Modeling and Forecasting the Equatorial Ionospheric Density and Scintillation

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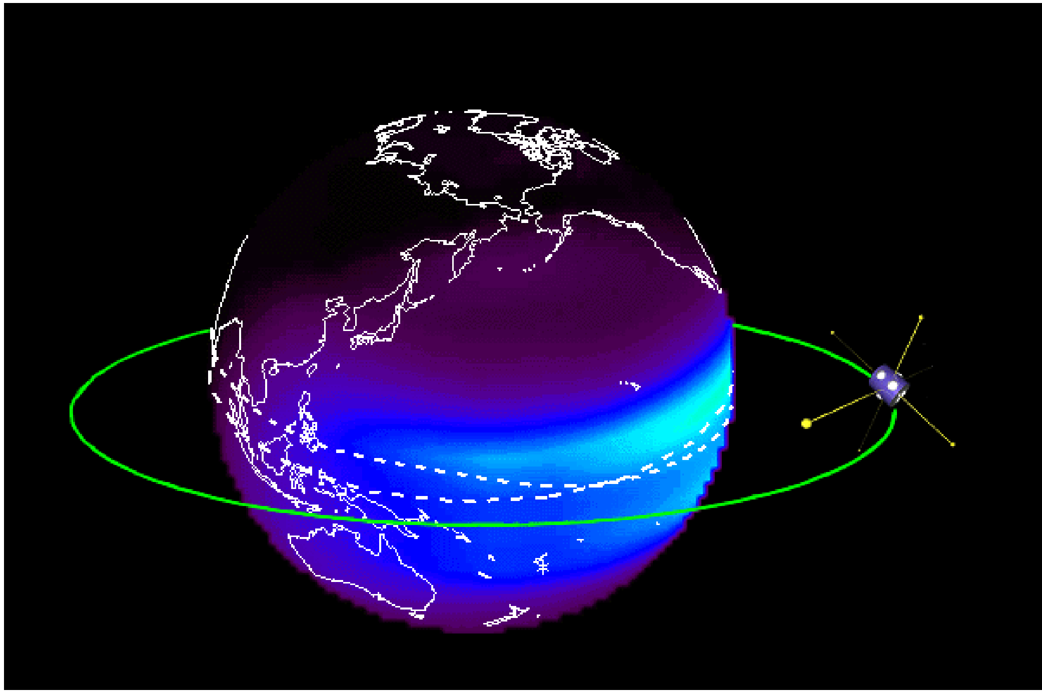
O. de La Beaujardière,
Y.-J. Su, J. Retterer, C. Huang, L. Gentile, C. Huang, P. Roddy
Air Force Research Laboratory, Space Vehicles Directorate
R. Pfaff, *NASA Goddard Space Flight Center*
C. Roth, *Atmospheric and Environmental Research Inc.*, **et al.**

Outline

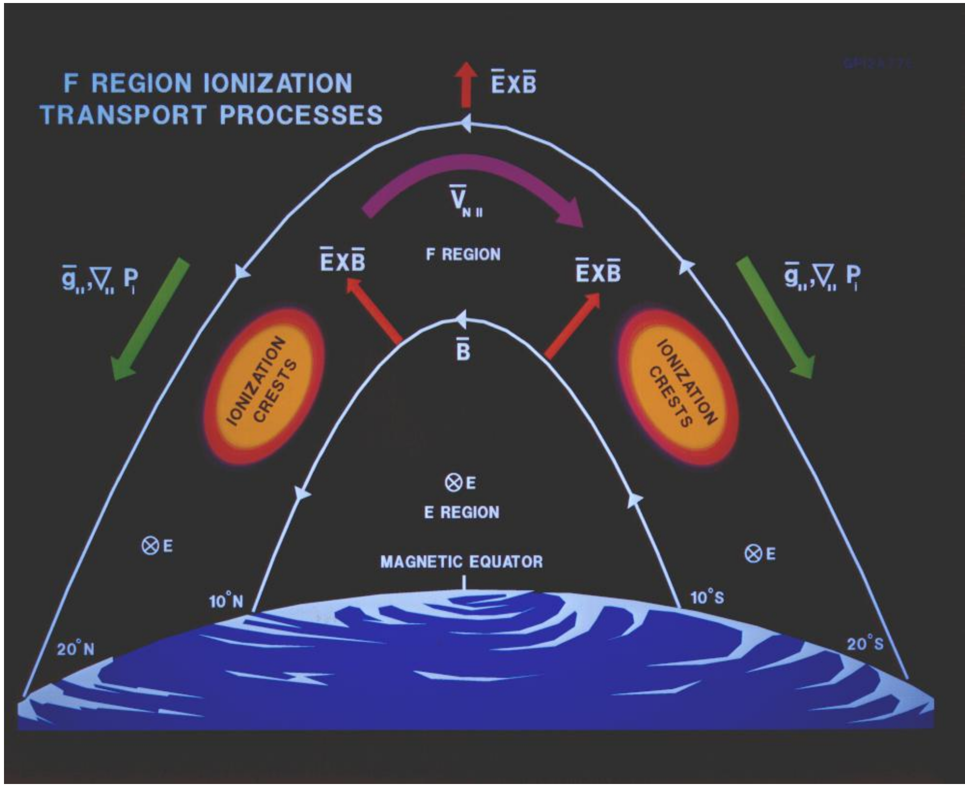
- Introduction
  - What is so special about the equator?
    - Fountain effect
    - Scintillation
  - Why do we care?
- What do we do about it?
  - C/NOFS Mission
- New C/NOFS results
- What are the major questions we still need to address with C/NOFS?
- Summary and Conclusions



The C/NOFS satellite launched in 2008 to study the equatorial ionosphere

Fountain in the Upper Atmosphere: Appleton Anomaly

Due to the fountain effect, "twin peaks" on either side of the equator are formed

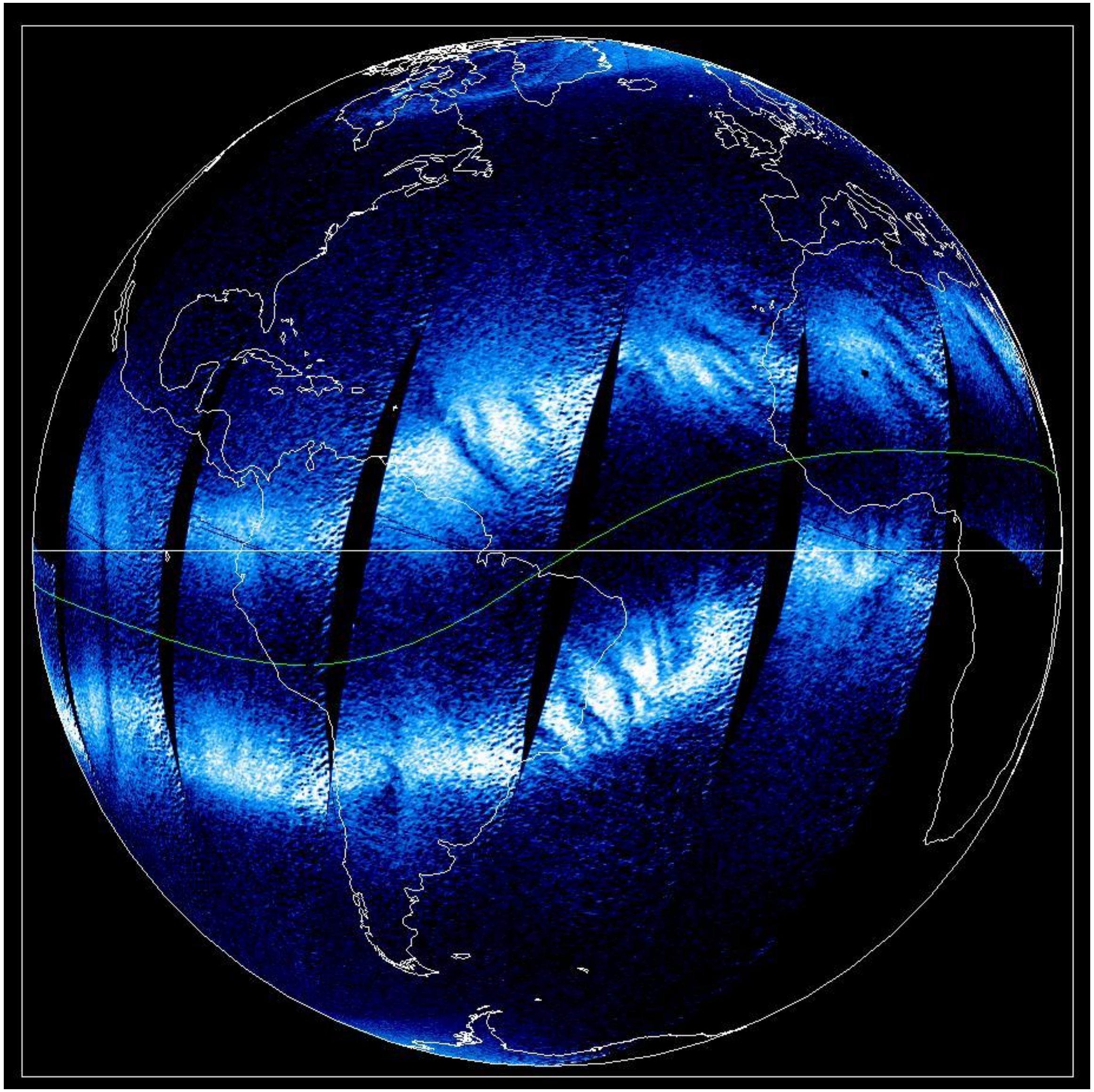


- **During daytime, ionosphere is driven upward above the magnetic equator (due to solar heating)**
- **Plasma then diffuses along the magnetic field**
- **This fountain-effect forms two crests**
  - **maximum ionization density near ±15° magnetic latitude,**
  - **minimum ionization at the magnetic equator**

The Appleton Anomaly Seen from Space

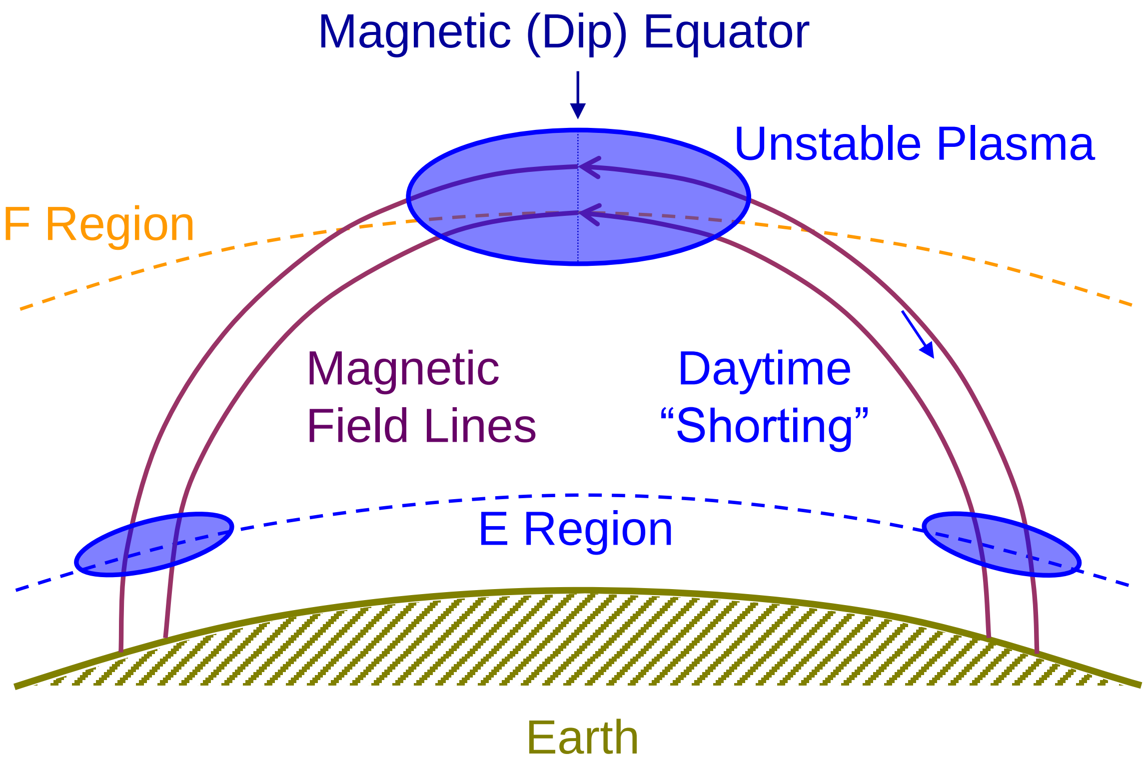
- **Image of the Earth seen from the TIMED satellite (GUVI instrument)**
- **Green line is magnetic equator**
- **Integrated emission proportional to N_e^2**
- **These images are all obtained at the same local time**
- **Black streaks are equatorial Plasma bubbles (EPB), seen on most satellite passes**

- 135.6 nm emission from O^+ radiative recombination



Turbulent Plasma

- Plasma moves easily along field lines
- Upward plasma drift supports plasma against gravity ⇒ unstable configuration
- E-region "shorts out" electrodynamic instability during day
- At night, E-region conductivity too small to short-out E field
- Instability in plasma grows to form bubbles

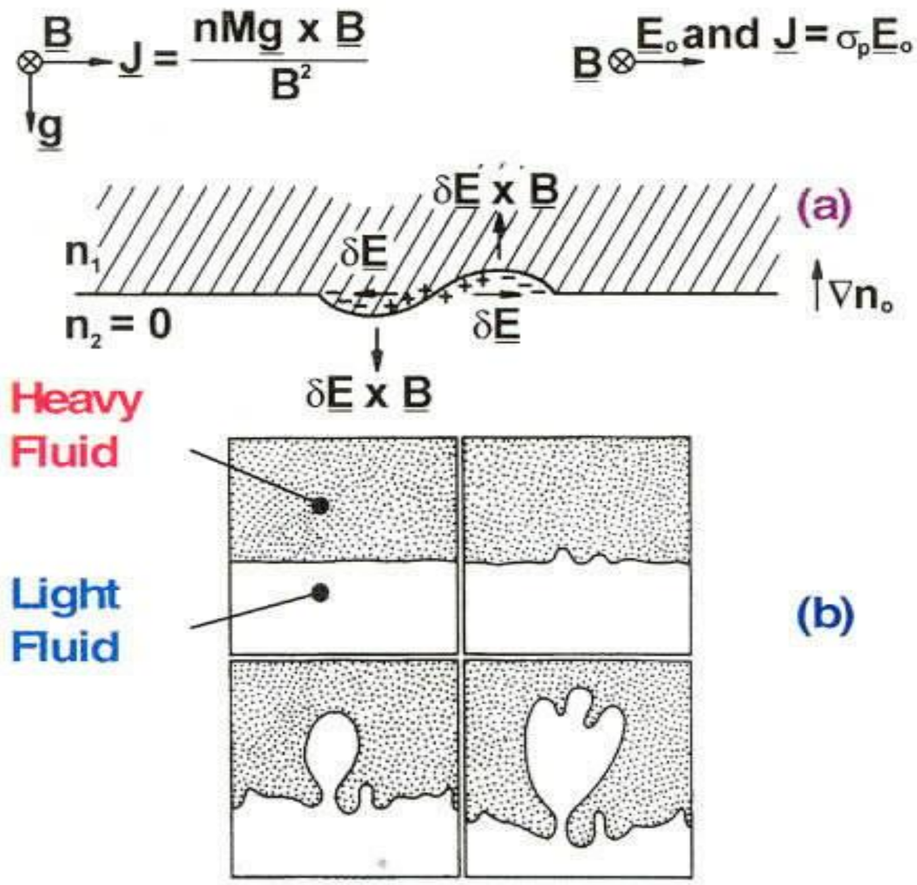


The Rayleigh Taylor Instability

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

The growth rate is function of variables integrated along the magnetic field line.

A small perturbation at the bottom of the F region will grow due to space charges that produce a “positive feedback”.



Generalized Rayleigh-Taylor Instability

Exponential Growth

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

Growth Rate — Electric Field — Neutral Wind — Gravity

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

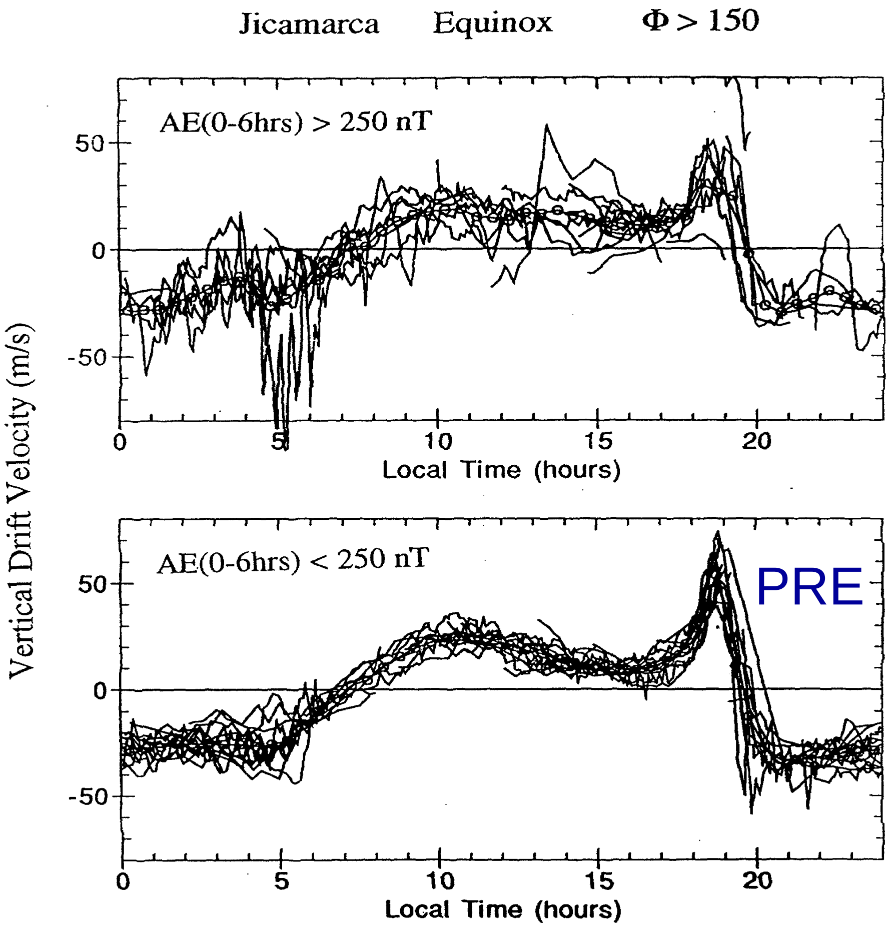
Conductance — Magnetic Field — Log Density Gradient

R-T growth rates are controlled by the variability of E, U_n, Σ_E, Σ_F, ν^{eff}, and through the flux-tube integrated quantities by the height of the F layer.

Forecast ambient ionosphere
Electric-field Pre-Reversal Enhancement

Fejer et al.

- **During daytime E field is eastward → upward velocity (V=E x B/ B^2)**
- **At sunset eastward field may increase (Pre Reversal Enhancement, PRE)**
- **Around 19 LT, E-field reverses to westward**
- **PRE is important driver**
  - **Used for forecasting**

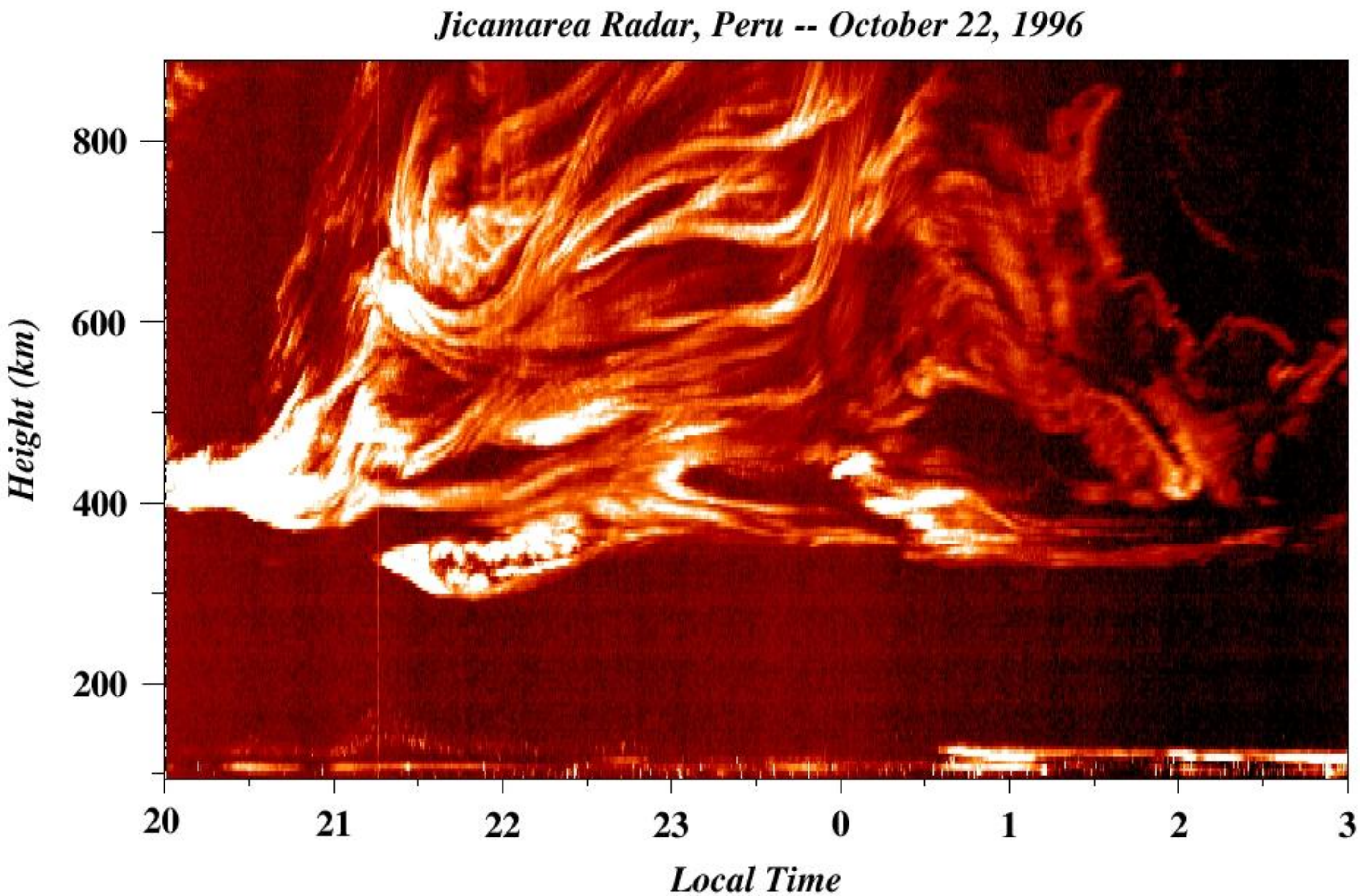


Vertical Ion drift, Jicamarca for active and quiet periods

•Is PRE the only cause of night time irregularities?
• What drives PRE?
• Which parameters control its magnitude?

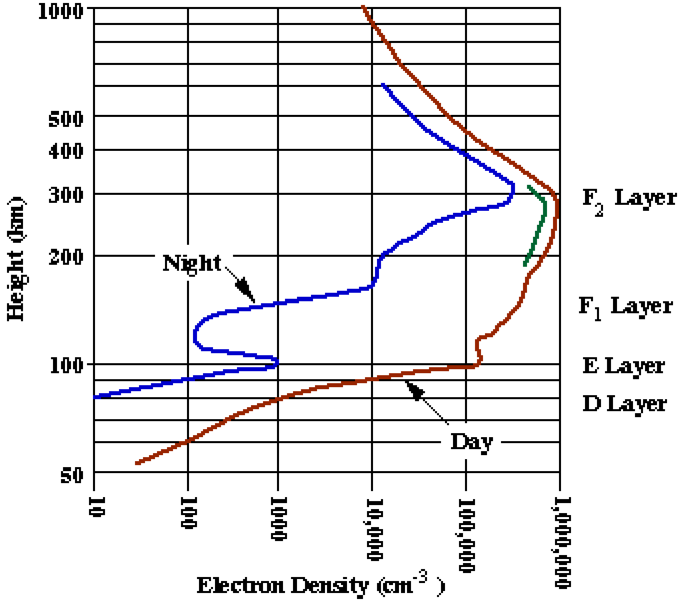
Example of Large Equatorial Bubble

- Irregularities detected with the Jicamarca Radar
- Meter-scale irregularities cause strong backscatter
- Bubbles are spectacular; they rise rapidly, at times reaching 2000 km altitude

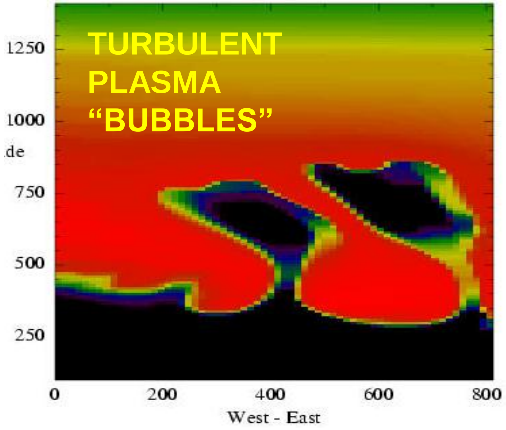


Why do we Care about the Ionosphere?

