

# Radio Occultation in Ionospheric Science and Space Weather

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C. H. Liu *Academia Sinica Taiwan*



NCU



NSPO

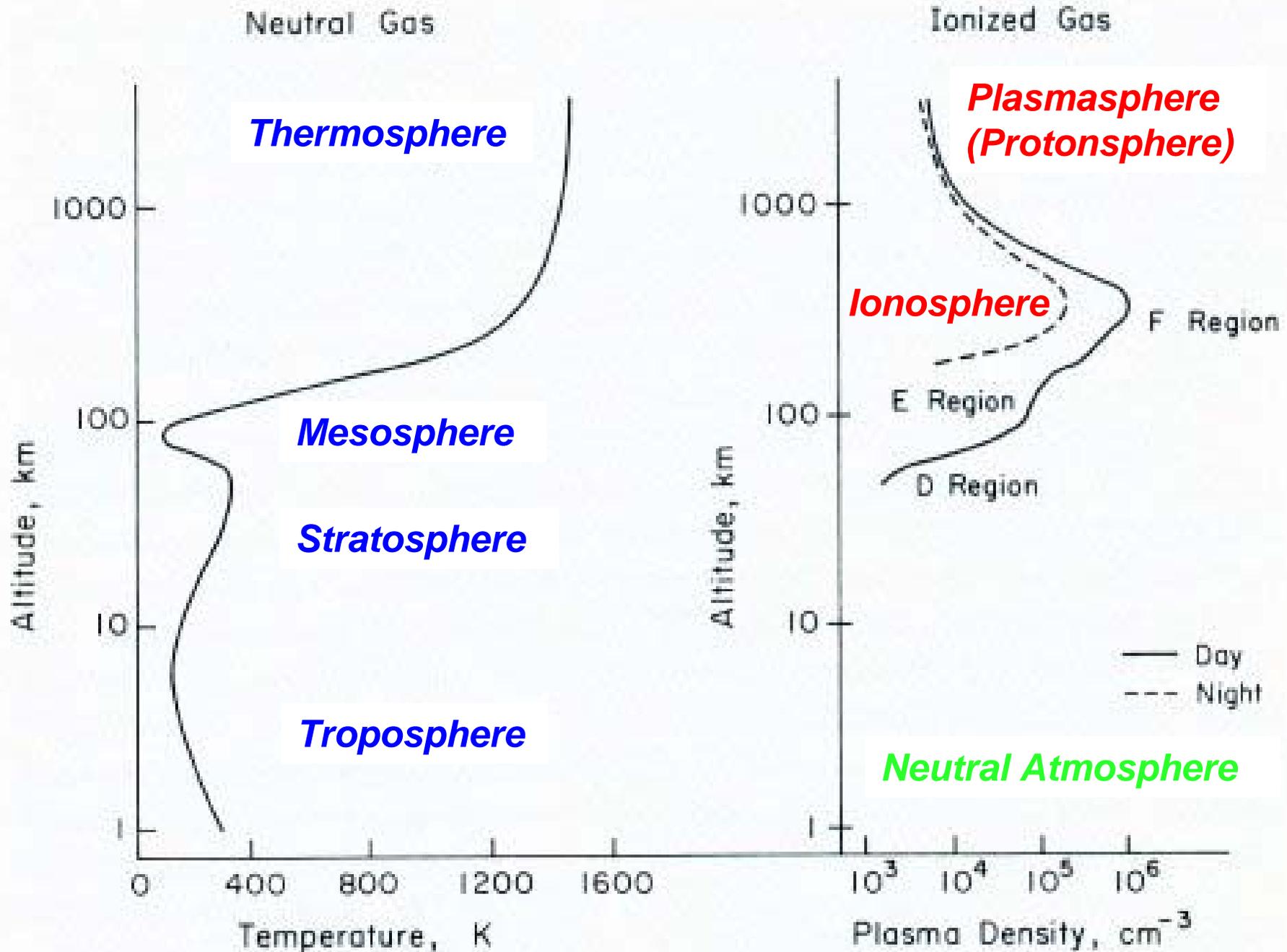
NATIONAL SPACE ORGANIZATION



# Content

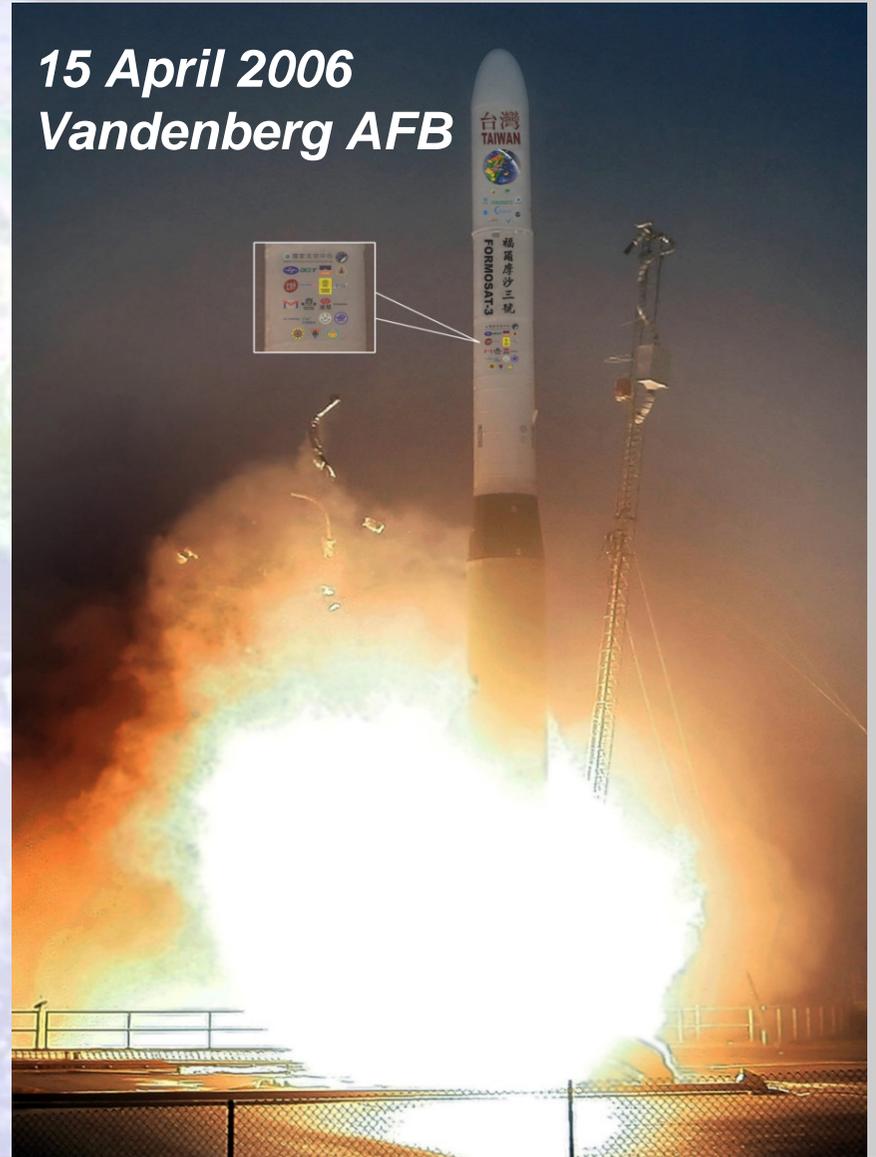
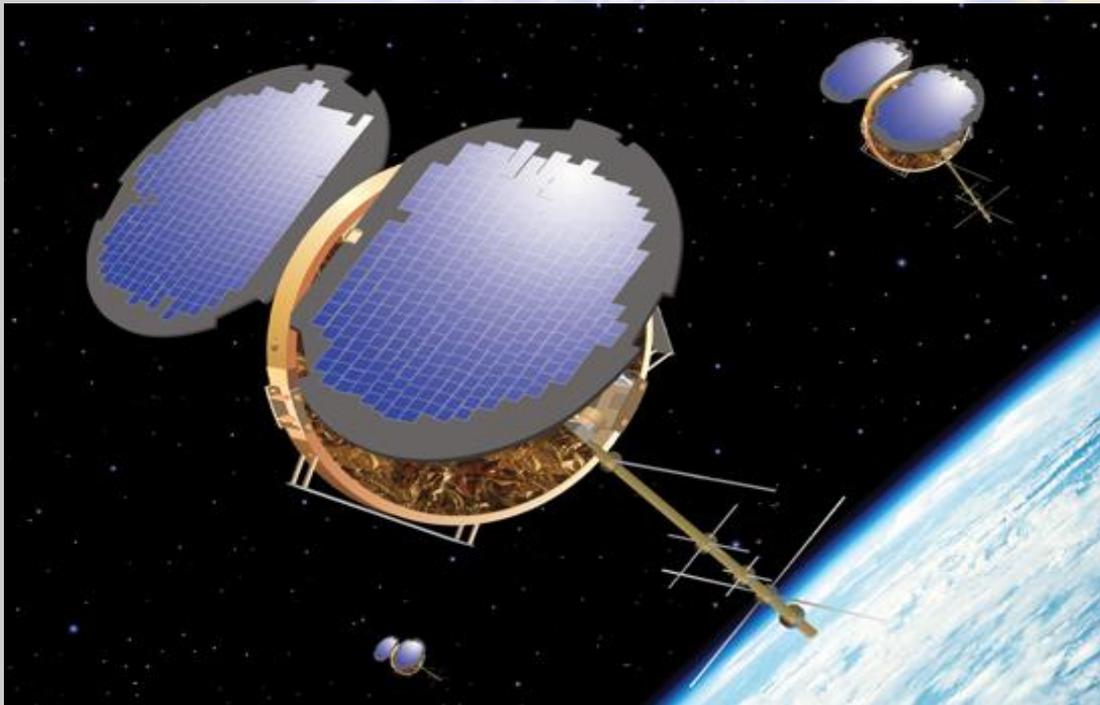
- **Introduction**
- **Ionospheric interesting phenomena**
  - **Equatorial Ionization Anomaly (EIA)**
  - **Mid-latitude Trough (MT)**
  - **Mid-latitude Summer Nighttime Anomaly (MSNA)**
  - **Plasma Depletion Bay (PDB)**
- **Lithosphere-Ionosphere Coupling**
- **Troposphere-Ionosphere Link**
- **Solar Wind-Ionospheric Effect**
- **Ionospheric Solar Eclipse Signature**
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# Introduction

