spheres) separated by -pauses which are defined as the inflection points in the temperature profile.

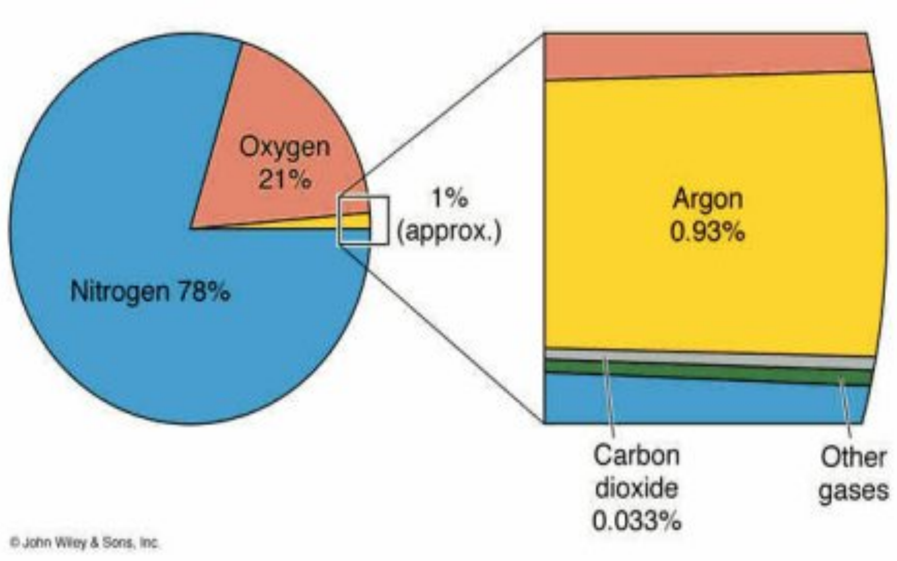
As an example: the *tropopause* defines the top of the troposphere where the temperature gradient turns over from negative to positive.

Why this thermal structure ?

- **The *troposphere* is heated mainly by the ground, which absorbs solar radiation and re-emits it in the infra-red.**
- **The *stratosphere* above the troposphere has a positive temperature gradient due to heating from the *ozone* which absorbs the solar ultra-violet radiation that penetrates down to these altitudes.**
- **In the *mesosphere*, above 50 km, the density of ozone drops off faster than the increase in incoming radiation can compensate for and the temperature decreases with altitude.**
- **The *thermosphere* is heated mainly by absorption of EUV and XUV radiation through dissociation of molecular oxygen.**

Atmospheric composition: ground level

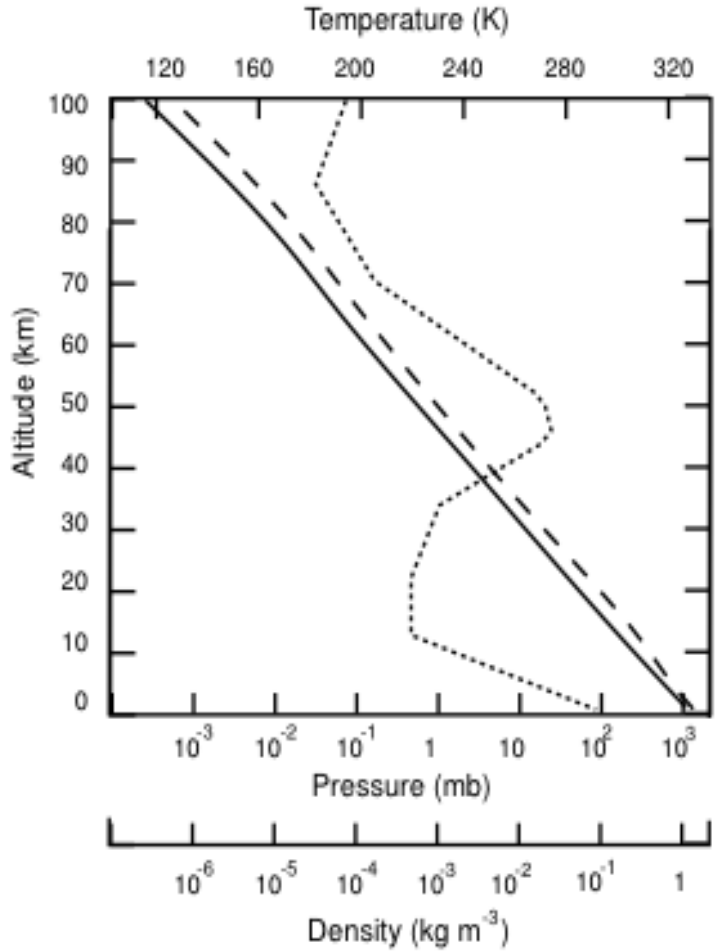
- **By mass**
  - **Nitrogen: ~ 76%**
  - **Oxygen: ~ 23 %**
  - **Argon: ~ 1%**
- **By volume**
  - **Nitrogen: ~78%**
  - **Oxygen: ~21%**
  - **Argon: ~1%**



Atmospheric composition as a function of height

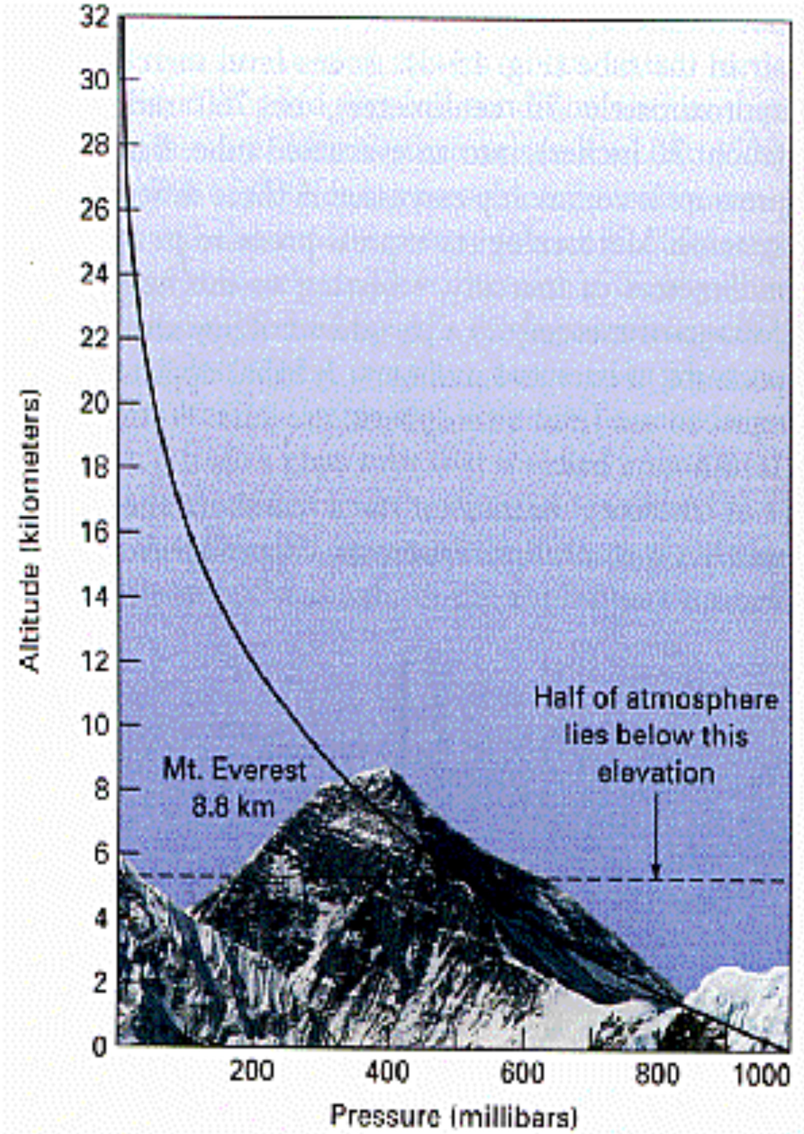
Mixing and molecular diffusion:

- **Turbulent mixing: *lower and middle atmosphere***
  - **Does not depend on molecular weight.**
  - **Composition tends to be independent o height**
- **Diffusion: *upper atmosphere***
  - **Mean molecular weight of mixture gradually decreases with height.**
  - **Only lightest gases are present at highei levels.**
  - **Each gas behaves as if it were alone.**
  - ***Density drops-of exponentially with height***

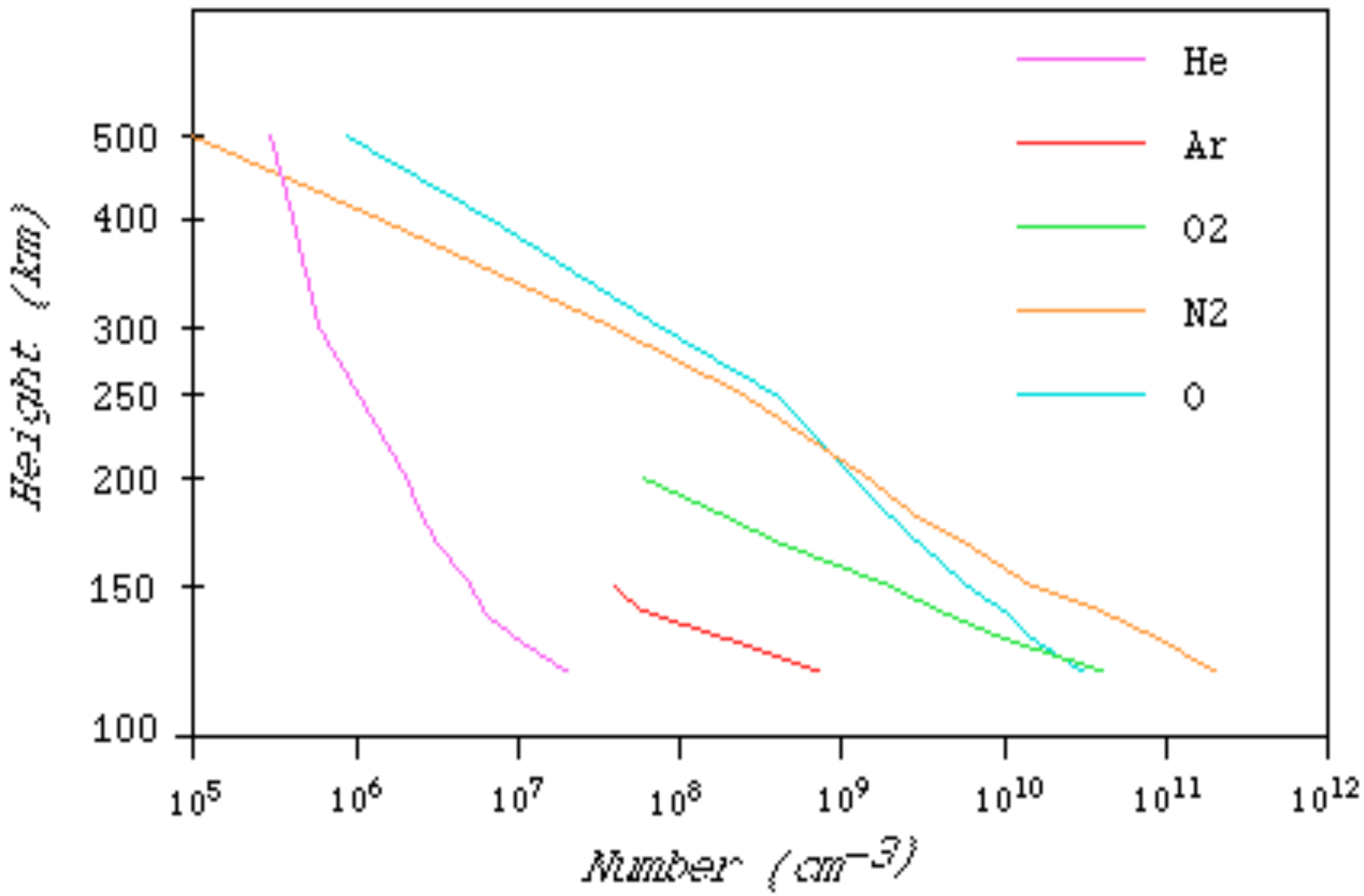


Near 100km: diffusion = turbulent mixing.

A closer look to the atmospheric pressure



Neutral atmosphere composition in the upper atmosphere



Atmospheric Hydrostatic Equilibrium

Pressure Gradient: $$\frac{dp}{dz} = -g(z)\rho$$ height derivative of pressure equals acceleration of gravity times density

Perfect Gas Law: $$p = nkT = \frac{\rho}{M}kT$$

Approximation: If g and T are not functions of z, then:

$$\frac{dp}{dz} = -p\frac{Mg}{kT} = -\frac{p}{H} \qquad H = \frac{kT}{Mg}$$

H = scale height (e-folding distance)

$$\frac{dp}{p} = -\frac{dz}{H} \qquad p(z) = p(z_0)\exp\left[-\frac{z - z_0}{H}\right]$$

Scale Height

In various scientific contexts, a "Scale Height" is a distance over which a quantity decreases by a factor of *e*.

The "scale height" defined in the previous slide is the "*pressure scale height*" that, considering the perfect gas law and the troposphere composed mostly by N_2 (m=2 x 14 x 1.66x10^{-27} kg):

$m = 4.65 \times 10^{-26}$ kg
$g = 9.8$ m/s^2
and
T ~ 300 K,
we get:

$$H = 9 \times 10^3 \ \underline{m} = 9 \ km$$

Formation of the ionosphere

Photochemical processes in the atmosphere

- **The atmosphere of the Earth is made up of a large number of chemical constituents.**
- **We have seen that the most abundant or major constituents are N_2, O_2 and Ar, but many more constituents are produced in the atmosphere itself by *photochemical processes* or at the surface by different natural processes and human activity.**
- ***Photochemical processes play a fundamental role in the middle and upper atmosphere including the ionosphere.***

Main photochemical absorption processes of solar radiation

Photodissociation **$AB + h\nu \rightarrow A + B$**

(wavelenght > 130 nm)

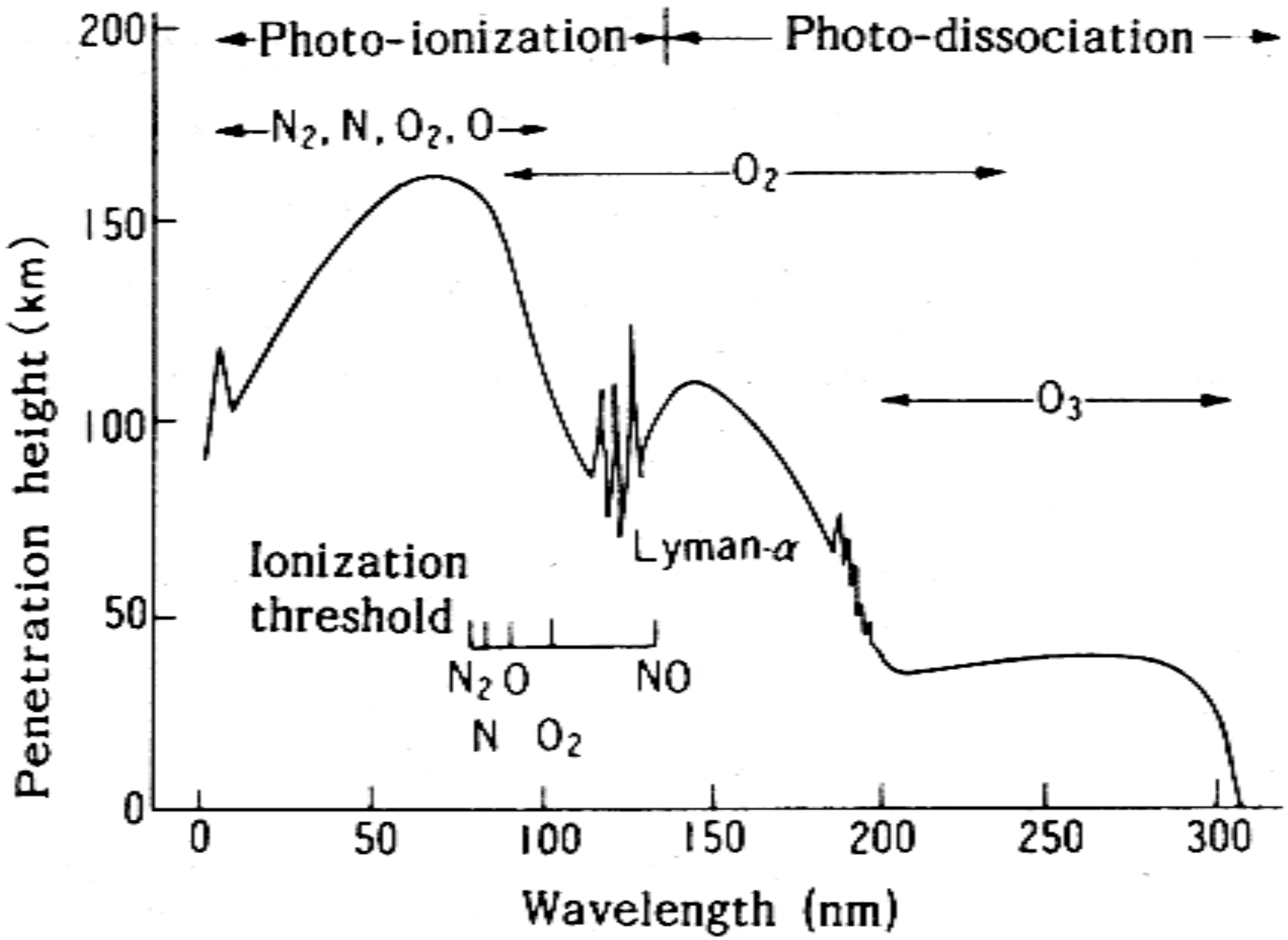
Photoexcitation **$AB + h\nu \rightarrow AB^*$**

(wavelenght < 130 nm)

Photoionization **$A + h\nu \rightarrow A^+ + e$**

(wavelenght < 100 nm)

Solar radiation penetration heights



Ionic species recombination processes

Radiative recombination $X^+ + e \xrightarrow{\alpha_R} X + Y$

Dissociative recombination $XY^+ + e \underset{\alpha_i}{\overset{\alpha_D}{\longrightarrow}} X + Y$

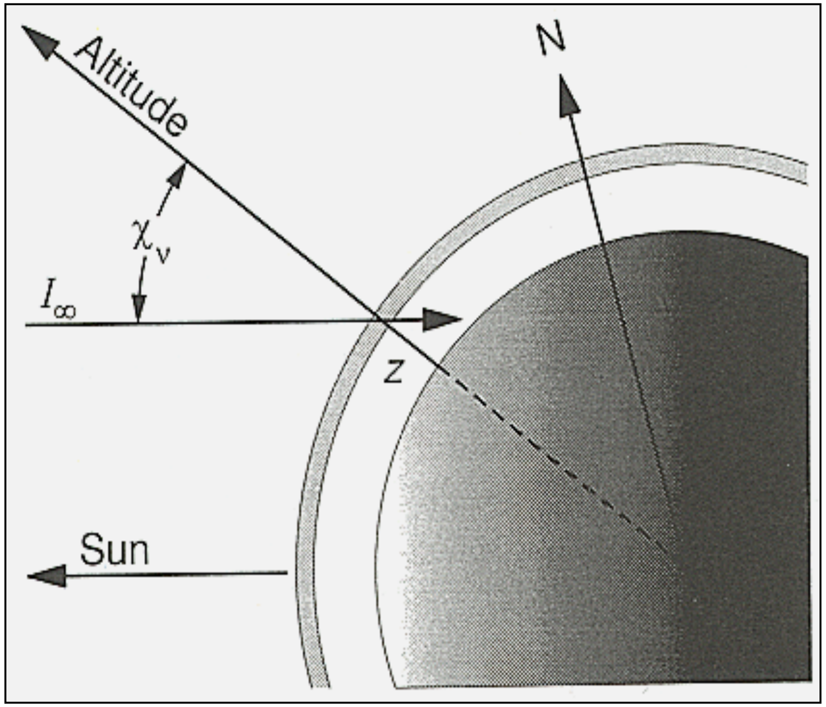
Ion-Ion recombination $XY^+ + Z^- \longrightarrow$ **neutrals**

Formation of the Ionosphere

Solar UV and X radiation impinges at angle χ_v,

It is absorbed in the upper atmosphere and ionizes the neutral atmosphere

I_∞ is the flux on top of the layer.