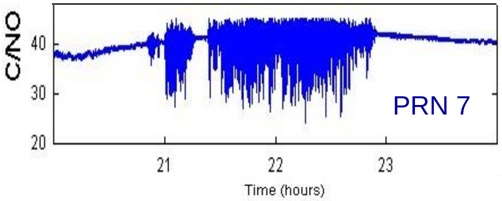
Ionosphere formed by solar EUV/UV radiation



Subject to Raleigh-Taylor instability during day to night transition

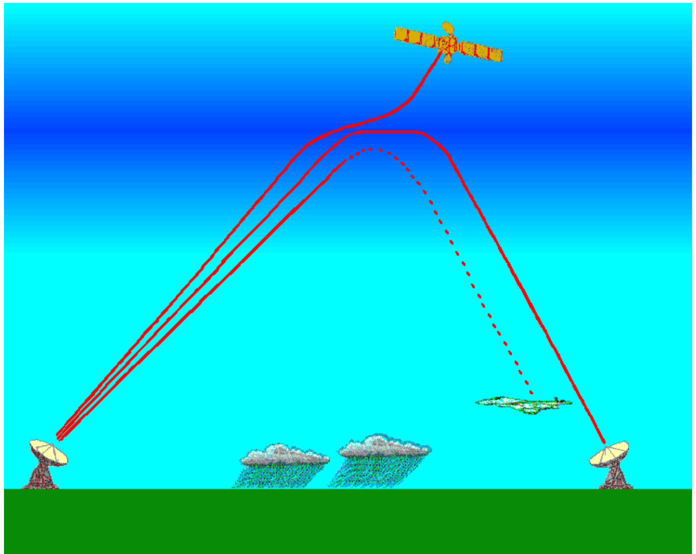


Leads to highly variable reflection/refraction = "SCINTILLATION"



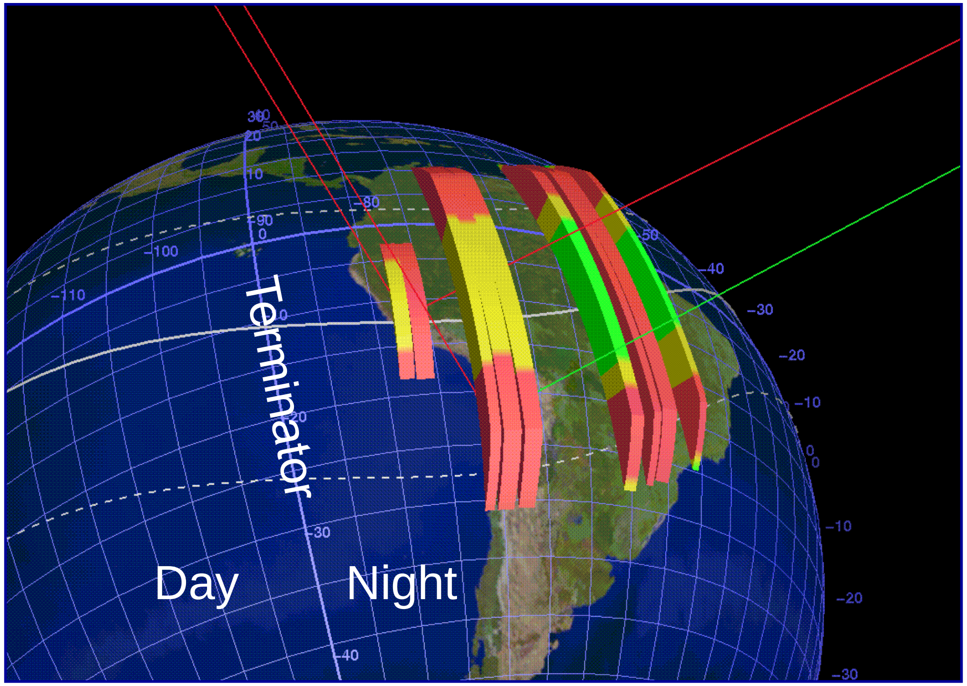
Scintillated GPS Signal

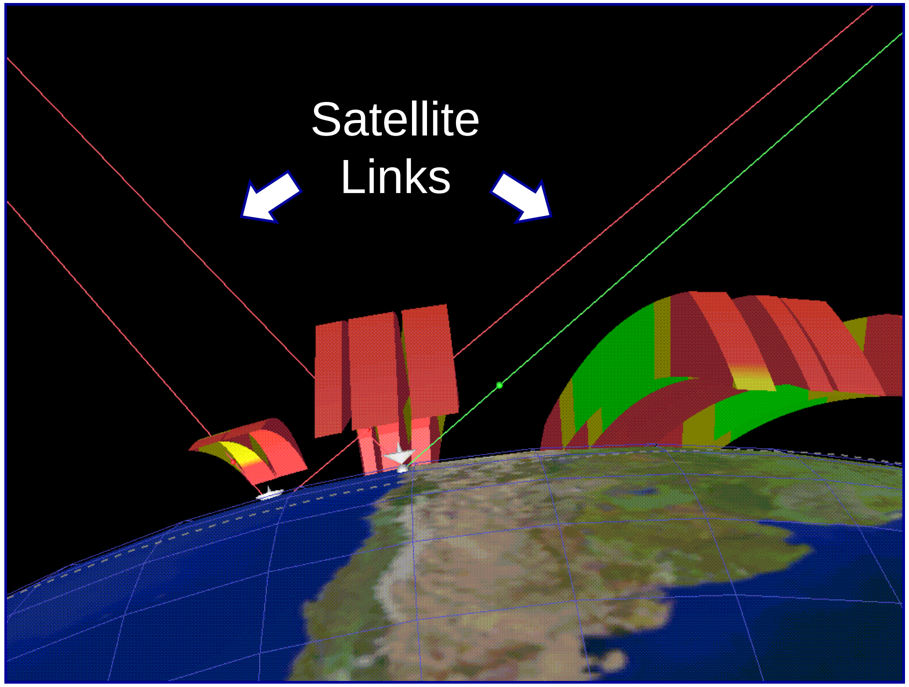
Reflects, refracts, diffracts & scatters radio waves



Why do we Care about Scintillation?

Scintillation prevents communications with satellites





Scintillation Strength

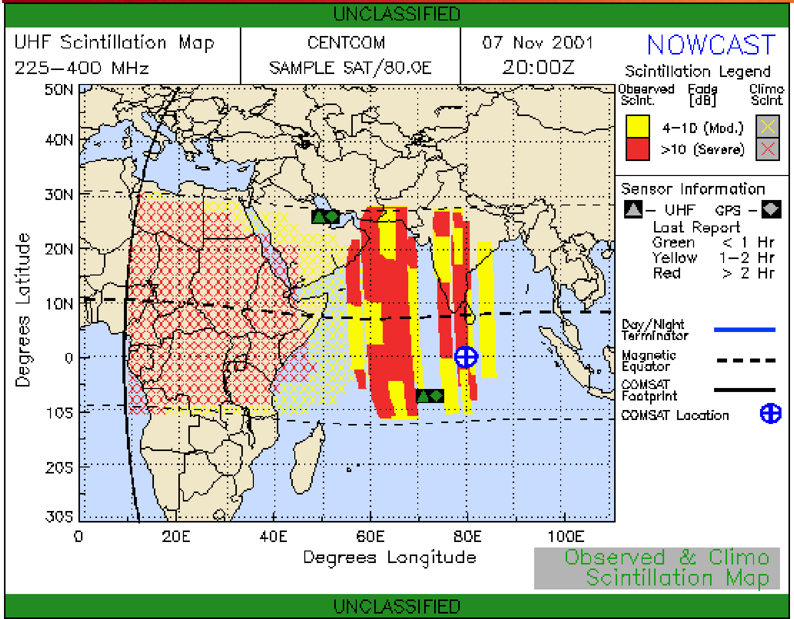
SEVERE MODERATE WEAK

SCINDA = Scintillation Network Decision Aid
(AFRL-developed system)

Communication is impossible when large irregularities are present between receiver and transmitter

Why do we Care about Scintillation?

- Global Positioning Satellite (GPS) relies on transmissions at GHz frequencies
  (L band, 1066 GHz)
- GPS signal is affected by L Band scintillation
  - Effect is max in equator regions
- Many systems depend on GPS
  - Aviation (FAA)
  - Navigation
  - Timing
  - Many more
- Scintillation at lower freq affects communications with geo satellites
- Ex of scintillation operational product illustrated to the right

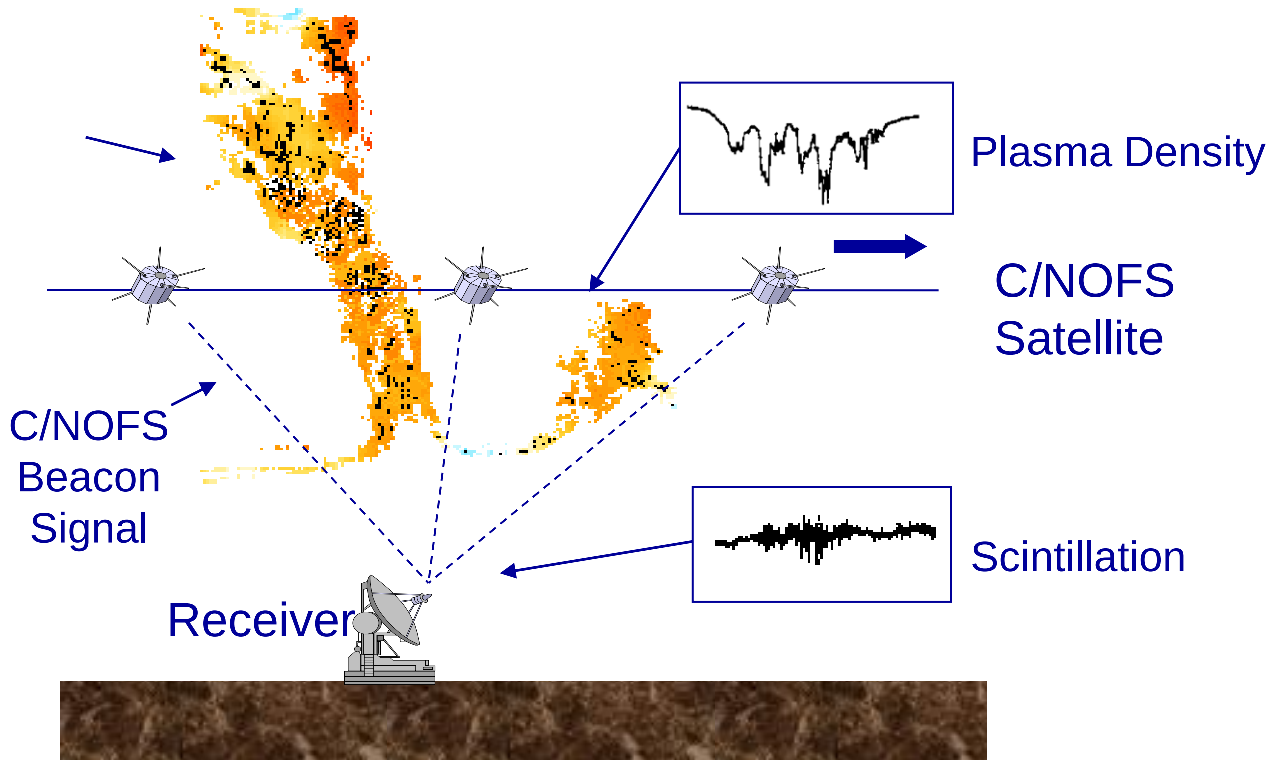


Communication/Navigation Outage Forecasting System

C/NOFS

First-ever system for continuous global scintillation forecasts of communication and navigation outages

- *Satellite*
- *Ground-based instruments*
- *Models*
- *Data center*



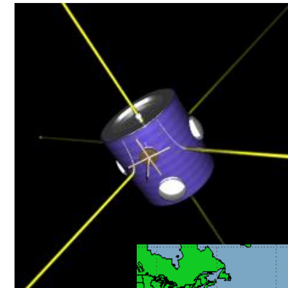
C/NOFS Goals

• **Provide ionosphere and scintillation nowcast**

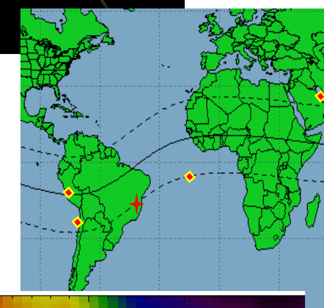
• **Develop capability to produce:**

- **Ionosphere and scintillation forecasts (4-6 hrs)**
- **Long term outlooks (24-72 hrs)**

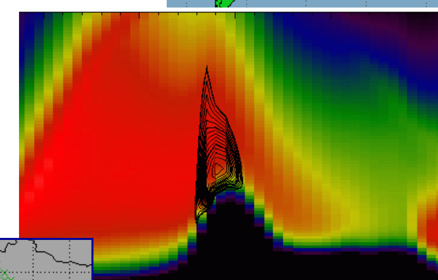
• **Develop improved understanding of equatorial ionosphere and scintillation triggers / inhibitors**



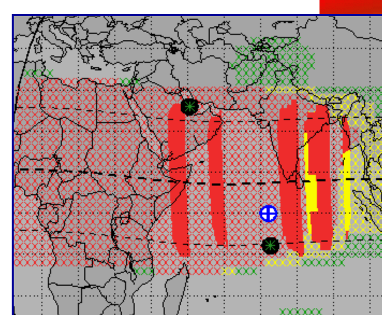
Satellite System



Ground Based Sensors



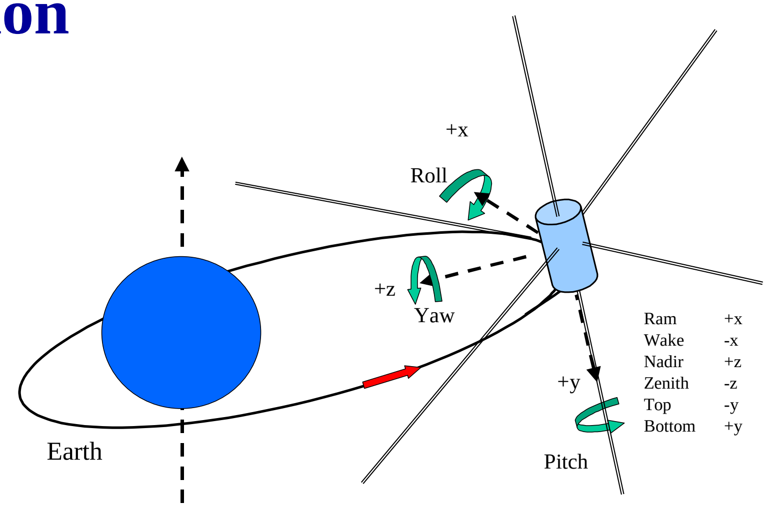
Forecast Modeling



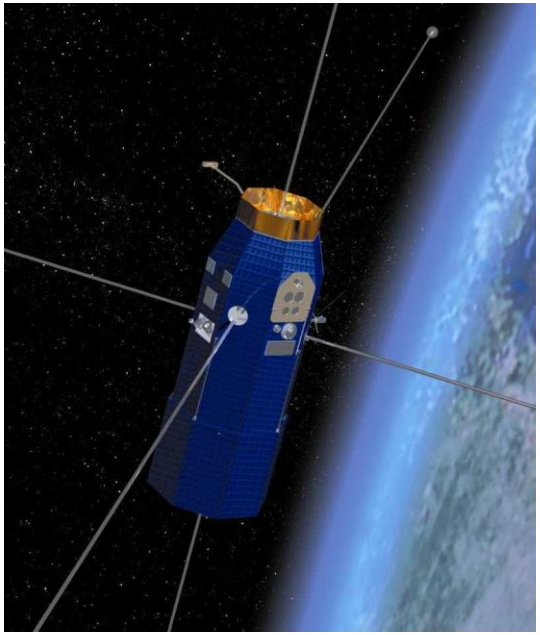
Scintillation regions

C/NOFS Mission Components

- **Satellite – low altitude / low inclination**
  - Inclination: 13 deg
  - Perigee/ Apogee: 400 and 800 Km
  - Orbital Period: 96 min/rev
  - TDRSS transmitter for near-real-time downlink



- **Launched**
  - April 2008
  - Dedicated Pegasus XL launch



- **Ground-based component:**
  - Scintillation and beacon receivers
  - Other Ground-based instruments

Payload Description
Six Instruments

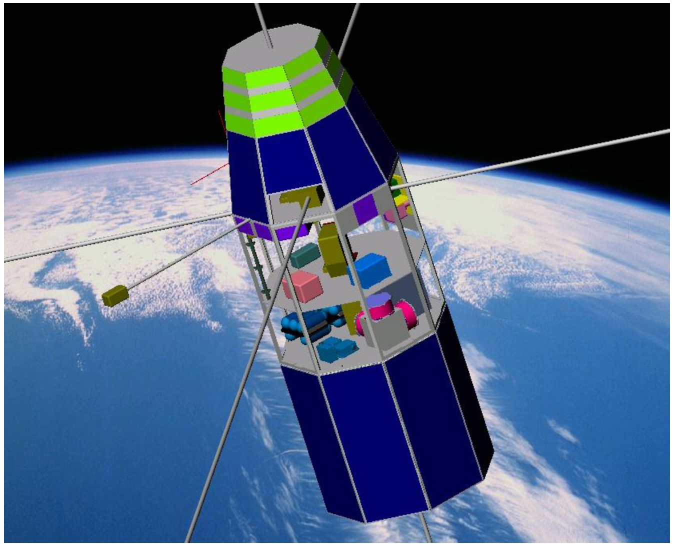
GPS Receiver

C/NOFS Occultation Receiver for Ionospheric Sensing and Specification (CORISS)

- Developed by Aerospace (P. Straus PI)
- Measures: Remote sensing of LOS TEC

Planar Langmuir Probe (PLP)

- Developed by AFRL/VS (D. Hunton PI)
- Measures: Ion Density, Ion Density Variations, Electron Temperature



Electric Field Instrument

Vector Electric Field Instrument (VEFI)

- Developed by NASA/GSFC (R. Pfaff PI)
- Measures: Vector AC and DC electric as well as magnetic fields
- Includes lightning detector

Ion Velocity Meter (IVM)

- Developed by Univ. of Texas Dallas (R. Heelis PI)
- Measures: Vector Ion Velocity, Ion Density, Ion Temperature

Neutral Wind Meter (NWM)

- Developed by Univ. of Texas Dallas (G. Earle PI)
- Measures: Vector Neutral Wind Velocity

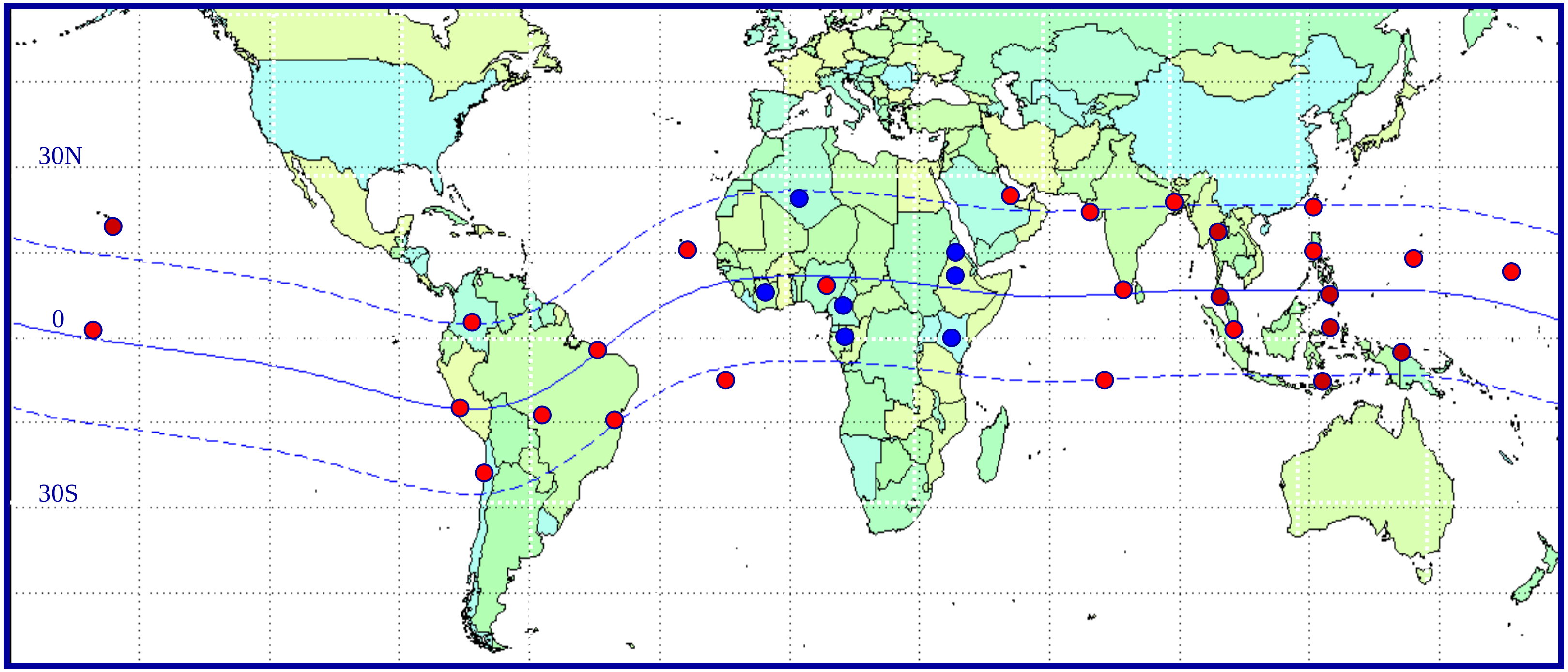
RF Beacon

Coherent EM Radio Tomography (CERTO)

- Developed by NRL (P. Bernhardt PI)
- Measures: Remote sensing of RF scintillations and LOS TEC

Equatorial Scintillation Ground Stations

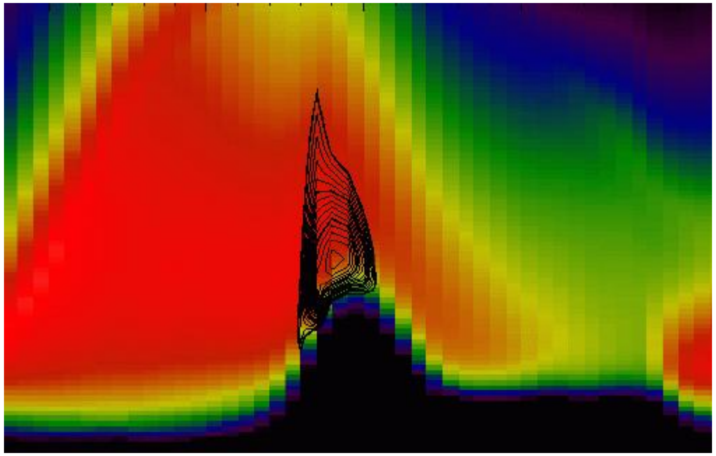
SCINDA Ground Stations

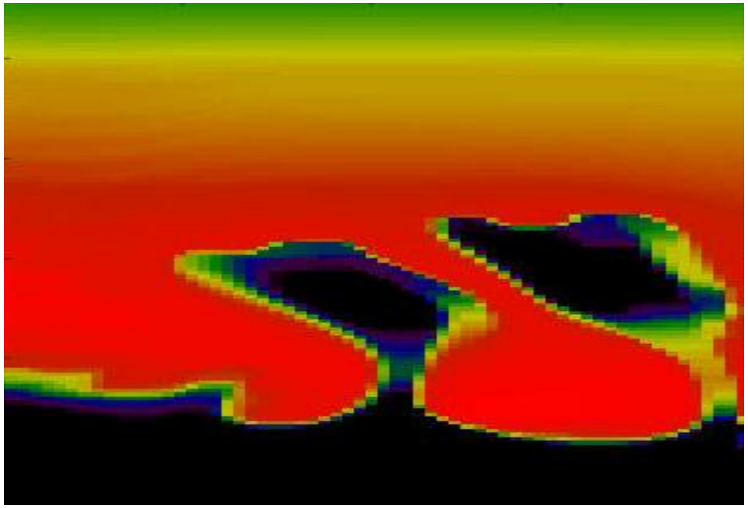


Several stations provide real-time scintillation data at 140, 250 MHz (between Earth and Geo satellite)
+ scintillation at L band with GPS

C/NOFS Forecasting Tasks

1. Forecast ambient ionosphere
   - Calculate E-field
   - Calculate other drivers
   - Derive global N_e
2. Derive linear growth rate
3. Calculate non-linear plasma irregularities evolution
4. Calculate irregularities spectral index
5. Derive scintillation indices
6. Where possible, reconcile model and observations of scintillations
7. Produce maps of scintillation



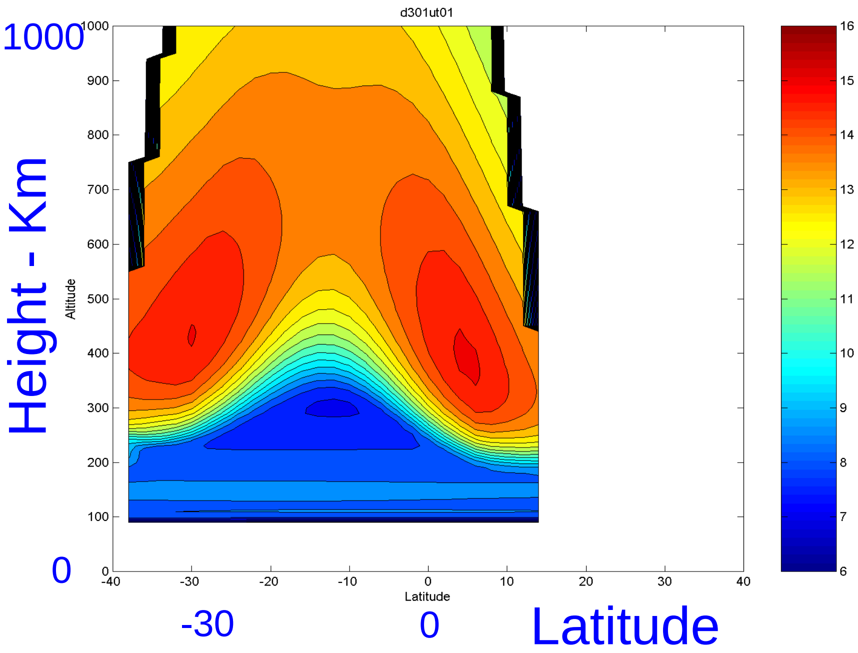


Retterer et al.

Forecast Ambient Ionosphere

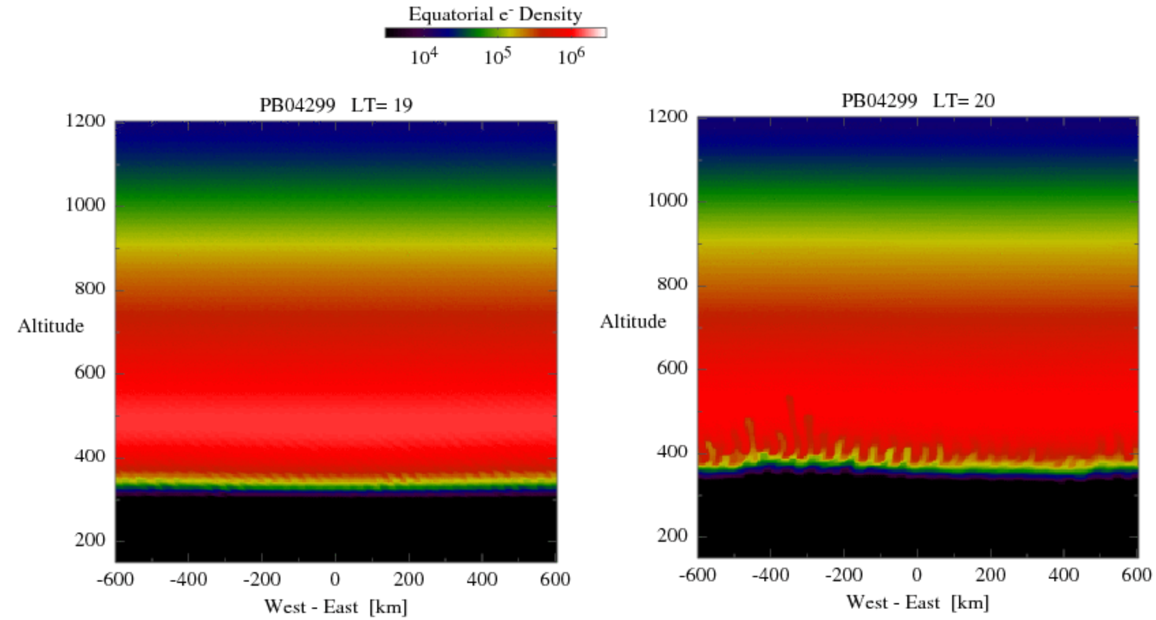
- **C/NOFS Physics-Based Model (PBMod) Ionospheric model derives & forecasts ambient ionosphere and scintillation index**
  - **PBMod ingests ion drifts and winds**
  - **Produces 3-D electron density profiles**
  - **Estimates RT growth rate**
  - **Launches separate instability model**
  - **Derives scintillation index**

Oct 28,2003, 01UT



N_e profiles from C/NOFS model showing Appleton anomaly at 19 LT

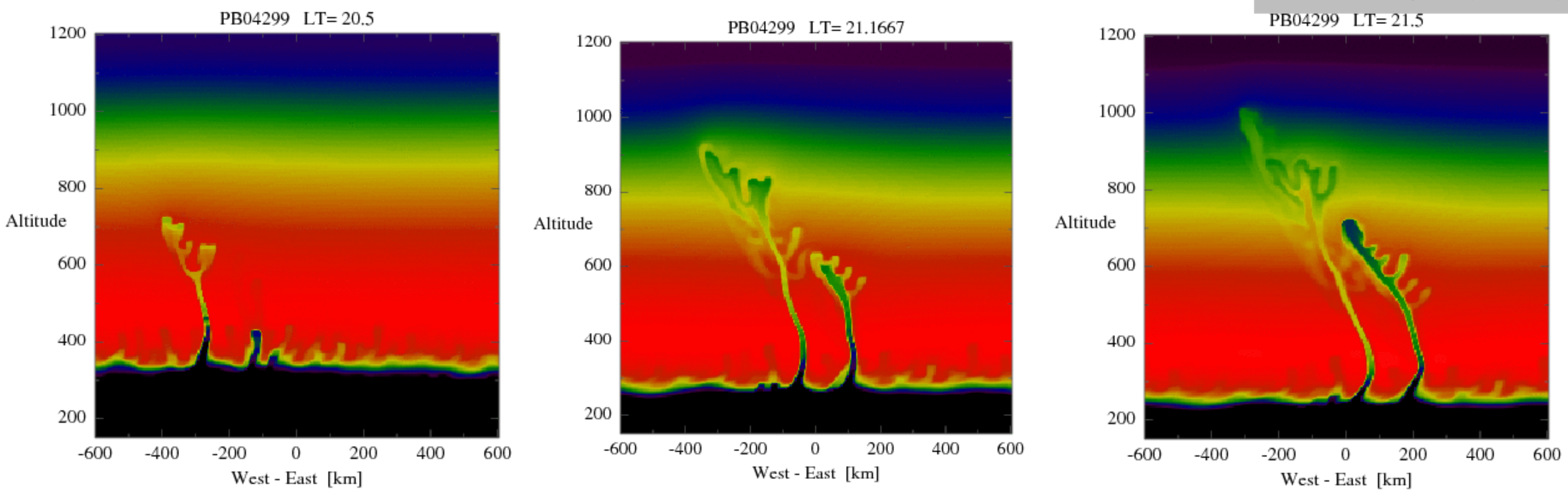
C/NOFS Physics-based Model (PBMod)
Birth and Growth of Equatorial Bubbles