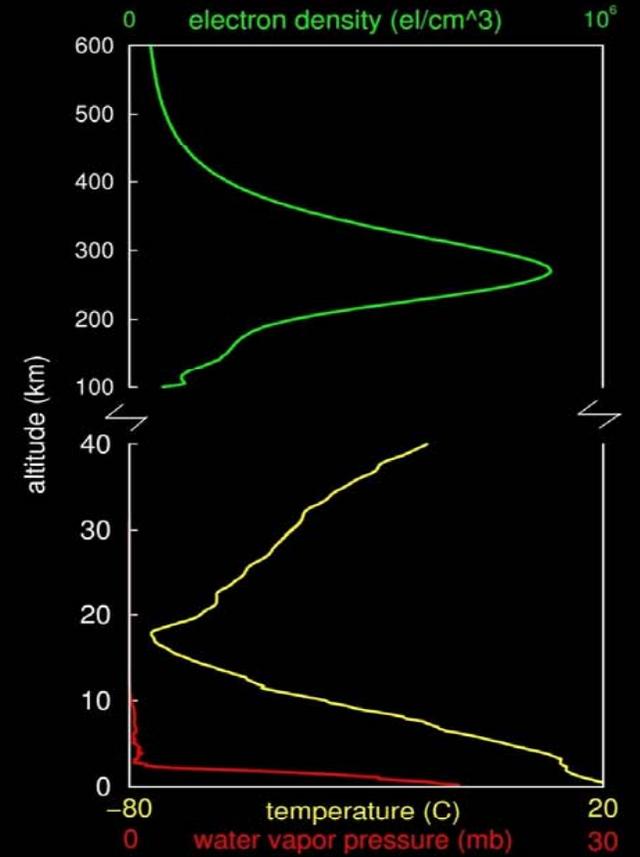
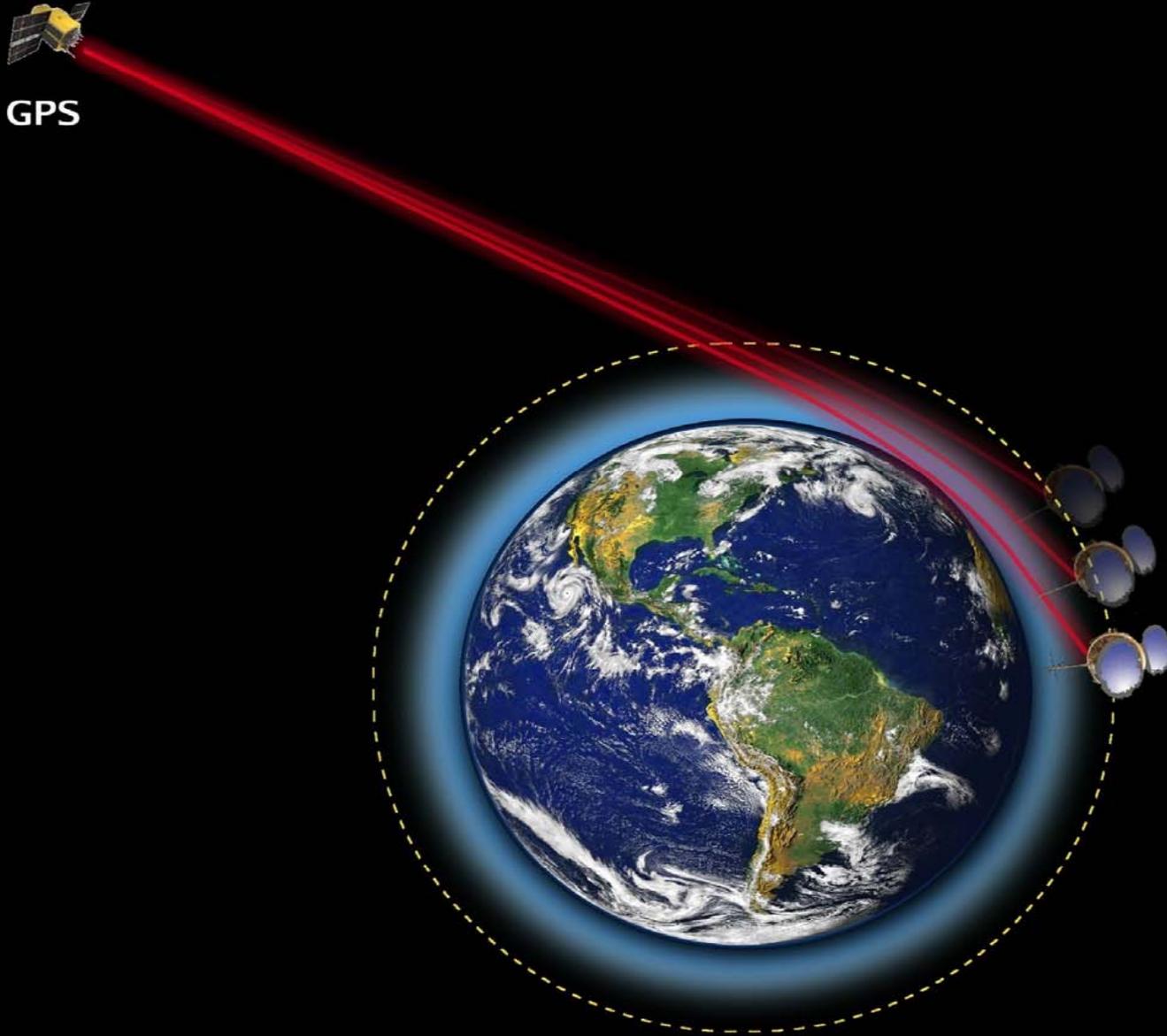


# FORMOSAT-3/COSMIC Satellite Constellation

*Transformative  
Atmospheric Profiling*

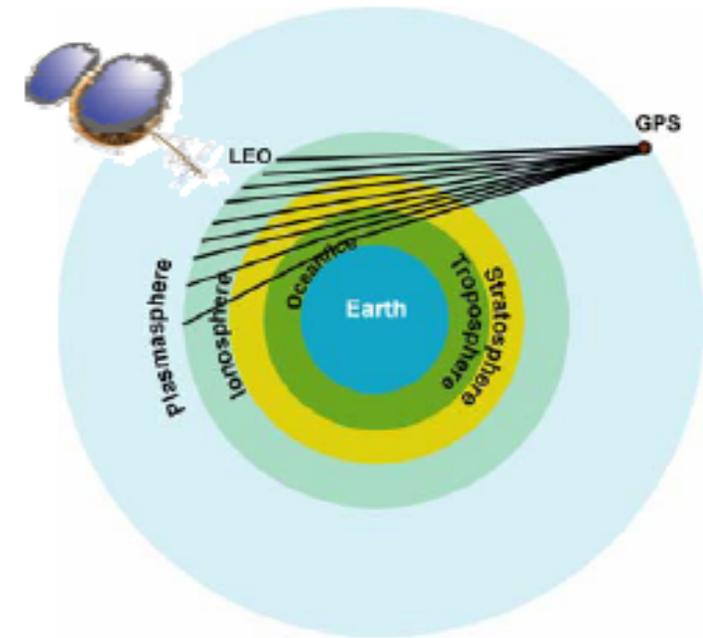
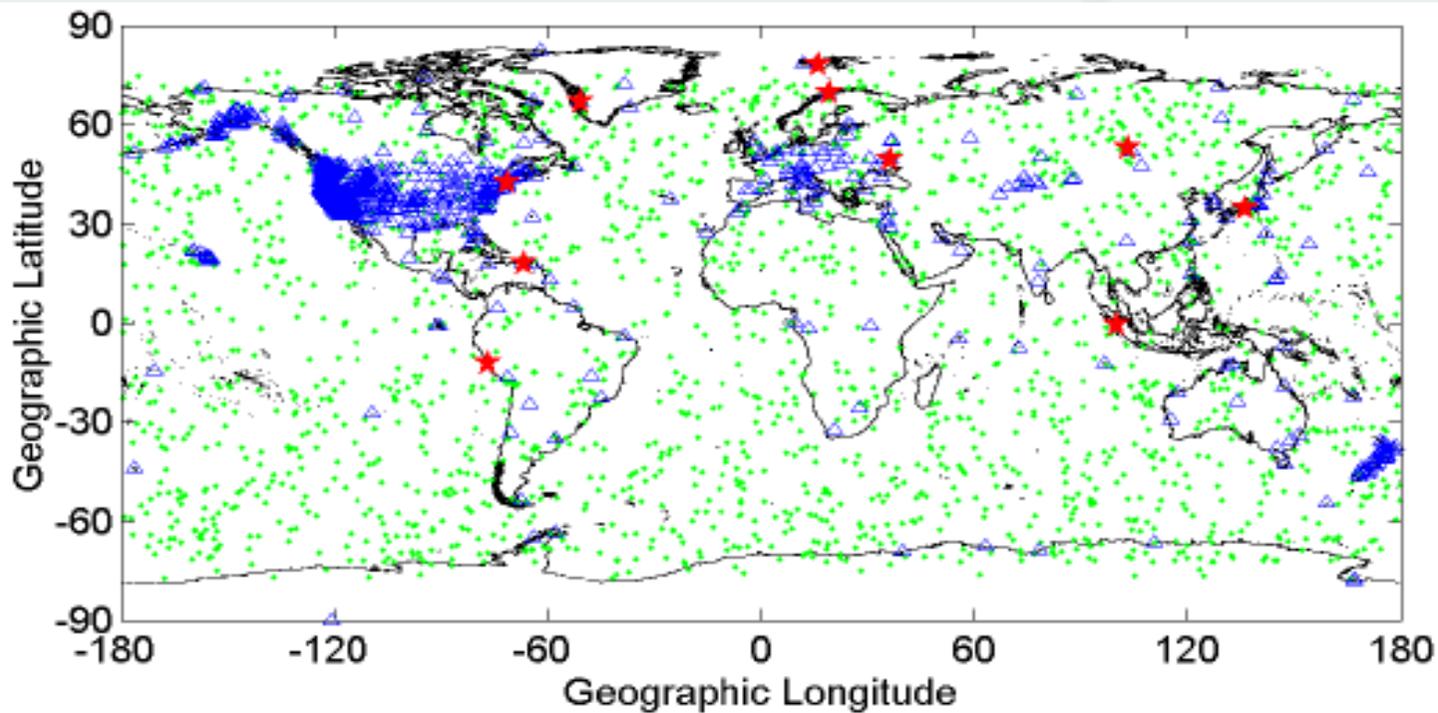