Basic equations of solar radiation absorption in the atmosphere (1)

H **is the scale height,**

$H = k_B T_n / m_n g$,

with *g* being the gravitational acceleration at height $z = 0$, where the density is n_0.

$$n_n(z) = n_0 \exp(-z/H)$$

According to radiative transfer theory, the incident solar radiation diminishes with altitude along the ray path in the atmosphere.

$$dI = \sigma_\nu n_n \frac{dz}{\cos \chi_\nu} I$$

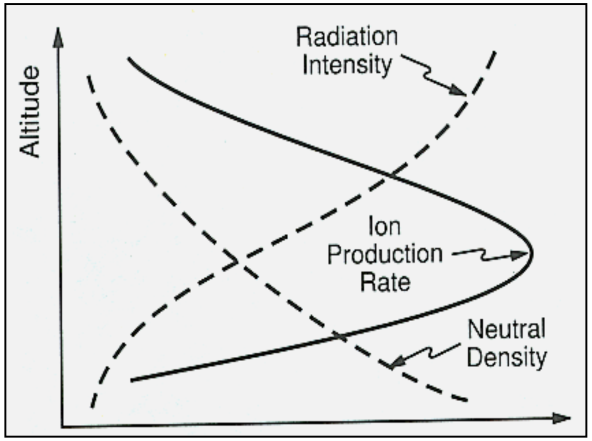
σ_ν **is the radiation absorption cross section for radiation (photon) of frequency ν.**

Basic equations of solar radiation absorption in the atmosphere (2)

Solving for the intensity yields:

$$I(z) = I_\infty \exp\left[-\frac{\sigma_\nu n_0 H}{\cos\chi_\nu}\exp(-z/H)\right]$$

The figure shows the exponential decrease of the intensity with height, the decrease of neutral density and the resulting ion production given analitically by the next equation



Basic equations of solar radiation absorption in the atmosphere (3)

$$q_\nu(z) = \kappa_\nu \sigma_\nu n_0 I_\infty \exp\left[-\frac{z}{H} - \frac{\sigma_\nu n_0 H}{\cos\chi_\nu}\exp(-z/H)\right]$$

The number of electron-ion pairs locally produced by the solar radiation, the photoionization rate per unit volume $q_\nu(z)$, is proportional to the ionization efficiency, κ_ν, and absorbed radiation: $q_\nu(z) = \kappa_\nu \sigma_\nu n_n I(z)$.

This equation describes the formation of the Chapman layer and represents the basis of the theory of the photochemical processes in the atmosphere.

Basic equations of solar radiation absorption in the atmosphere (4)

Recombination, with coefficient α_r, and electron attachment, β_r, are the two major loss processes of electrons in the ionosphere.

In equilibrium quasi-neutrality applies:

$n_e = n_i$

Then the continuity equation for n_e reads:

$$\frac{dn_e}{dt} = q_{\nu,e} - \alpha_r n_e^2 - \beta_r n_e$$

Chapman layer theory

***A theoretical distribution of ionization as a function of height produced solely by the absorption of solar radiation by a single atmospheric constituent*.**

Named for Sydney Chapman, who first derived the shape of such a distribution mathematically.

Some of the basic assumptions used to develop the equation were that

- ***The ionizing radiation from the sun is monocromatic,***
- ***The single neutral constituent to be ionized is distributed exponentially (i.e., with a constant scale height),***
- ***There is equilibrium between the creation of free electrons and their loss by recombination.***

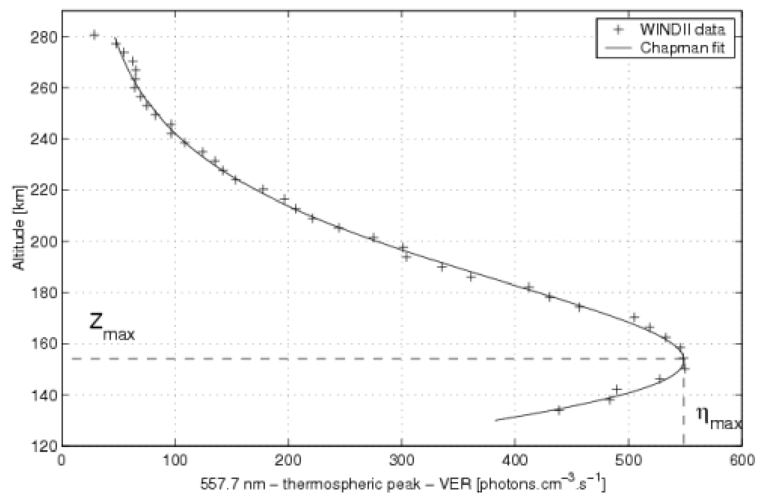
Chapman Layer Model

Chapman showed that the electron density of the resulting ionized layer can be expressed as:

$$N_e(h) = N_{max}e^{\{0.5(1-z-e^{-z})\}}$$

where $z = \left(\frac{h-h_{max}}{H}\right)$, and H = scale height

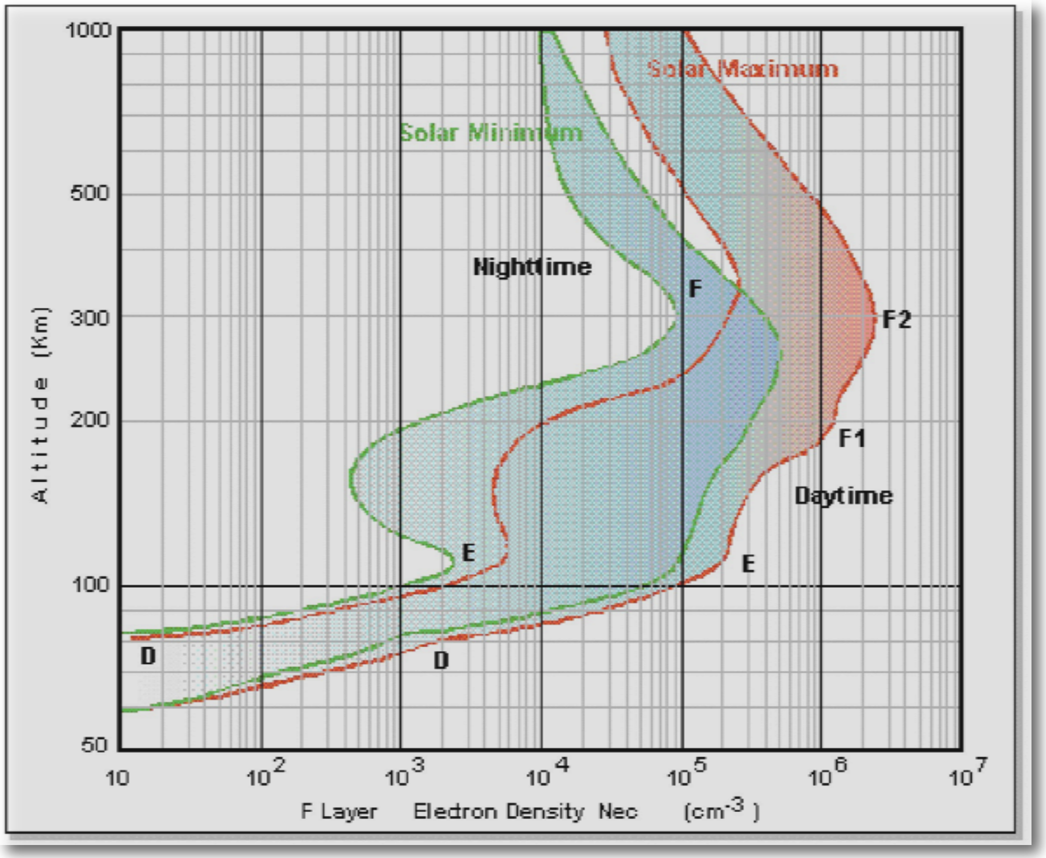
This provides a simple analytical expression to represent a layer in the ionosphere; used in models and data comparisons



Ionospheric structure

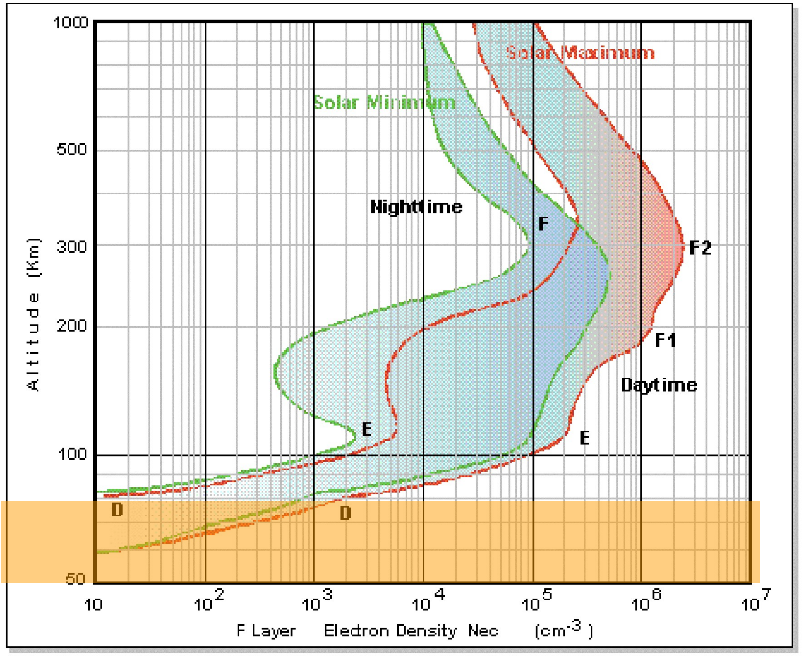
A layered structure

Due to *different ionization production and loss processes* the electron density profile with altitude shows a layered structure.



D region

- D-region (about 60 to 90 km altitude)
  Production: daytime ionization of nitric oxide (NO) by solar Lyman alpha (121 nanometer wavelength) and of nitrogen and oxygen (N2, O2) by solar X-rays (less than 20 nm). Molecular ions react with water vapor to produce water cluster ions.
  Loss: electrons recombine rapidly with water cluster ions and also attach to molecules to make negative ions (but rapidly detach again in daylight).
  Balance: layer disappears at night (within several minutes) as production essentially ceases and electrons undergo rapid recombination and attachment.



E region

- E-region (about 90 to 140 km altitude)

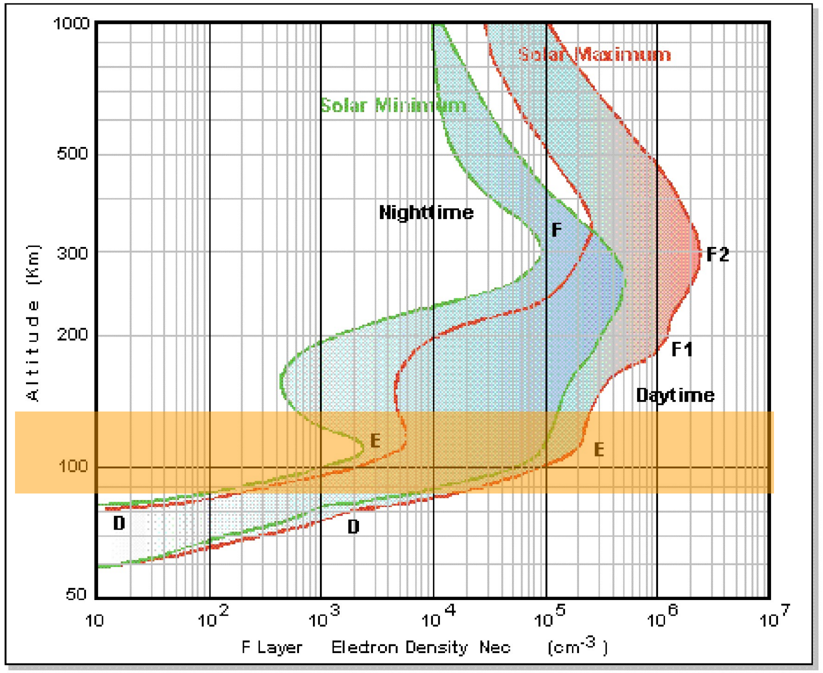
  Production: daytime ionization of molecular oxygen (O2) by extreme ultraviolet solar radiation (90-103 nm), ionization of meteoric vapors.

  Loss: electrons recombine with molecular ions (O2+ and NO+).

  Balance: layer persists, although diminishes, during night due to slower recombination (than in D-region) and presence of atomic metallic ions such as Na+ (sodium) and Fe+ (iron). Electrons recombine with atomic ions (such as Na+ or O+) very inefficiently.

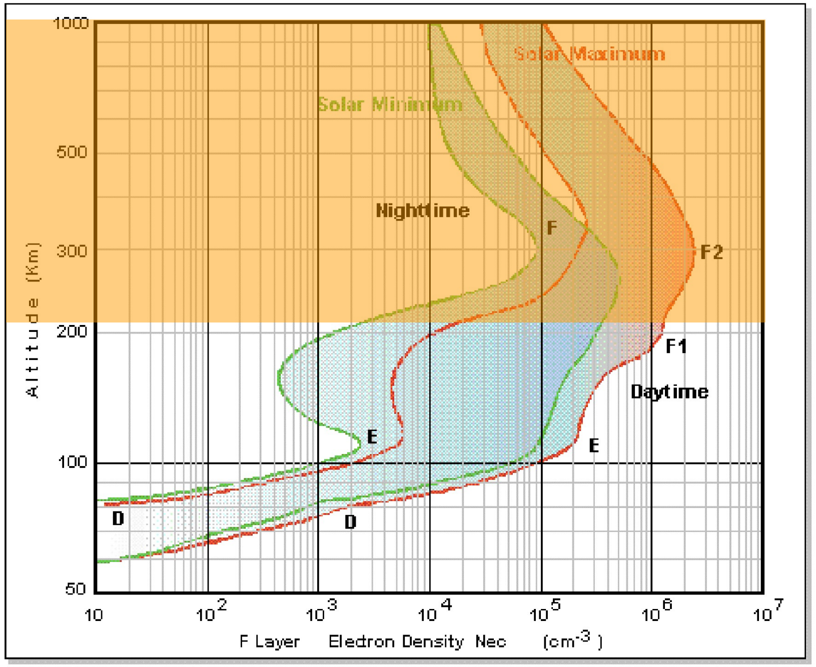
  E region behaves as a Chapman layer.

  At the E region heights sporadic thin layers can be formed that can have electron densities well above the background values.



F region

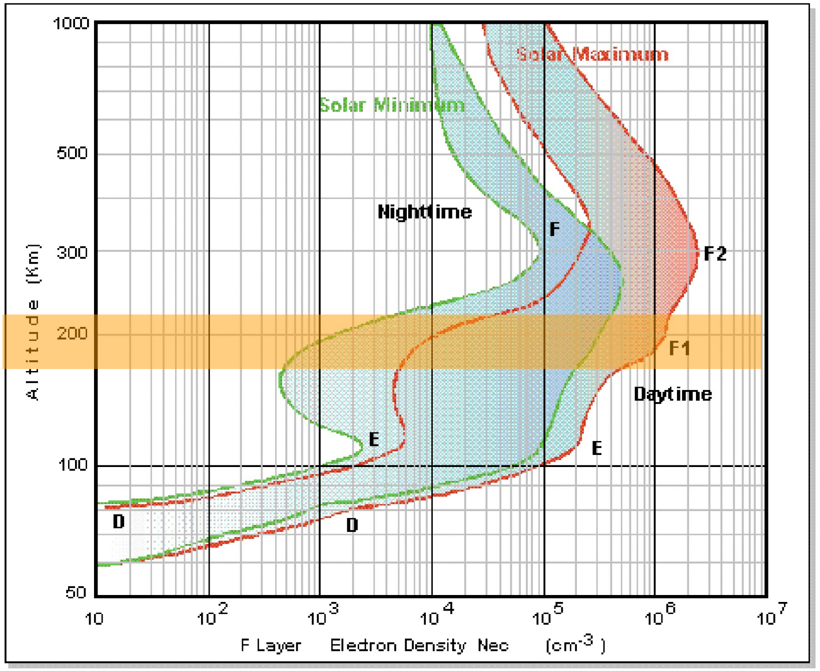
- F-region (above 140 km altitude)
  Production: daytime ionization of atomic O by extreme ultraviolet (EUV) solar radiation (20 - 90 nm). O+ converted to NO+ by molecular nitrogen (N2)



F1 layer

- F1-layer (about 140 to 200 km altitude)
  Loss: controlled by recombination of NO+ ions with electrons.
  Balance: layer diminishes at night as electrons recombine with NO+.

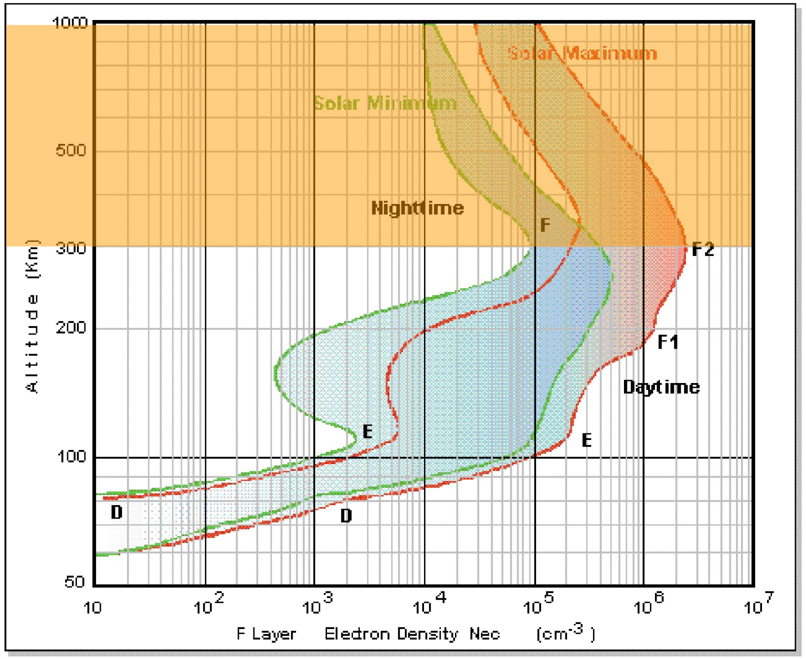
  F1 layer behaves as a Chapman layer



F2 layer

- F2-layer (peak about 300 to 400 km altitude)
  Loss: controlled by O+ reaction with molecular nitrogen (N2), electrons recombine quickly with ion product (NO+) as it is created.
  Balance: layer persists through night (becoming simply the F-region) since the small supply of N2 leads to slow conversion of O+ to NO+ and hence only a small reduction in the number of electron.

  Transport processes become important in the F2 and upper F regions, including ambipolar diffusion and wind-induced drifts along B, and and electrodynamic drifts across B.



F2 region chemistry

The recombination process is two-stage:

$O^+ + N_2 \rightarrow NO^+ + N$ (attachment like) **rate $\propto \beta\, [O^+]$**

- *controls the rate at high altitudes*

$NO^+ + e \rightarrow N + O$ **rate $\propto \alpha\, [NO^+][Ne]$**

- *controls the rate at low altitudes*

$$\frac{dn_e}{dt} = q_{\nu,e} - \alpha_r n_e^2 - \beta_r n_e$$

Continuity equation and Ion transport in the F region

Ions and electrons, once formed (P), will tend to recombine (L) but they are also affected by transport with a plasma drift V.