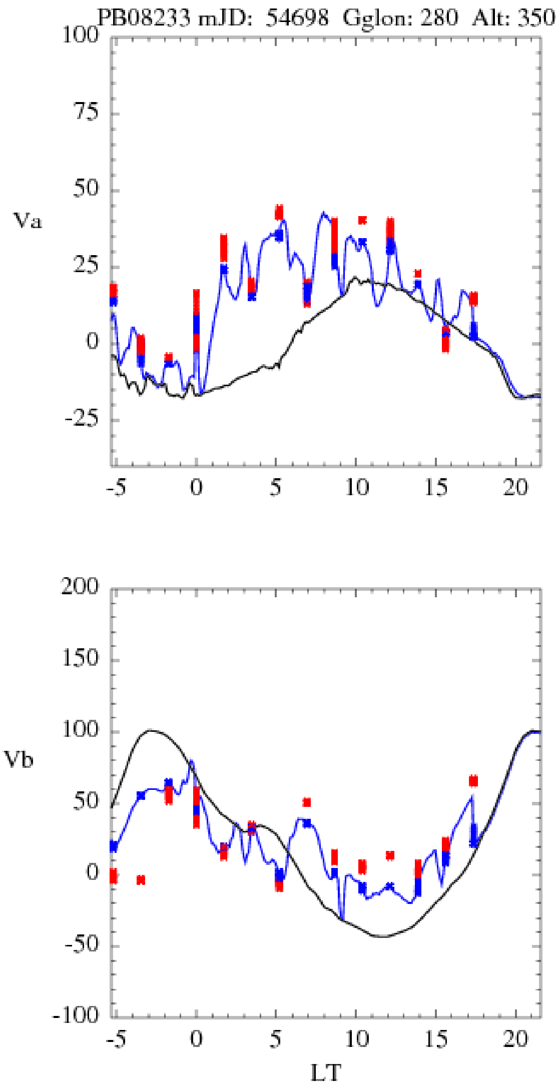
PBMod snapshots of plasma density by altitude and longitude at five local times in the equatorial plane

- **C/NOFS encounters bubbles at all stages of development**
- **Explains enhanced density C/NOFS observes when flying above depletions**

Retterer (2004, 2010a,b)



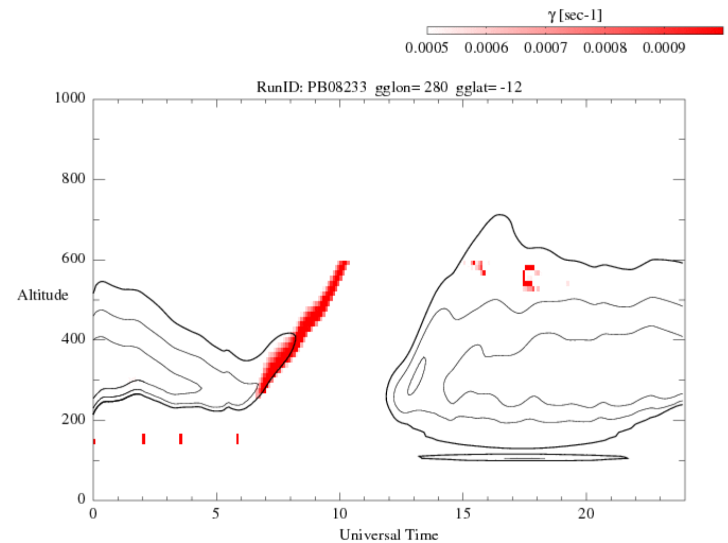
PBMOD simulation

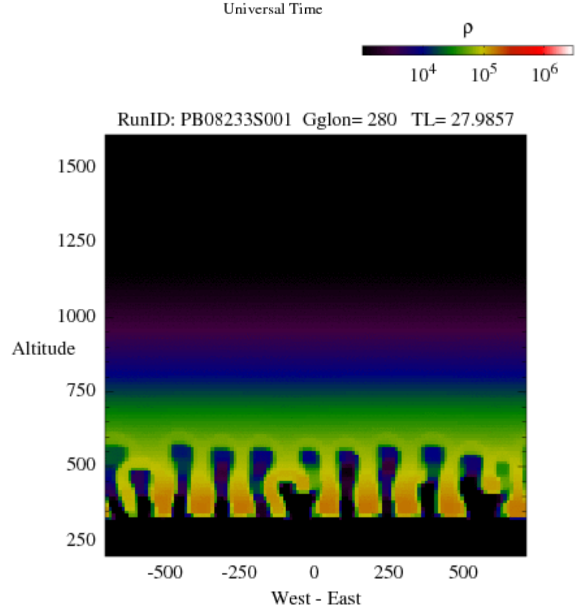


Given plasma drifts, PBMOD can explain observations

But why do drifts occur at the time they do?

(see Retterer's presentation)



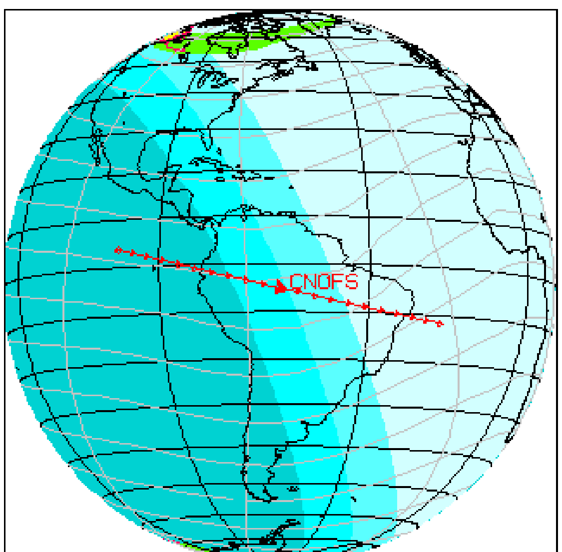


C/NOFS Observations During Deep Solar Minimum

- **C/NOFS provides unique opportunity to study the ionosphere during the lowest solar minimum in 100 yrs**
- **Pre-reversal enhancement in upward drift rarely seen**
- **Most plasma irregularities are observed after midnight**
- **Unforeseen deep plasma minima often present at dawn**
  - **One type caused by upward drifts**
  - **Other type cased by downward drifts maximizing at 05-06 LT**
- **Tidal effects often predominant**
- **Even relatively small changes in solar wind and Dst have large effect in nighttime ionosphere and can produce intense irregularities**

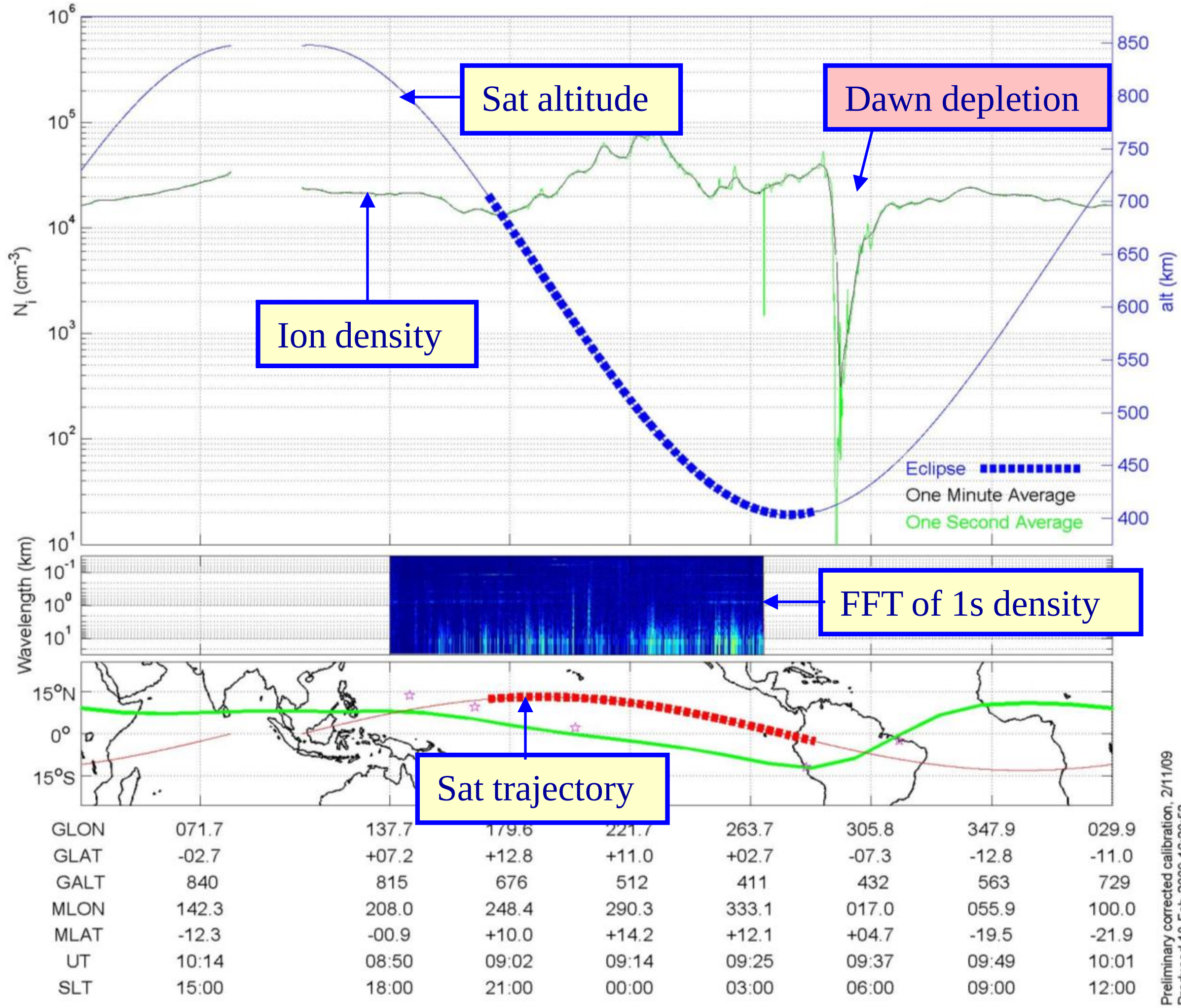
Dawn N_e Depletion

- **Example of N_e dawn depletion at 05 LT**
- **Just before the E-region sunrise**
- **Unexpected result**



Time: 2008/169 17 Jun 09:35:00 Sunlit

PLP data, 17Jun 08, orbit 915



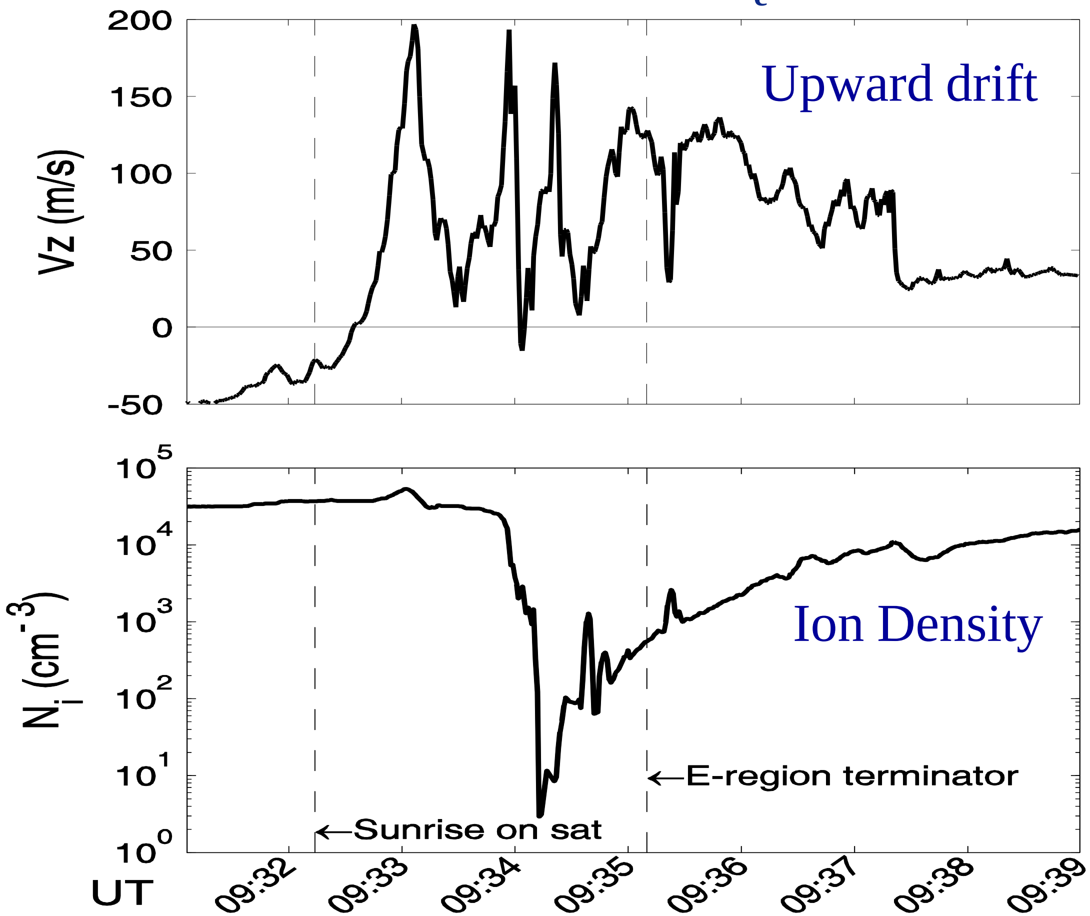
From de La Beaujardière et al., GRL, 09

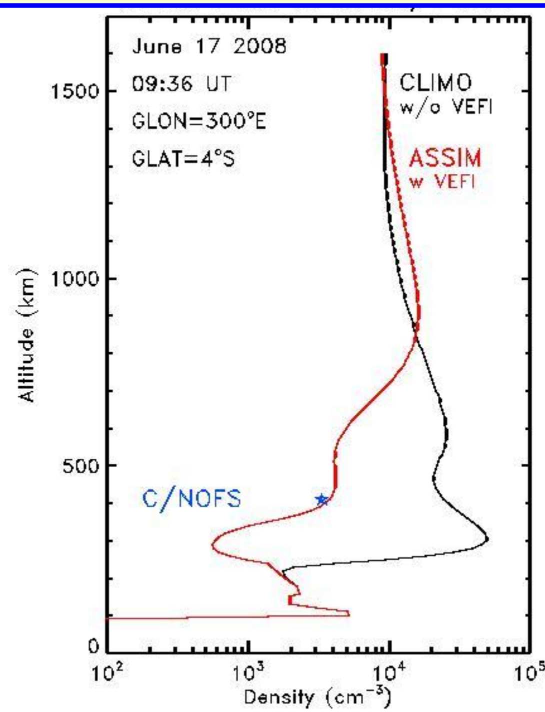
Dawn Depletion
Close-up & Modeling

N_e and V_i – close up around the dawn depletion

- Intense, short spikes in upward drift seen before depletion & on its west wall
- Measured V_i from several orbits assimilated into model
  – Results match observed N_e

Model N_e profile assimilating actual E-field provides better results than assimilating average E

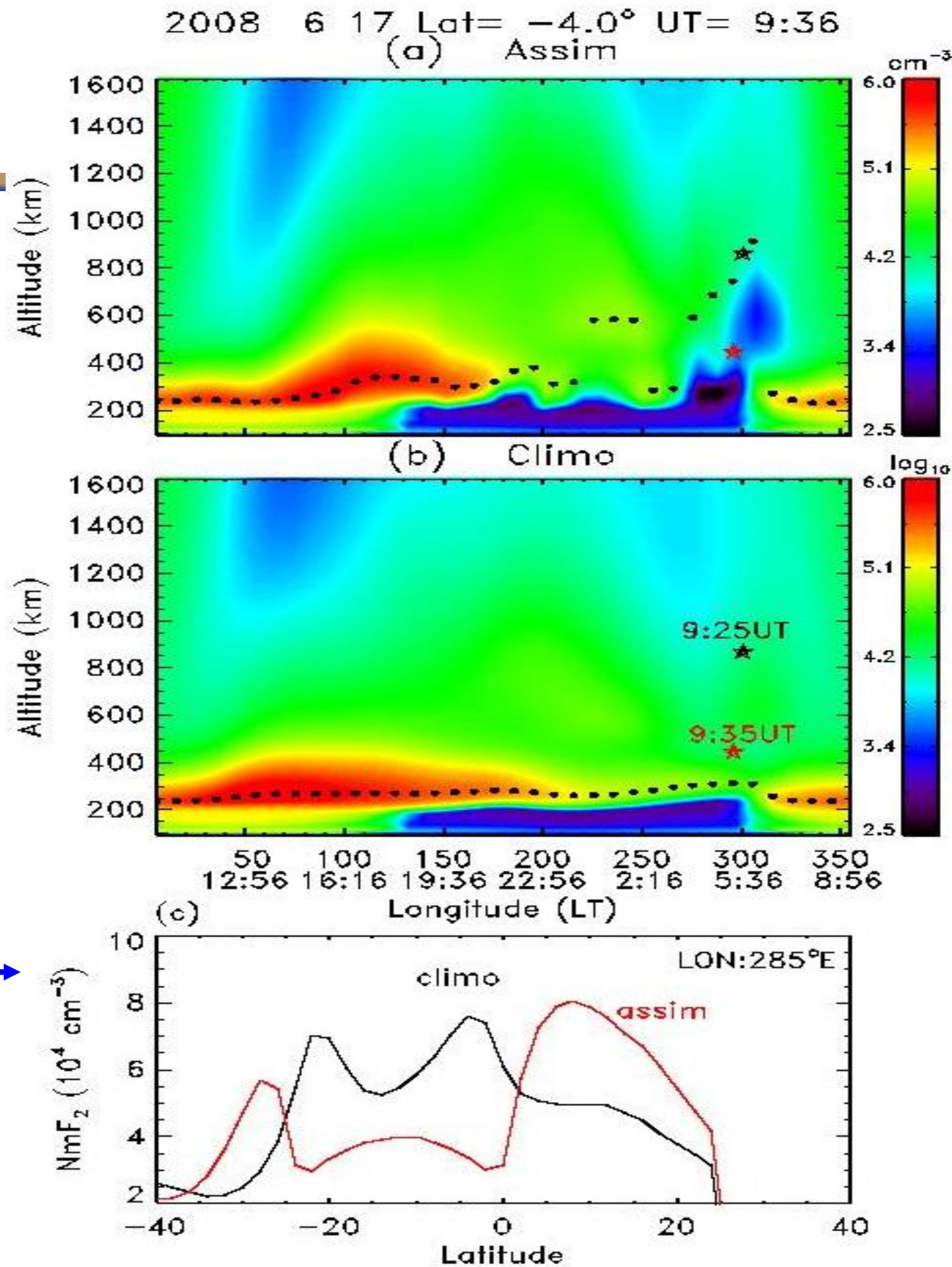




17 Jun 08, orbit 915
Dawn depletion caused by upward plasma drift
First type of Dawn Depletion

Modeling Dawn Depletion

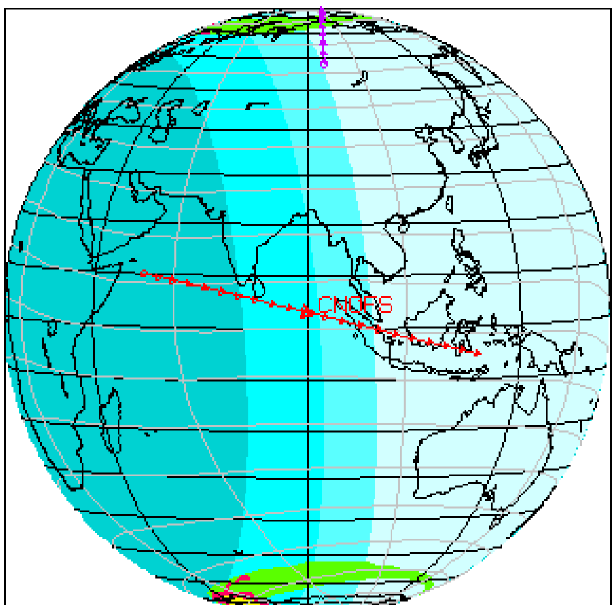
- **C/NOFS model, PBMod, 17Jun 08**
  - **EDP (color)**
  - **Height of F-region max (black dots)**
- **Top: Model assimilates the E-field data** →
- **Altitude of the peak density is above 900 km during the early morning**
- **Middle: Model uses climo for E-Field - drastic difference: $H_m f_2$ remains low, no depletion** →
- **Bottom: Latitude variation of max ionospheric density ($N_m f_2$)** →
  - **Calculated with and without actual E-Field values**
  - **C/NOFS model matches observations of coincident C/NOFS & DMSP passes**



From Su et al., GRL, 09

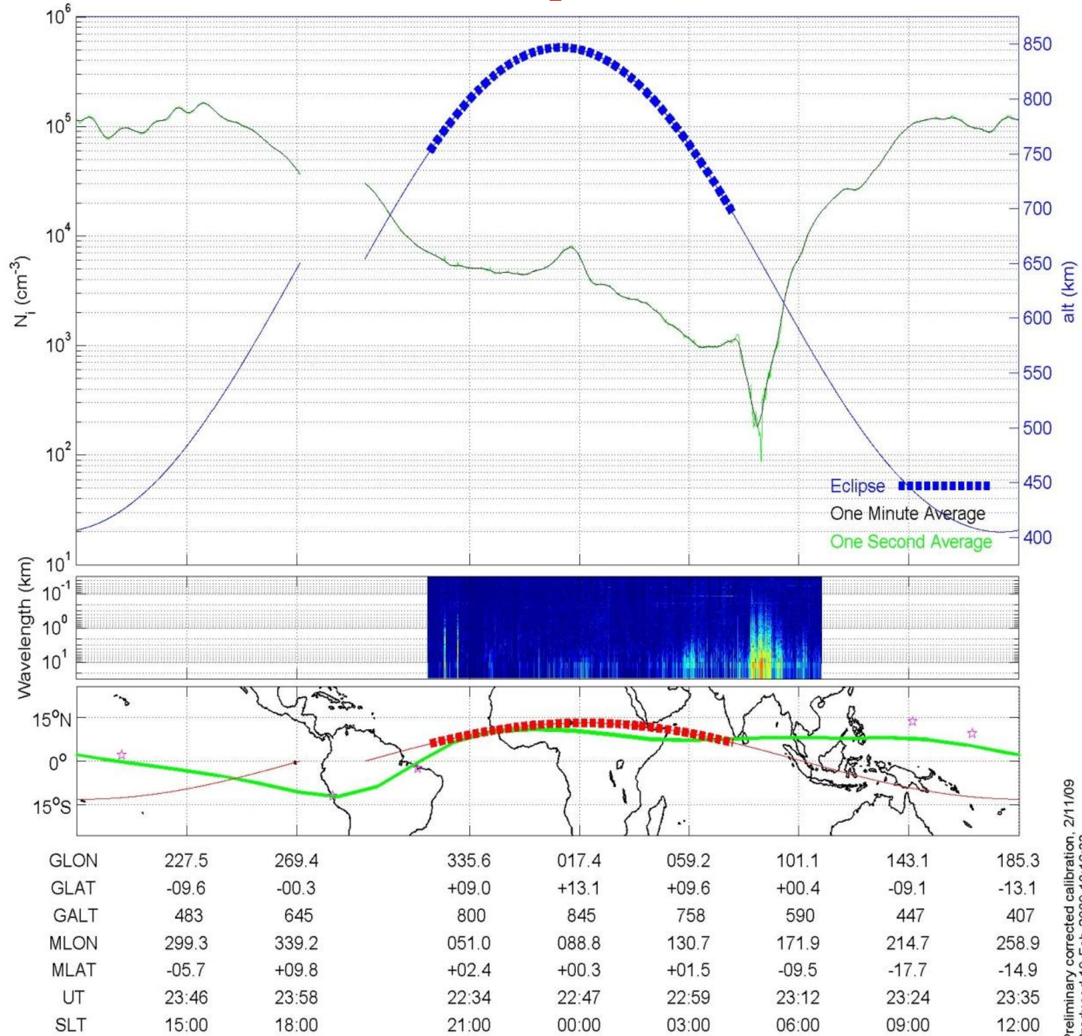
Dawn Depletion Size

- **Coincident CHAMP & C/NOFS dawn depletion**
  - C/NOFS alt = ~ 670 km
  - PLP sees dawn depletions at all altitudes
  - E-W width ~ 14 deg



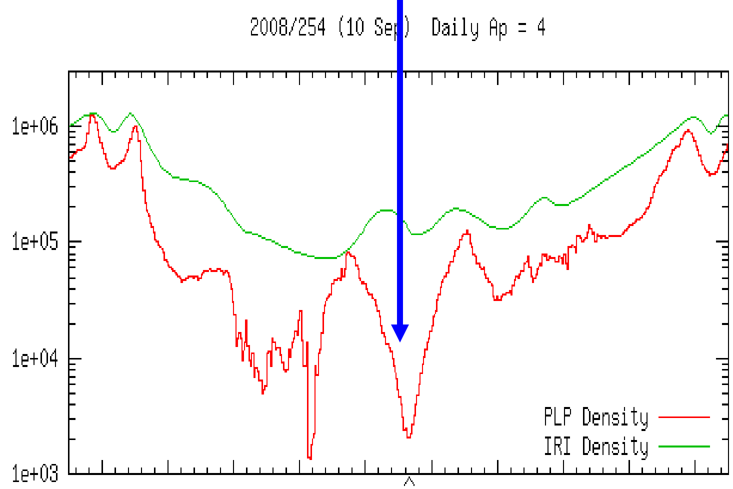
Time: 2008/254 10 Sep 23:09:00 Sunlit

PLP data, 10 Sep 08, orbit 2185



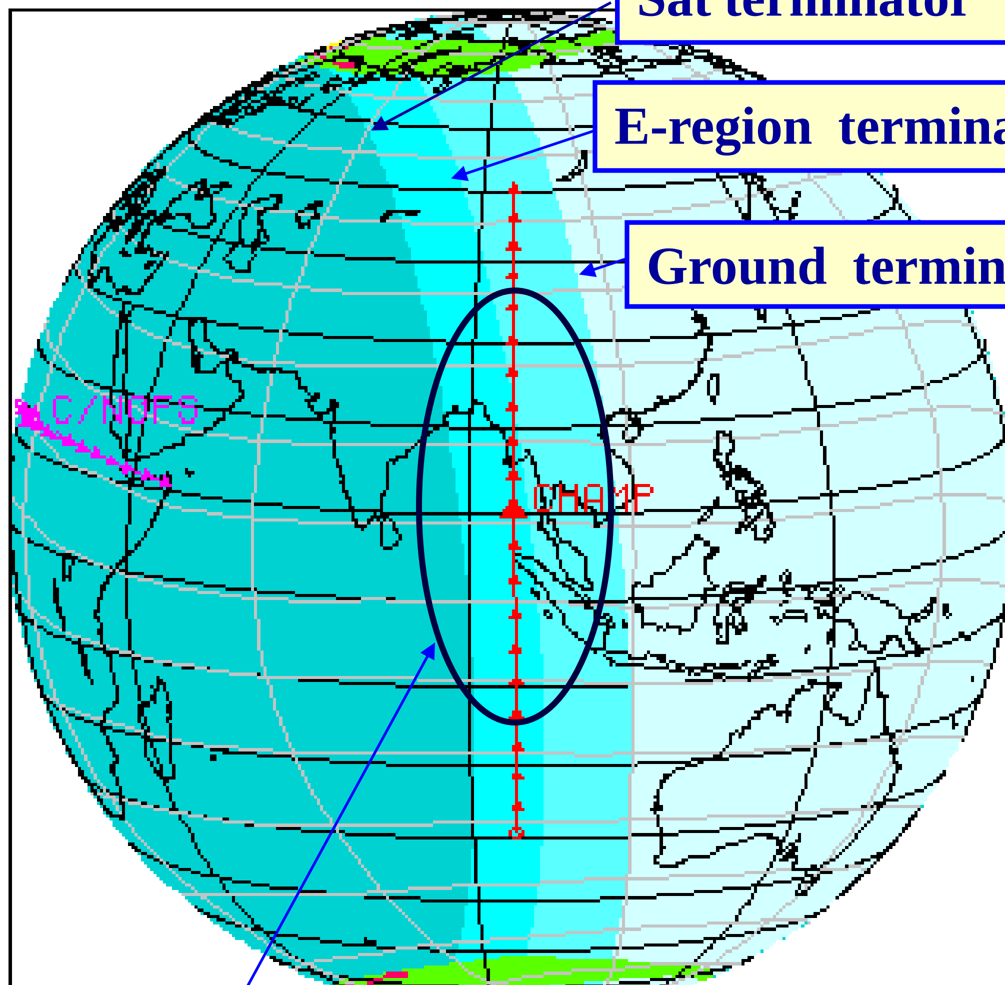
Dawn Depletion Size

- **CHAMP, polar sat**
  - **Alt = 350 km**
  - **Champ & C/NOFS ~ coincident**
- **CHAMP shows deep & wide N_e depletion at equator**