# FORMOSAT-3/COSMIC



**Profiling the Troposphere, Stratosphere and Ionosphere by Radio Occultation**

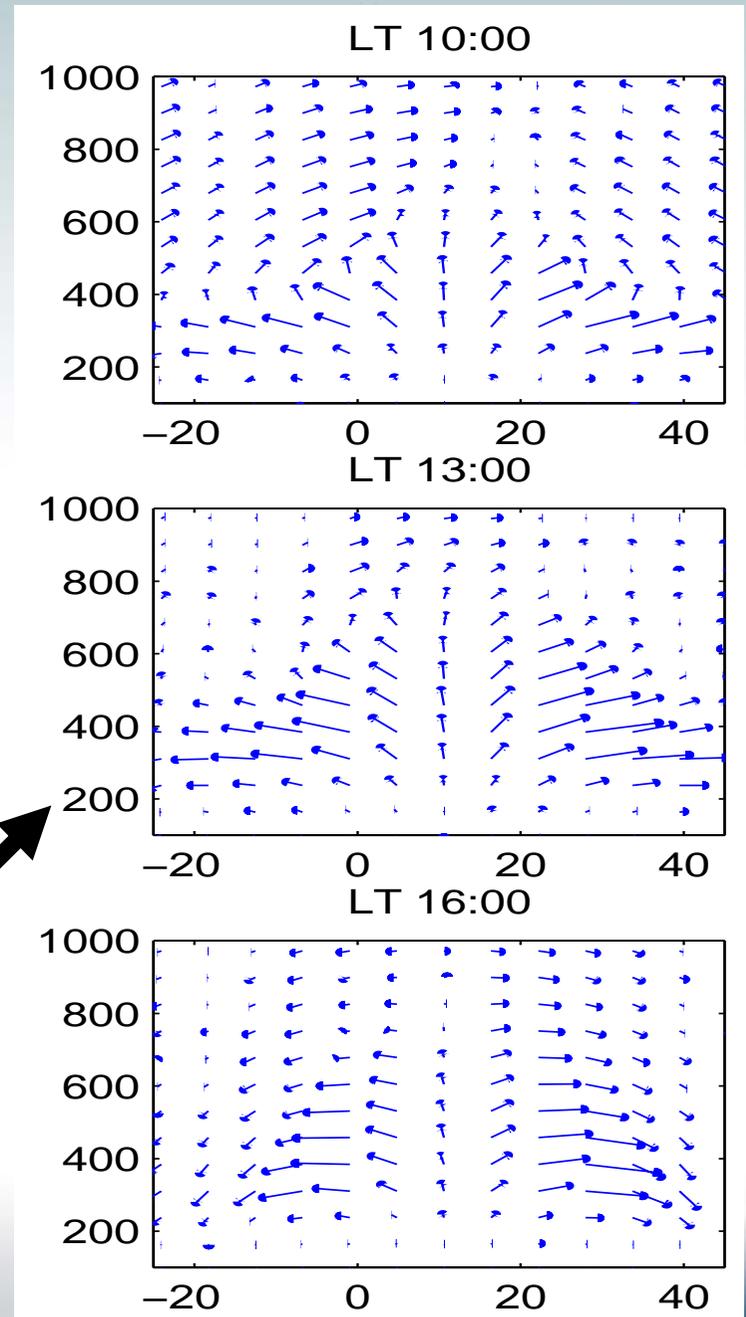
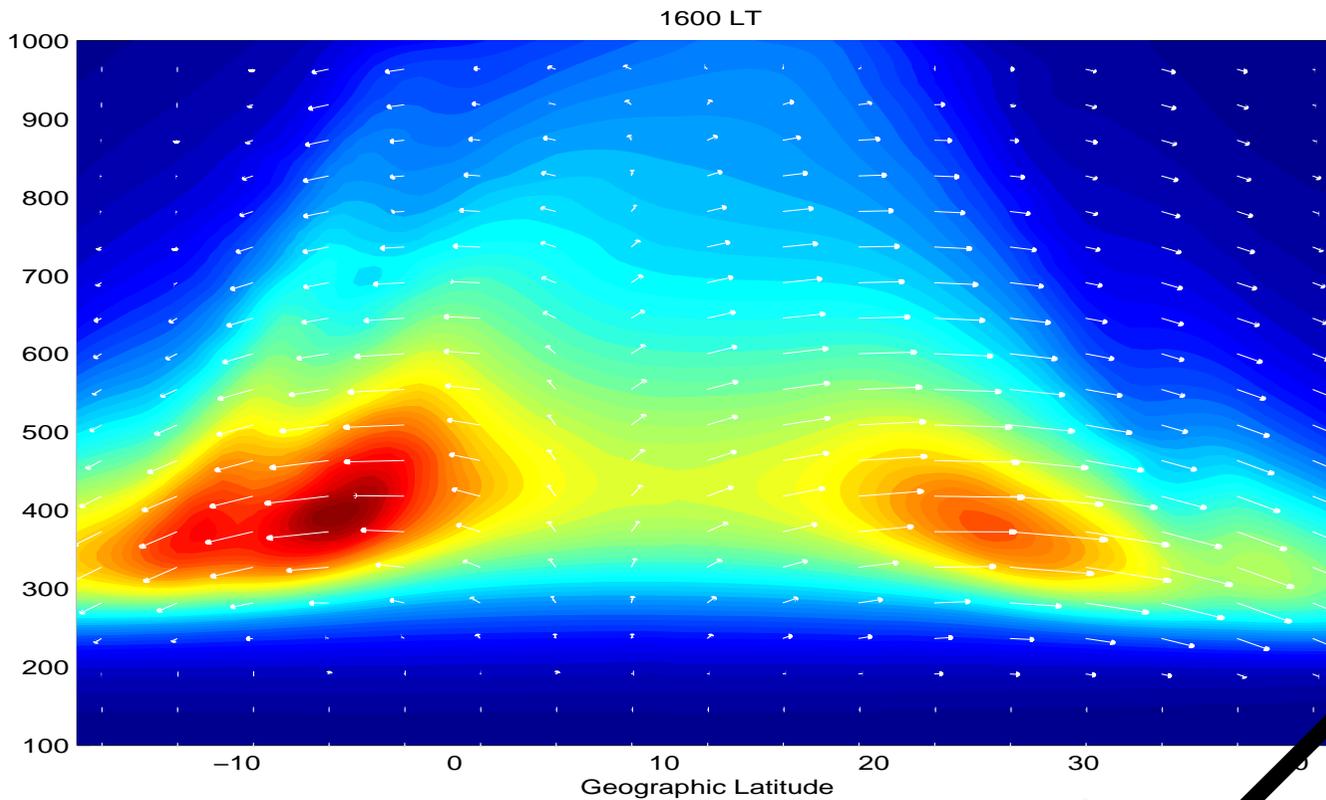
# FORMOSAT-3/COSMIC GOX Observation



# Equatorial Ionization Anomaly

# Equatorial plasma fountain

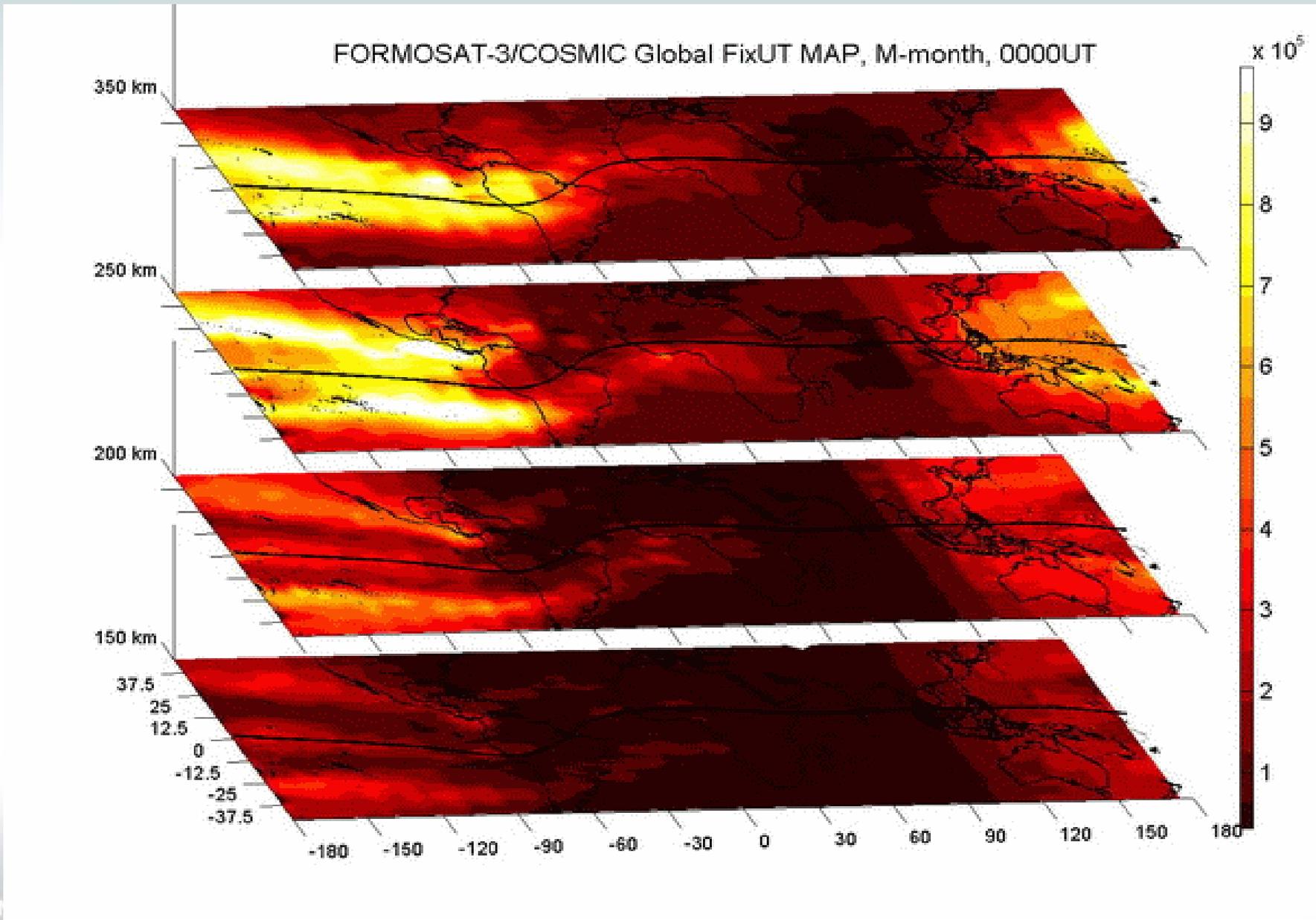
*Low-Latitude Ionosphere is dominated by the electrodynamics*



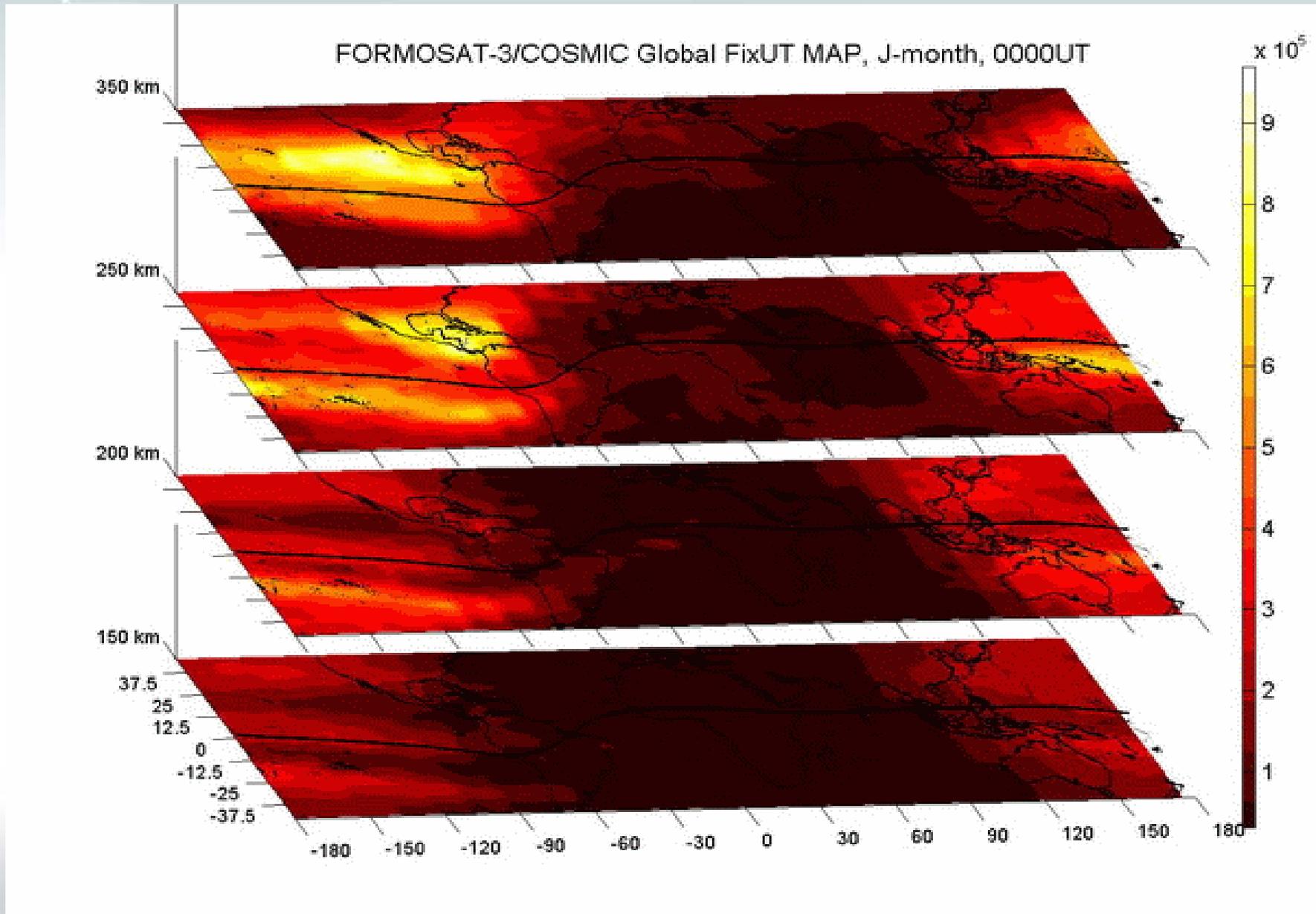
**Ratcliffe [1972]**

*A model simulated plasma fountain effect starting in the morning and enhance to its maximum around noon*