Ions and electrons will be influenced by the vertical pressure gradient, and the heavier ions will tend to 'settle'. But, the resultant separation will form an electric field which will tend to restore the system.

$$\frac{\partial n_e}{\partial t} = P - L - div(n_e V)$$

$$\frac{\partial n_e}{\partial t} = q - \beta n_e - div(n_e V)$$

F region in summary

- The lowest region (F1), where photochemistry dominates.
- The transition region from chemical to diffusion (lower F2).
- The upper region, or topside, where diffusion dominates
- In the F2, including the topside, the presence of transport processes influenced by the geomagnetic field became important.

Ionospheric variations

Ionospheric variations

- ***The Earth's ionosphere shows marked variations with altitude, latitude, longitude, universal time, season, solar cycle, and magnetic activity.***

- **This variation is reflected in all ionospheric properties: electron density, ion and electron temperatures, and ionospheric composition and dynamics.**

- **This is primarily a result of the ionosphere's coupling to the other regions in the solar-terrestrial system: the sun, the interplanetary medium, the magnetosphere, the thermosphere, and the mesosphere**

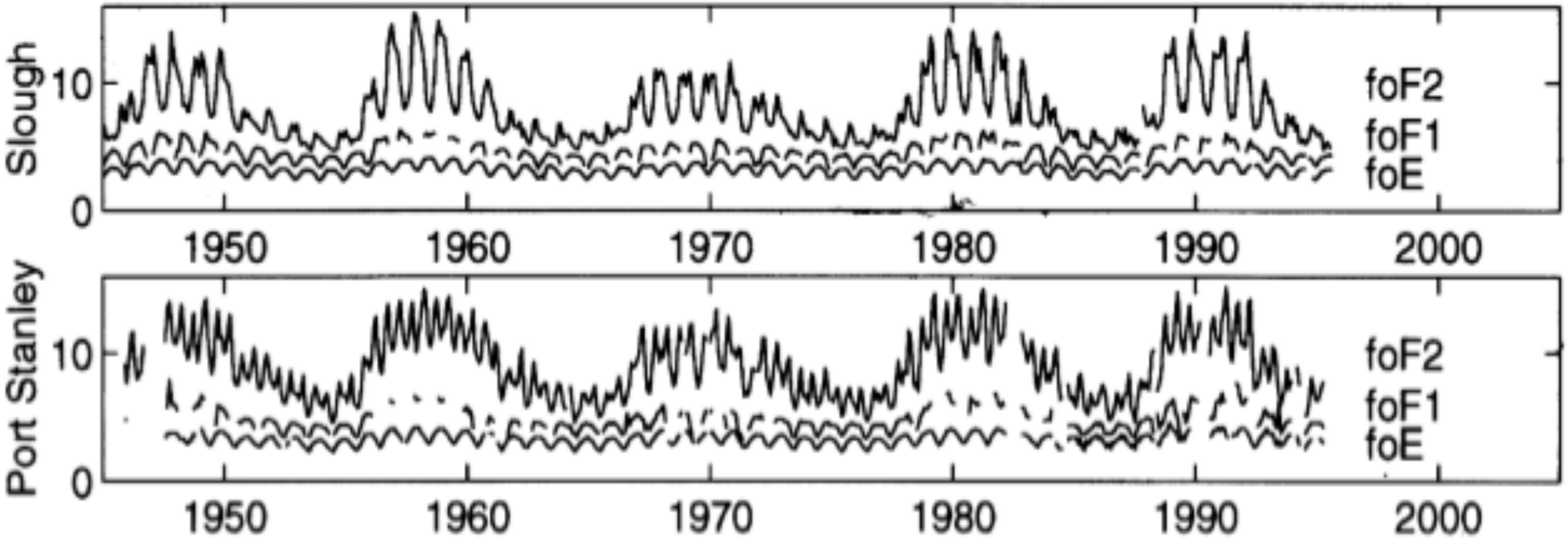
- **Variations are of two general types:**

  – **(1) *(more or less) regular*, occurring in cycles and that can be predicted in advance with reasonable accuracy (*quiet ionosphere*)**

  – **(2) *irregular*, mostly due to the irregular behavior of the sun and that cannot be easily predicted in advance (*disturbed ionosphere*)**

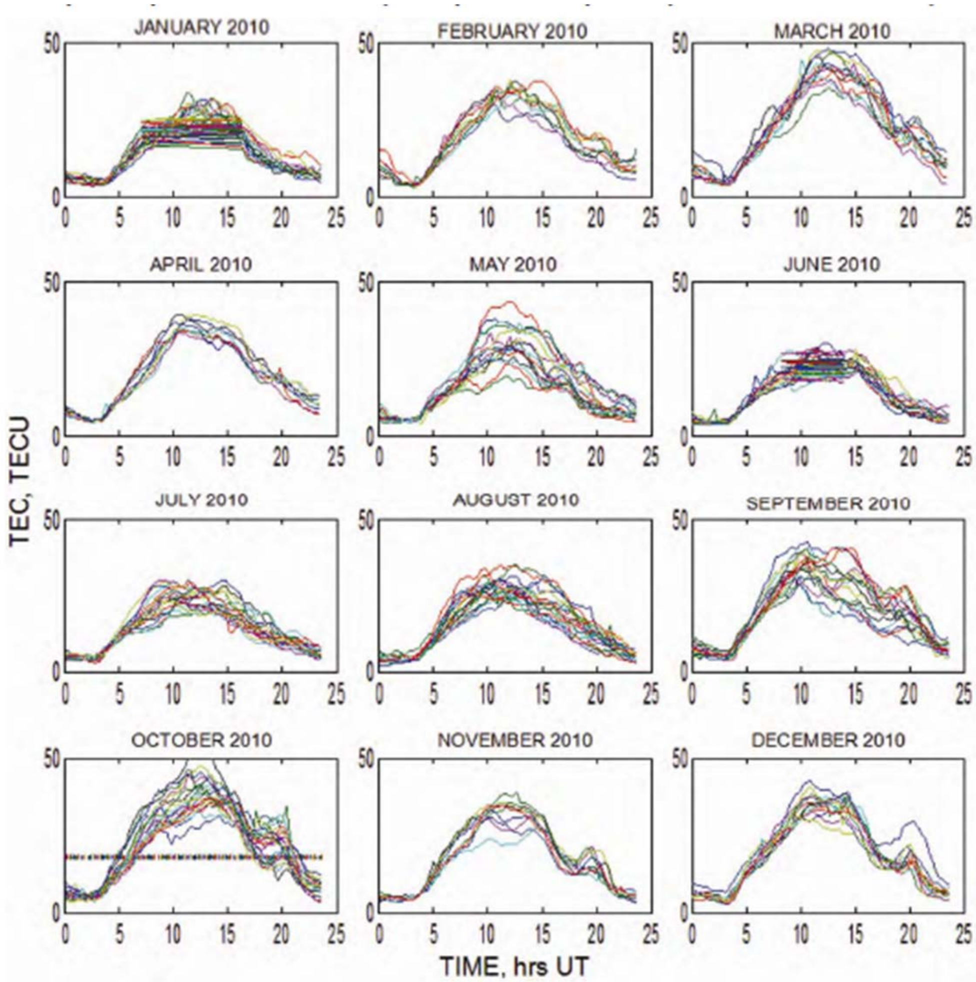
Both regular and irregular variations have important effects on radio wave propagation.

Ionospheric median critical frequencies variations



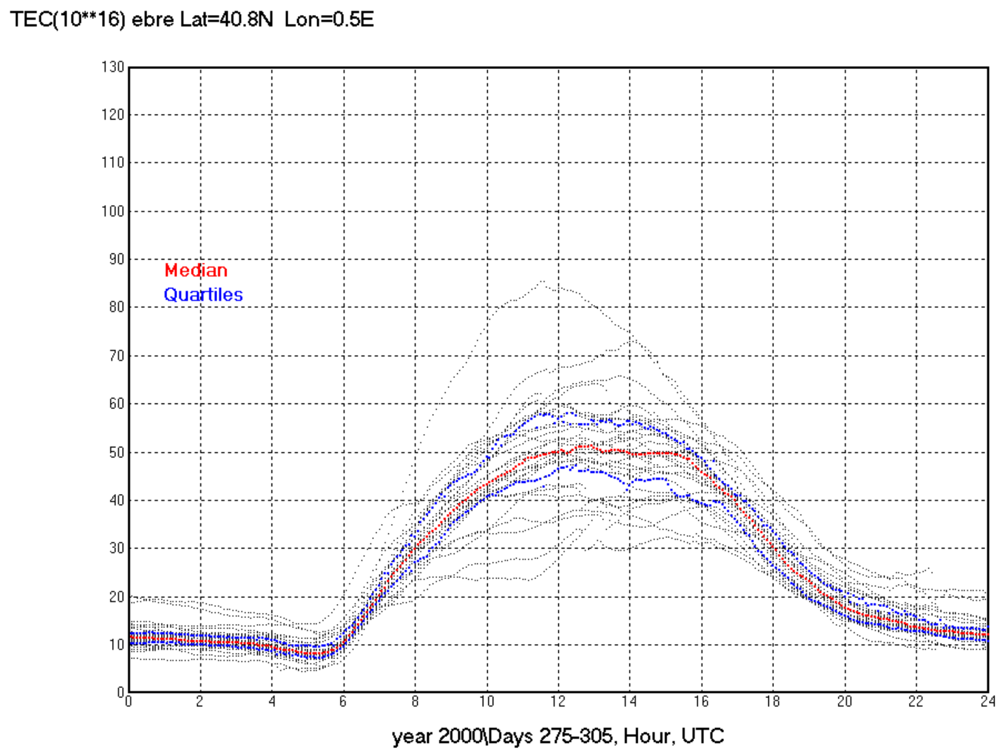
Rishbeth, H., Journal of Atmospheric and Solar-Terrestrial Physics, 60 p.1385-1402 (1998)

Seasonal Variability of Total Electron Content



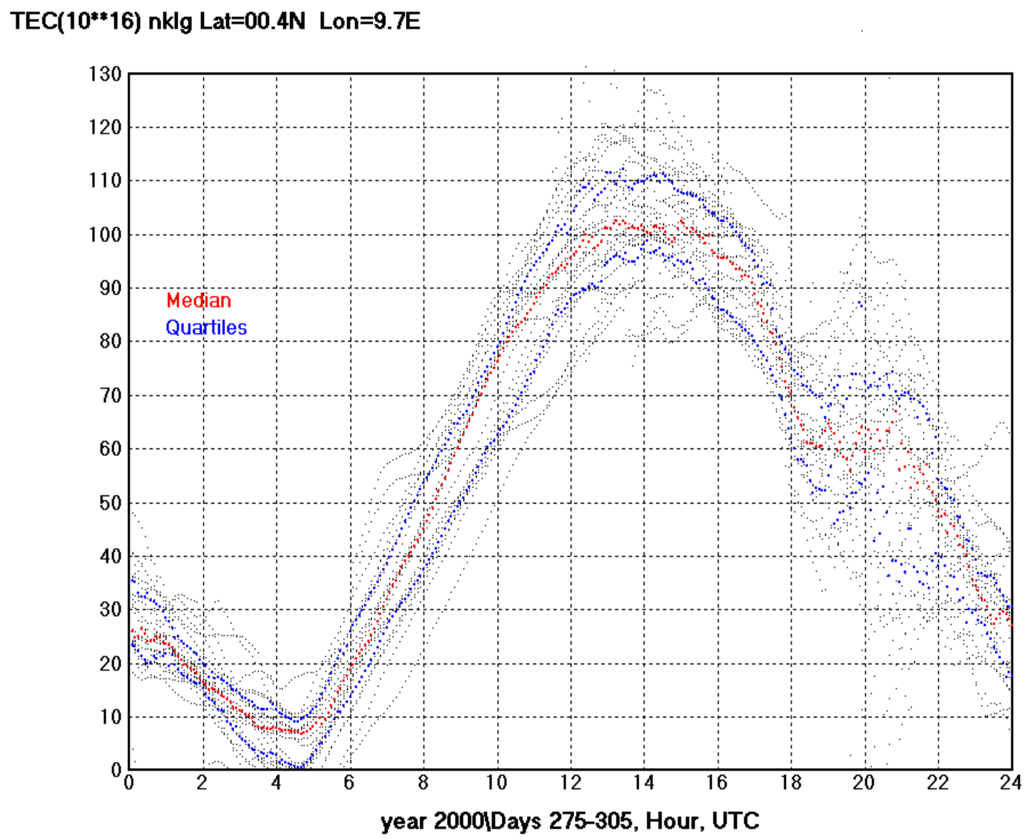
TEC observations from Kampala, Uganda
(Oron, D'ujanga & Ssenyonga, Indian J. of Phys, 2013)

Vertical TEC diurnal and day-to-day variations (1)



GPS derived vertical TEC at 5 min interval for Roquetes (Lat. 40.8°, Lon. 0.5° E,Mag. Dip 57°), October 2004

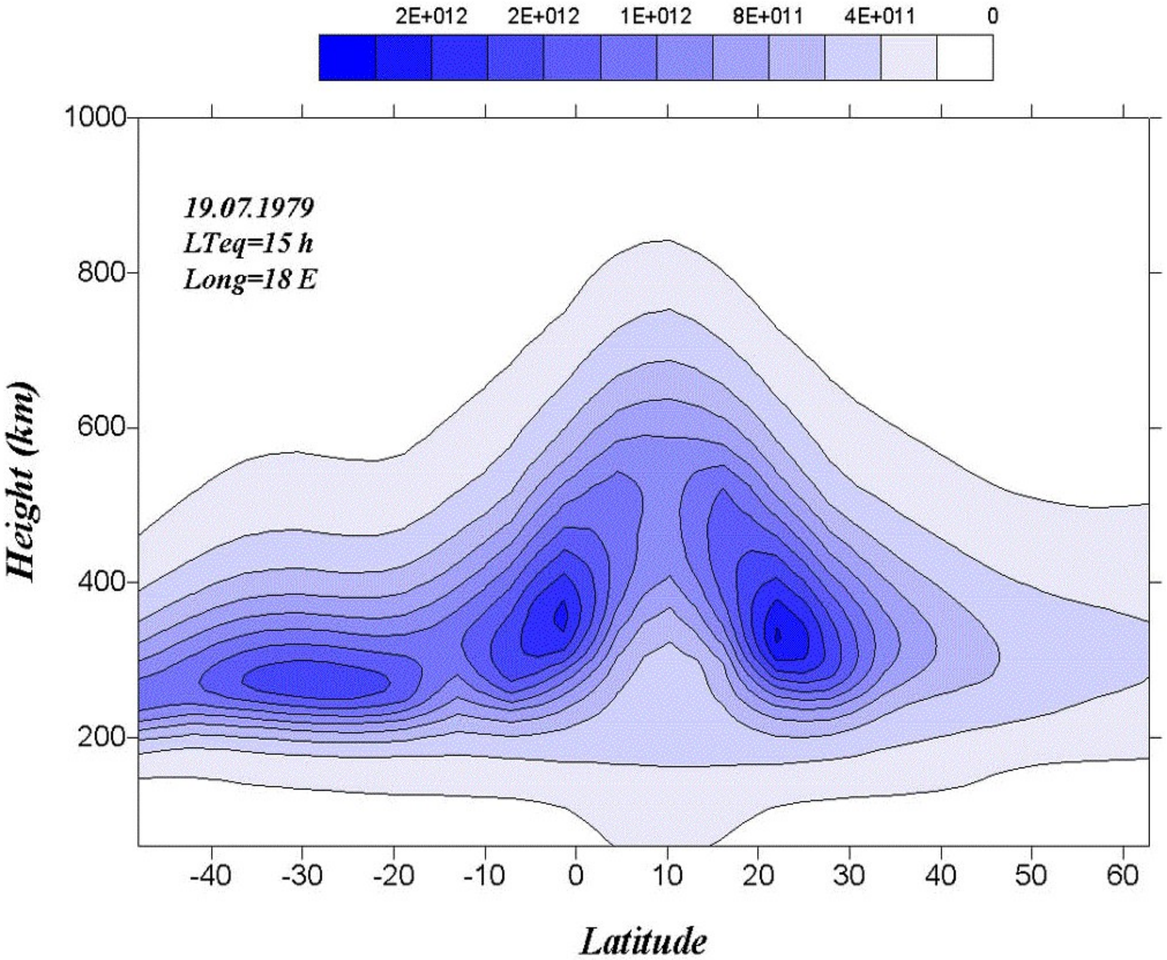
Vertical TEC diurnal and day-to-day variations (2)



GPS derived vertical TEC at 5 min interval for Libreville

(Lat. 0.4° N, Long. 9.7° E, Mag. Dip –25°), October 2000.

Geographical variations: the equatorial anomaly

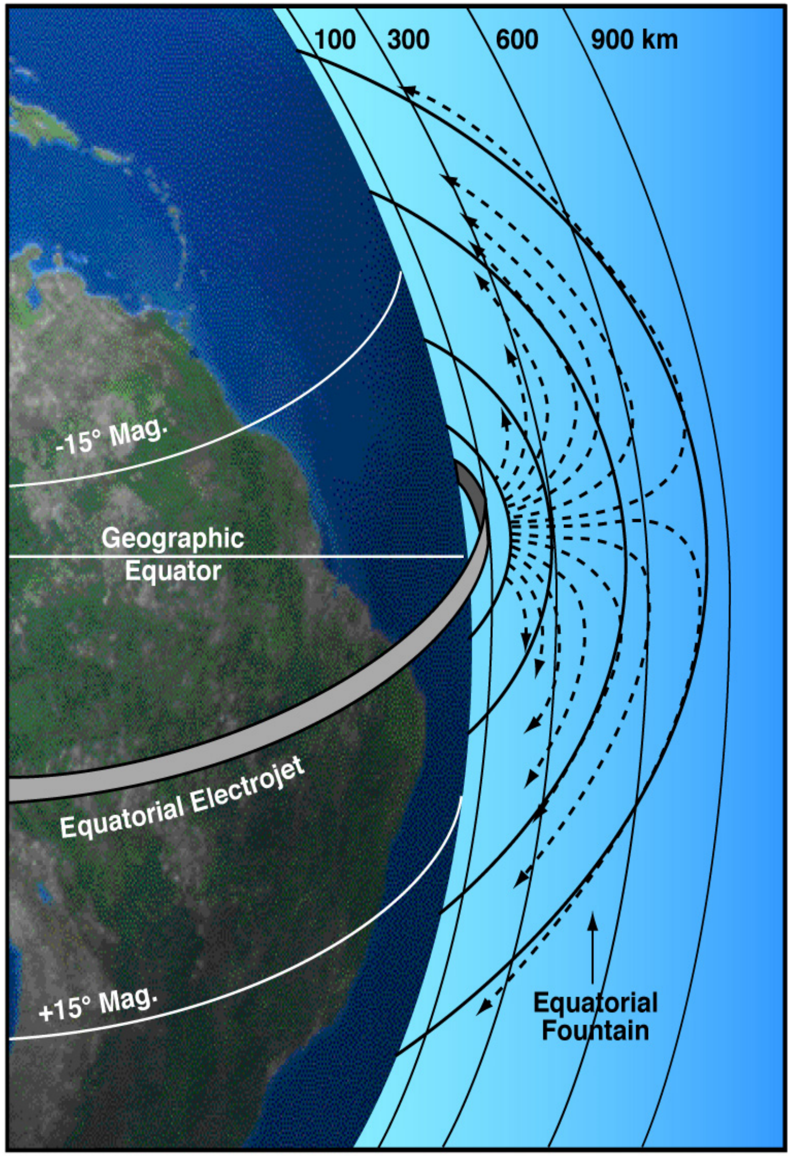


Nava B., Radicella S.M., Pulinets S. and Depuev V. "Modelling bottom and topside electron density and TEC with profile data from topside ionograms", Advances in Space Research, V. 27, pp. 31-34, 2001.