UT	22:00	22:10	22:20	22:30	22:40	22:50	23:00	23:10	23:20	23:30
GLAT	-5.1	-44.7	-83.5	-56.6	-17.2	22.6	62.1	78.1	38.9	-0.8
GLON	286.7	286.7	306.4	94.8	95.6	95.1	96.7	255.7	264.2	263.9
ALT	329.1	343.1	354.4	347.6	331.9	327.1	334.4	336.9	329.8	328.3
MLAT	8.0	-29.7	-67.3	-69.3	-28.7	14.8	56.8	84.9	49.6	8.5
MLON	357.5	0.2	17.1	144.7	165.0	166.3	168.9	275.1	330.1	333.7
MLT	17.16	17.52	18.82	3.50	5.03	5.29	5.63	12.88	16.71	17.12

From de La Beaujardière et al., GRL, 09

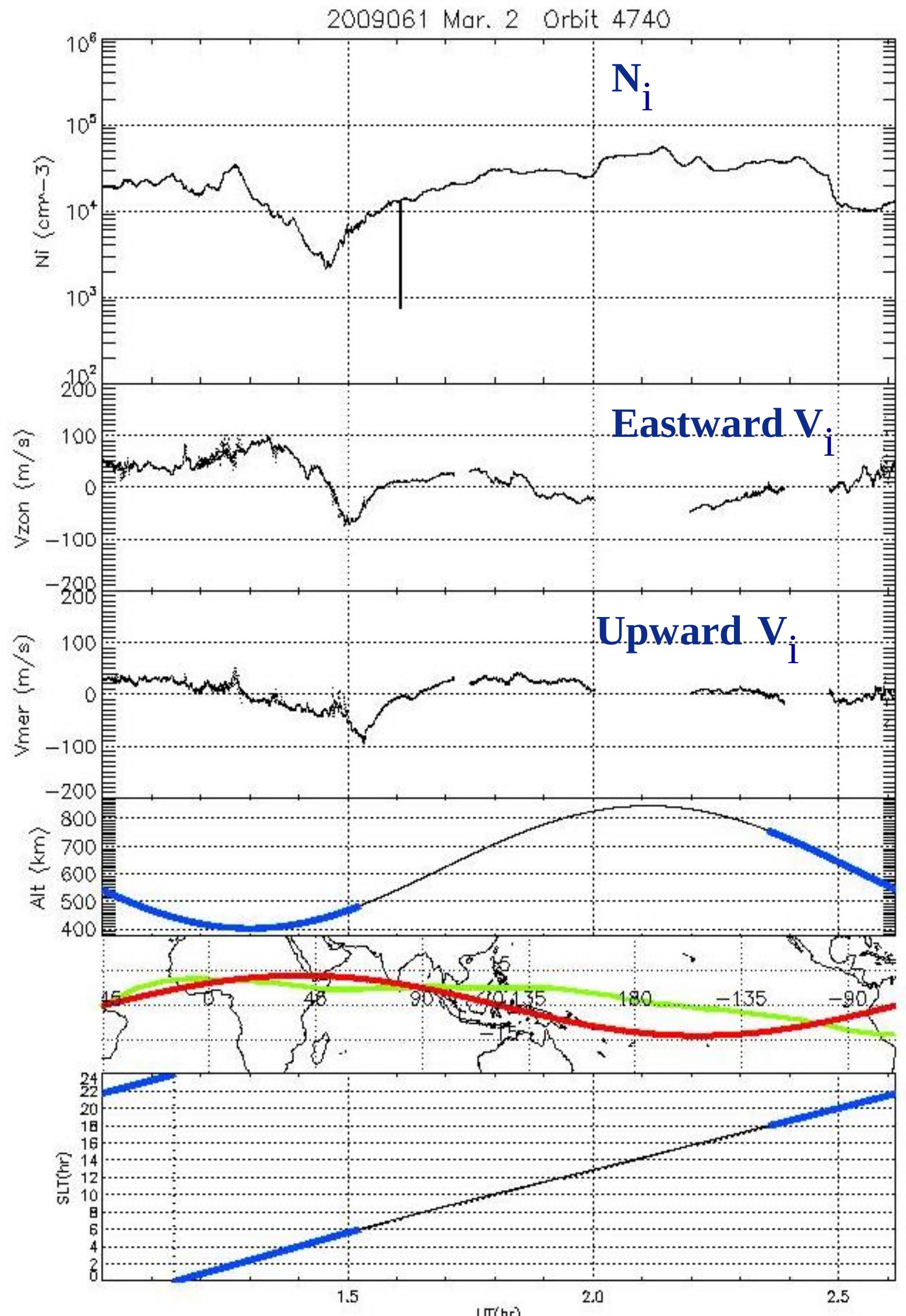


Depletion forms at E-region terminator
Size ~ 50 x 14 deg

Dawn Depletion Associated with Downward Ion Drift

- **Decrease in density over wide longitude span**
  - **Here, long width ~33º can reach 50º**
- **Density decrease associated with downward drift.**
- **N_e decrease possibly due to lowering of the F-region peak**
- **In numerous cases we have:**
  - **Minimum in N_e at dawn (~05 LT)**
  - **Minimum in V_i occurs later (~06 LT)**
  - **In June minimum in V_i occurs ~05LT**

Example of second type of dawn depletion, 2 Mar 09
Associated with downward V_i
Wider in longitude than those associated with upward V_i

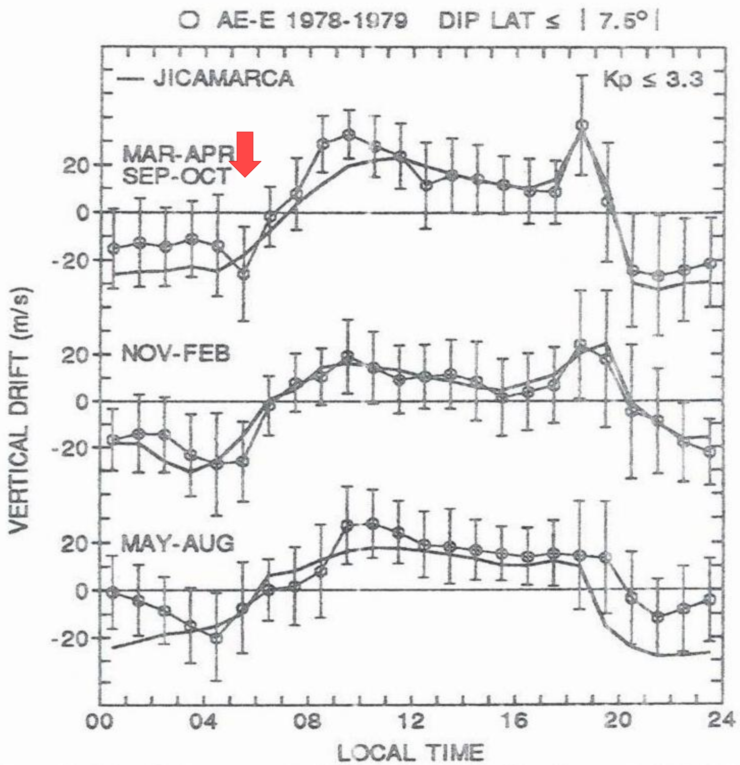


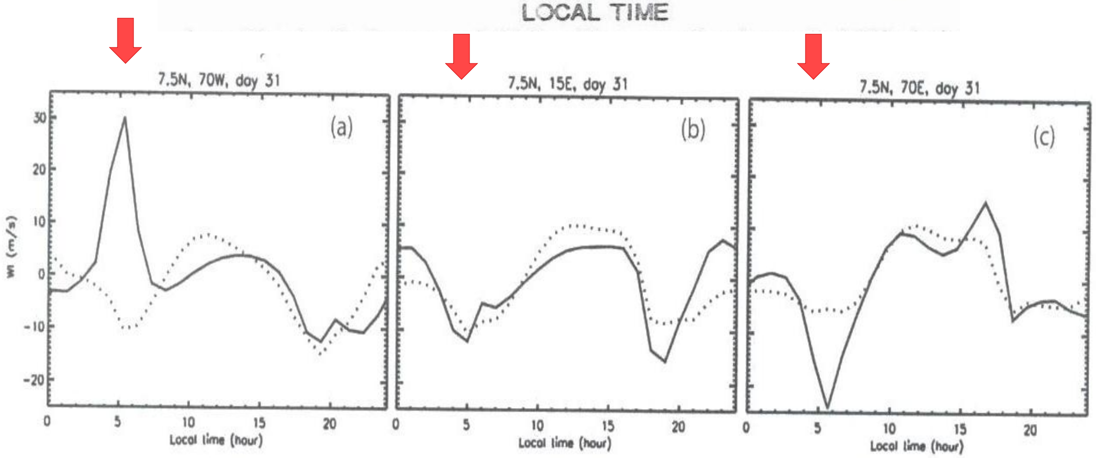
Vertical Drifts Associated with Dawn Depletions

Other models & data related to Ne & drifts at dawn:

- Fejer's model shows minima in upward drift at 5 or 6 LT, depending on season
- See also Eccles (1998) model

- Liu et al. (2010) introduce a quasi stationary planetary wave in model
  - Show that upward drift at dawn is either up, small and down, large and down, depending on longitude

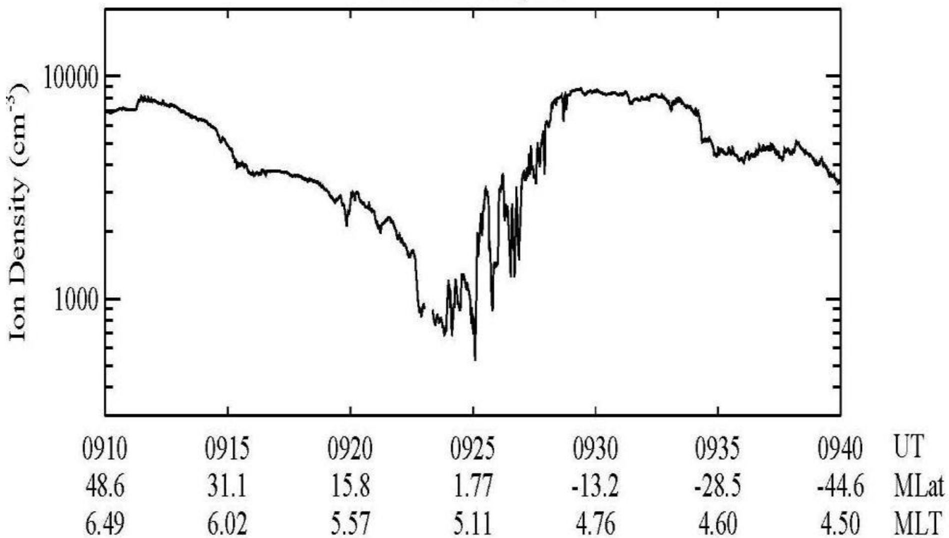




Dawn Depletions Variation with Lat, Long, Season, LT

- **Longitudinal dependence:**
  - Frequent over Africa, America & Asia
- **Seasonal dependence:**
  - From 10 to 15 Sept 08, PLP minimum at dawn seen in 77% of C/NOFS orbits
  - From 1 to 6 Nov, only seen in 15%
- **Local time dependence:**
  - Maximum frequency around 5 am
  - Occur above E-region terminator
- **Latitudinal dependence:**
  - Wider in latitude than in longitude
- **Seen in polar satellites**
  - CHAMP at 325 Km alt
  - DMSP at 840 Km
- **Often associated with plasma irregularities**

Ion density from DMSP F17, 17 Jun 09



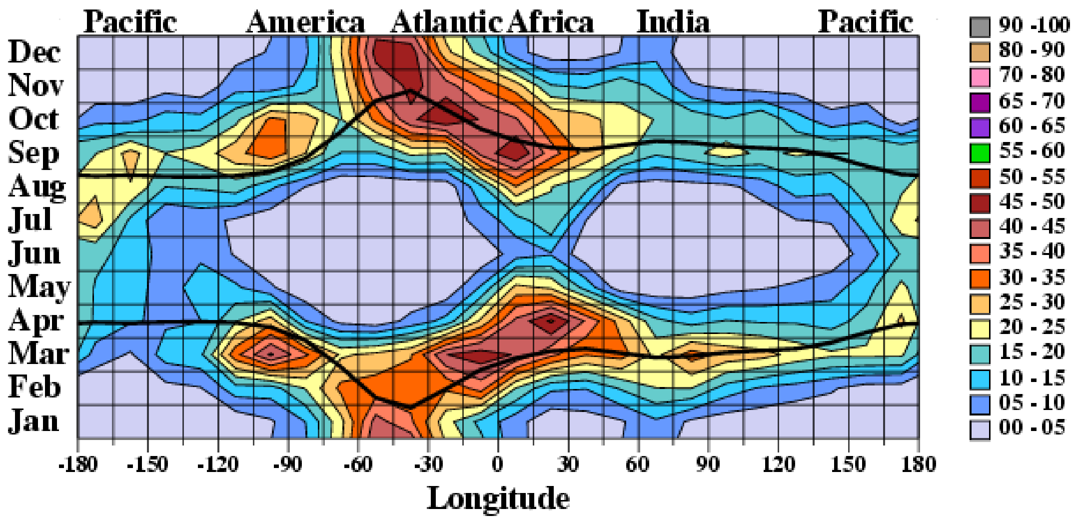
From de La Beaujardière et al., GRL, 09

DMSP EPB Climatology

Evening Sector -- Solar Max vs. Solar Min

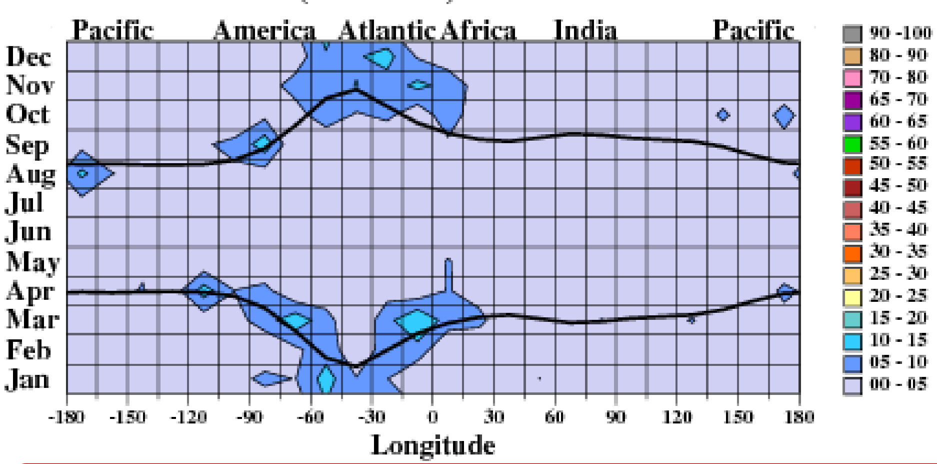
DMSP solar max EPB climatology confirms Tsunoda's 1985 model

DMSP EPB Rates 1999 - 2002

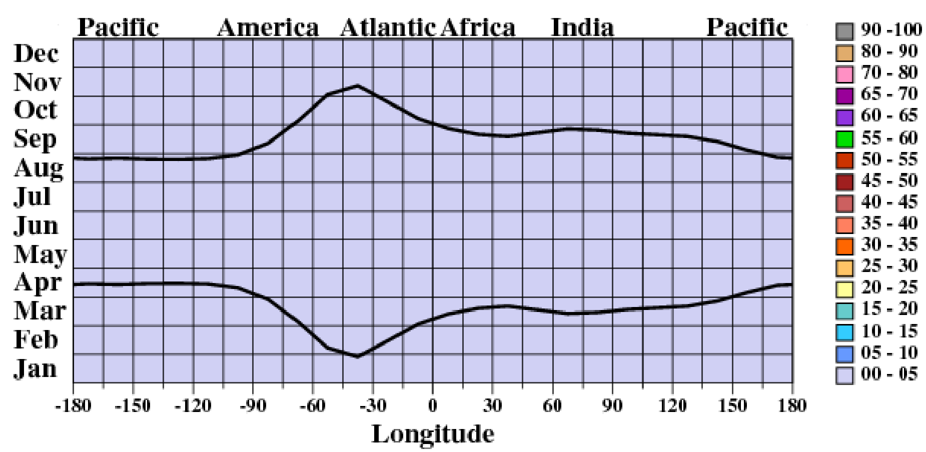


Most EPBs occur in Atlantic-Africa sector and when terminator aligned with magnetic field

DMSP F12 (21.4 LT) EPBs 1994-1997



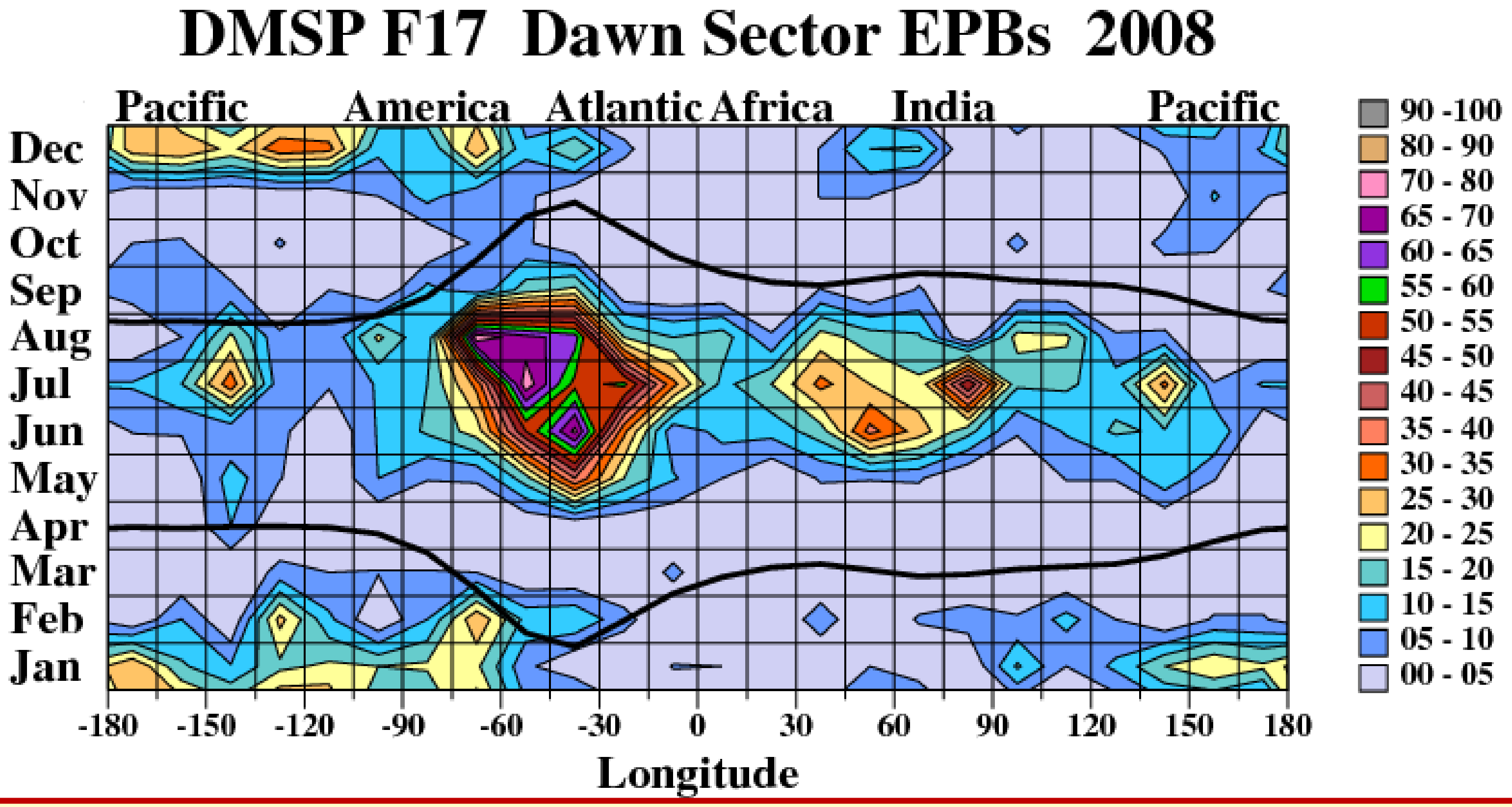
DMSP F15 and F16 EPBs 2007



Solar min climatology sparse, but consistent

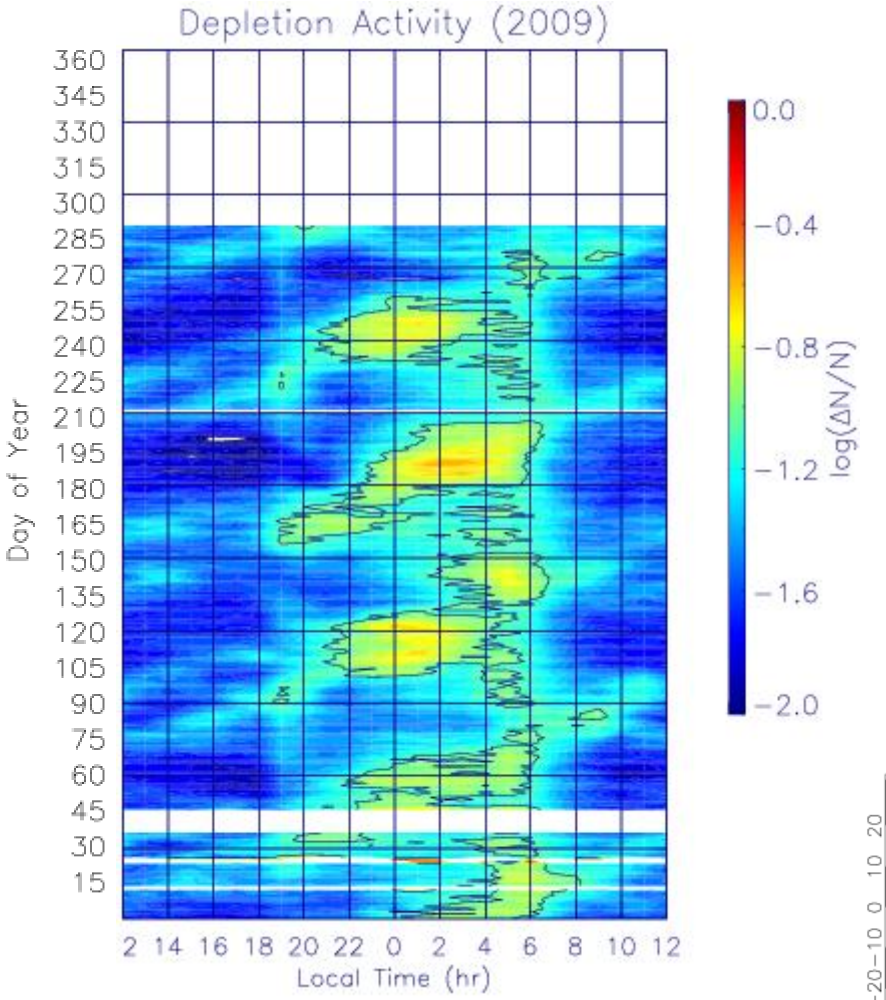
This solar min is the lowest yet!

DMSP EPB Climatology
Dawn Sector during Solar Min



DMSP F17 dawn sector EPB rates for 2008 at 5:30 MLT are dramatically different from any evening sector observations. Maximum rates (~ 70%) occur around the June solstice in the America-Atlantic sector. Rates are moderate (~ 30%) in the Pacific around the December solstice, and extremely low (< 10%) when the magnetic field is aligned with the terminator.

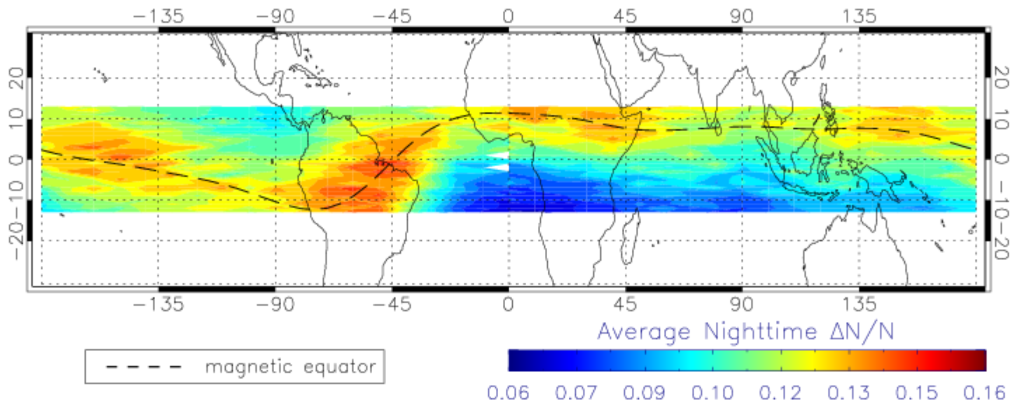
Climatology of C/NOFS Density Depletions at solar min



Statistical study of PLP density depletions by Eugene Dao (Cornell) (see Dao's CEDAR presentation and poster)

Local-time dependence of ΔN/N in 2009 (left)

Longitude dependence (below) of nighttime ΔN/N from May 2008 to October 2009

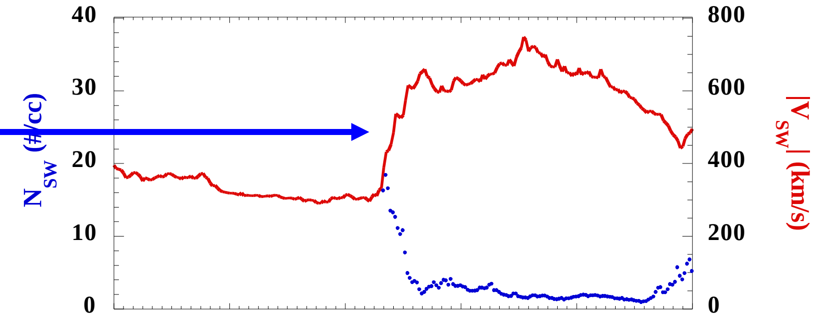


Dao et al., 2010

Solar Coronal Hole Effect

Scintillation and large changes in Densities

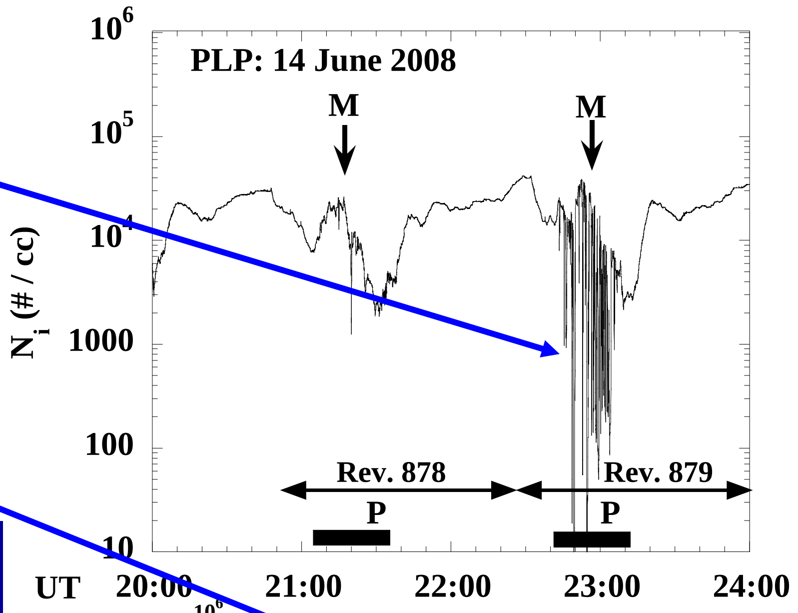
- **Interplanetary parameters: sudden increase in solar wind velocity (300 to 600 km/s)**

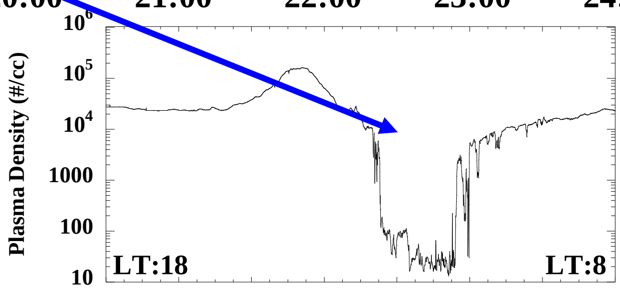


Plasma drift and plasma density respond immediately:

- **Scintillation-producing irregularities**

- **Followed 3 hrs later by almost total "disappearance" of ionosphere– plasma moved above the C/NOFS altitude**





Changes in solar-wind density and velocity are seen almost instantly by C/NOFS
- Scintillation-causing irregularities form
- Later, ionosphere is "blown away".