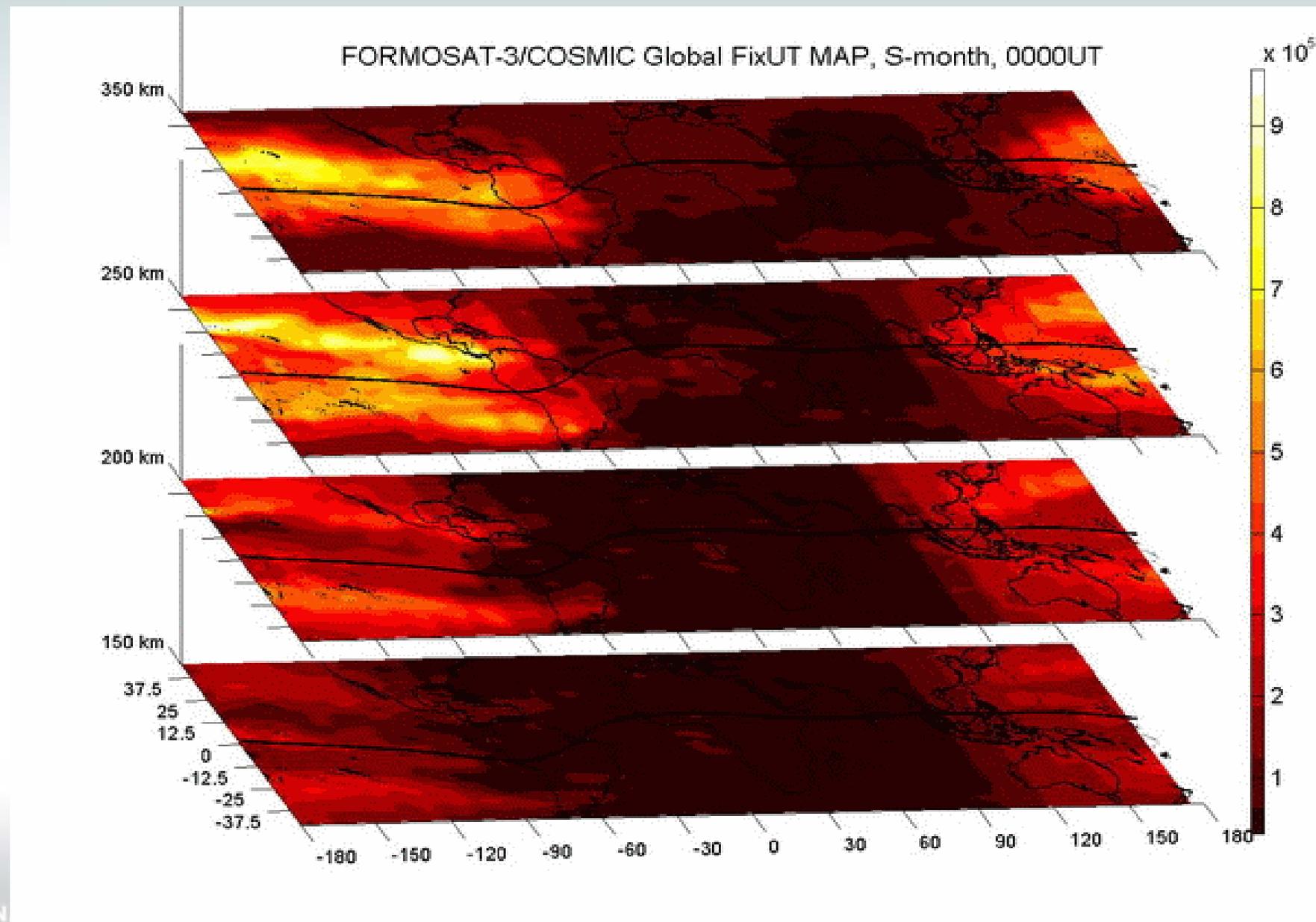
# 2007 M-month



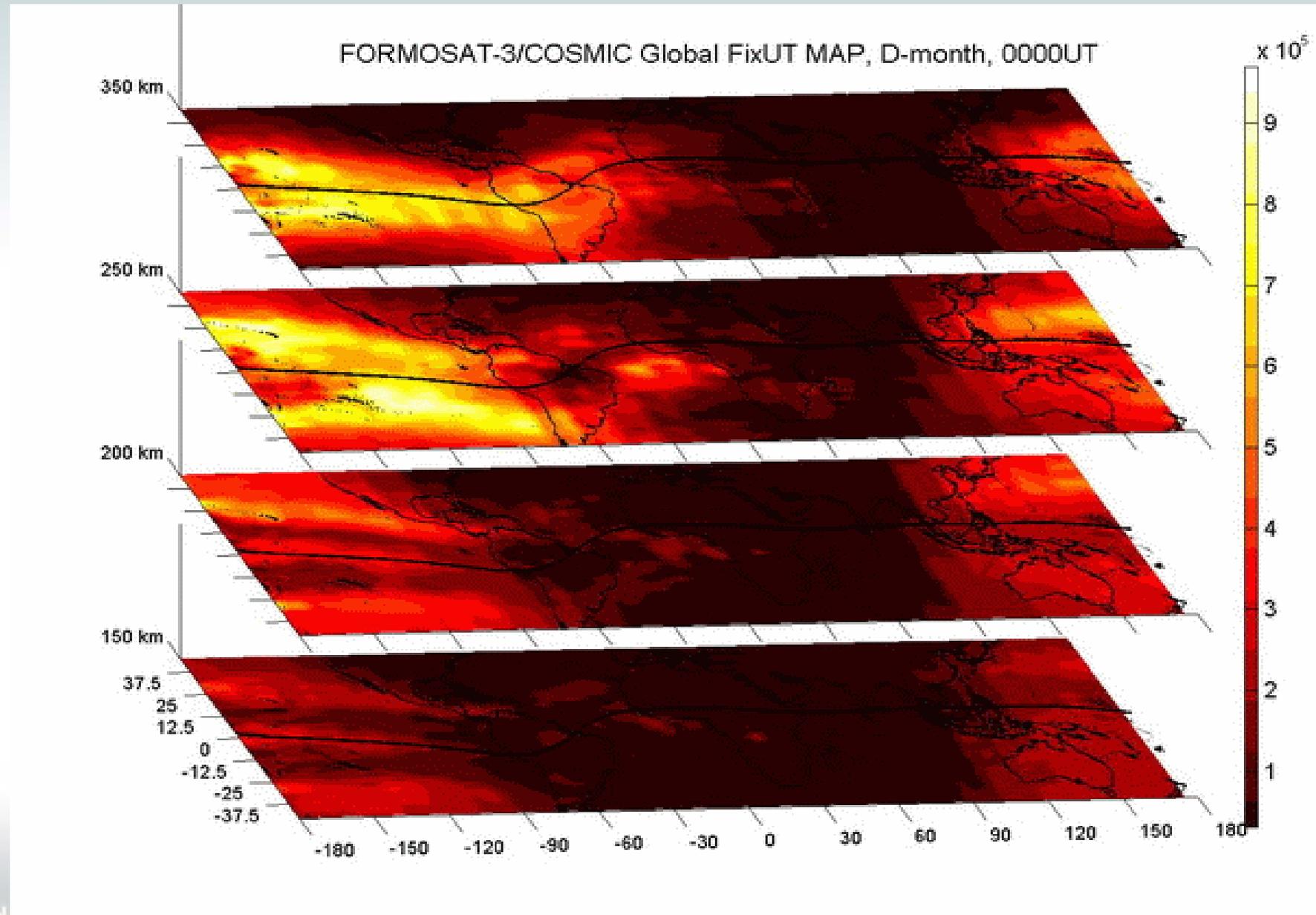
# 2007 J-month

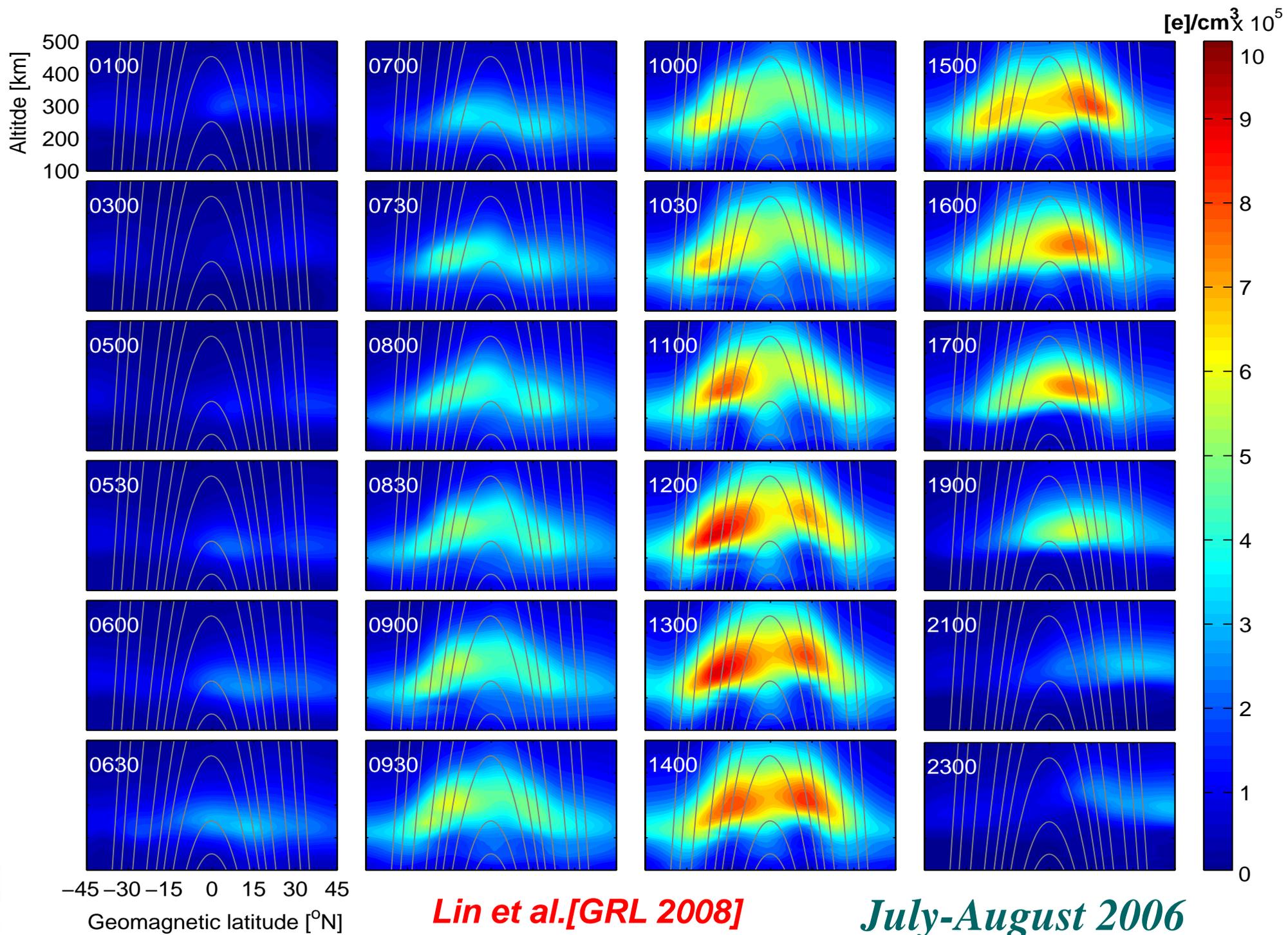


# 2007 S-month

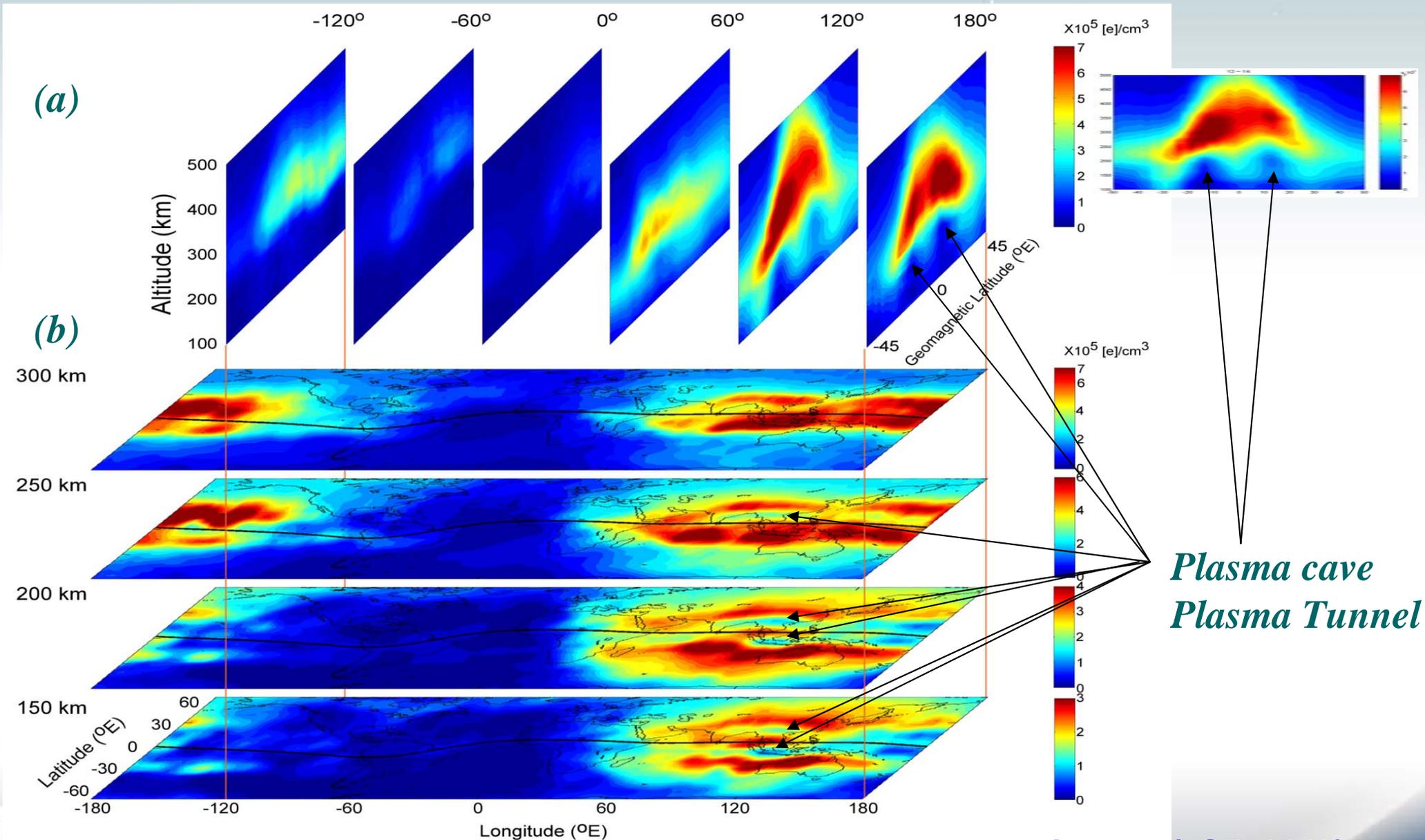


# 2007 D-month



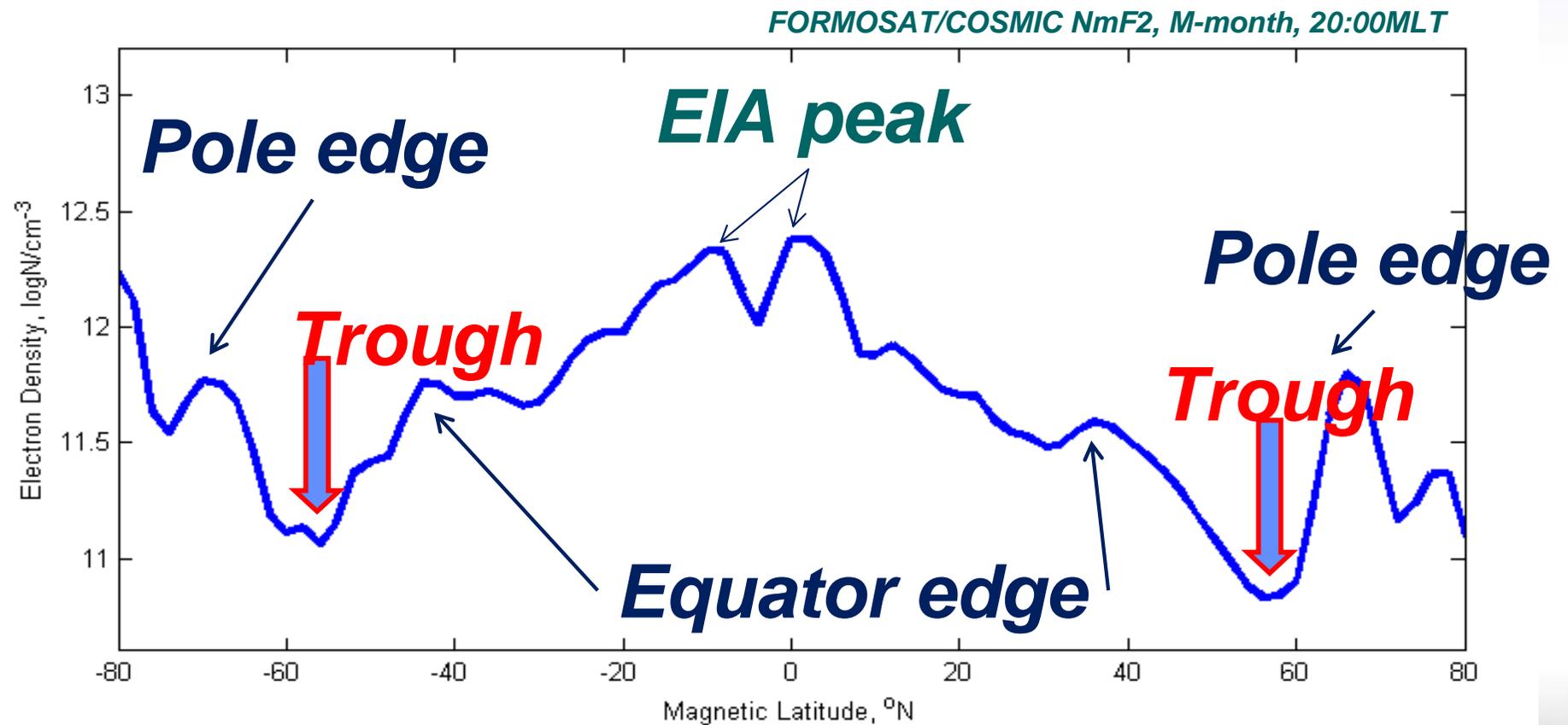


# *Ionospheric plasma cave/tunnel*

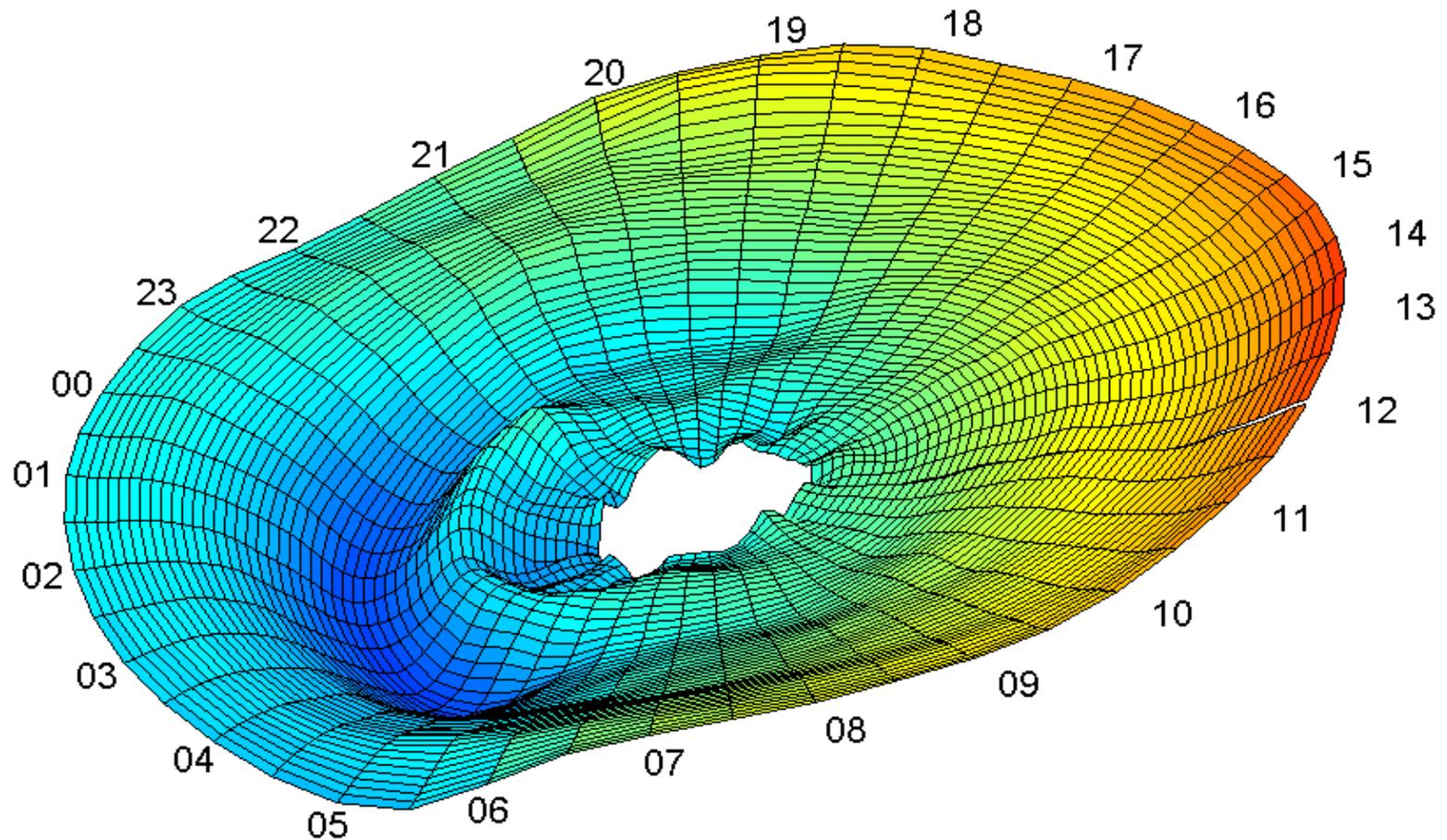


*Liu et al. (JGR, 2010)*