From the Chapman theory it can be expected that the electron density maximises over the geographic equator at equinox. However, it actually maximises ~ 10-20 degrees of geomagnetic latitude N and S, with a small minima at the equator due to the effect of the geomagnetic field: the 'fountain effect'.

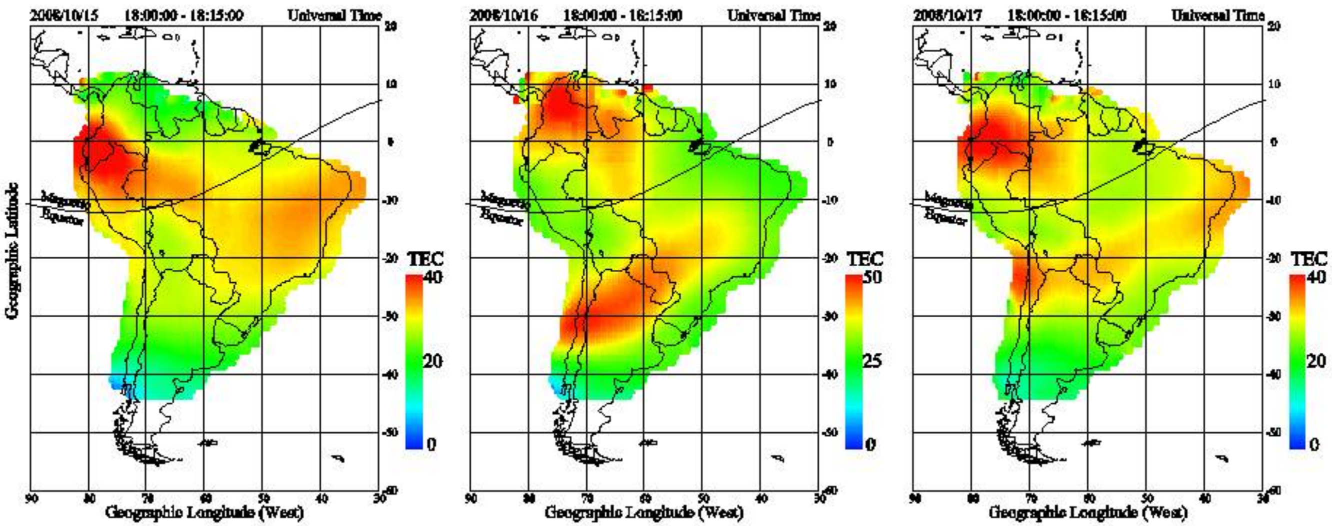
The "fountain effect"

The Equatorial Electrojet drives the F-region motor. E-field is zonal, magnetic field is meridional, so plasma drift is vertically upwards. Plasma then descends down the magnetic field lines either side of the geomagnetic equator.



Day-to-day regional TEC Variability

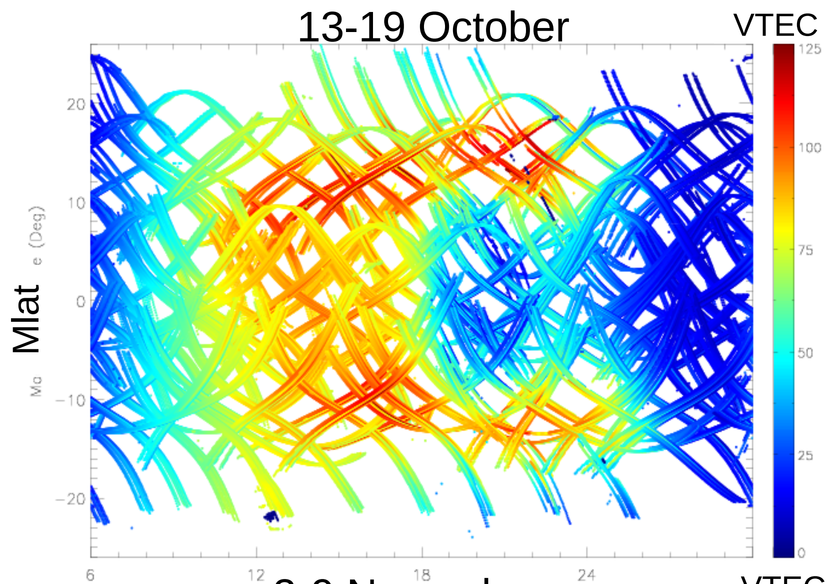
Characterize TEC variability in a regional Context: TEC values observed on 3 consecutive days (Oct 15-18, 2008) at same local time (2 PM at 60° W)



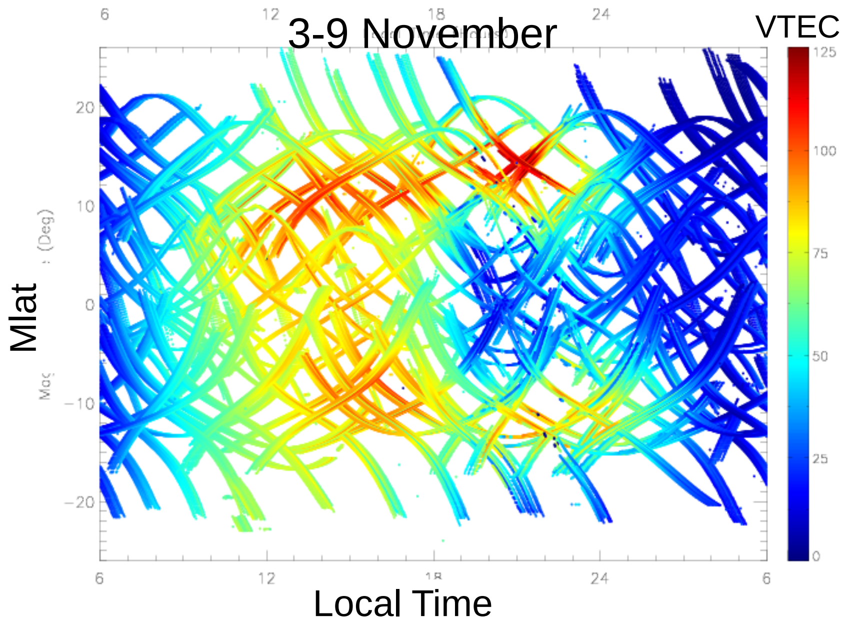
Courtesy of P. Doherty and C. Valladares

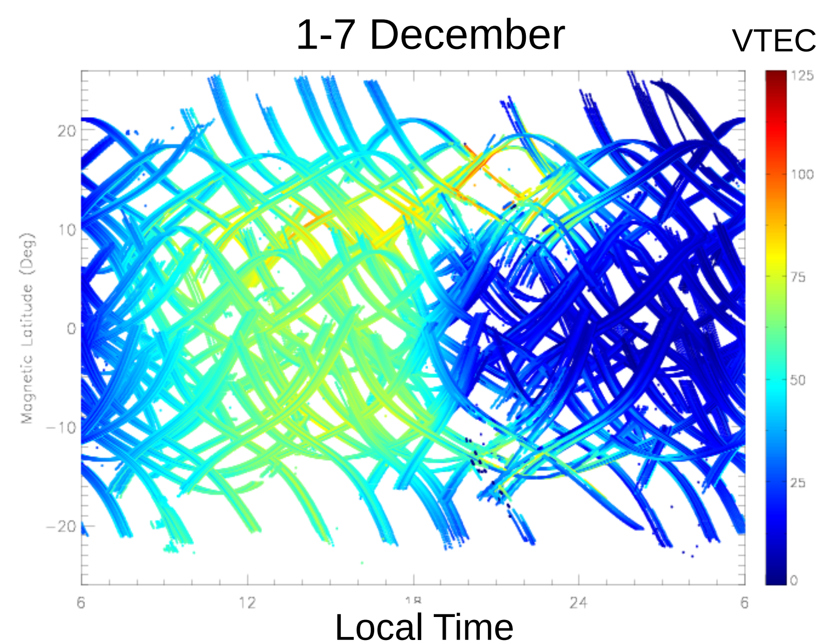
Equatorial Ionospheric Structure & Evolution

GPS TEC Central Brazil Oct-Nov 2002



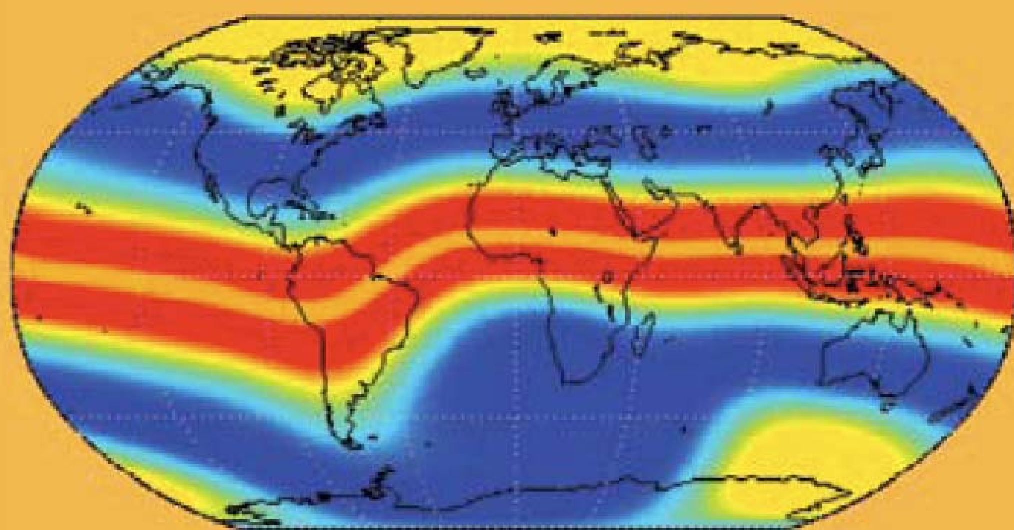
- Combined data from 3 GPS stations reveals dramatic low latitude density structure and variation
- Asymmetric anomaly structure driven by inter-hemispheric neutral wind





The Magnetic Equator

- The anomaly region is associated with the magnetic equator, shown below
- This region encompasses about 1/3 of the earth's surface and includes most of the African continent

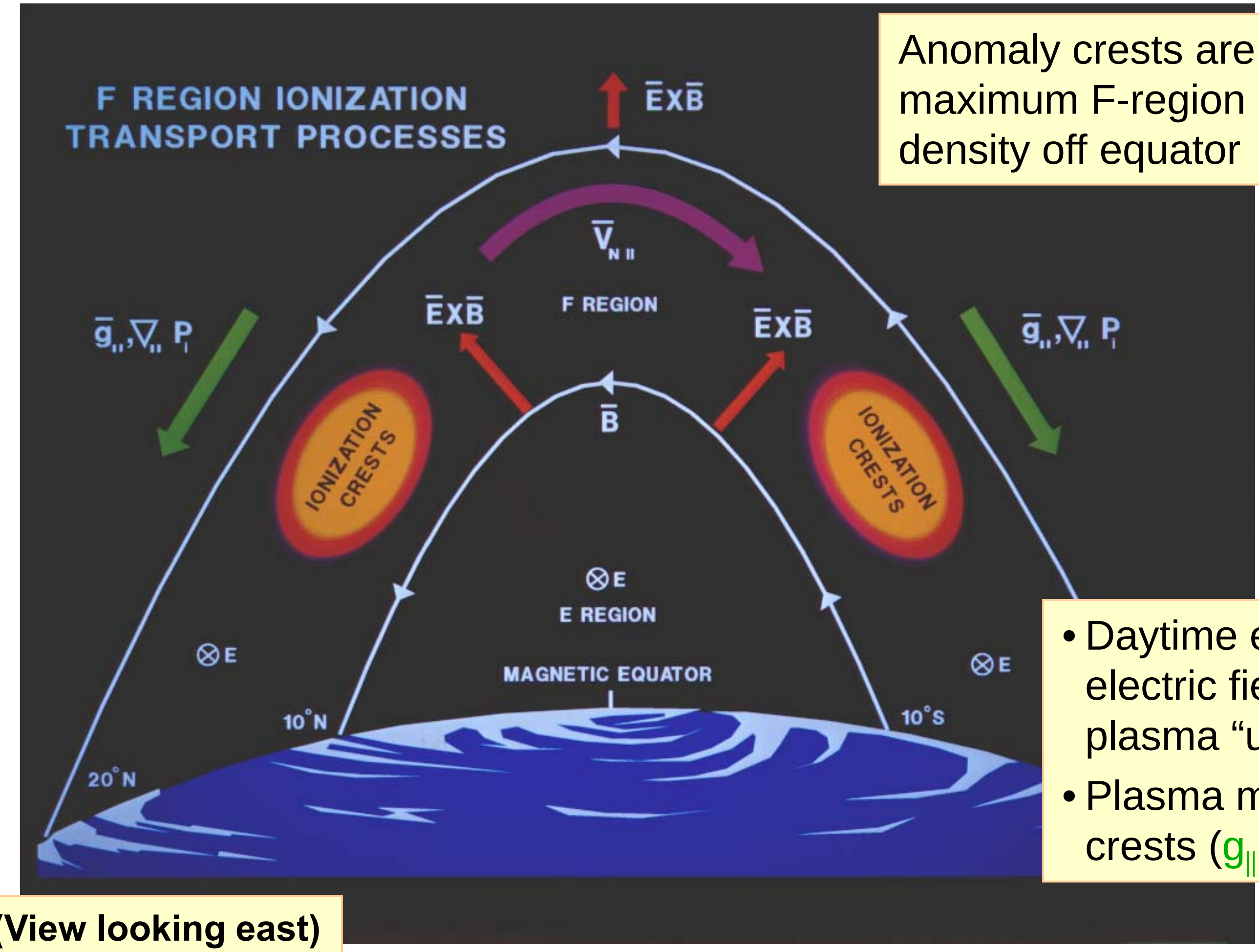


Let's take a closer look

What Are Equatorial Dynamics?

Formation of Anomaly Region

- Presence of anomaly crests strengthens off-equator scintillations
- State of anomaly formation is indicative of equatorial dynamics



Anomaly crests are areas of maximum F-region ionization density off equator

- Daytime eastward electric field (E) drives plasma "up" ($E \times B$)
- Plasma moves toward crests ($g_{||}$, $\nabla_{||}P_{||}$)

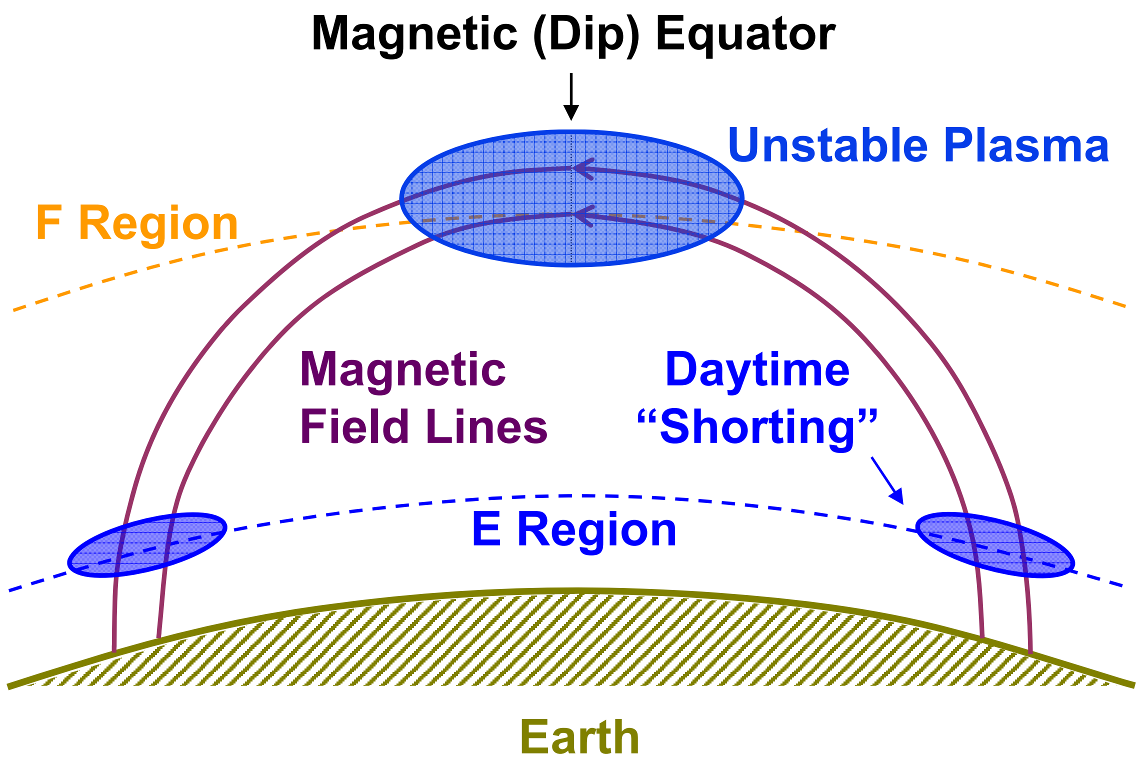
(View looking east)

Why Do Disturbances Form?

Unique Equatorial Magnetic Field Geometry

Equatorial scintillation occurs because plasma disturbances readily form with horizontal magnetic field

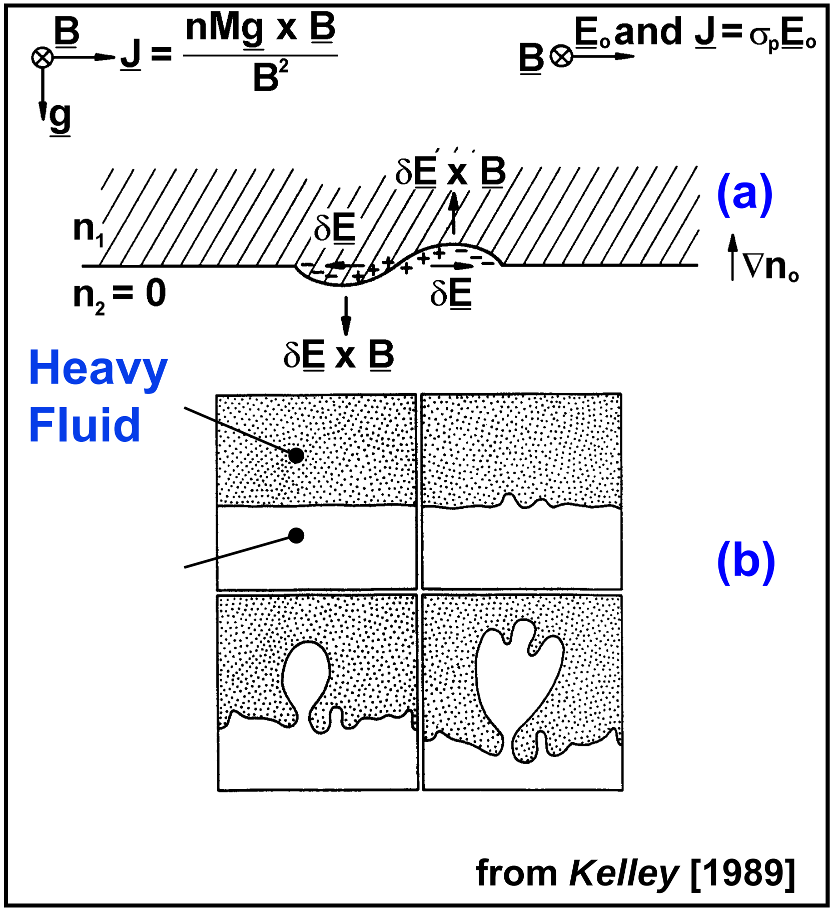
- Plasma moves easily along field lines, which act as conductors
- Horizontal field lines support plasma against gravity– unstable configuration
- E-region "shorts out" electrodynamic instability during the day



What Is Instability Process?