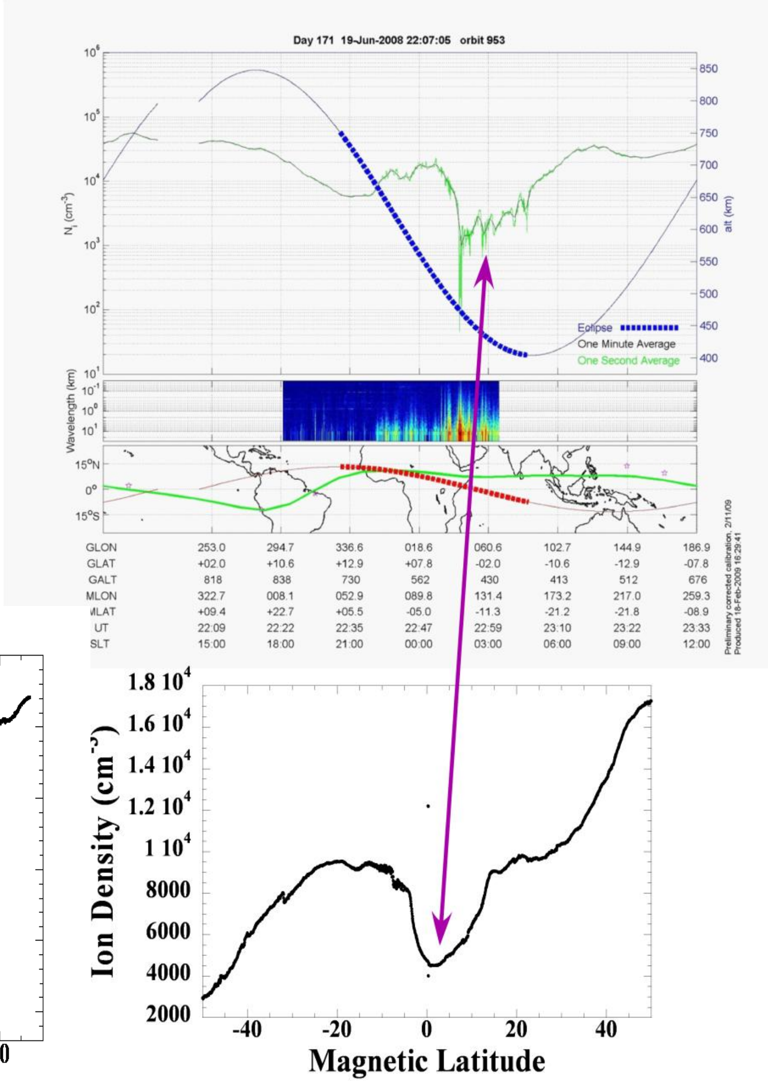
Burke et al., 09

Large Reductions in Ion & Neutral Density

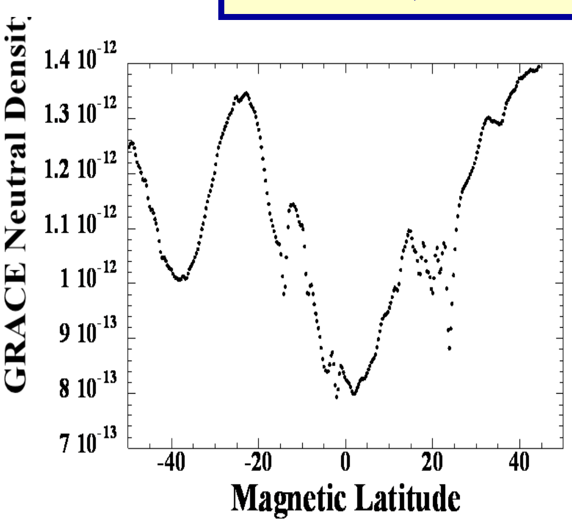
- **Deep minima in ion and neutral density revealed in C/NOFS, DMSP, CHAMP, GRACE observations**
  - During northern hemisphere summer
  - Mostly in Atlantic Anomaly sector (SAA)
  - During solar minimum
  - Due to tides (most obvious on dayside)
  - See Cheryl Huang's presentation on Monday

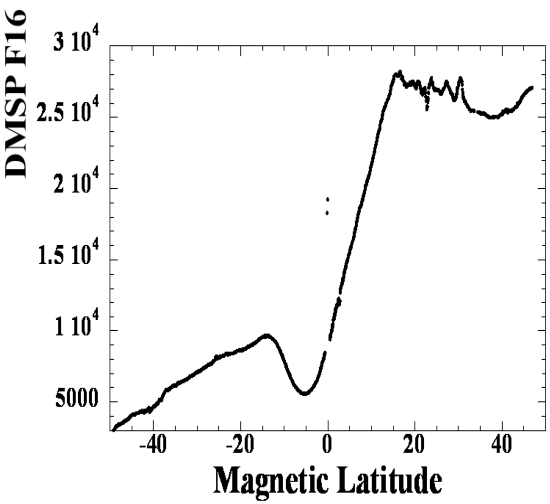
Huang et al., 09

19 Jun 08, C/NOFS & DMSP

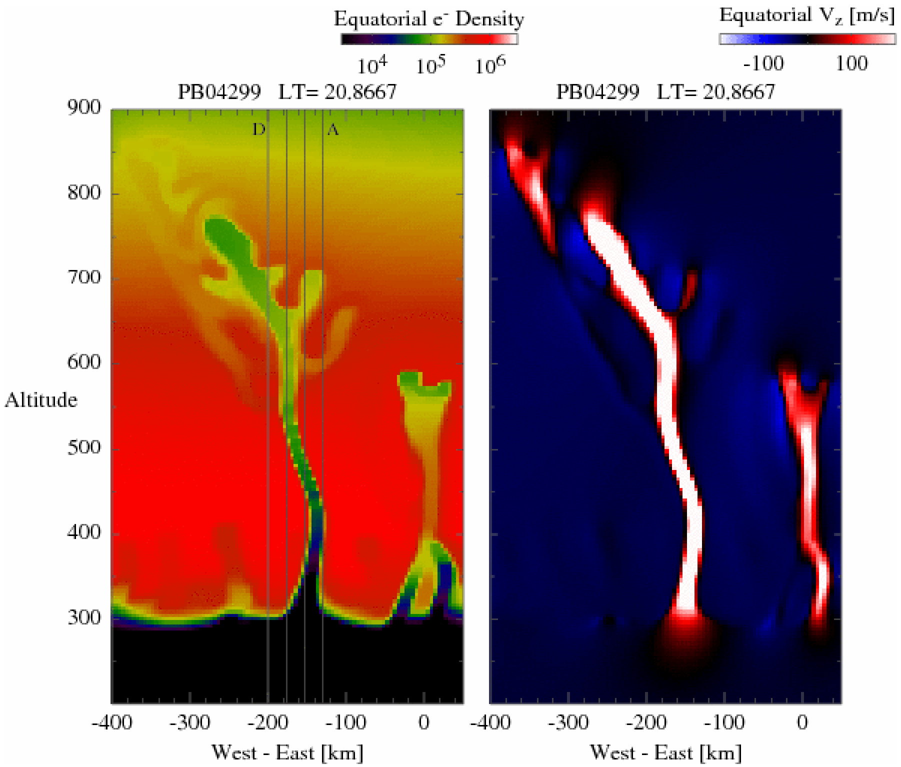


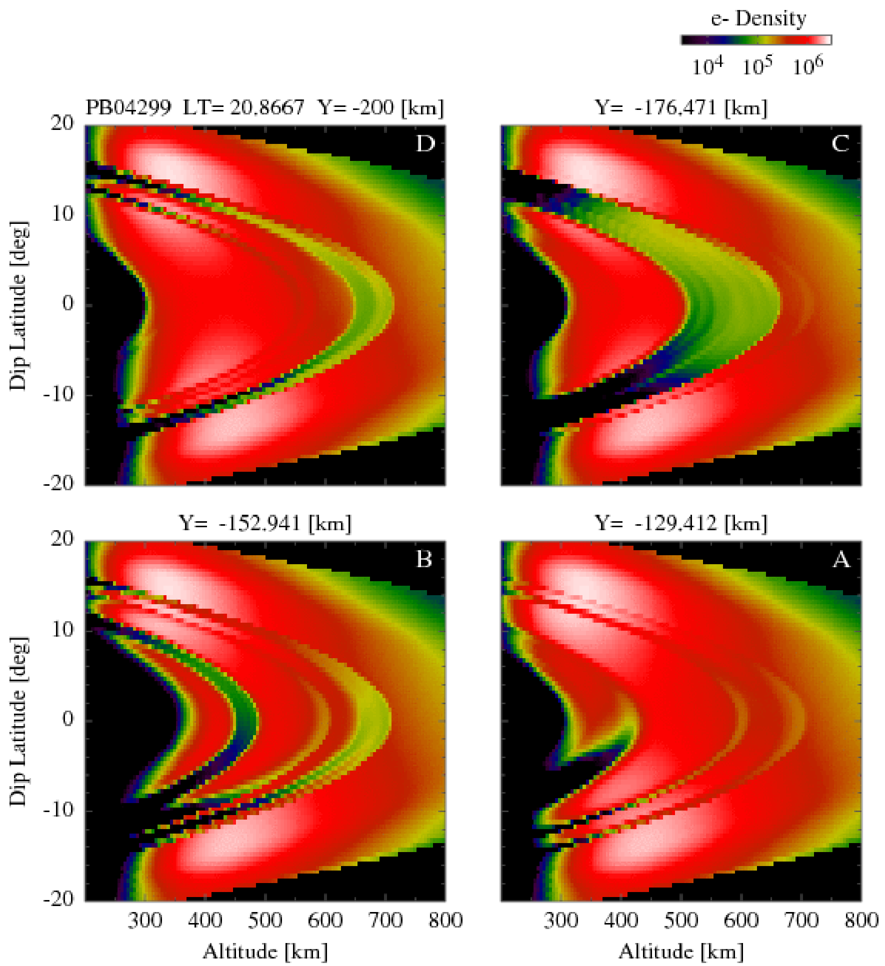
5 Jun 05, GRACE & DMSP





3-D Plume Model



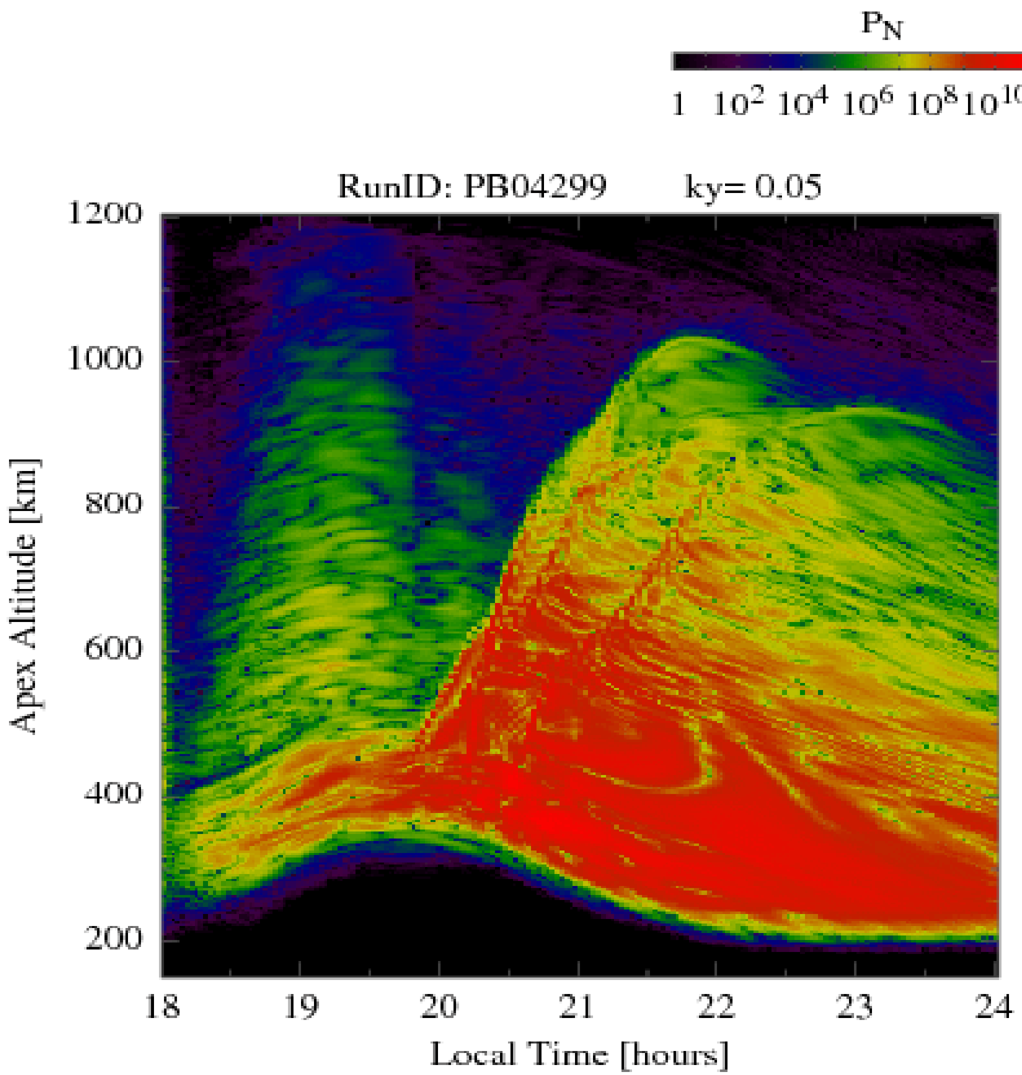


Retterer (2010a,b)

3-D structure of a plume

Altitude and longitude (above); altitude and latitude (right)

3-D Plume Model



Spectral density of the density irregularities in the equatorial plane.

Calculated by:

- **taking the Fourier transform of the East-West variation of the density in the equatorial plane,**
- **forming the spectral density, choosing that particular wavelength,**
- **and plotting as a function of time and altitude.**

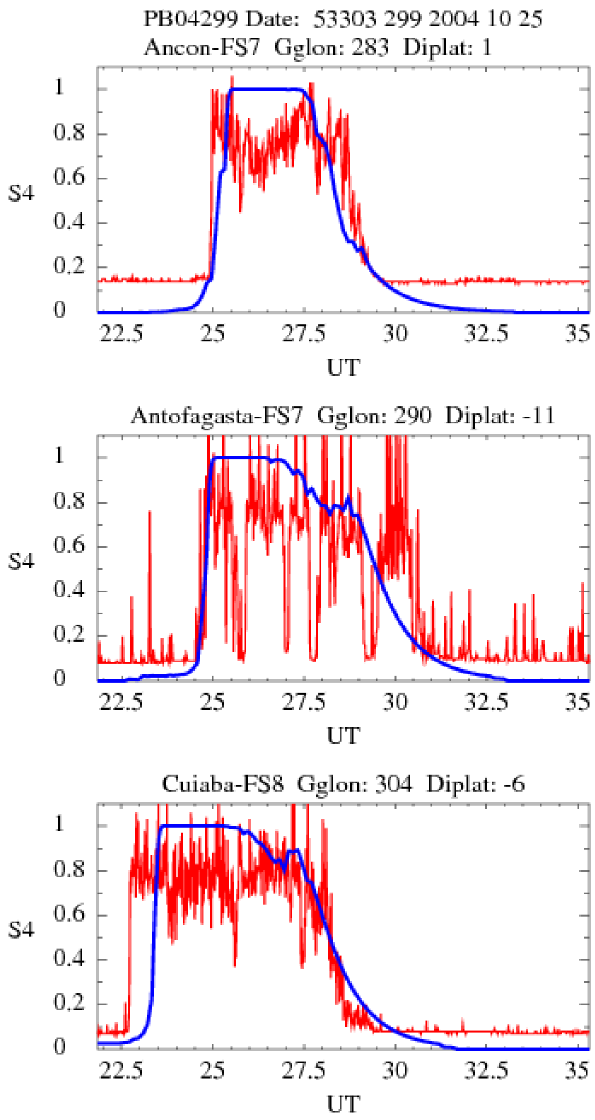
Evolution of 20-km wave amplitude – See John Retterer's presentations

3-D Plume Model
Plume/Scintillation Decay

Scintillation calculated with 3-D plume model, shows duration of scintillation observed by SCINDA (red curves) is well described by the model (blue curves)

Duration of scintillation tied to duration of short-scale density irregularities

The model scintillation is calculated using a phase-screen formula and an extrapolation of the irregularity spectrum of the plume model

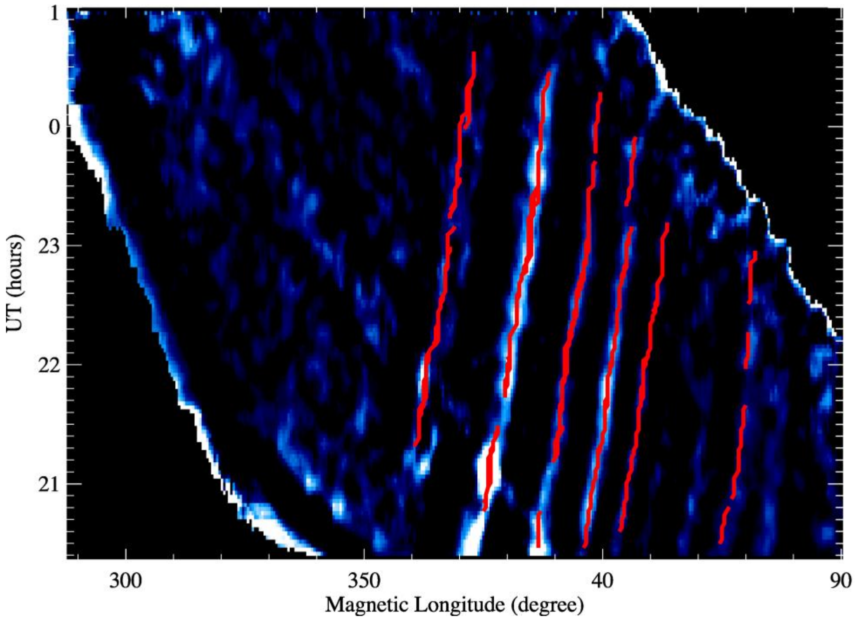


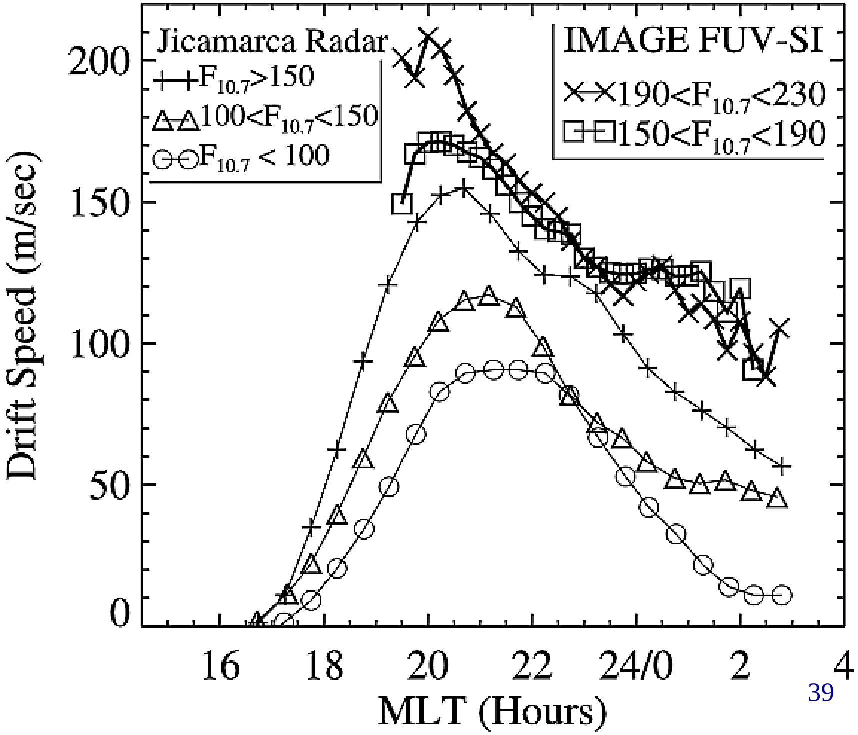
The zonal drift velocity of equatorial plasma bubbles

Early studies suggested that plasma bubbles drift with the ambient plasma, so the zonal drift velocity of plasma bubbles can be used as an indicator of the ambient plasma drift. However, no simultaneous measurement of the background plasma drift was made in most experiments.

Recent studies suggested that the zonal drift of plasma bubbles is generally faster than the average F-region plasma drift. What causes the difference?

IMAGE FUV measurements: Immel et al. (2003), Park et al. (2007).





Chaosong Huang et al. et al., 2010 a

Zonal Drift of plasma inside bubbles

In the post-midnight sector:

The zonal drift is westward in the 2 Jun case, East, West, East in the 9 Jun case

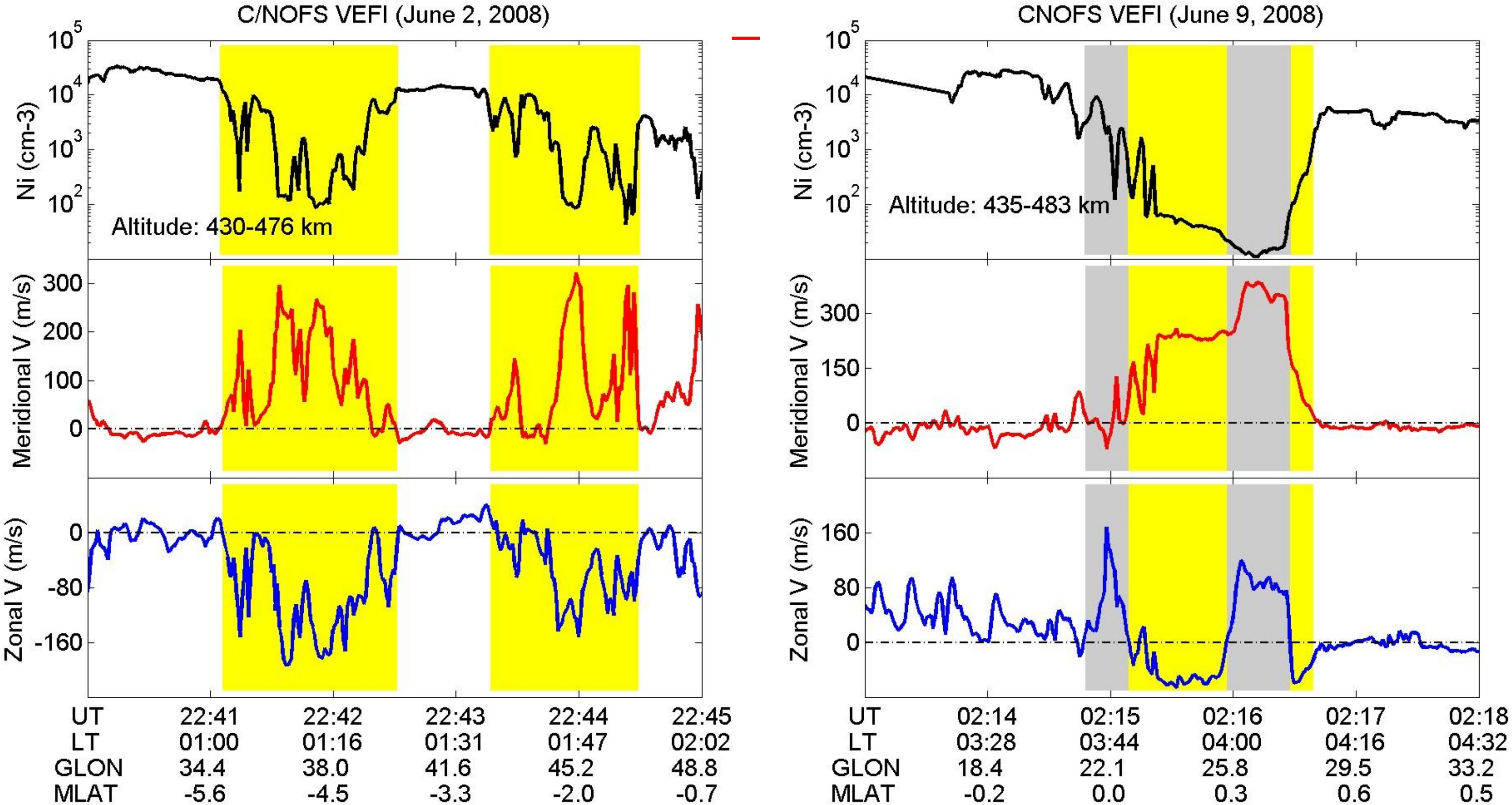
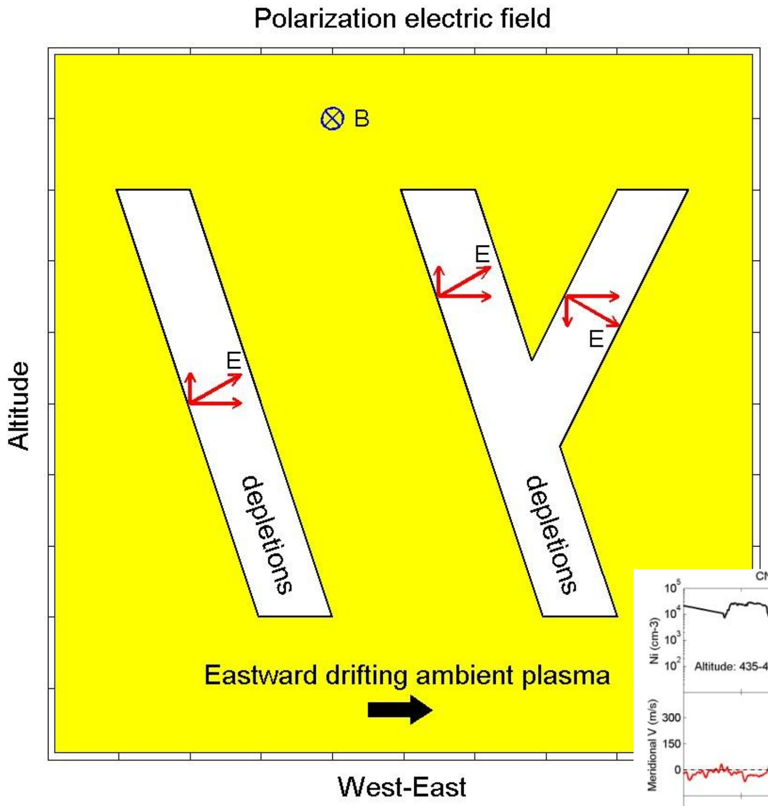
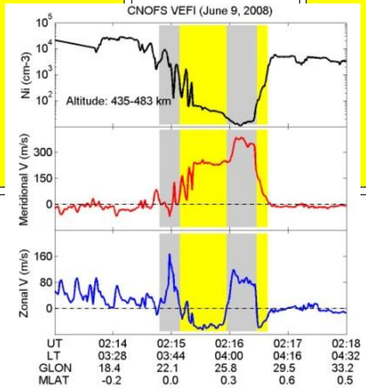
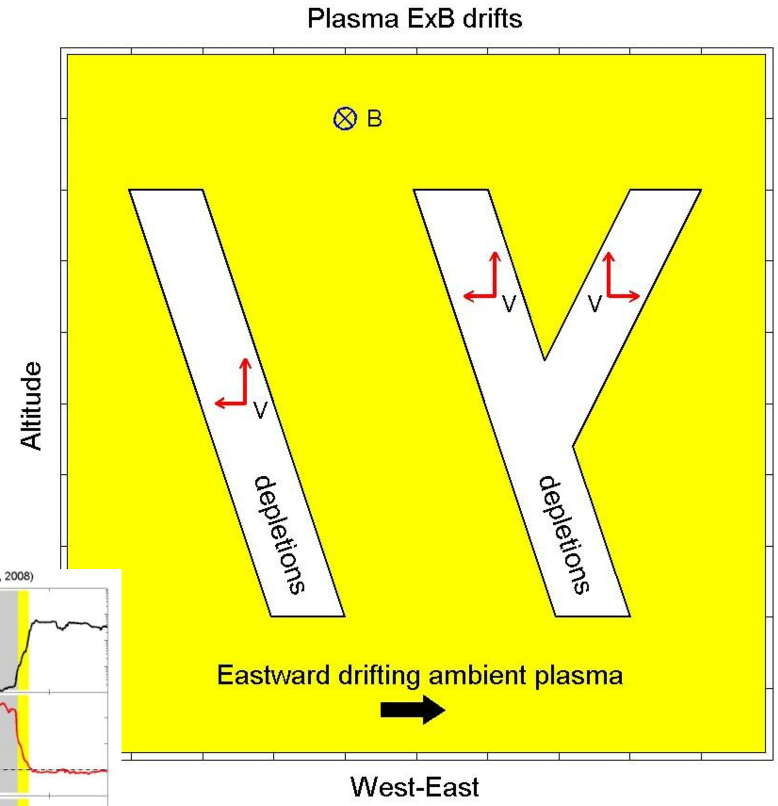