# Mid-latitude trough



# ***FORMOSAT-3/COSMIC NmF2 Pseudo-3D structure Northern Hemisphere, M-month***

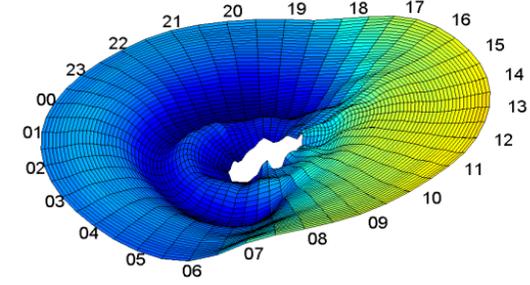


***lat xheight xtime: 2°x2km x0.5hr***

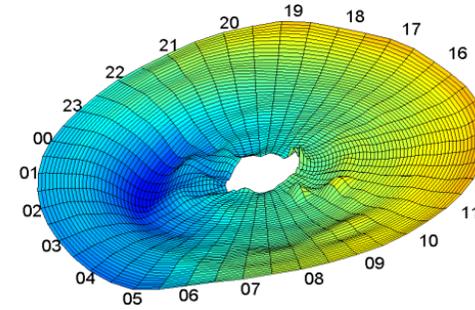
# Seasonal Variation

## Northern hemisphere

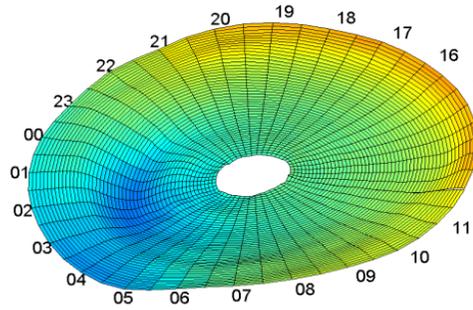
Northern D-month



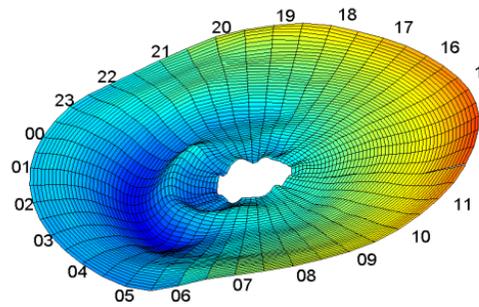
Northern S-month