Basic Plasma Instability

View along bottomside of ionosphere
(E-W section, looking N from equator)

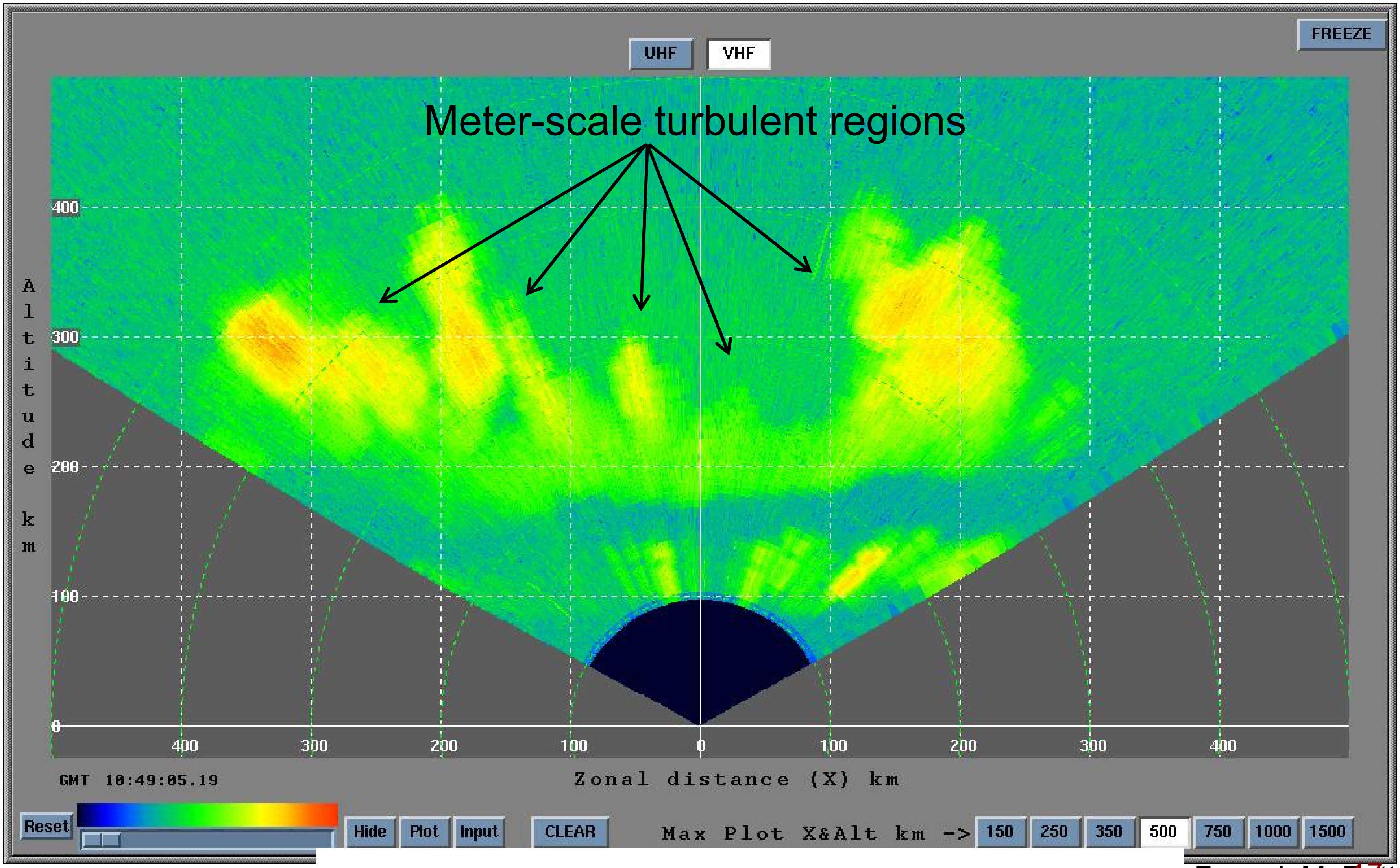


Plasma supported by horizontal field lines against gravity is unstable

- (a) Bottomside unstable to perturbations (density gradient against gravity)
- (b) Analogy with fluid Rayleigh-Taylor instability
- Perturbations start at large scales (100s km)
- Cascade to smaller scales (200 km to 30 cm)

ALTAIR Coherent Scatter Radar Scan

27 Sep 2008 10:49 UT



Preliminary result: Real-time display

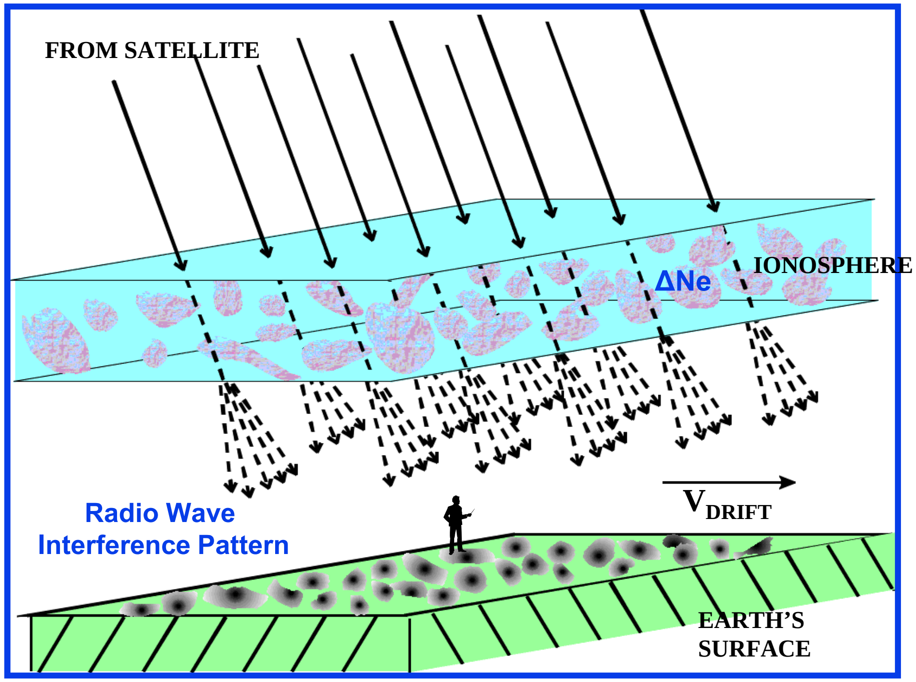
From J. M. Retterer

Scintillation Physics: A Simple Picture

$$\tau_d = R/c + \frac{r_e c}{2\pi}\frac{N_{tot}}{f^2}$$

$$\delta\varphi = 2\pi f R/c - r_e c \frac{N_{tot}}{f}$$

$$N_{tot} = \int N_e(z)dz$$



- Phase variations on wavefront from satellite cause diffraction pattern on ground
- Interference pattern changes in time and space
- User observes rapid fluctuations of signal amplitude and phase

Scintillation Parameters: S4 & $\sigma\varphi$

S4 and σ_φ are statistical variables computed over a "reasonable" time period that satisfies both good statistics and stationarity, as follows

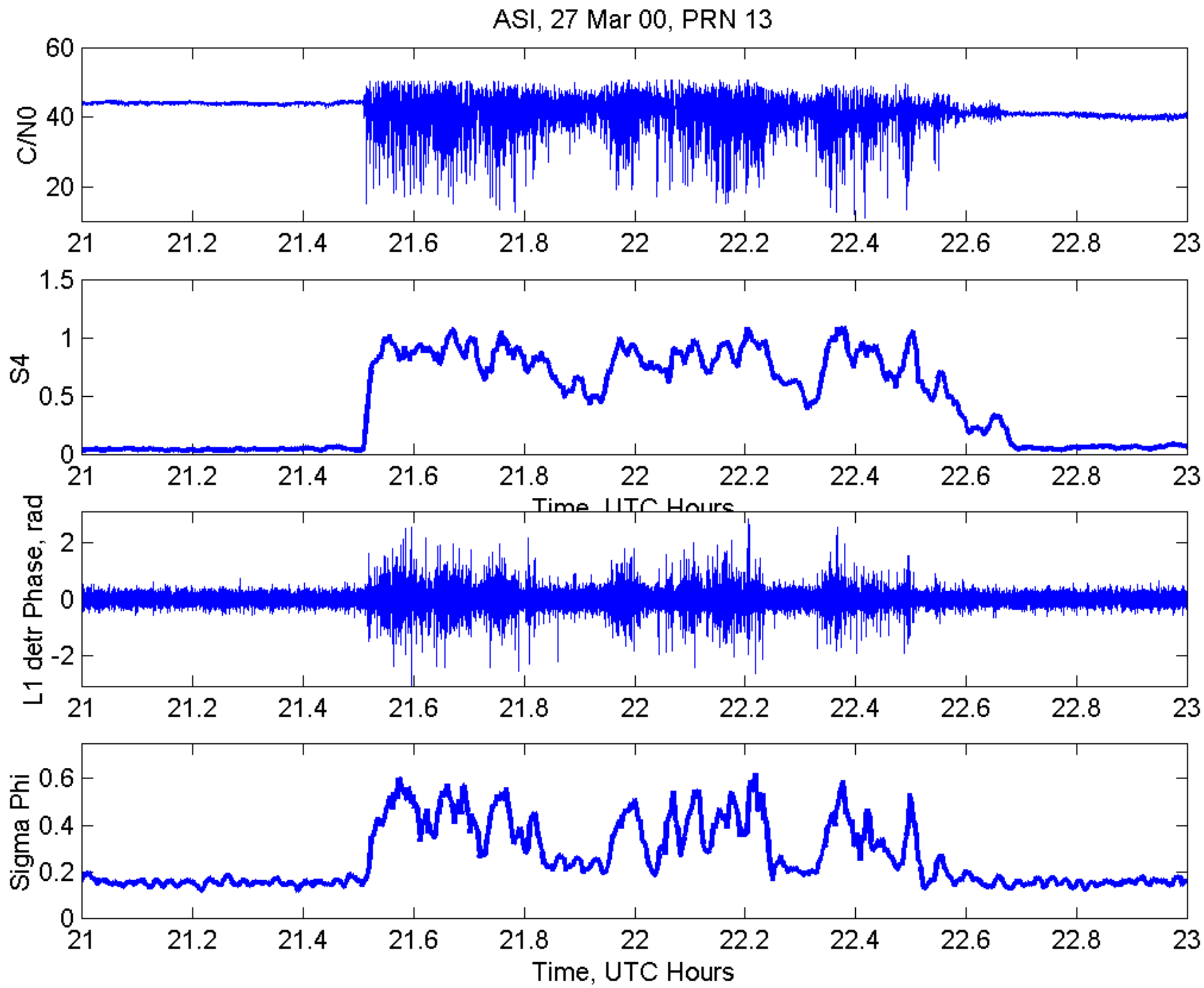
$$S_4 = \frac{\sqrt{\langle I^2 \rangle - \langle I \rangle^2}}{\langle I \rangle} \qquad \sigma_\phi = \sqrt{\langle \phi^2 \rangle - \langle \phi \rangle^2}$$

"Normalized" standard deviation — Standard Deviation

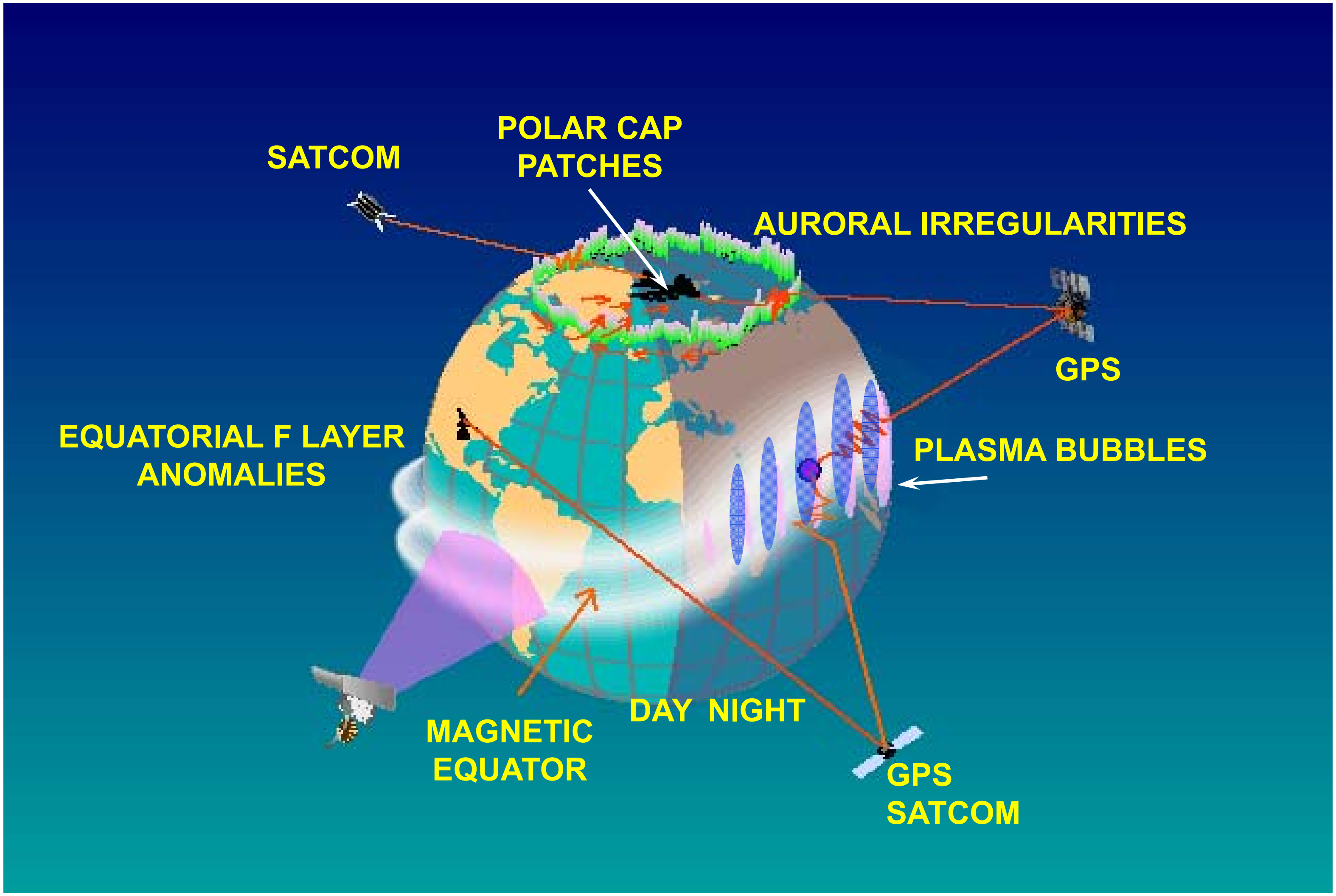
"Reasonable Time" depends primarily on the effective velocity of the satellite raypath; varies from 10 to 100 seconds; both quantities are derived from detrended time series to analyze only the fluctuations of the intensity and phase