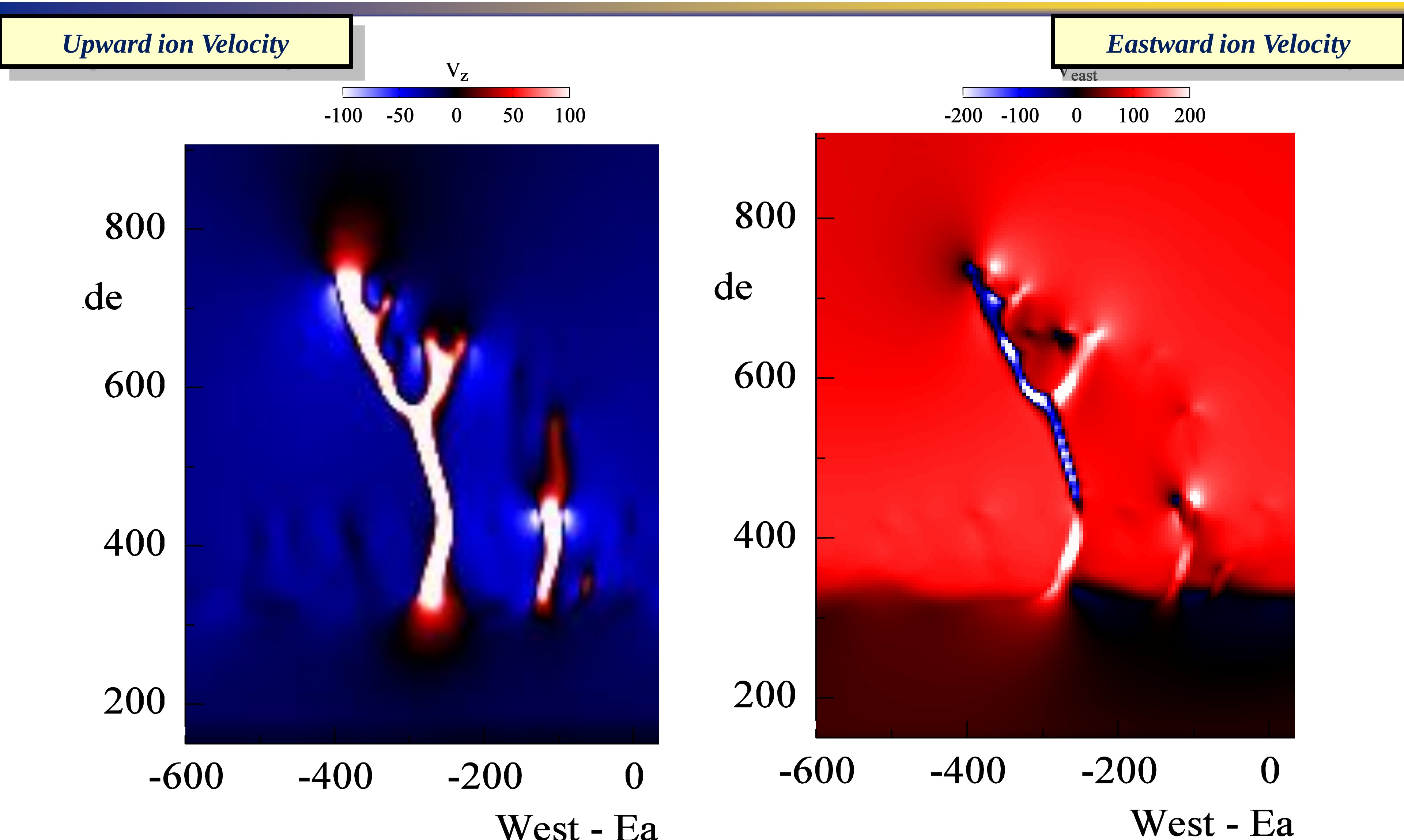
Illustration of polarization electric field and ExB drift velocity inside plasma bubbles







3-D numerical simulations of plasma drift velocity associated with plasma bubbles (Retterer, 2010)

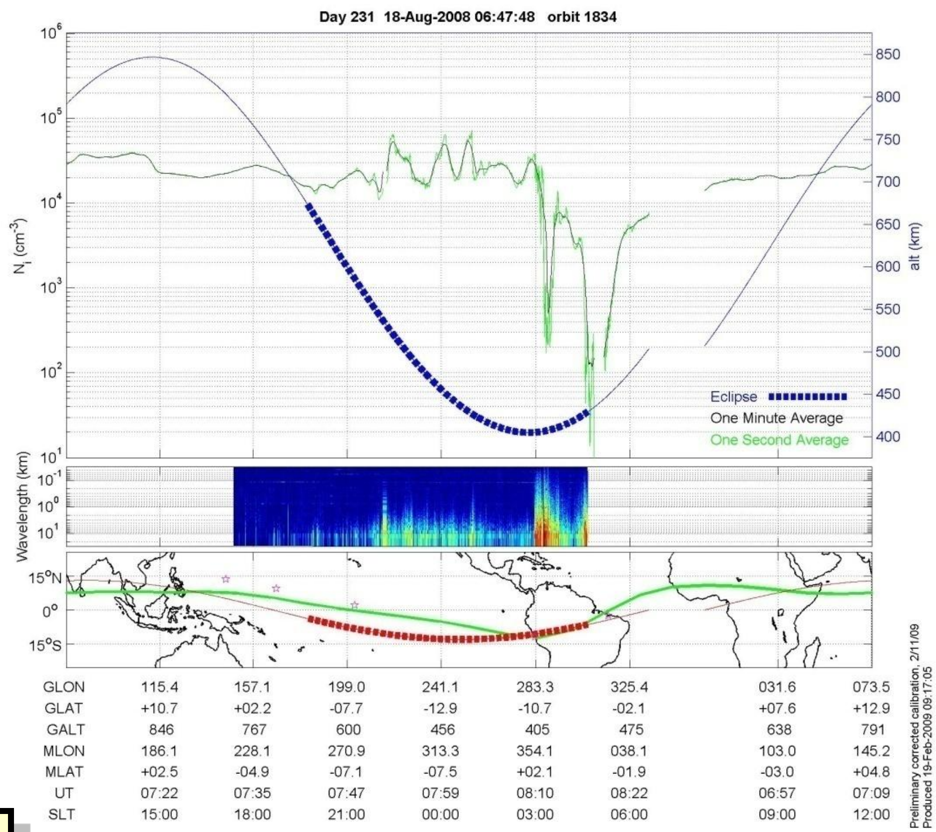


Drift inside is west for bubbles leaning west, and east for those leaning east

Generation and evolution of plasma bubbles

Where do the post-midnight plasma bubbles start to form?
What are the growth time and life time of the plasma bubbles?
How are plasma bubbles related to the deep depletions near dawn?

C/NOFS can detect the same plasma bubble over successive orbits.

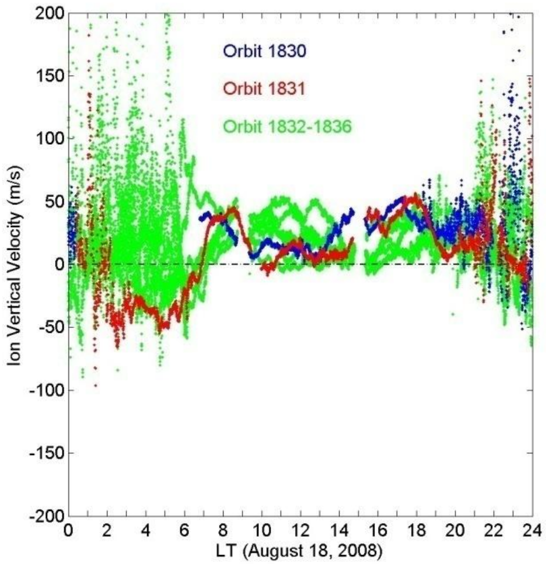


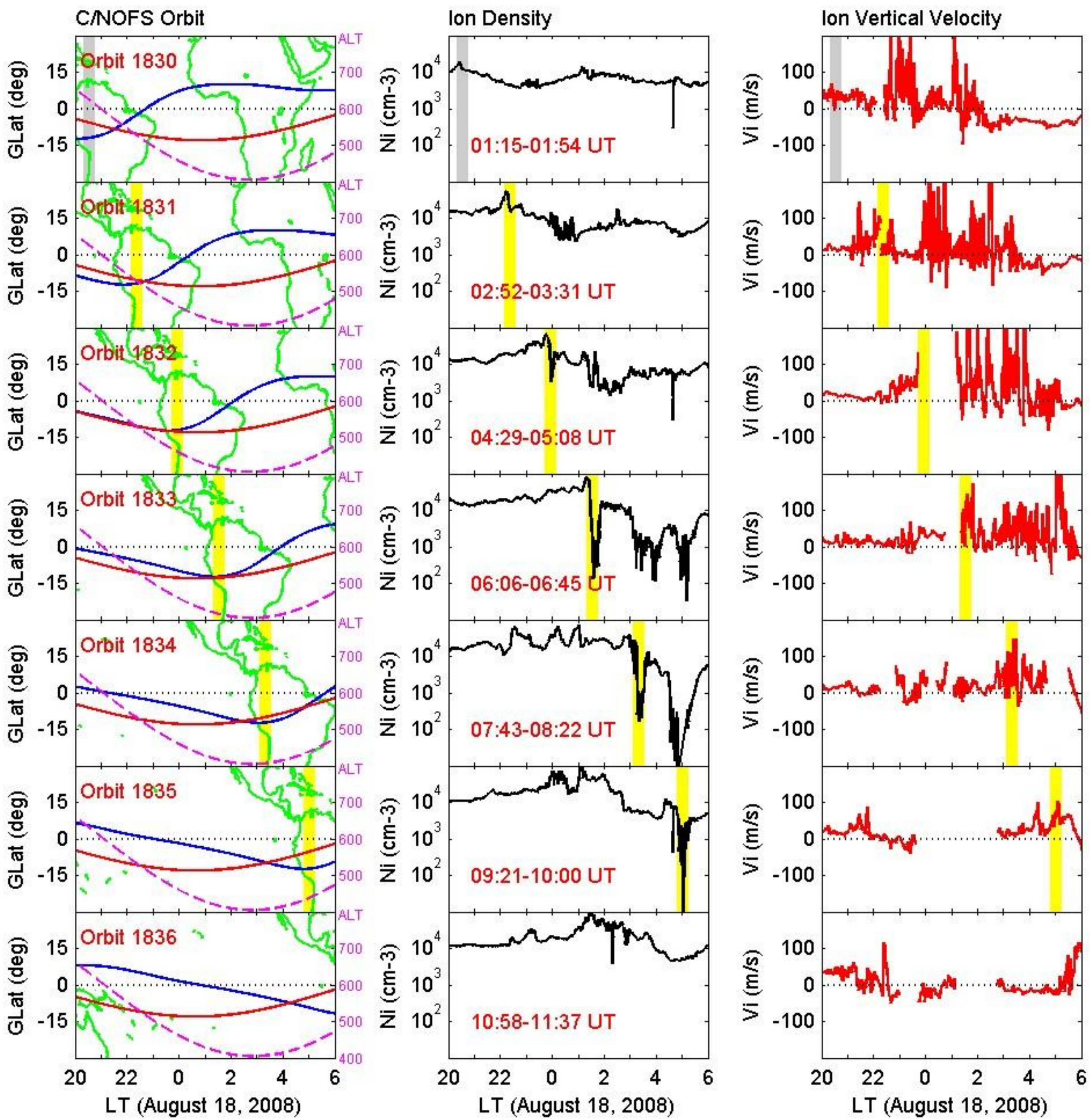
Chaosong et al. et al., 2010

Evolution of a plasma bubble

First observed: 22 LT
max size reached in ~4 hrs
Life time: ~8 hrs

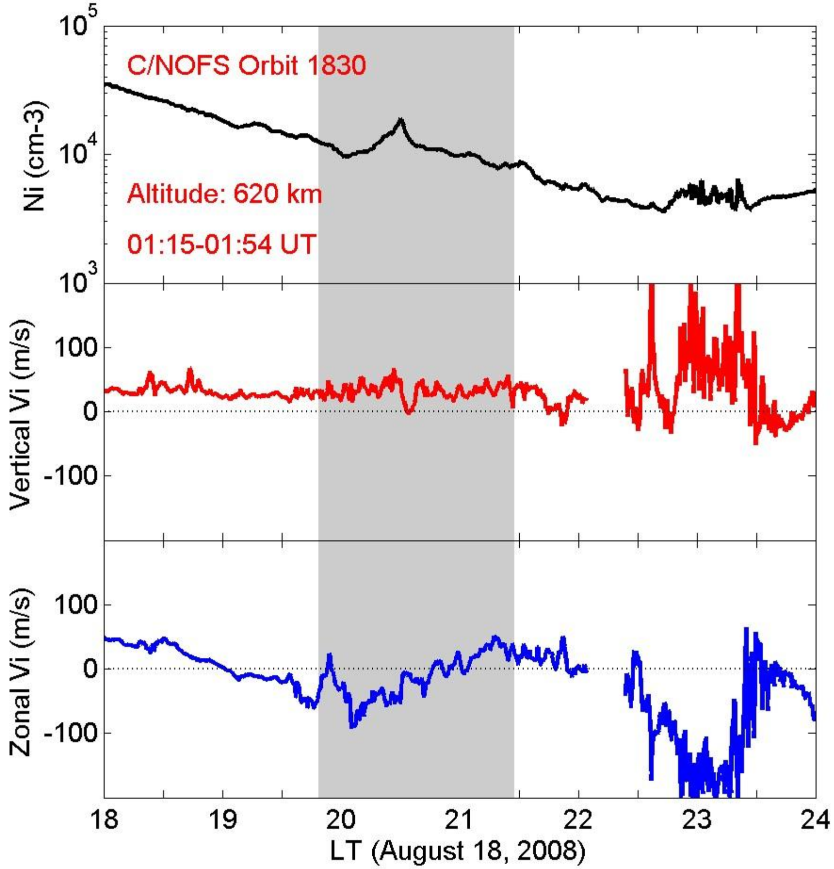
Upward drift near dusk

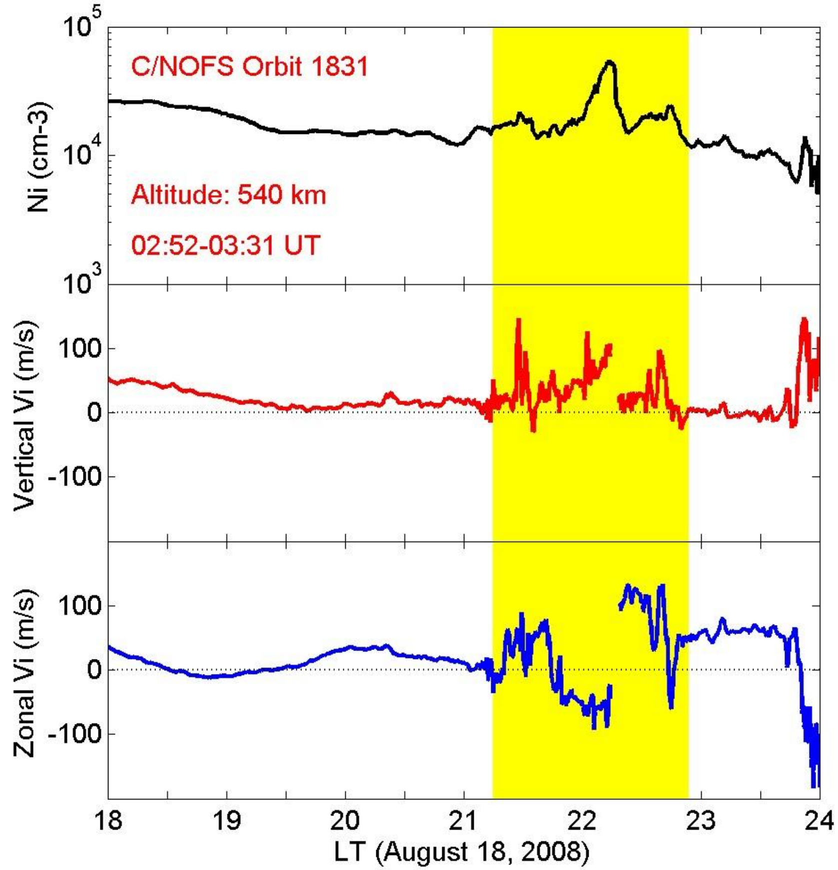




First detection of the plasma perturbations with enhanced ion drift velocity in the topside F region

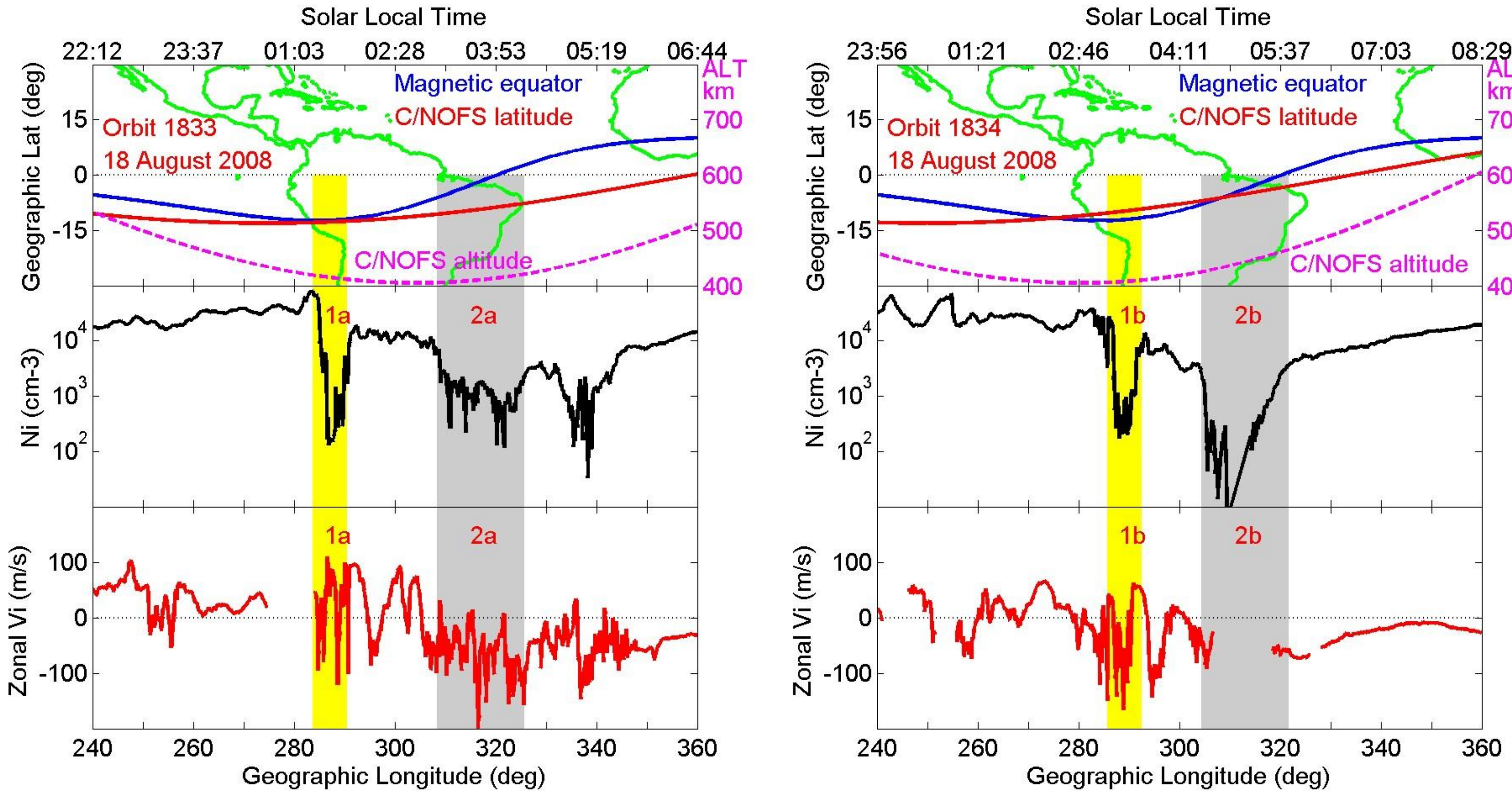
The Rayleigh-Taylor instability may have been excited in the bottomside F region 30-60 minutes ago (at 02:00-02:30 UT).





Using zonal drift velocity to identify the bubbles

Bubbles 1a, 1b: Eastward drift at 18 m/s, the same bubble.
Bubbles 2a, 2b: Westward drift at 40 m/s, the same bubble.
Bubbles 1a, 2b: Eastward drift at 400 m/s, unrealistic, not the same bubble.



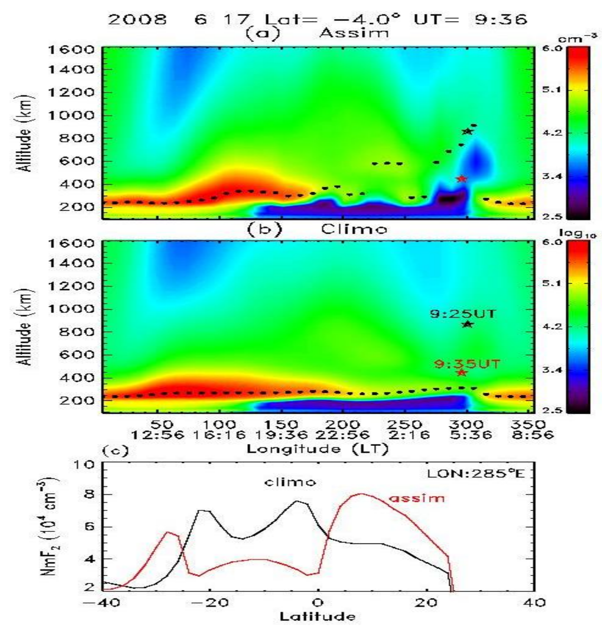
Summary - 1

- C/NOFS satellite launched to study & forecast ionospheric ionosphere and scintillation
- Several C/NOFS results are unexpected – still unclear if they are mostly manifestation of very low solar activity
- There are 2 types of dawn depletions
  - One is associated with upward plasma drifts
  - Other is associated with downward plasma drifts
  - First type typically 50^o x 14^o degrees in the N-S and E-W directions
  - Second type much wider, can reach 50^o in longitude
- Seen at all satellite altitudes
- Often associated with ionospheric irregularities
- Strong dependence on season and longitude
- Dawn depletions also observed in other data sets (e.g. DMSP, CHAMP)
- Numerical simulations (PBMod) reproduce observed dawn depletions
  - Show that the density depletions can be explained by changes in V_i
  - Increases in the vertical drift close to sunrise appear similar to the sunset pre-reversal enhancement

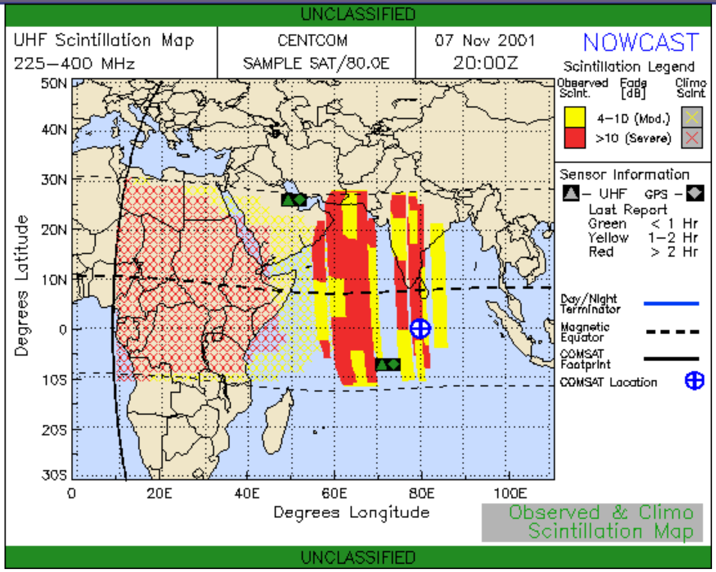
Summary - 2

- Given plasma drifts, PBMod can explain observations
  - But why do drifts occur at the time they do?
  - One of the greatest challenges is to understand and predict drifts and winds
- PBMod is used to model both ambient plasma and irregularities within
- Climatology of irregularities at 850 km alt (DMSP) reveals strong longitude and seasonal dependence
  - However, large differences in behaviors at dusk and dawn
  - During solar min, DMSP sees no irregularities at dusk, but sees a large amount at dawn
- Broad reductions in neutral and ion density observed
  - Could be explained by tidal effects?
- Zonal motion inside bubbles is east or west, depending on how the bubble is leaning
  - Results show that motion of bubbles is not a good indicator of ambient plasma drift
- Some bubbles stay “alive” for 8 hrs
  -- grow to reach their max size in ~4 hrs

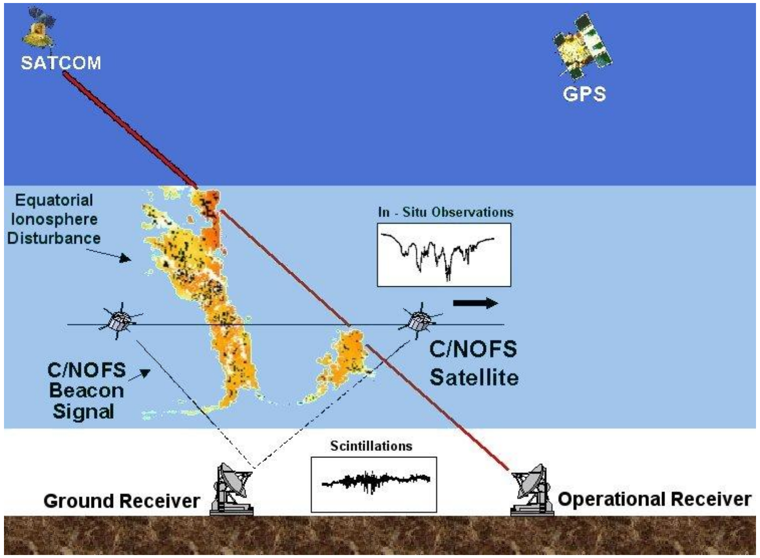
Questions?