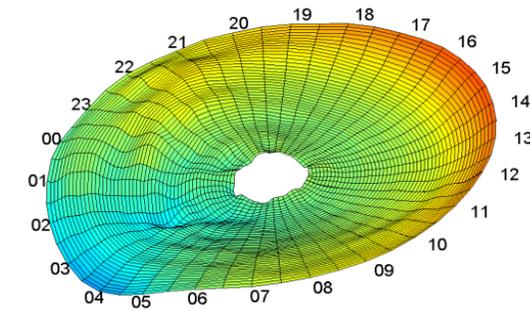
Northern J-month



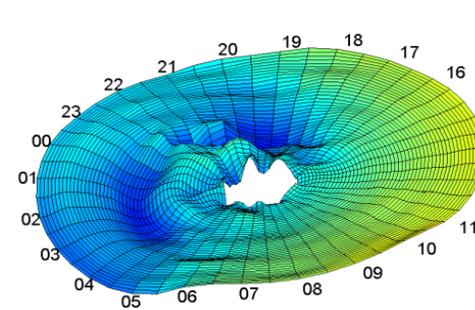
Northern M-month



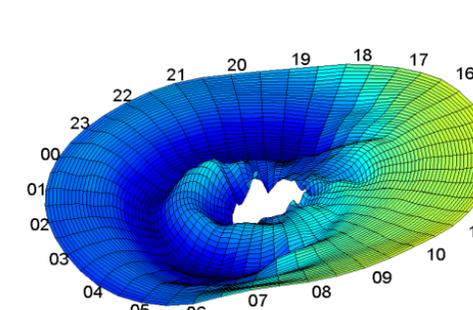
Southern D-month



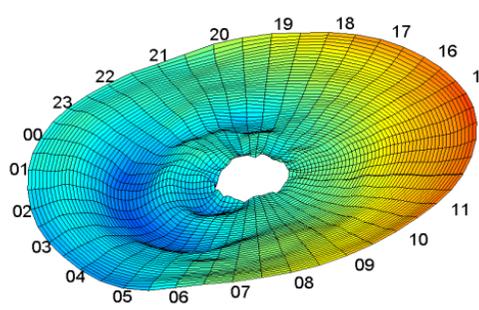
Southern S-month

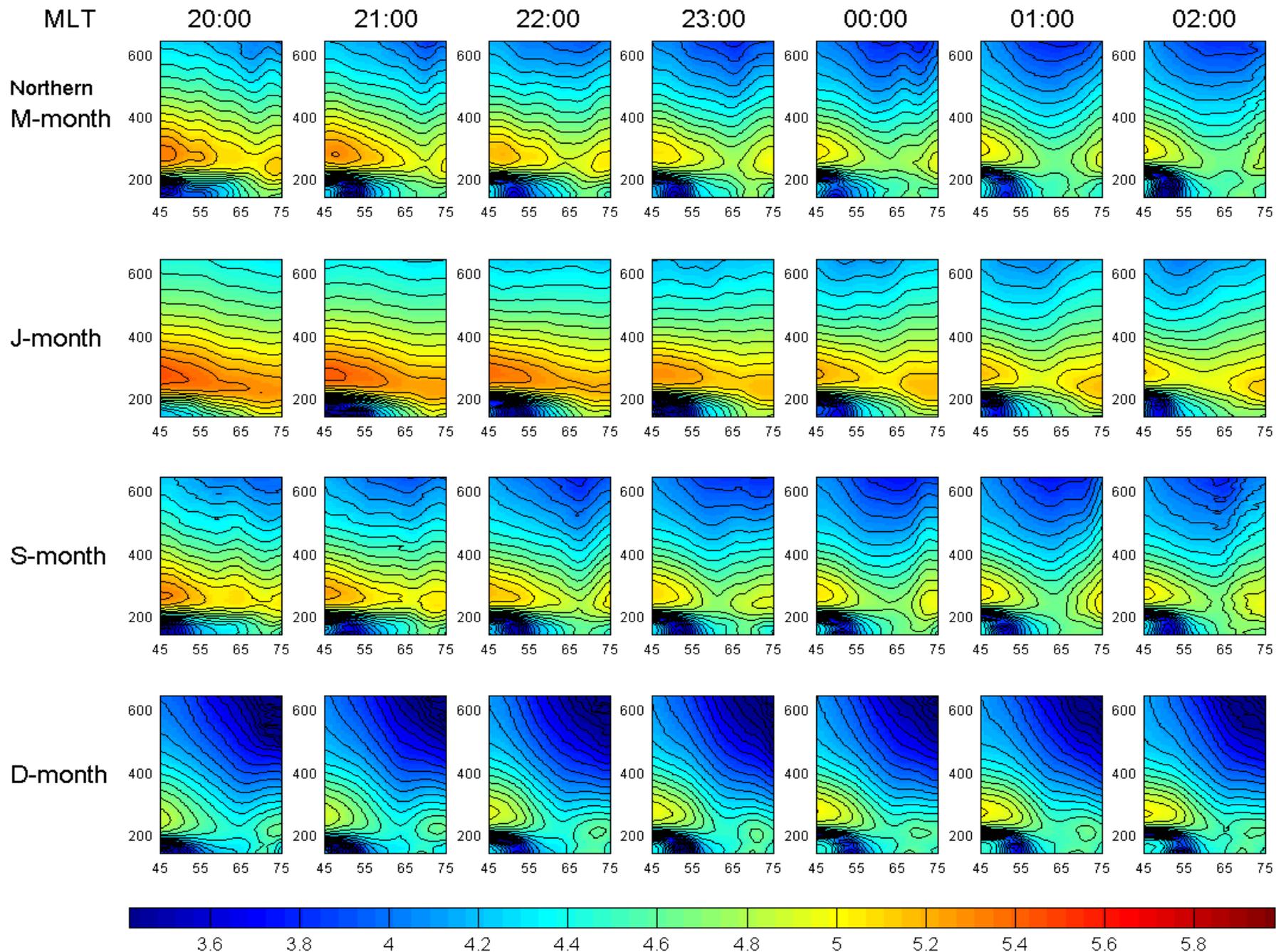


Southern J-month



Southern M-month

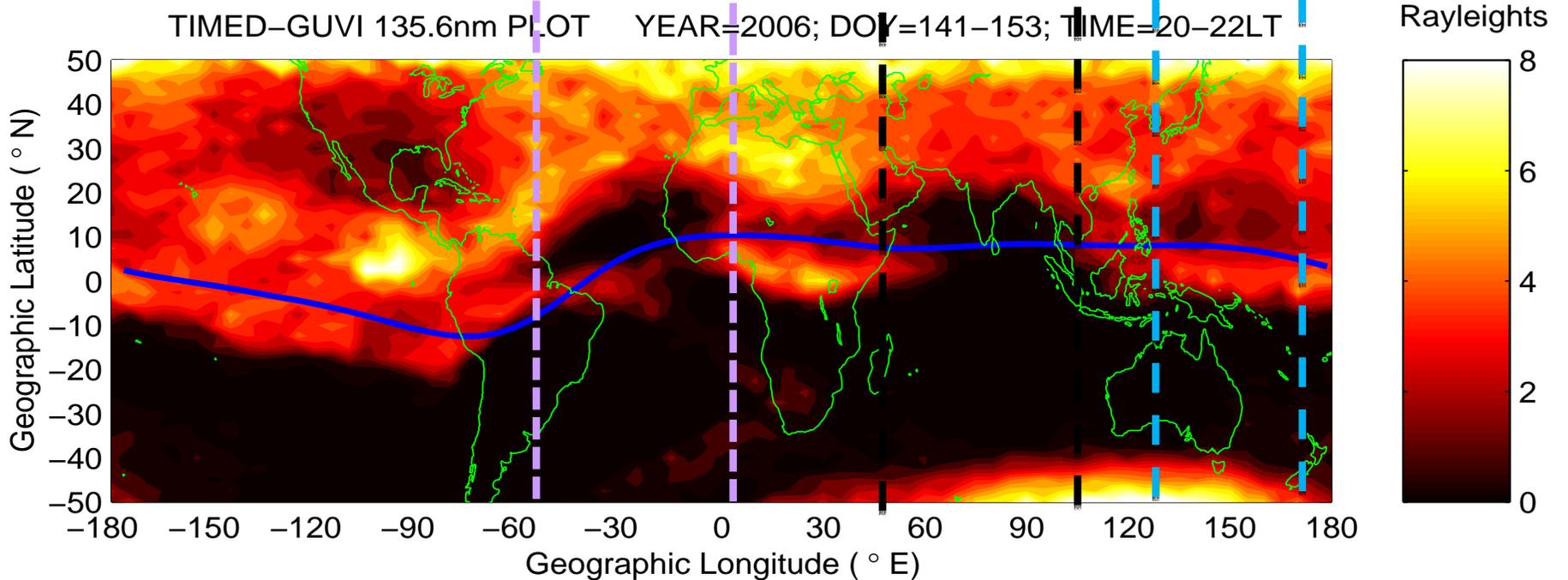
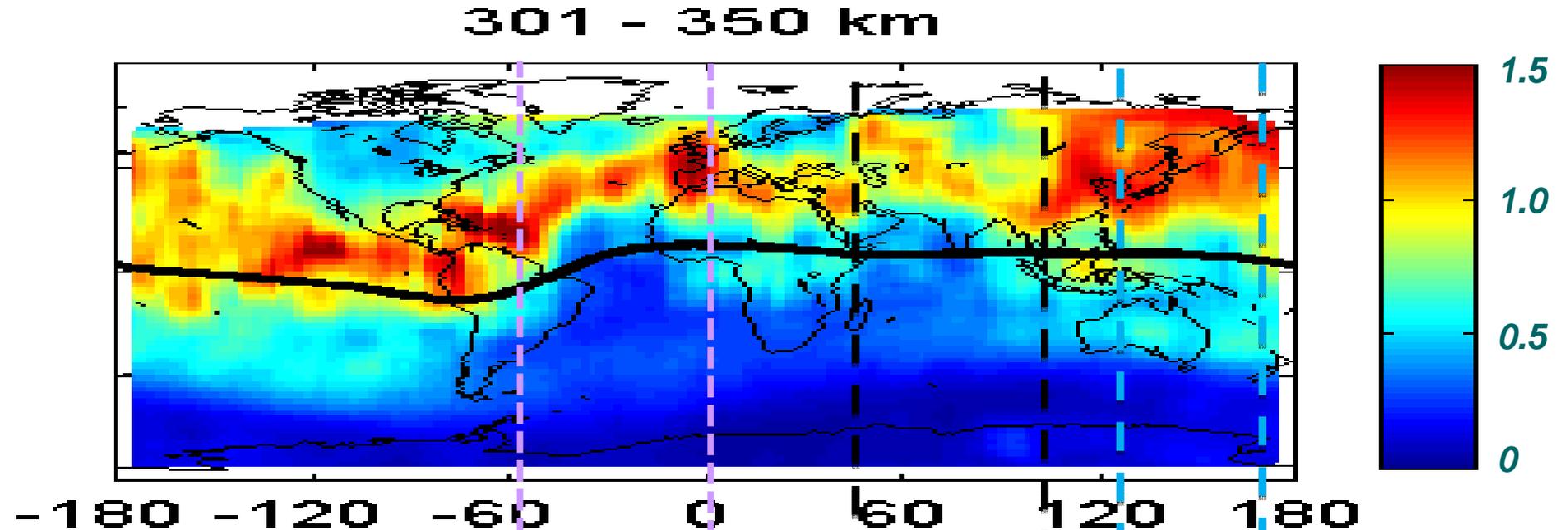