These quantities depend on the density fluctuations in the medium

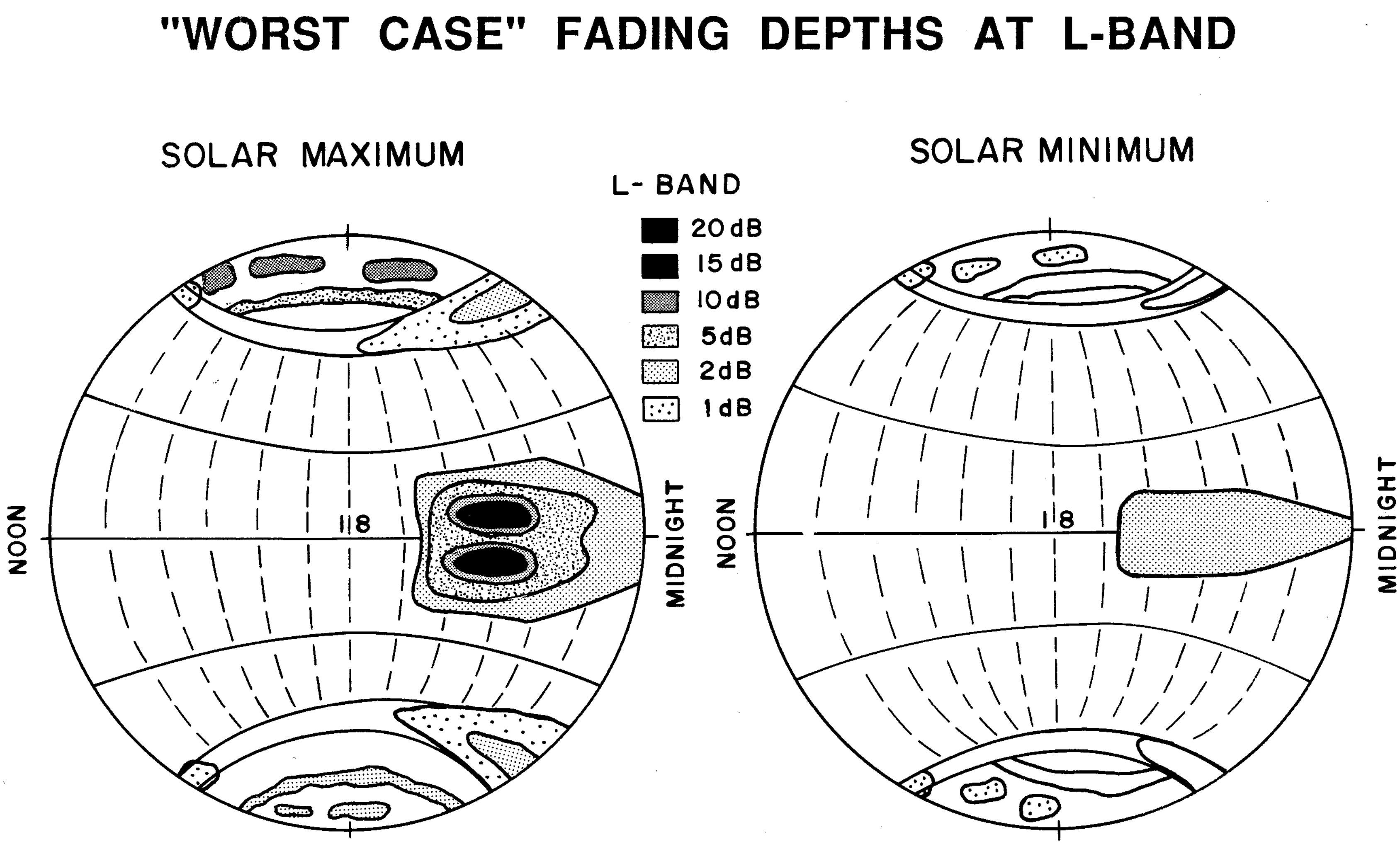
L1 Intensity & Phase Data: S4 and σ_ϕ



Disturbed Ionospheric Regions and Systems Affected by Scintillation



Global Morphology

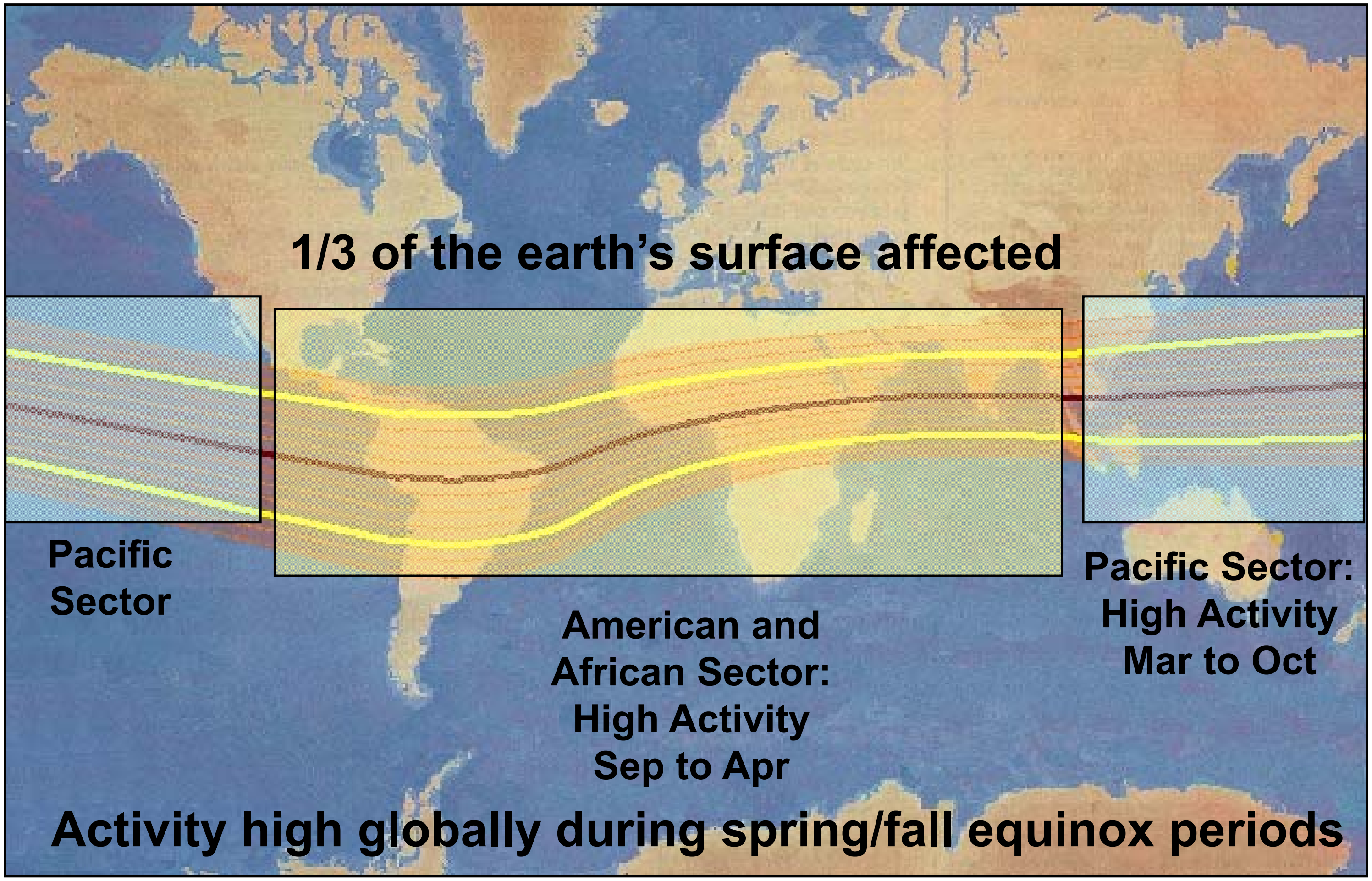


[After Basu, et al.]

Equatorial Scintillation

Seasonal and Local Time Dependence

Equatorial scintillation generally occurs 2000 to 0300 LT in listed seasons



Mission Focus: Forecasting Scintillation

Scientific Premise

- Extreme day-to-day variability makes physics-based forecasting the only viable approach to a solution
- Requires observations and models capable of describing a multi-dimensional system controlled by complex hydro- and electrodynamics stemming from interactions between the thermosphere and the ionosphere driven by both external and internal forcing from the troposphere to the sun

Keep it Simple: Scintillation Observations from 3 Sectors

Forecasting Equatorial Bubbles: Rayleigh-Taylor Instability

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

Growth Rate

Electric Field

Neutral Wind

Gravity

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

Conductivity

Magnetic Field

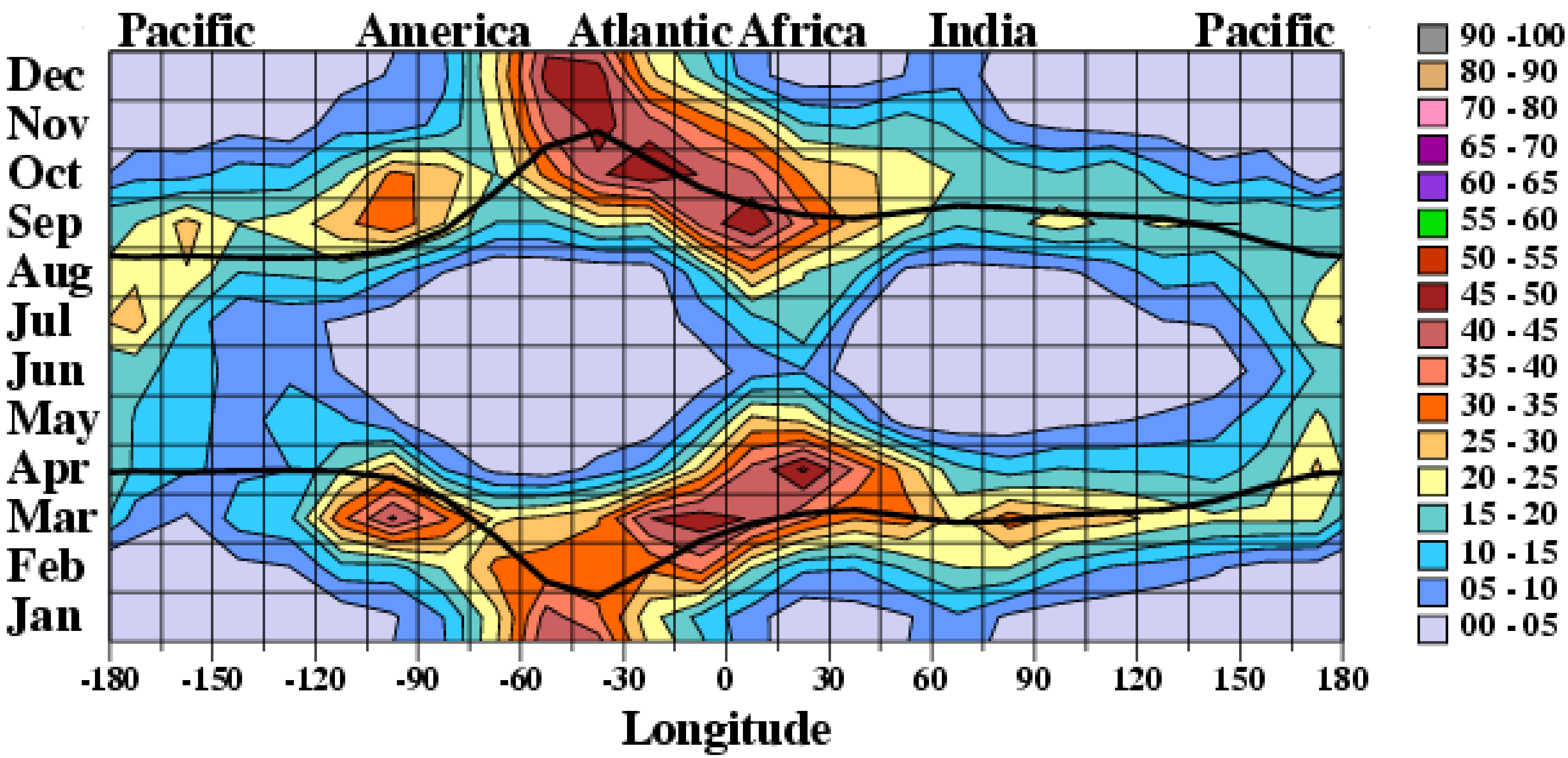
Collisions

Log Density Gradient

DMSP Bubbles 1999 - 2002

In situ irregularities detection statistics
800 km circular polar orbit

Relative Occurrence Climatology



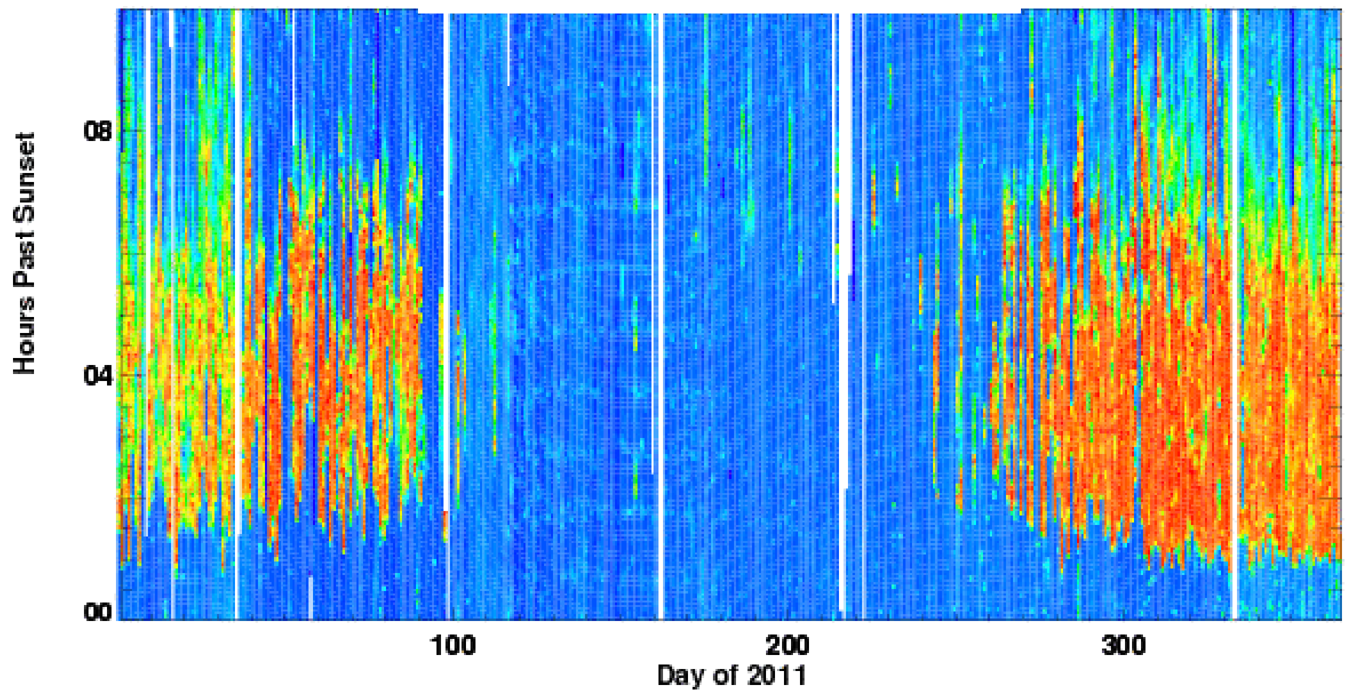
From Burke & Huang [2004]

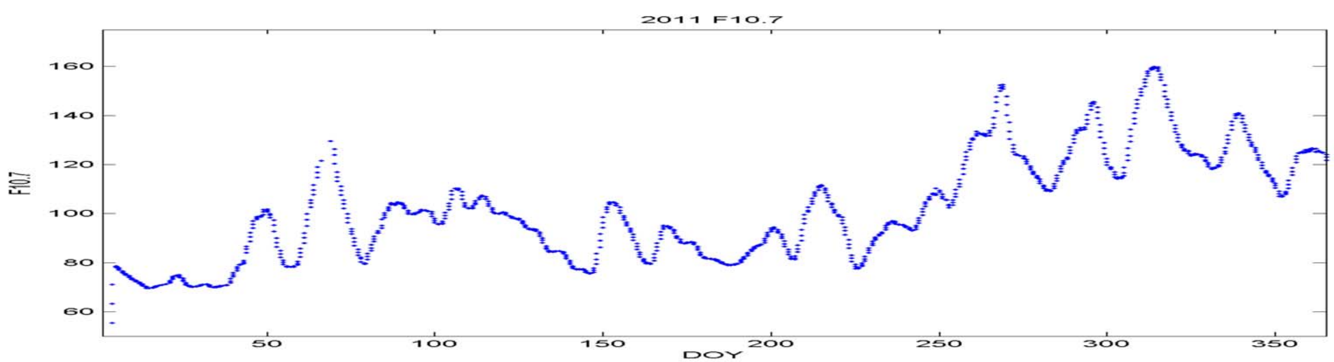
Longitudinal Variability

Examine 250 MHz scintillation observations from three separate longitude sectors in 2011

Extreme Day-to-Day Variability ?

Cuiaba, Brazil VHF 2011





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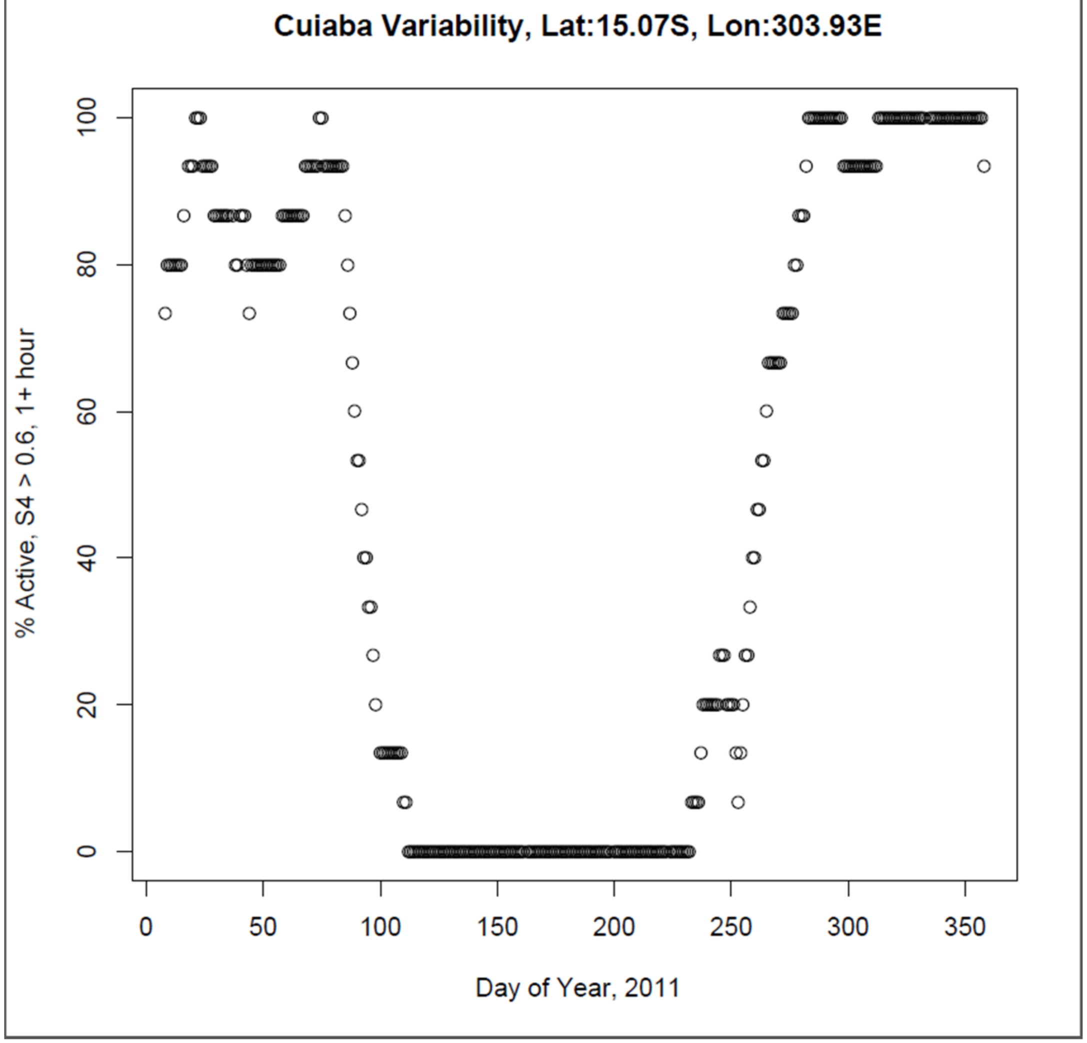
Scintillation "Variability" in Cuiaba, Brazil

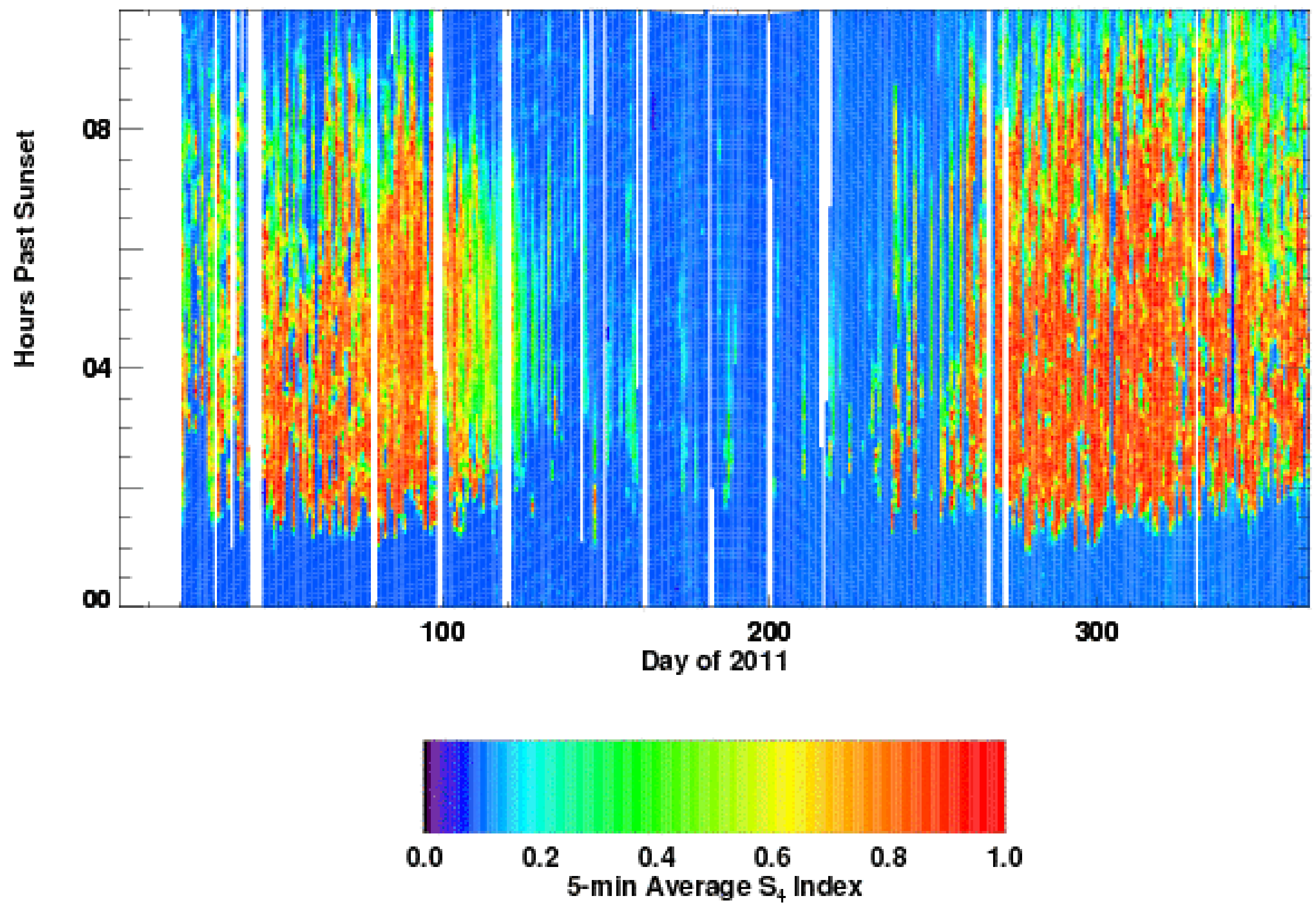
- Variability is mostly seasonal, not daily
- Forecasting challenge akin to predicting sunshine in NM
- Let's check some other sites