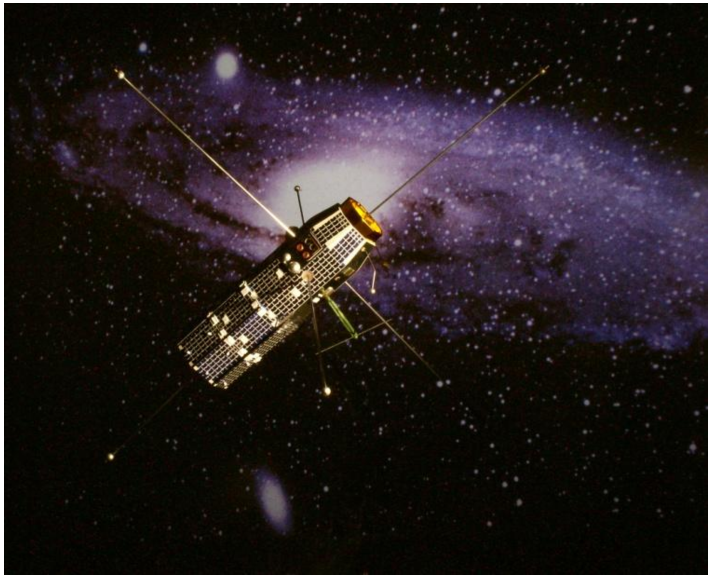
2008 6 17 Lat= −4.0° UT= 9:36
(a) Assim
(b) Climo
Altitude (km)
cm⁻³
log₁₀
9:25UT
9:35UT
Longitude (LT)
(c)
LON:285°E
climo
assim
Latitude



UNCLASSIFIED
UHF Scintillation Map
225–400 MHz
CENTCOM
SAMPLE SAT/80.0E
07 Nov 2001
20:00Z
NOWCAST
Scintillation Legend
Observed Scint.
Fade [dB]
Climo Scint
4–10 (Mod.)
>10 (Severe)
Sensor Information
UHF
GPS
Last Report
Green < 1 Hr
Yellow 1–2 Hr
Red > 2 Hr
Day/Night Terminator
Magnetic Equator
COMSAT Footprint
COMSAT Location
Degrees Latitude
Degrees Longitude
Observed & Climo Scintillation Map
UNCLASSIFIED



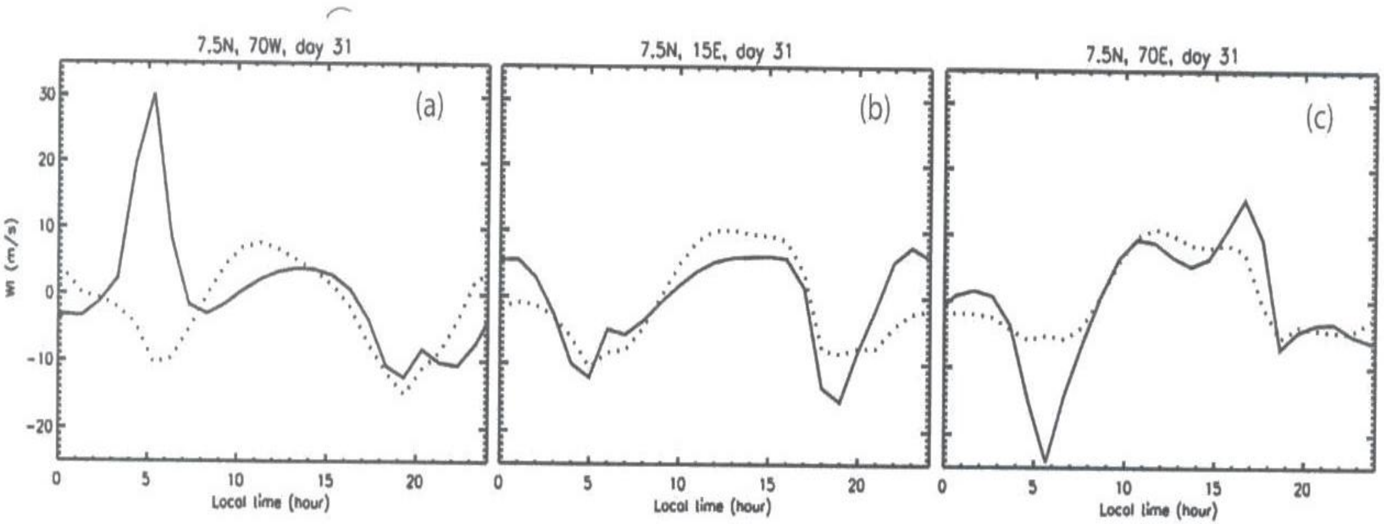
SATCOM
GPS
Equatorial Ionosphere Disturbance
In - Situ Observations
C/NOFS Beacon Signal
C/NOFS Satellite
Scintillations
Ground Receiver
Operational Receiver



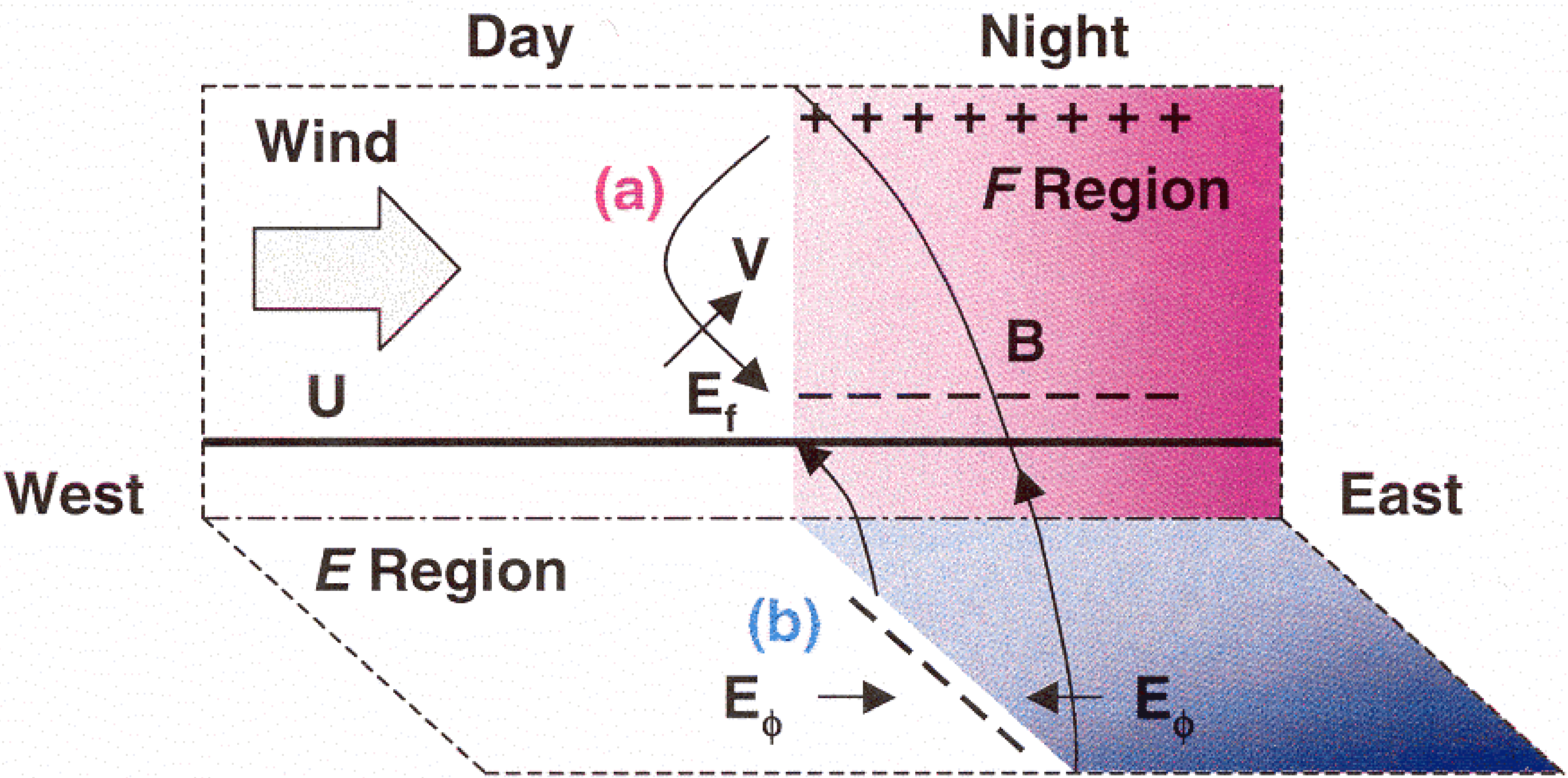
Discussion

- **Other data related to dawn depletions and changes in ion drifts**

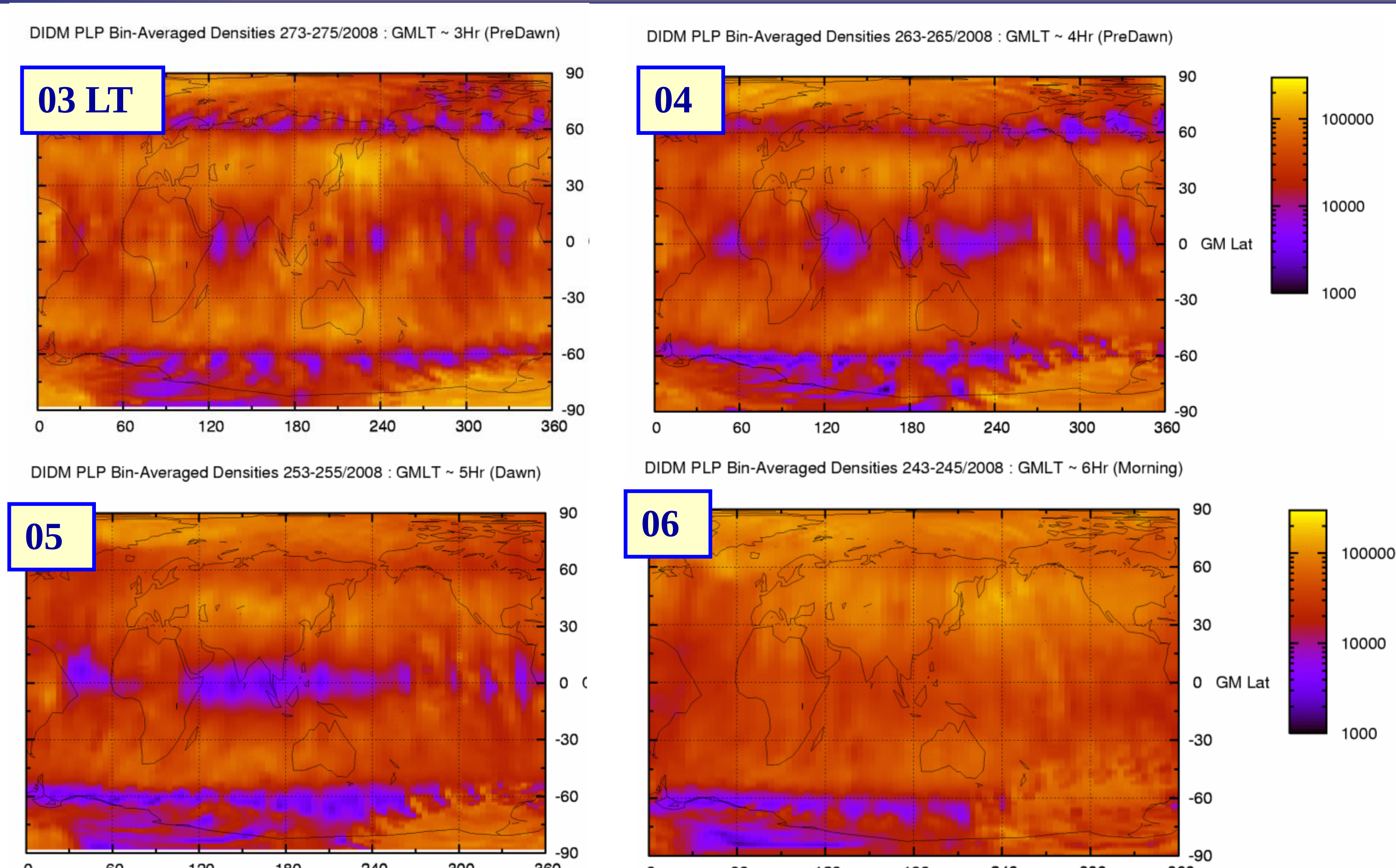
- **Liu et al. introduce a quasi stationary planetary wave in model**
  - **Shows that upward drift at dawn is either up, small and down, large and down, depending on longitude.**



Discussion



Local Time and Longitude Dependence
CHAMP N_e from 03 to 06 LT (Sep 08)

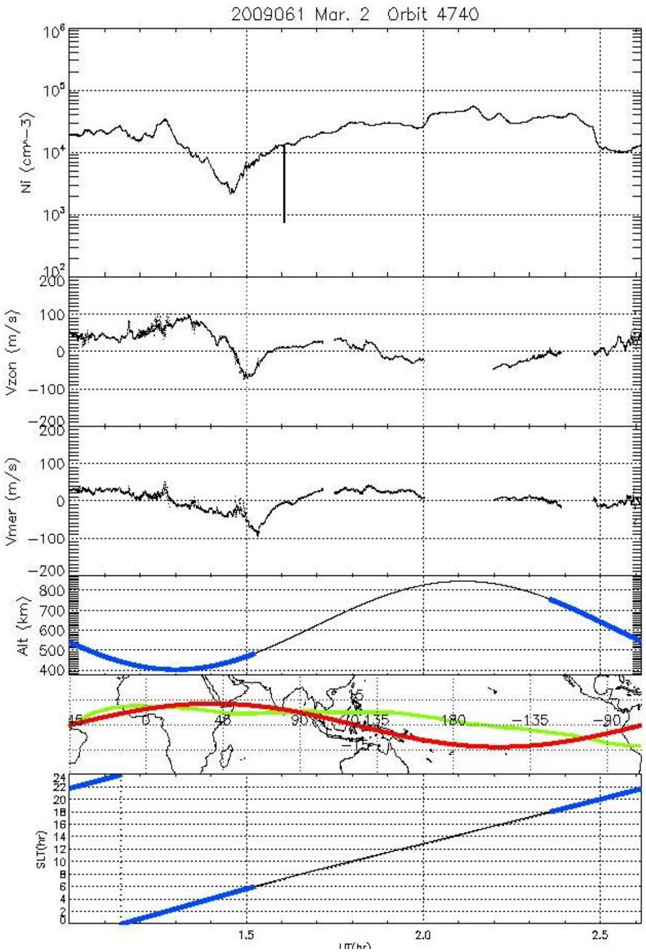


Sept 08: Equatorial dawn depletions deepest at 05 LT & in Atlantic and Asia longitudes

(Geom coords)

Dawn Depletion Associated with Downward Ion Drift

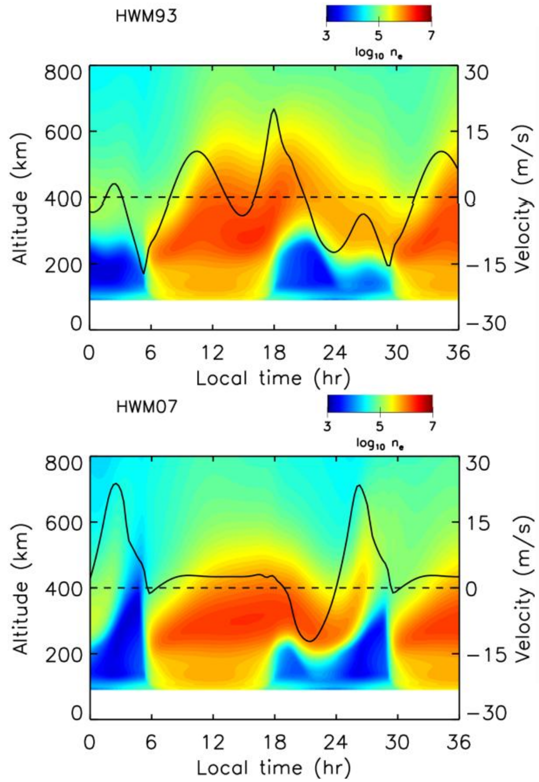
- On numerous occasions in March 09, the minimum in Vmer, which is in fact the maximum downward velocity, occurs exactly at 06 Solar Local Time (SLT).
- And the minimum in Ni from PLP occurs exactly at 05 SLT.
- The minimum in Veast, i.e. max in West velocity, occurs between these 2 times.
- In June 08, the minimum in Vi occurs ~ 1 hr earlier: at 05 SLT

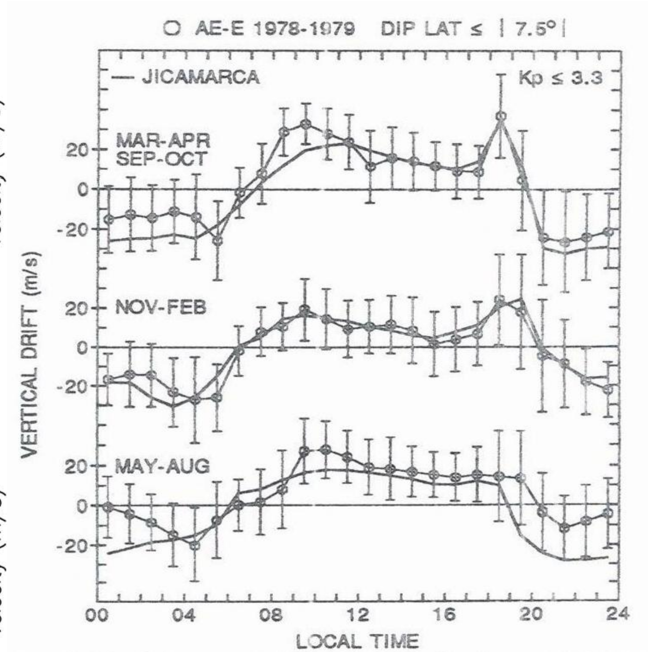


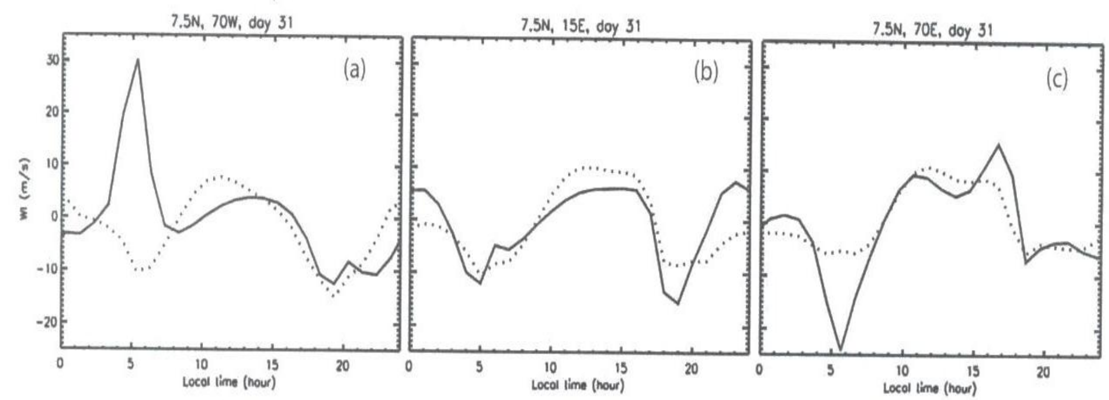
Discussion

Other data related to Ne & drifts at dawn:

- Fejer's model shows minima in upward drift at 5 or 6 LT, depending on season
- See also Eccles (1998) model
- Huba et al.(2010) used HWM07 wind model and reproduced dawn plasma depletion
- Liu et al. introduce a quasi stationary planetary wave in model
  - Show that upward drift at dawn is either up, small and down, large and down, depending on longitude



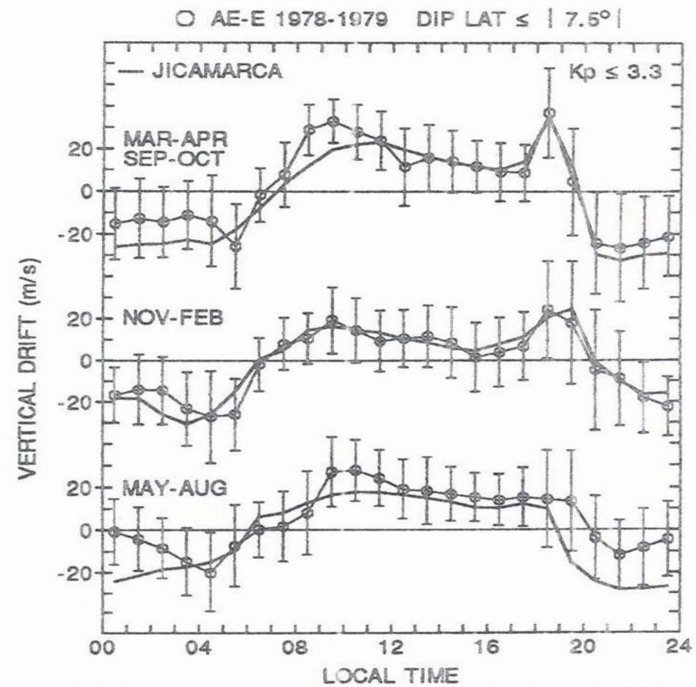




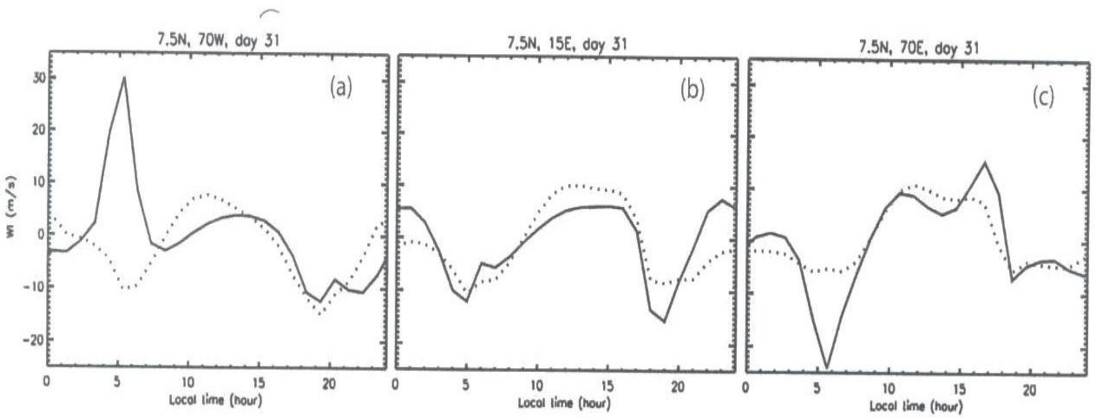
Discussion

Other data related to changes in ion drifts at dawn:

- **Fejer's model shows minima in upward drift at 5 or 6 LT, depending on season**
- **See also Eccles, 1998 model**

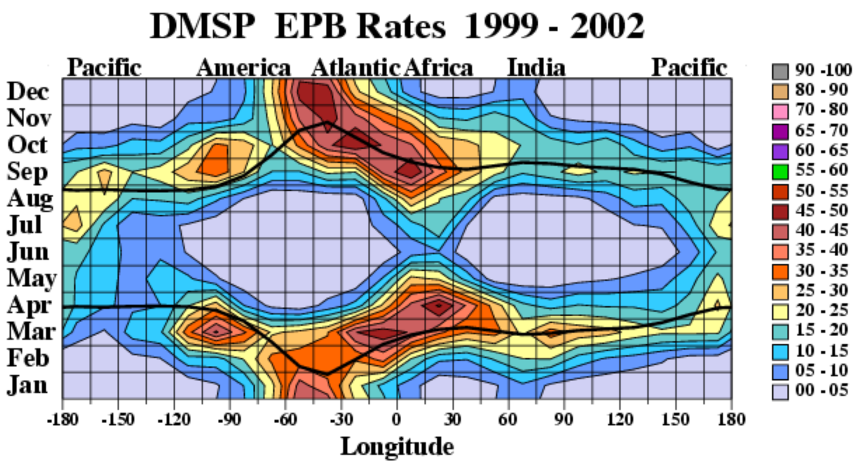


- **Liu et al. introduce a quasi stationary planetary wave in model**
  - **Show that upward drift at dawn is either up, small and down, large and down, depending on longitude**



C/NOFS and DMSP Observations

- **Unexpected C/NOFS results**
  - Deep plasma density depletions observed post-midnight to dawn, very few near sunset (until March 2010)
- **Recent DMSP observations**
  - No evening sector plasma bubbles
  - Dawn sector climatology dynamic
  - Different processes drive ionosphere-thermosphere system at dawn in solar minimum



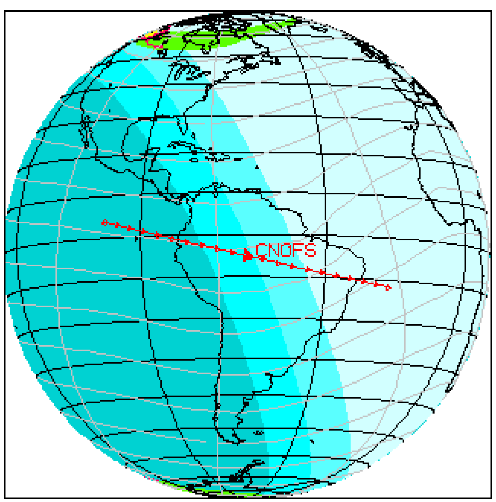
- **In deep solar minimum, even small changes in solar wind/IMF affect dynamics of equatorial plasmas and electric fields**

C/NOFS Mission

- Unique opportunity to observe unusual solar minimum
- Provides fundamental new knowledge of Earth's ionosphere
- Facilitates development of fully-integrated models and forecasts