# Plasma Depletion Bay

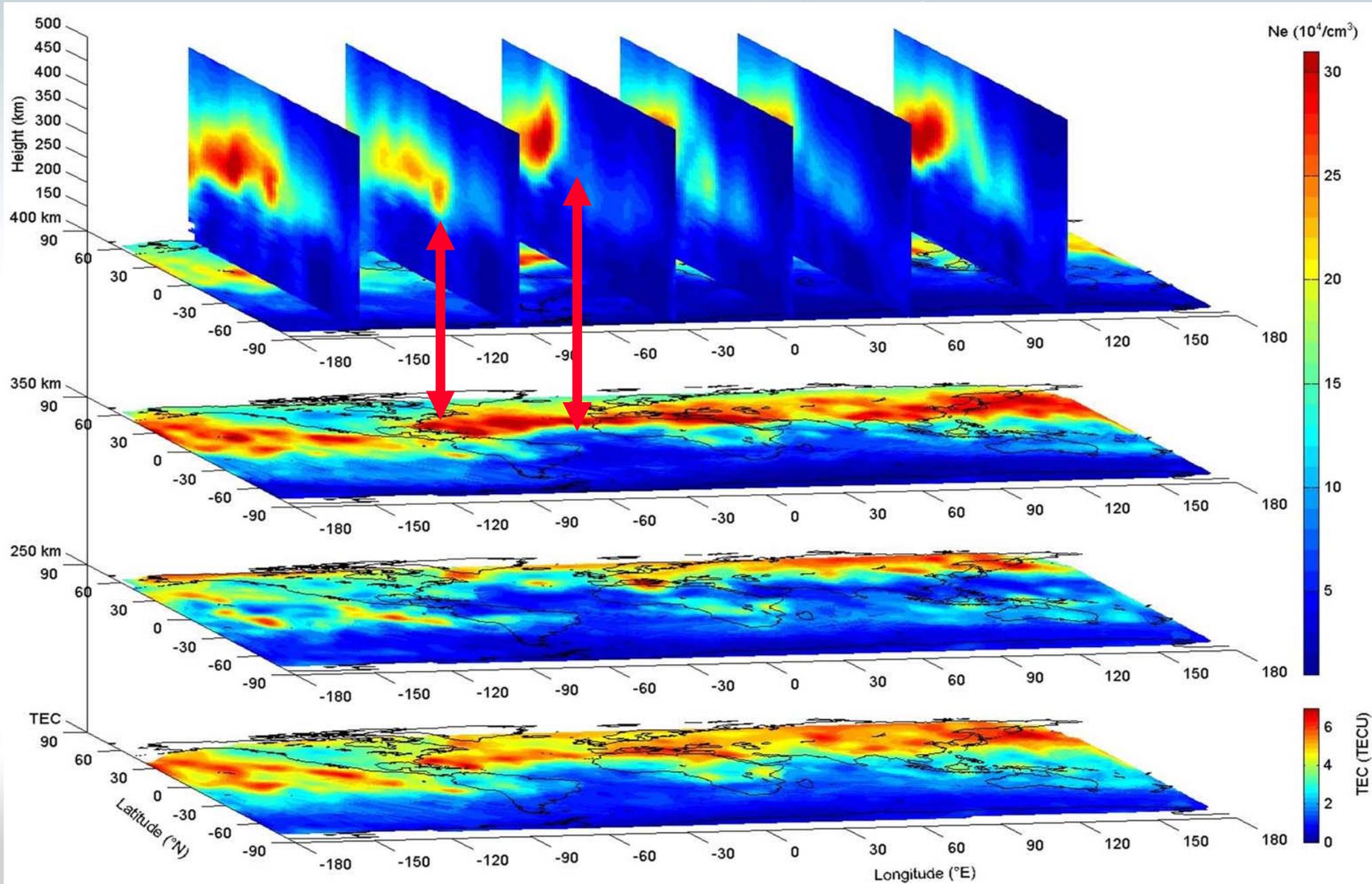
# Plasma Depletion Bay observed by F3/C and TIMED GUVI

Nighttime ionospheric structures, 23:00 LT (global fixed local time)