Probability of S4 > 0.6 for ≥ 1 hour



Scintillation Occurrence in W. Africa

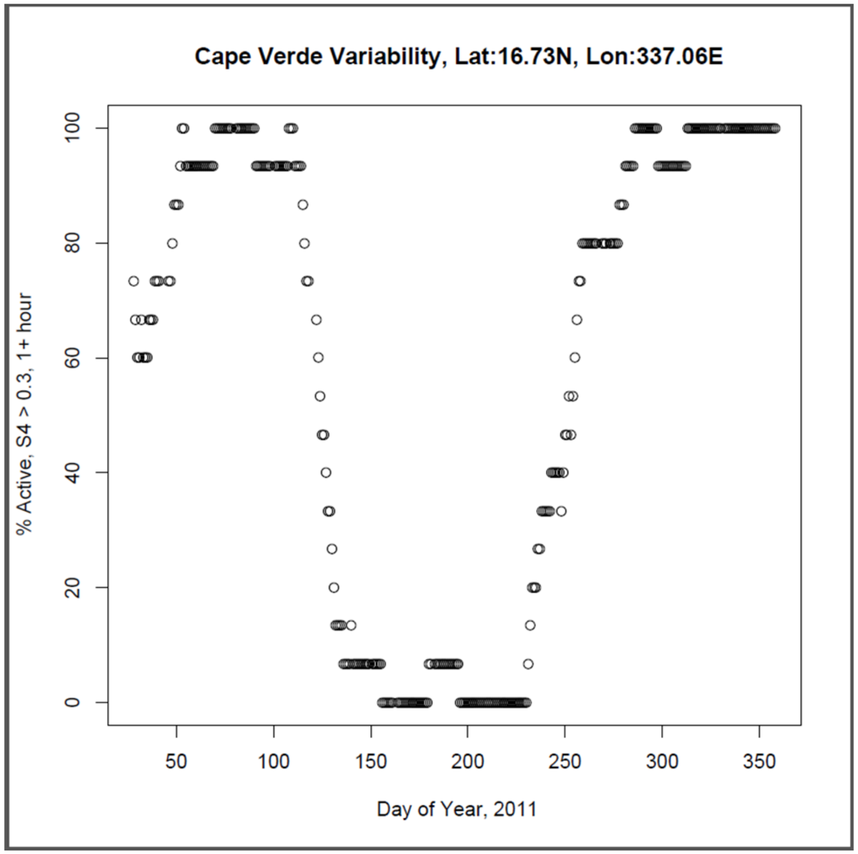
Cape Verde VHF 2011



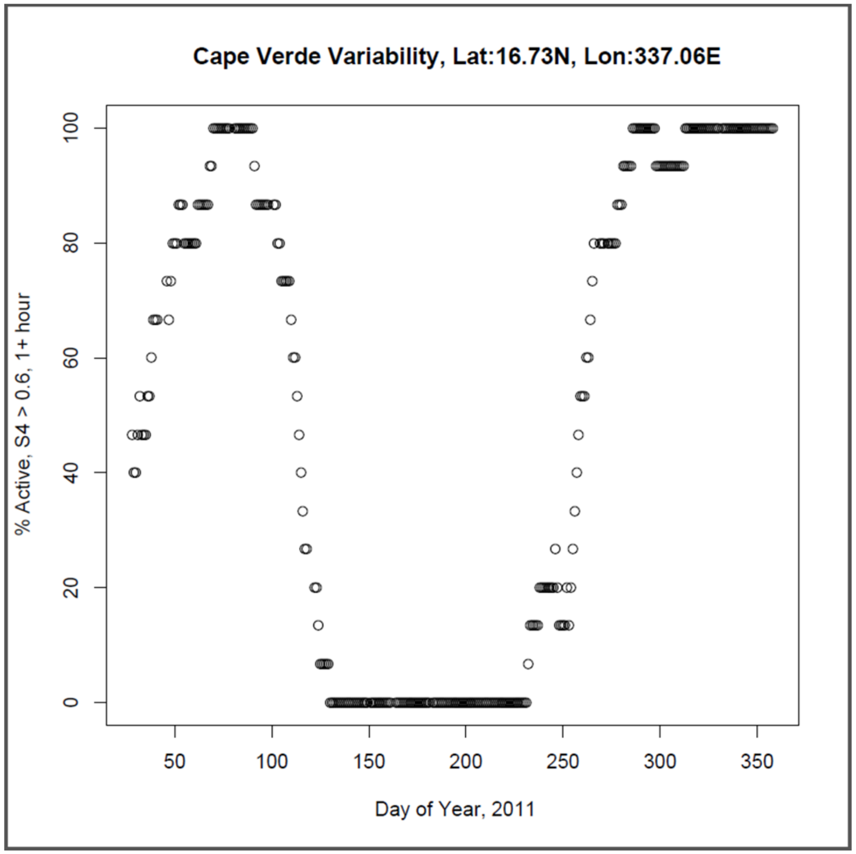
- Response looks pretty similar to Cuiaba
- Wet and Dry seasons

Cape Verde, West Africa

Probability of S4 > 0.3



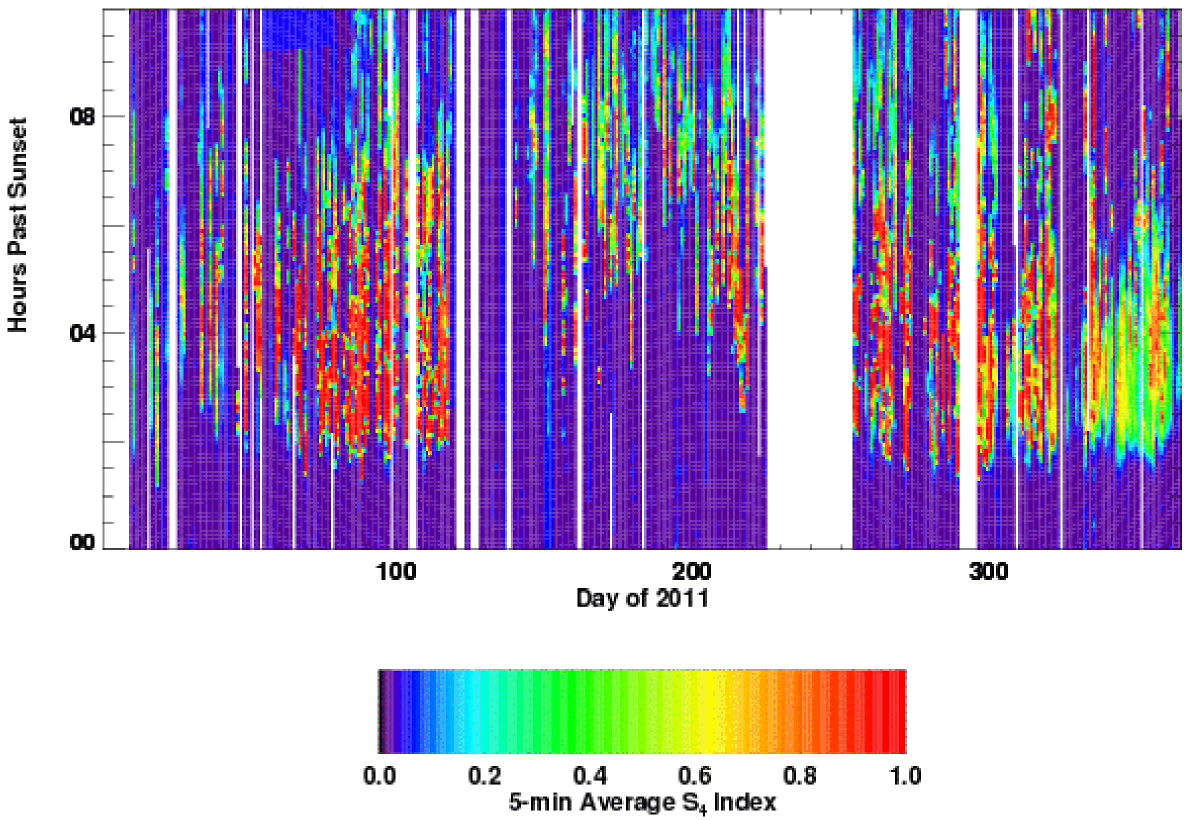
Probability of S4 > 0.6



- Occurrence suggests dominant mechanism(s); not dependent on GWs, tides, phase of the moon, nighttime ionization rate, etc.

Scintillation Occurrence in E. Africa

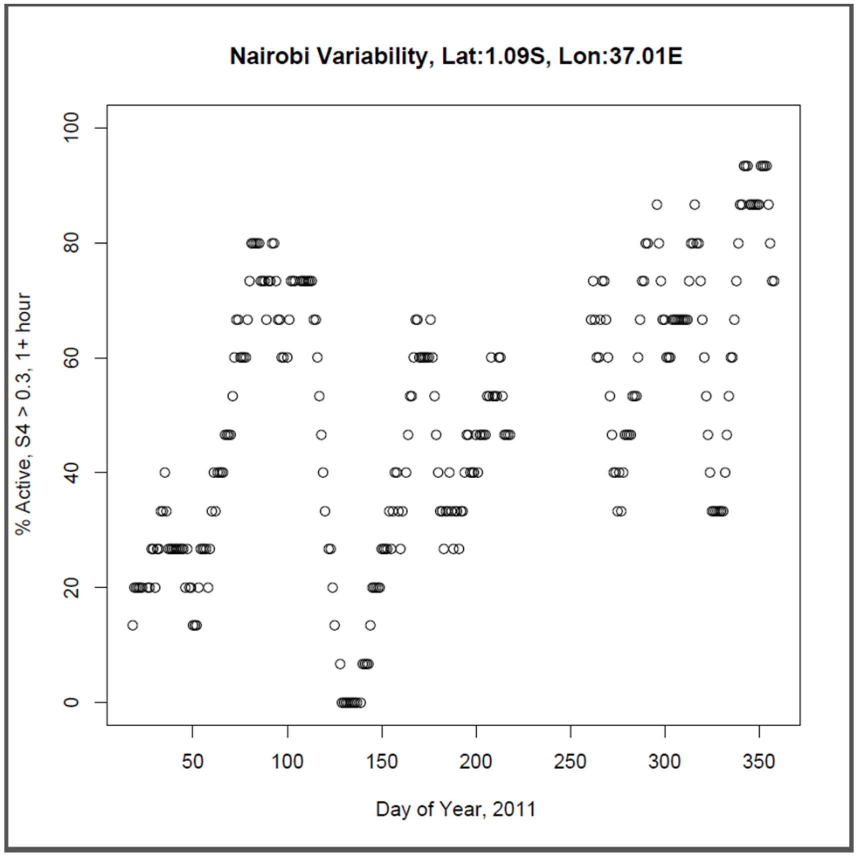
Nairobi, Kenya, VHF 2011



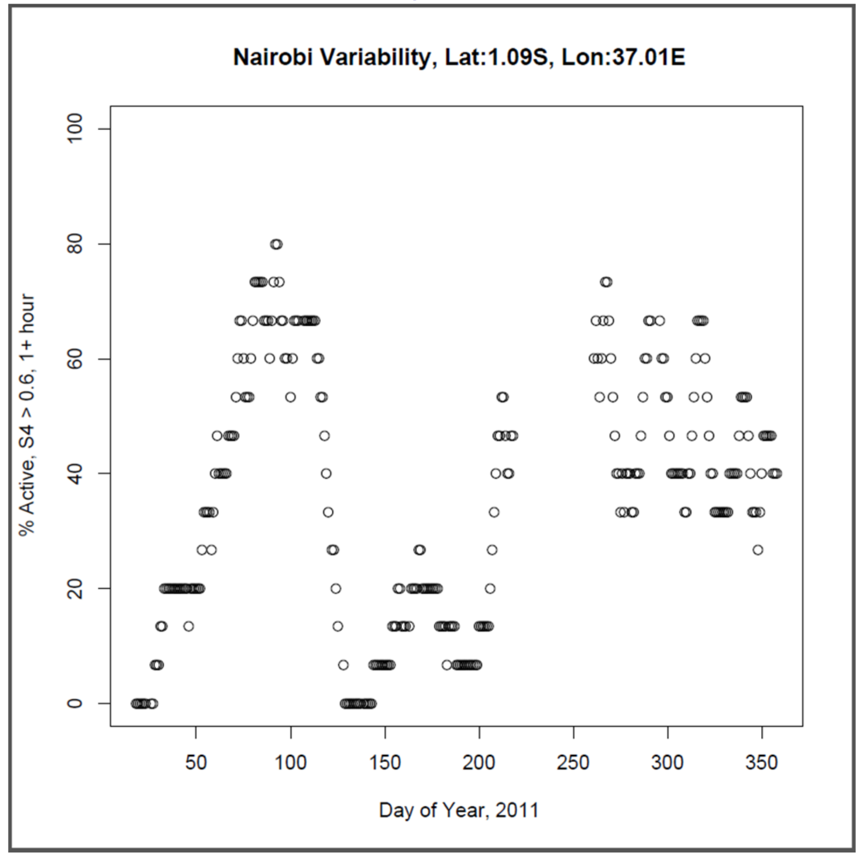
- Region shows a lot of activity
- Fundametal shift in local time of onset during June/July
- Data appears to show more variability than American sector

Nairobi, Kenya Variability

Probability of S4 > 0.3

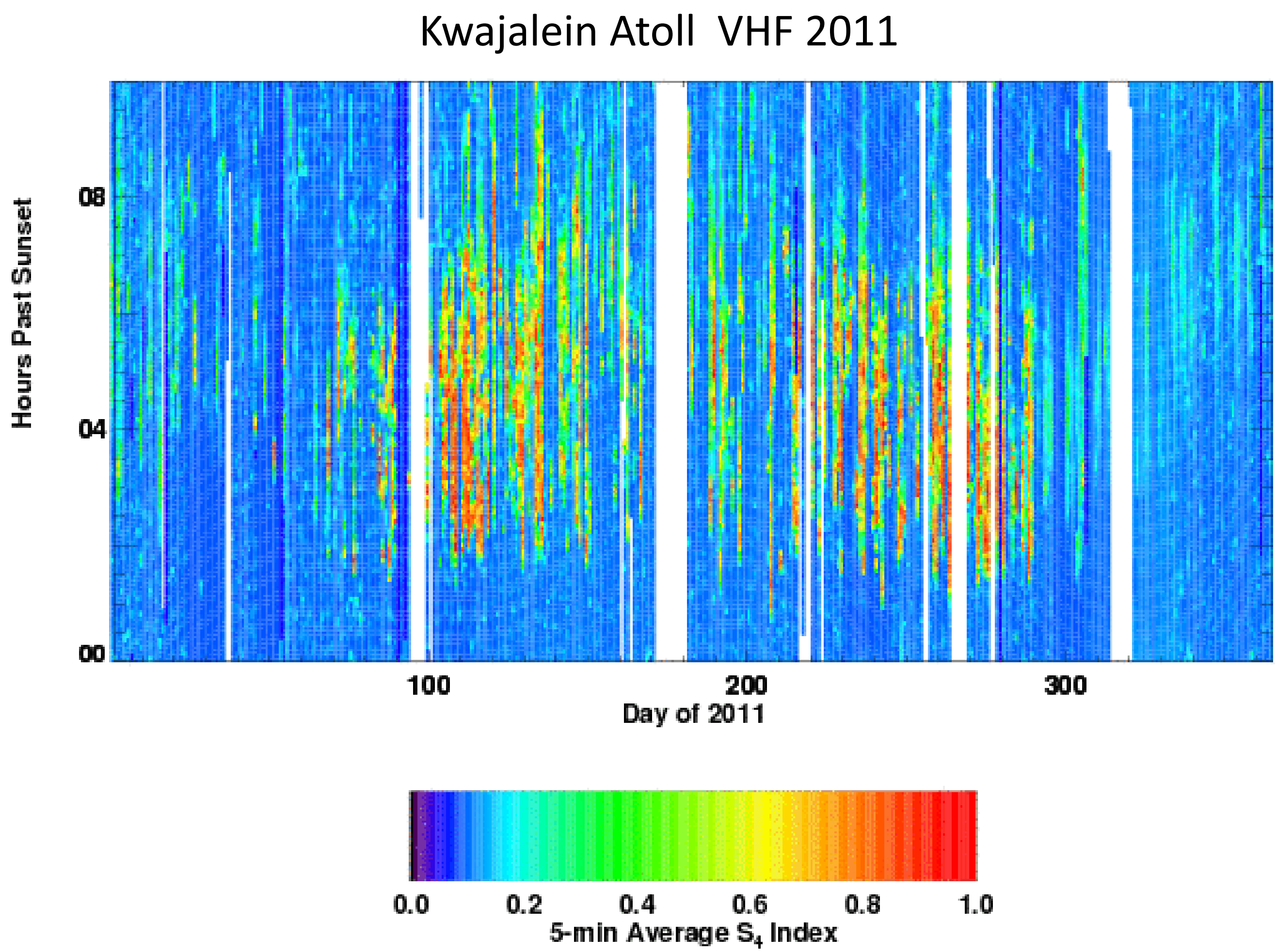


Probability of S4 > 0.6



- Variability exists throughout the year, even during the period of increased solar flux in the last quarter of 2011