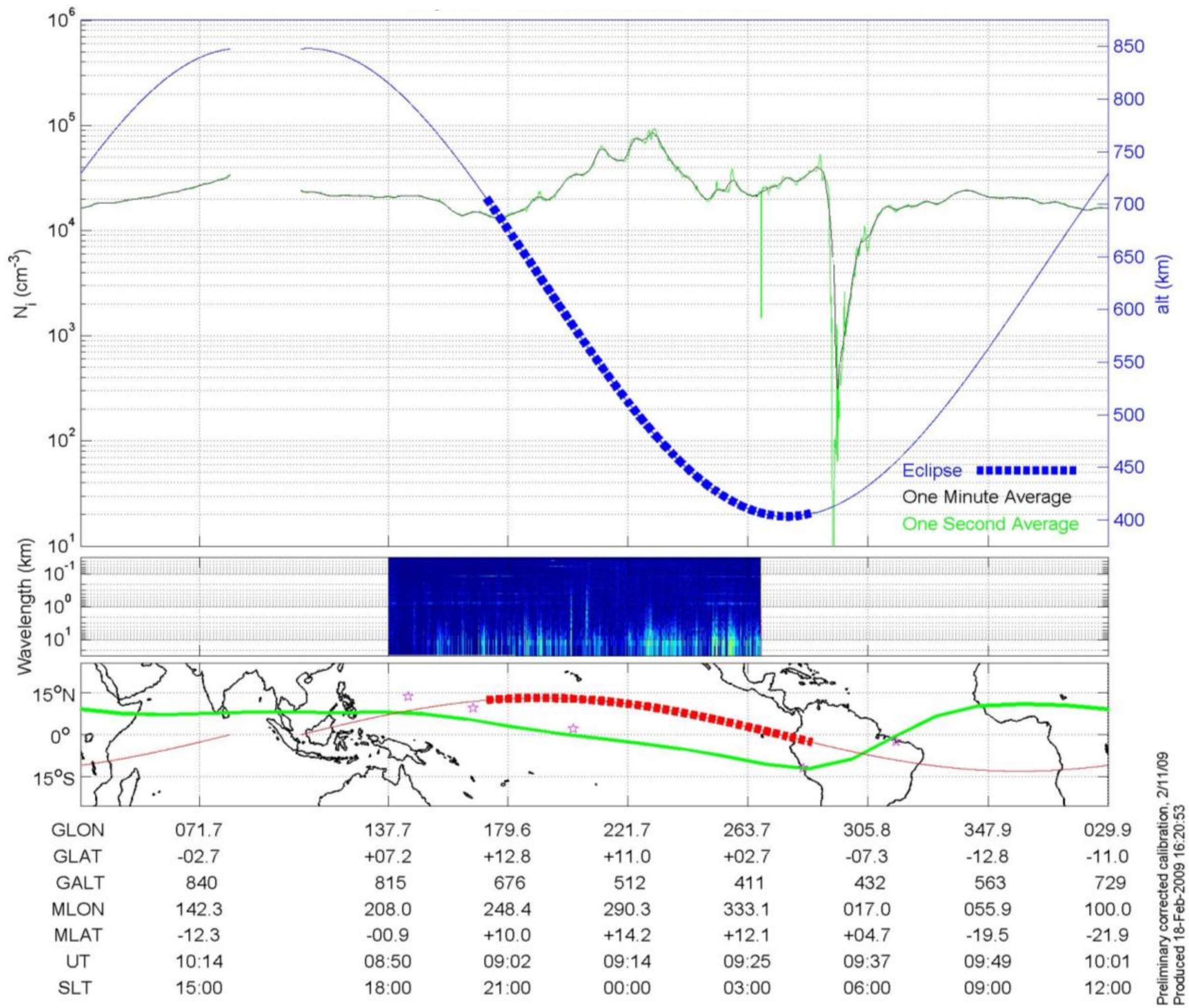
Dawn N_e Depletion

- Example of N_e dawn depletion at 05 LT
- Just before sunrise at E-region altitude
- Unexpected result
- Depletions seen in 75% of June passes
- Significant for both EDP and scintillation



Time: 2008/169 17 Jun 09:35:00 Sunlit

PLP data, June 17, 2008, orbit 915

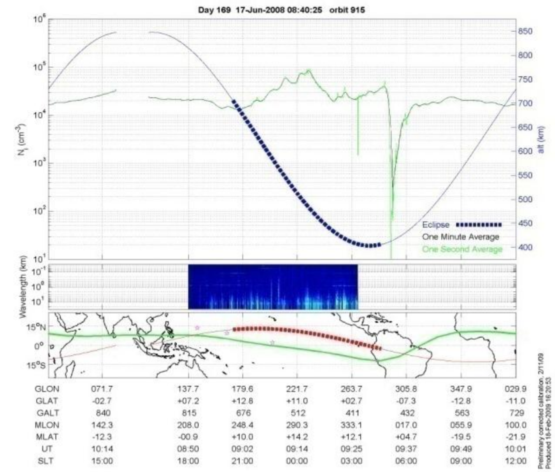


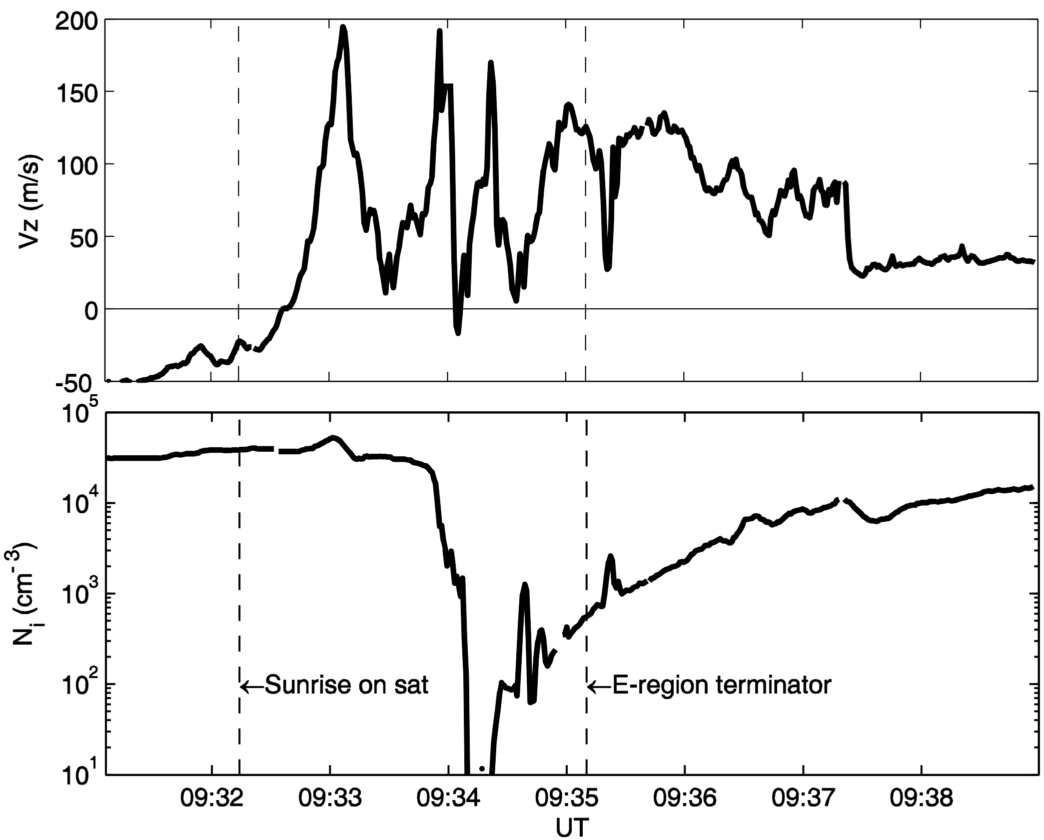
Dawn N_e Depletion

Ion density and Plasma drift – details

June 17, 2008

- **Intense, short spikes in upward drift**
- **Seen before depletion & on its west wall**





Upward drift

Depletions are associated with either upward (this example) or downward plasma drifts.

Ion Density

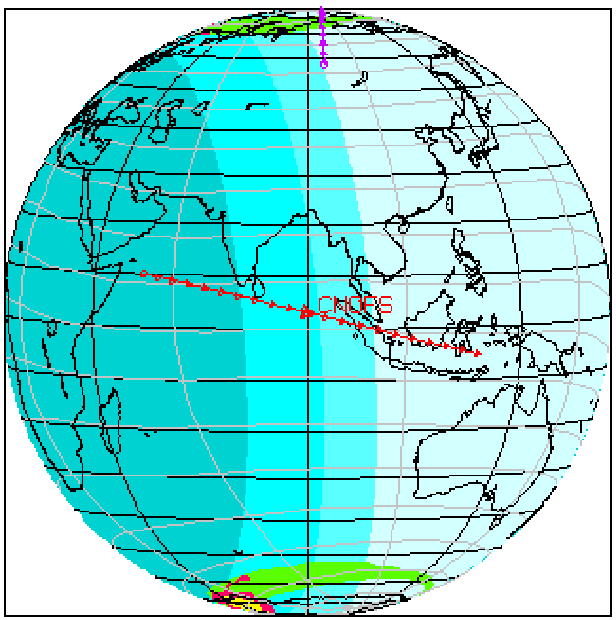
De La Beaujardiere et al., 09

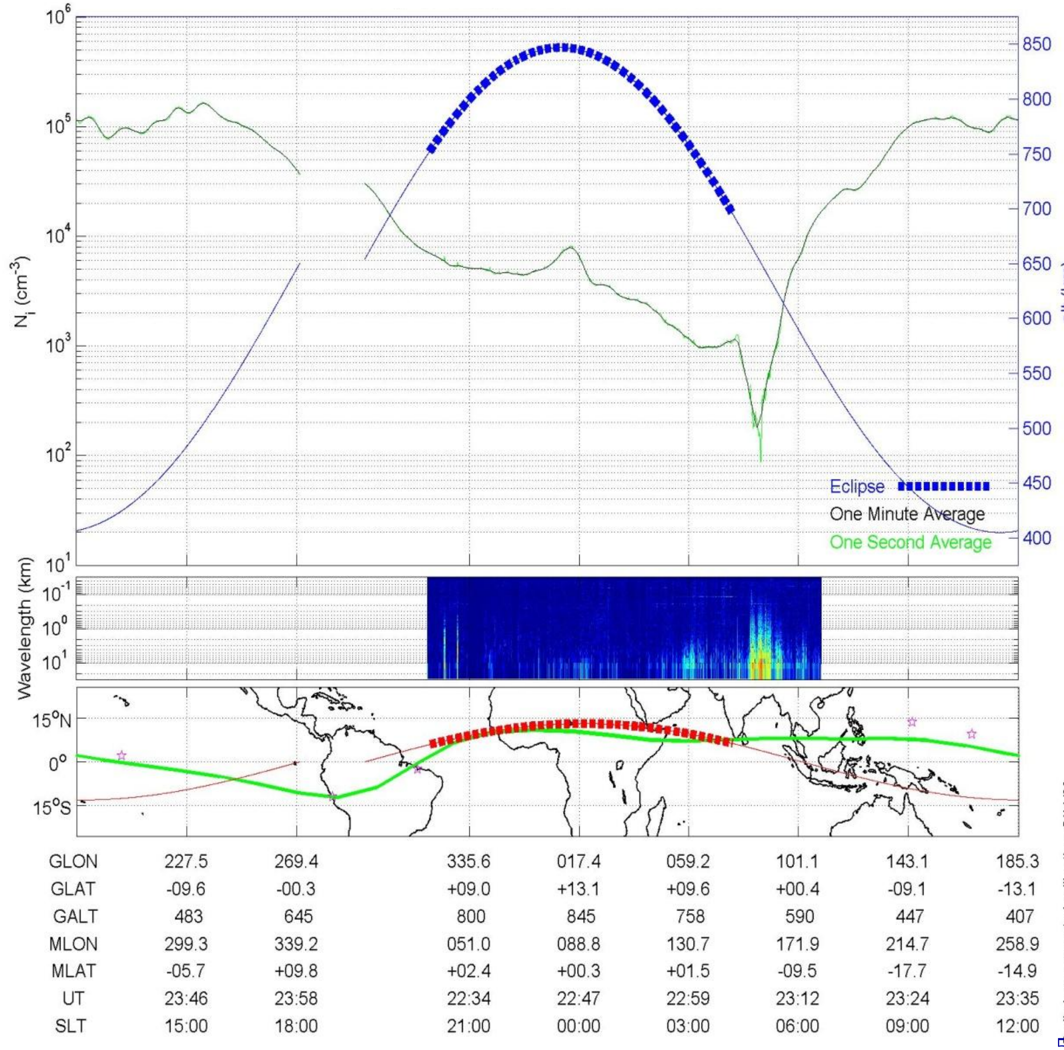
Extent of Dawn Depletion

Example with CHAMP

- **CHAMP & C/NOFS observe deep dawn depletion**
  - **- Irregularities only present within depletion**
- **C/NOFS alt ~ 670 km**
- **E-W width ~ 14 deg**

PLP data, Sept 10, 2008, orbit 2185

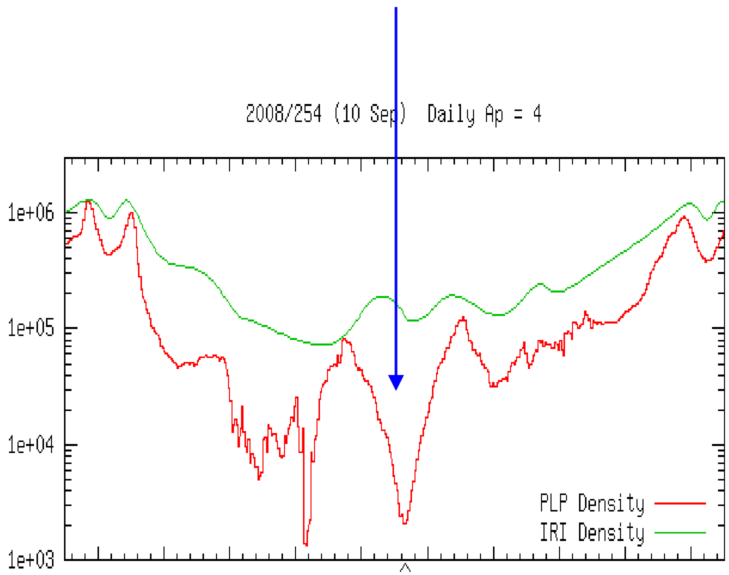




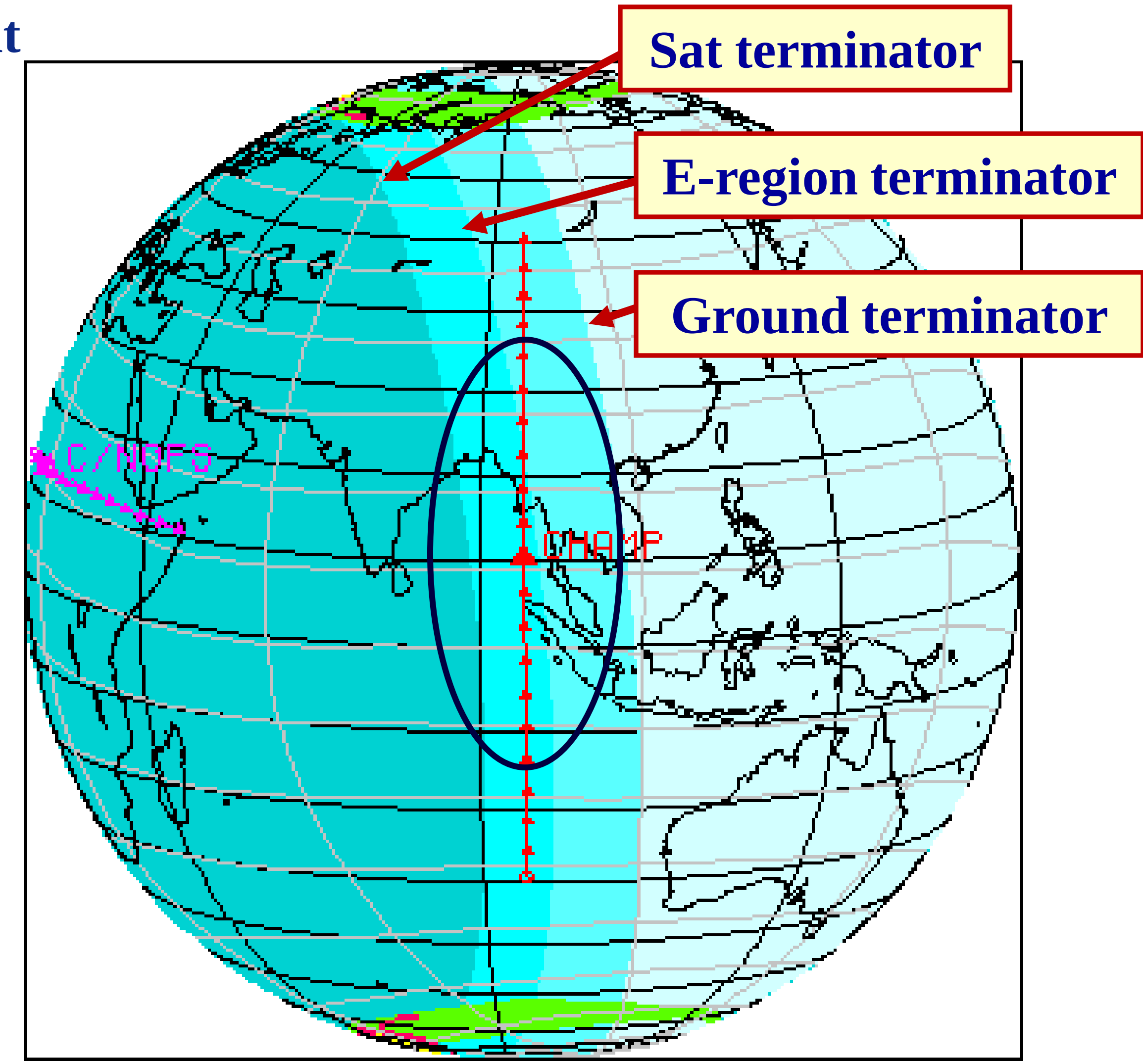
Extent of Dawn Depletion

Example with CHAMP

- CHAMP, polar sat, 350 km alt
- ~ Coincident pass
- 1.5 orbit of CHAMP shows deep and wide Ne depletion at equator

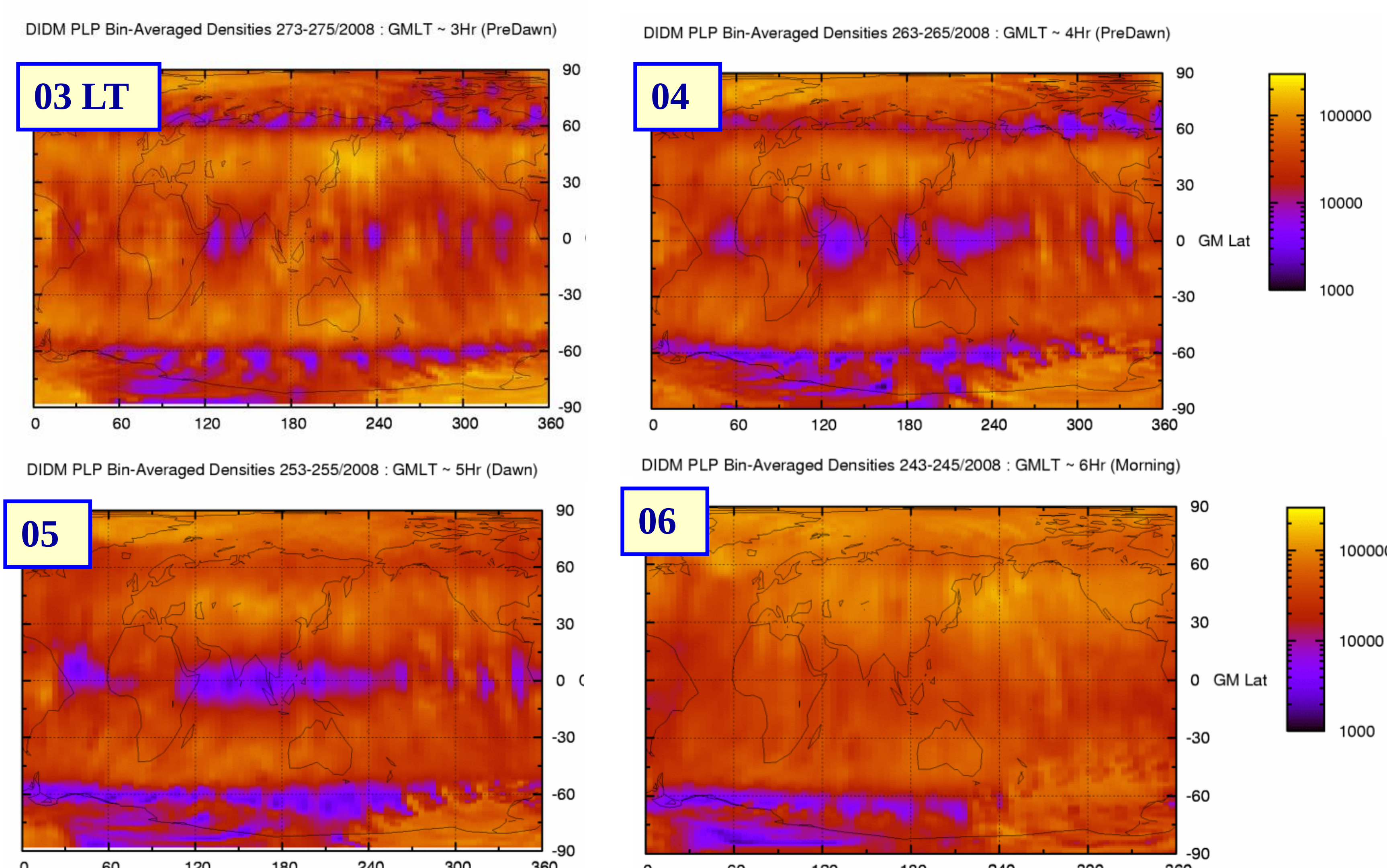


UT	22:00	22:10	22:20	22:30	22:40	22:50	23:00	23:10	23:20	23:30
GLAT	-5.1	-44.7	-83.5	-56.6	-17.2	22.6	62.1	78.1	38.9	-0.8
GLON	286.7	286.7	306.4	94.8	95.6	95.1	96.7	255.7	264.2	263.9
ALT	329.1	343.1	354.4	347.6	331.9	327.1	334.4	336.9	329.8	328.3
MLAT	8.0	-29.7	-67.3	-69.3	-28.7	14.8	56.8	84.9	49.6	8.5
MLON	357.5	0.2	17.1	144.7	165.0	166.3	168.9	275.1	330.1	333.7
MLT	17.16	17.52	18.82	3.50	5.03	5.29	5.63	12.88	16.71	17.12



Depletion size ~ 50 x 14 deg

Local Time and Longitude Dependence
CHAMP N_e from 03 to 06 LT (Sep 08)



Equatorial dawn depletions deepest at 05 LT & in Atlantic and Asia Longs

(Geom coords)

Space Situational Awareness Environment Monitoring Mission

- **The Space Situational Awareness Environment Monitoring Mission (SSAEM) is planned after C/NOFS**
- **May have similar suite of sensors**
- **Orbit: equatorial, circular, with propulsion & at altitude ~ $H_m f_2$**
- **Launch ~2015**
- **Purpose is to predict scintillation and electron density profiles**

Pathfinder for new paradigm in SSA monitoring
Will demo the ability to launch small operational missions on time and on budget

Space Situational Awareness Environment Monitoring Mission

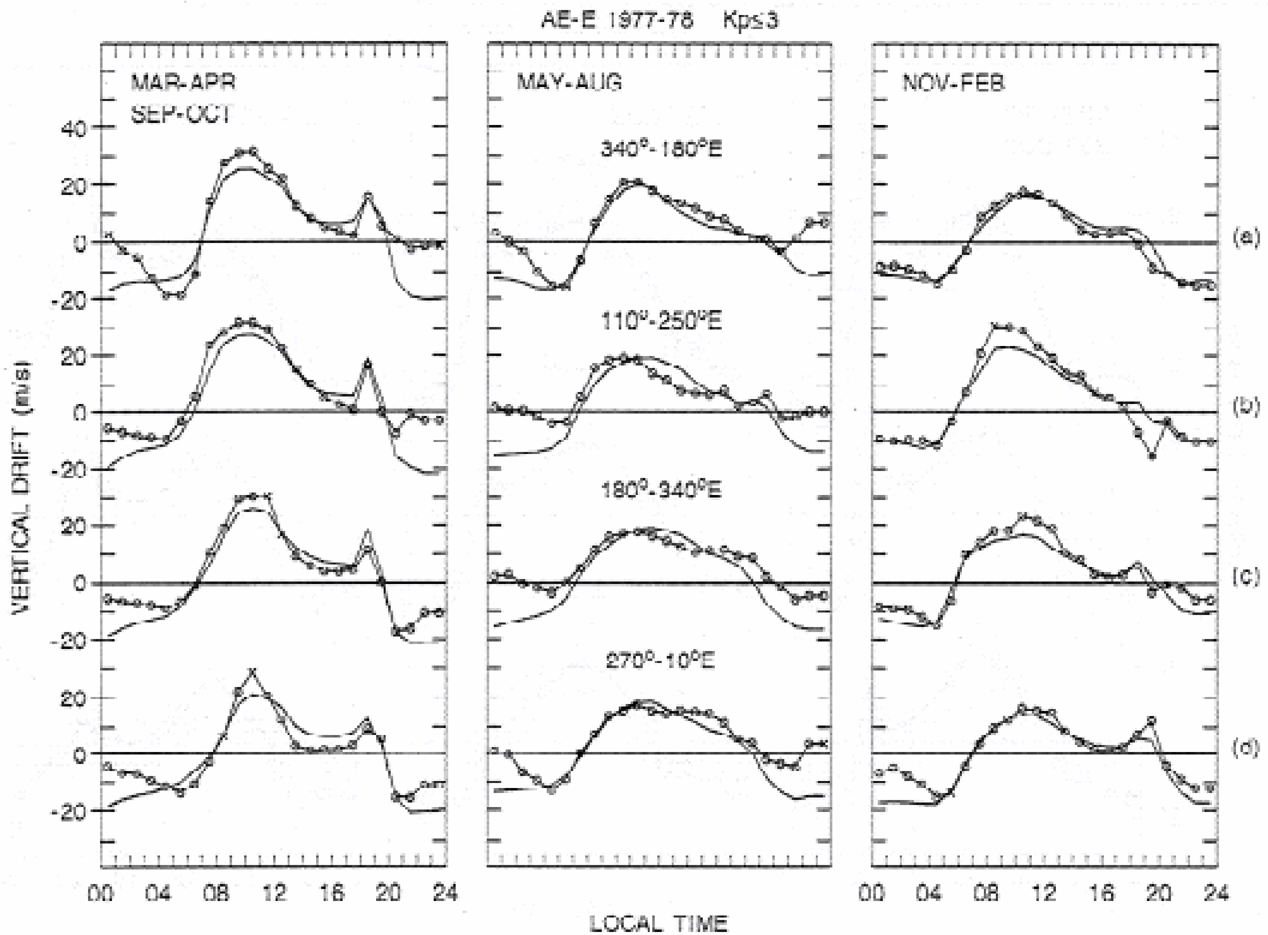


Figure 4. Comparison of the model predictions (solid curves with no symbols) with AE-E vertical drift observations in four longitudinal sectors and low solar flux conditions. The asterisk denotes averages from less than 30 data points.

Global Electrodynamical Consequences

This pattern of electric fields (no downward nighttime drift) has been observed before
in solar-min AE-E data used by Scherliess and Fejer to build their empirical drift model (see shaded examples)

SCHERLIESS AND FEJER: GLOBAL EQUATORIAL VERTICAL DRIFT MODEL 6835

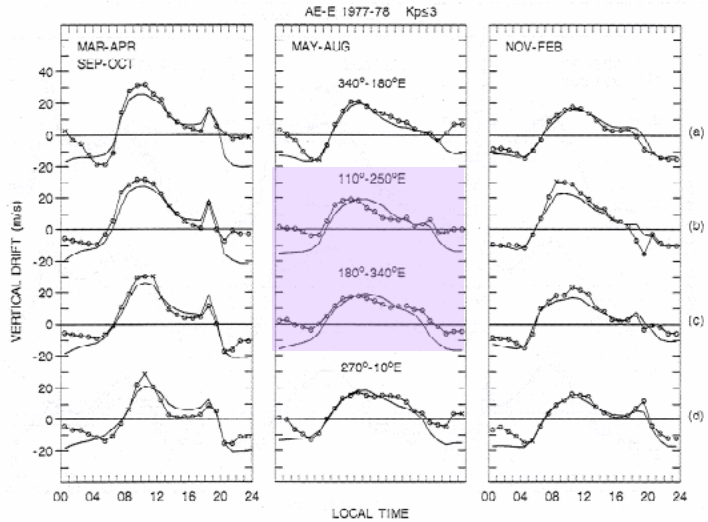


Figure 4. Comparison of the model predictions (solid curves with no symbols) with AE-E vertical drift observations in four longitudinal sectors and low solar flux conditions. The asterisk denotes averages from less than 30 data points.

If we expect integral of longitudinal electric field around globe to be zero, then when nighttime vertical drift is zero, daytime drift will be zero, too, on other side of globe.

C/NOFS IVM data suggest more structured large-scale fields, down drift later can compensate for no drift or upward drift earlier