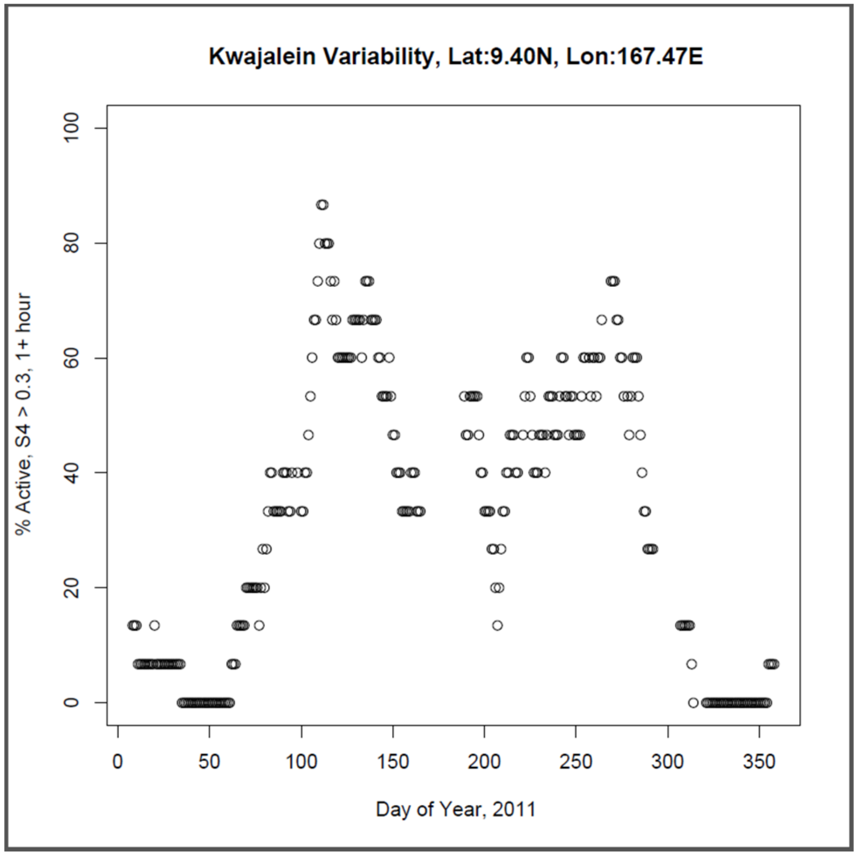
Kwajalein Scintillation



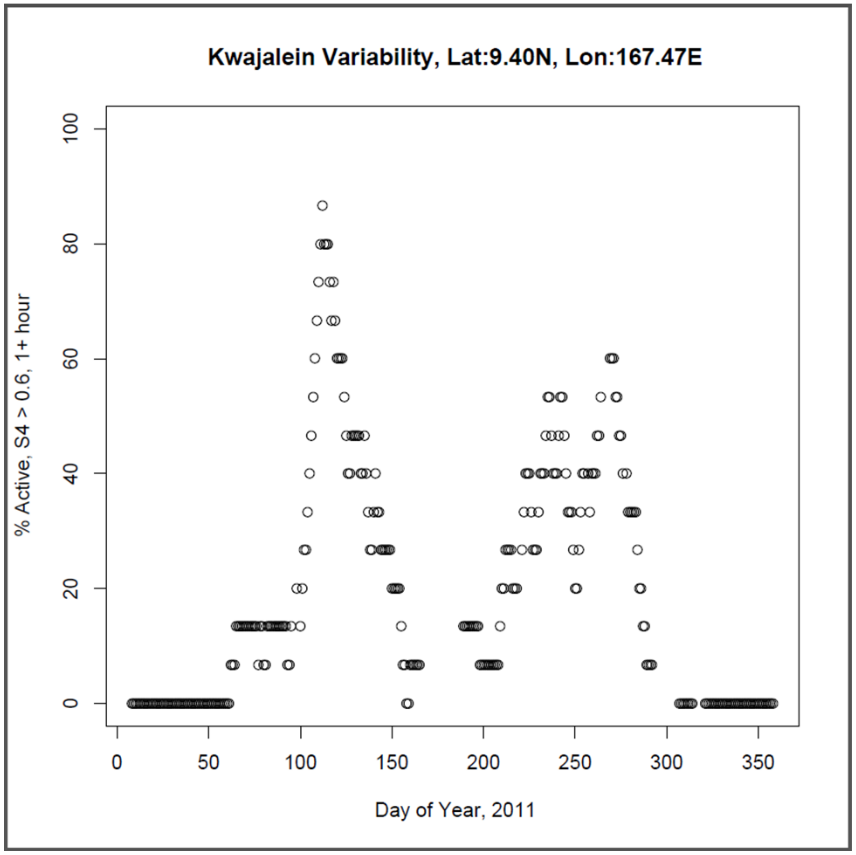
- Variability exists throughout the year, but average severity is markedly less than in Nairobi
- Part of the difference in severity may be attributable to mag lat

Kwajalein Variability

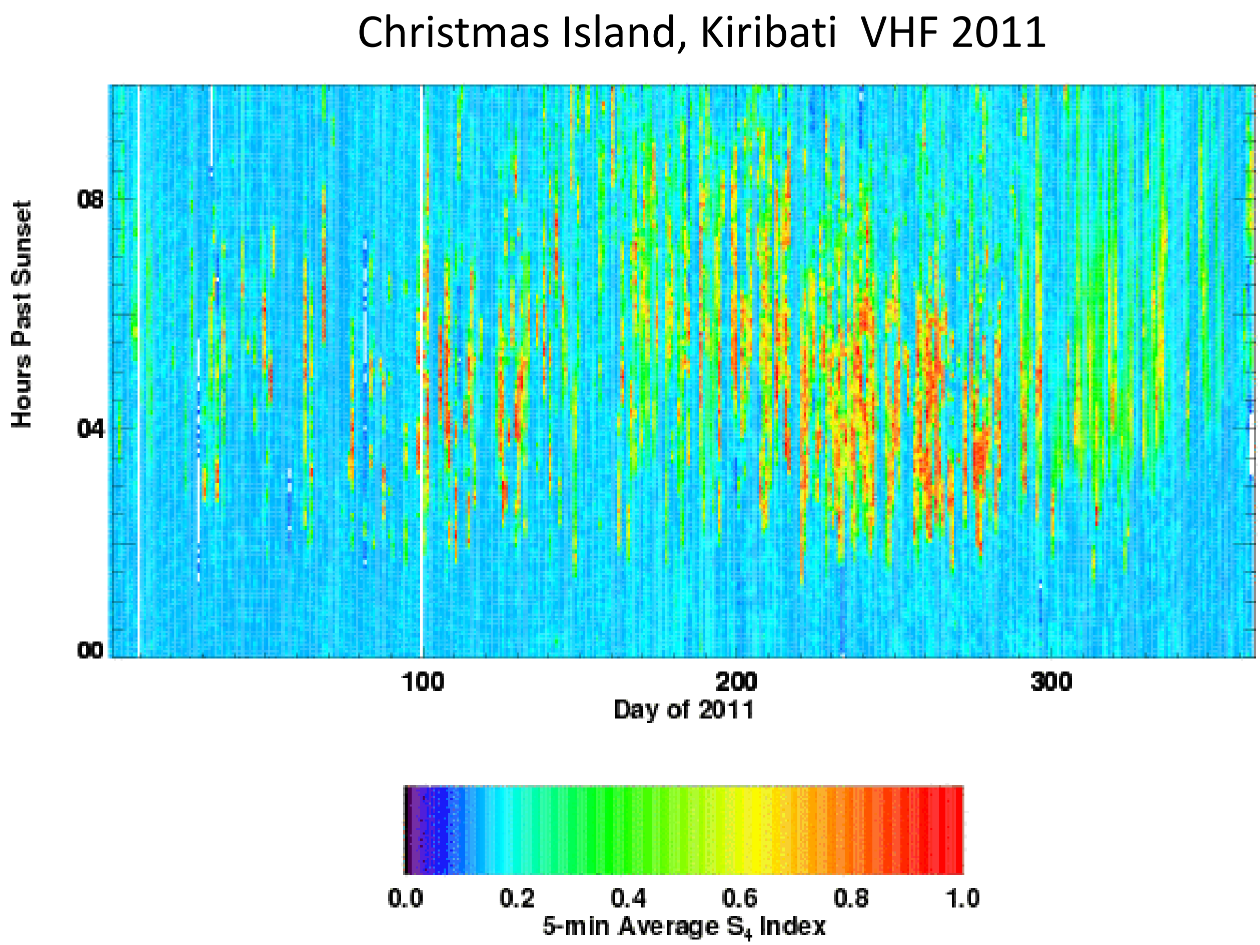
Probability of S4 > 0.3



Probability of S4 > 0.6



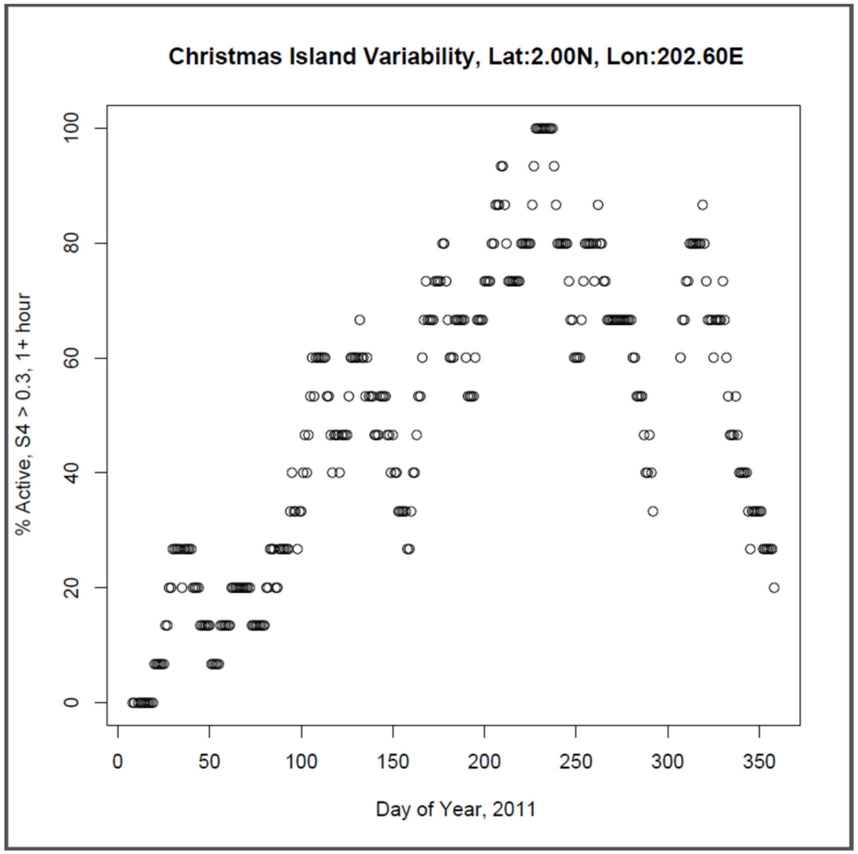
Christmas Island



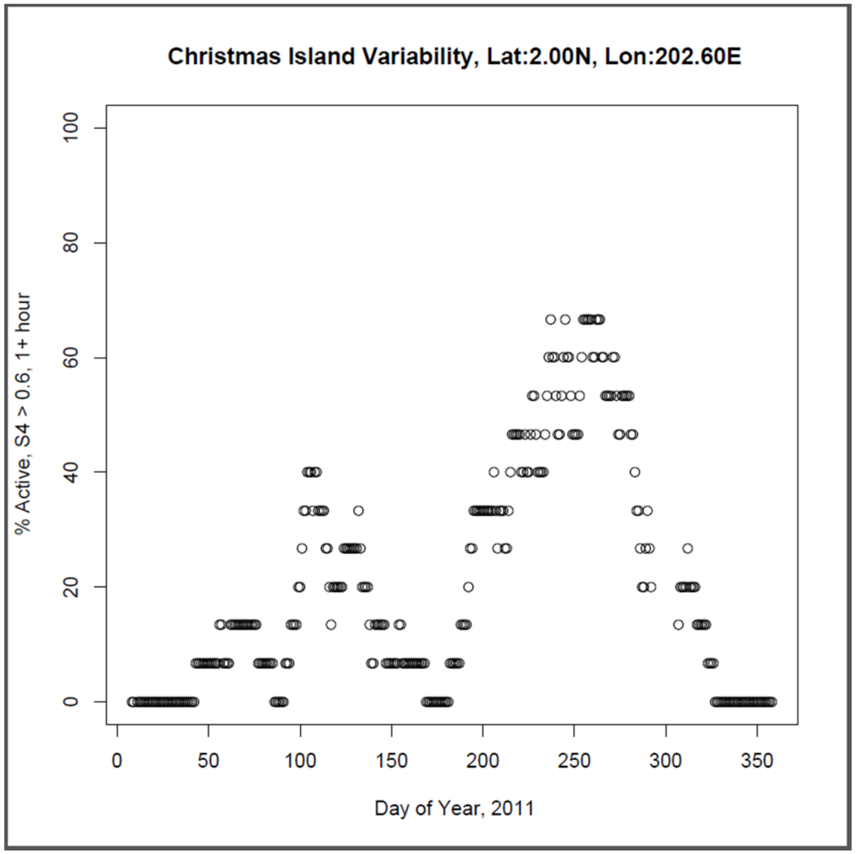
- Overall pattern similar to Kwajalein
- Decrease in severity may be magnetic latitude effect (1° vs 4°)

Christmas Island Variability

Probability of S4 > 0.3



Probability of S4 > 0.6

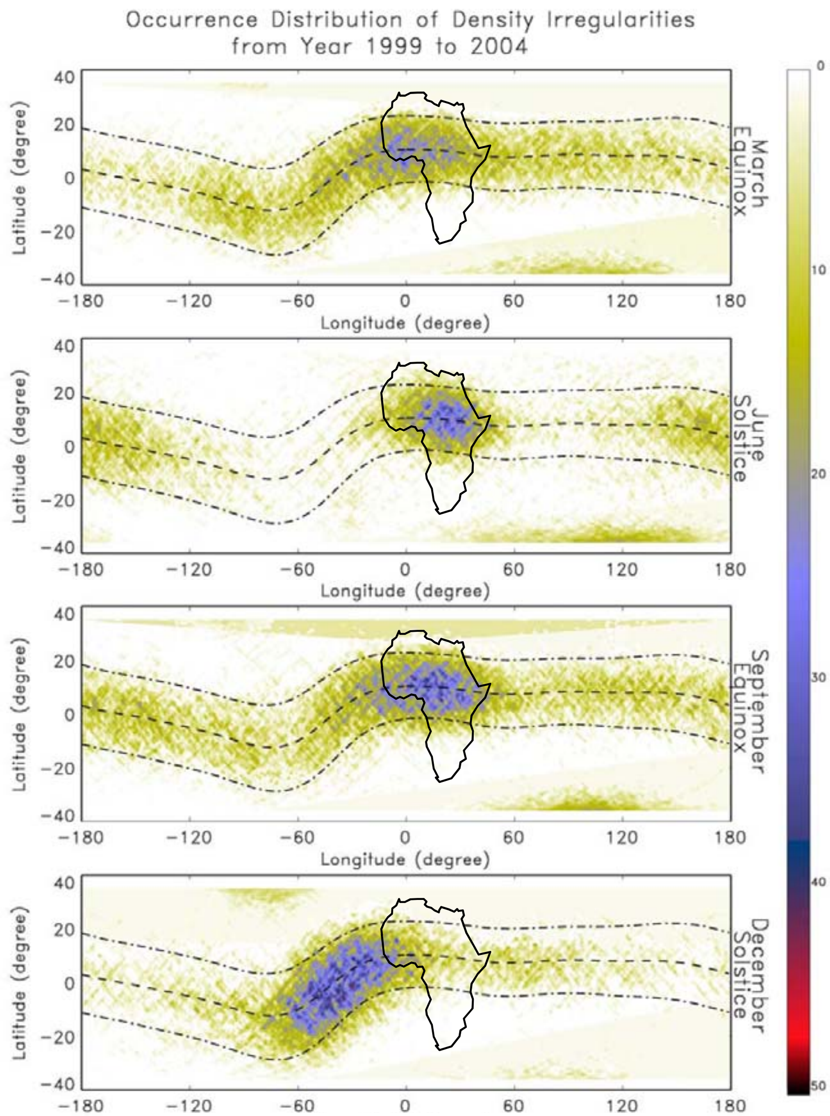


- Highly variable
- Severity further decreased, probably due to mag lat effects

Global Distribution of Irregularities

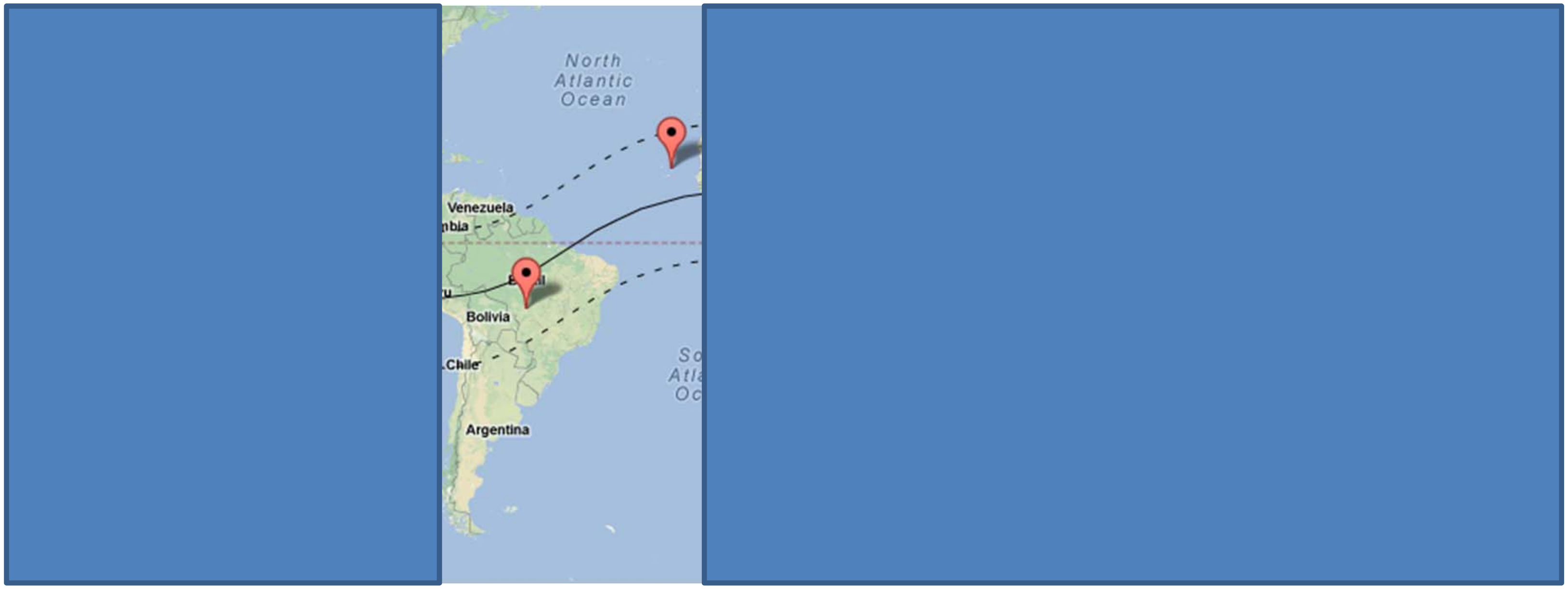
Africa and South America are active nearly year-round; activity peaks in these sectors

- Yet we find that Africa (and Pacific) exhibit significant variability relative to American sector
- The question is **Why?**



Adapted from S.Y. Su, 2005

Regional Forecasts?



- So the Pacific and African sectors show real variability requiring real physical modeling
- Is it possible to model the American sector with less than a high fidelity description of the ionosphere/thermosphere system?
- Note that the region with low variability has westward magnetic declination—can this explain the difference in variability?

Factors Contributing to Spread F

What about "seeds"?

- Region of low variability characterized by significant (> ~5°) westward declination and relatively low B-field strength
- Variability usually associated with "seeds" (e.g., gravity waves)

x Gravity wave activity cannot be a critical factor (no rationale for differences in AGW activity across such a range of longitudes/land mass/ocean environments)

x Non-migrating tides (i.e., classic 4-cell pattern) cannot be a critical factor since low variability region encompasses both maxima and minima

x Large-scale tropospheric systems, such as the inter-tropical convergence zone (ITCZ) cannot be factors since the low-variability region encompasses a range of +/- latitudes

Is it all about "B"?

- If seeds and tropospheric forcing are not critical, what's left?
- Consider equation for RTI linear growth rate

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

- At all seasons, small |B| suggests larger growth rate (favorable to onset)
  - Small |B| implies higher vertical drift which reduces collision frequency and reinforces high growth rate
- But a large declination angle results in significant differences between solar terminator angle and magnetic flux tube orientation during a portion of the year (implies high integrated E-region conductivity at sunset: Low growth rate)

Summary

- American longitude sector seems fairly predictable with respect to scintillation occurrence; suggests dominant driver(s) determined by terminator/B-field flux tube alignment and |B|
- Predictability improves as solar flux increases and scintillation is most severe (and therefore of greatest importance and concern)
- Other longitude sectors show greater variability
- Westward and/or magnitude of declination of magnetic field appears to be a critical determinant; more modeling needed to fully understand

Understanding the longitudinal differences in scintillation activity may provide important insights into the critical processes controlling equatorial Spread F occurrence

Presentation Summary

- Covered a tremendous amount of territory from 40,000 feet: Beginning with the sun’s radiation on the neutral atmosphere through a consideration of the variability in a specific ionospheric instability
- The objective was to provide a basis for understanding why the ionosphere exists and how it impacts people
- Of the many details not presented, some can be filled in through self-study via the internet and scientific literature
- Other questions raised can only be answered through original research, such as the longitudinal variability in equatorial bubble occurrence