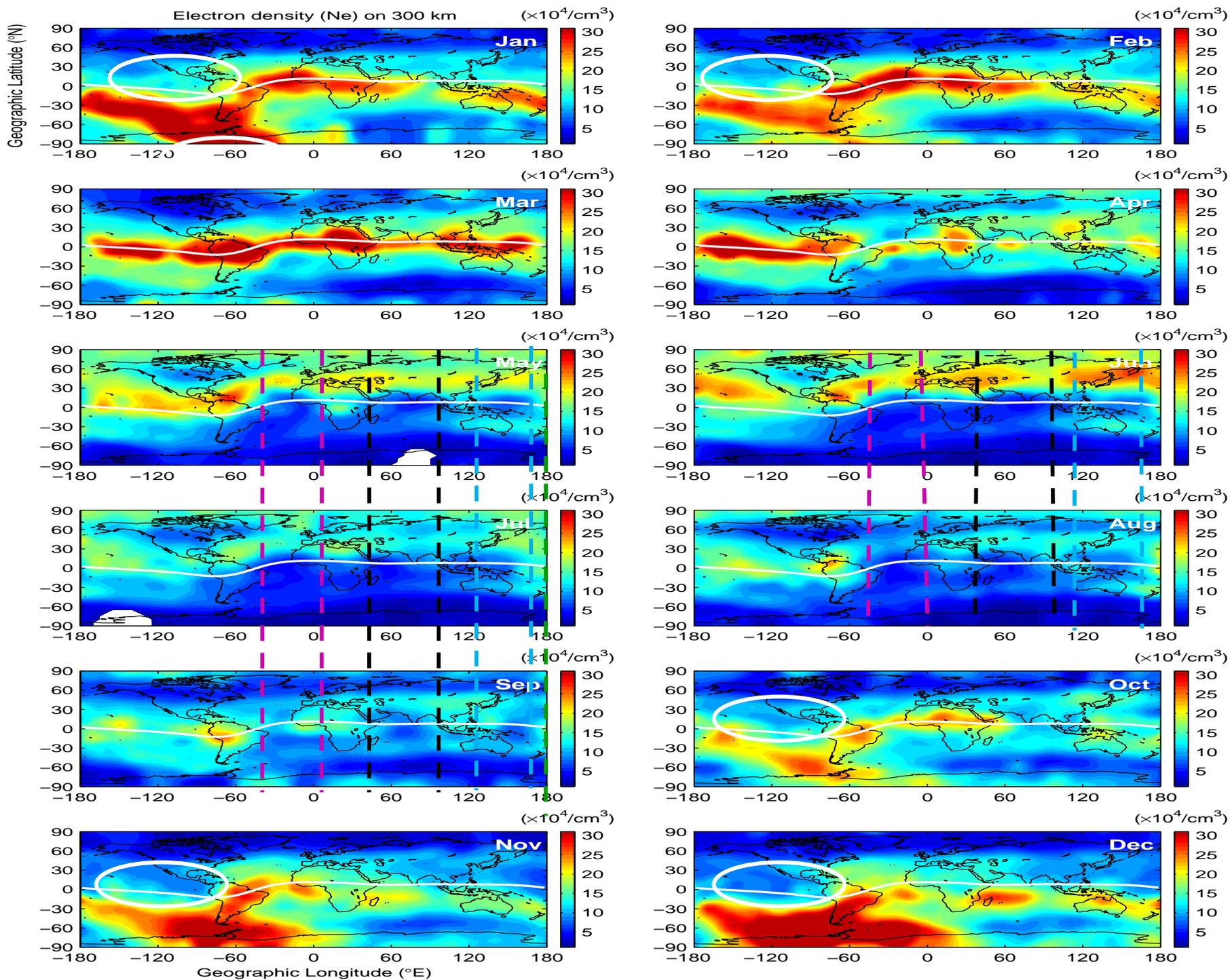


# Plasma depletion bay

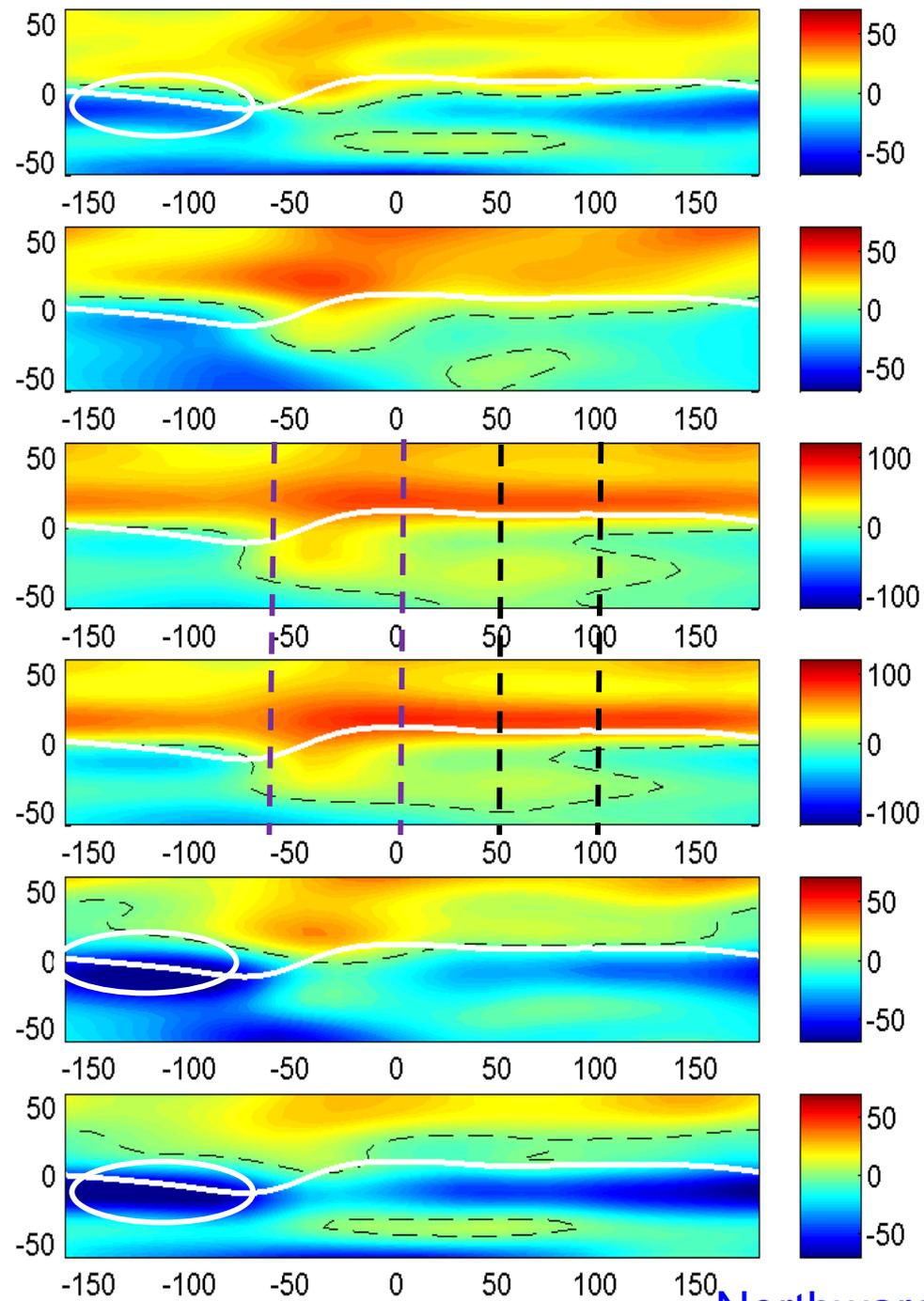
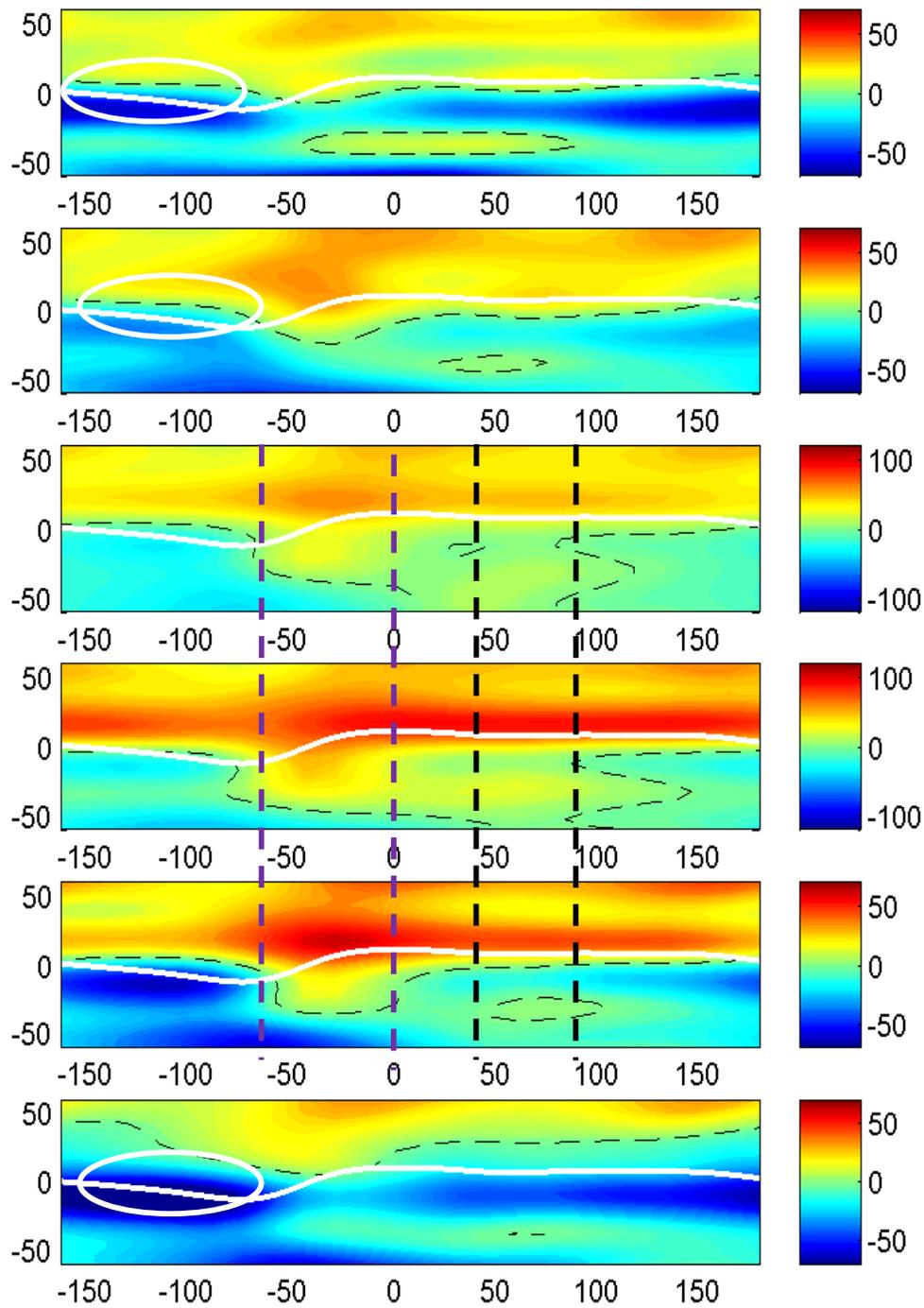
## Nighttime ionospheric structures: 3-D images



# Monthly variation of the ionospheric electron density 24:00 LT, 300 km altitude



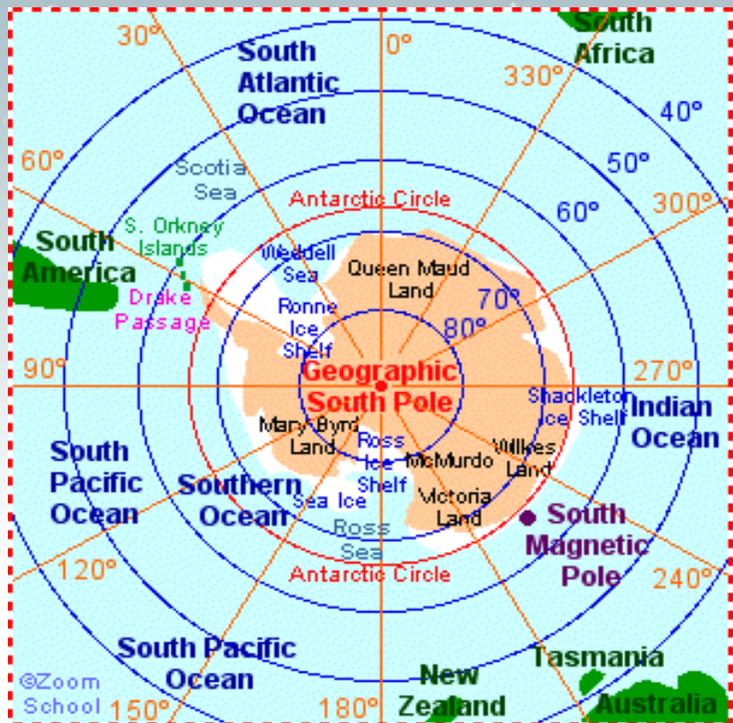
Southward



Northward

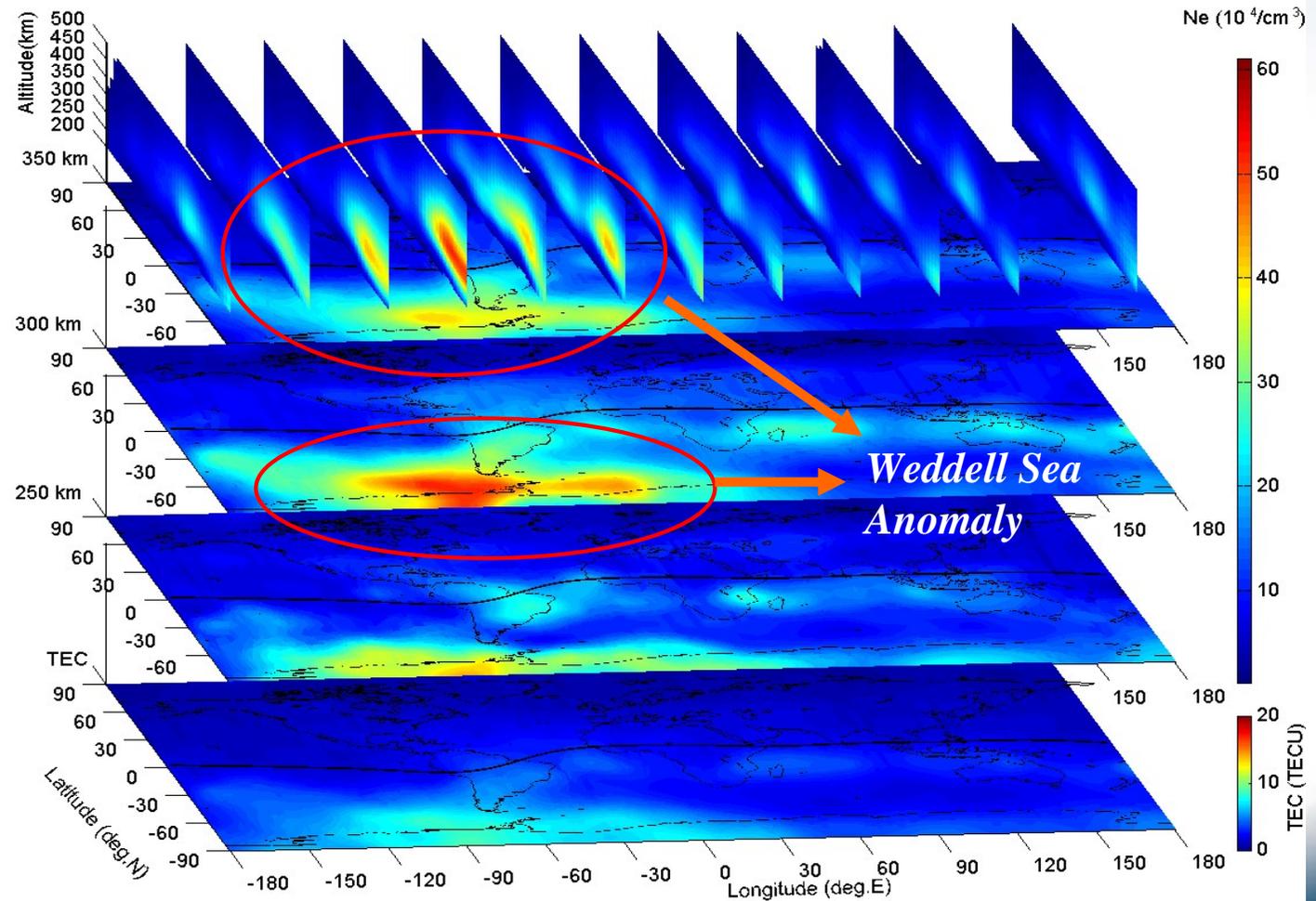
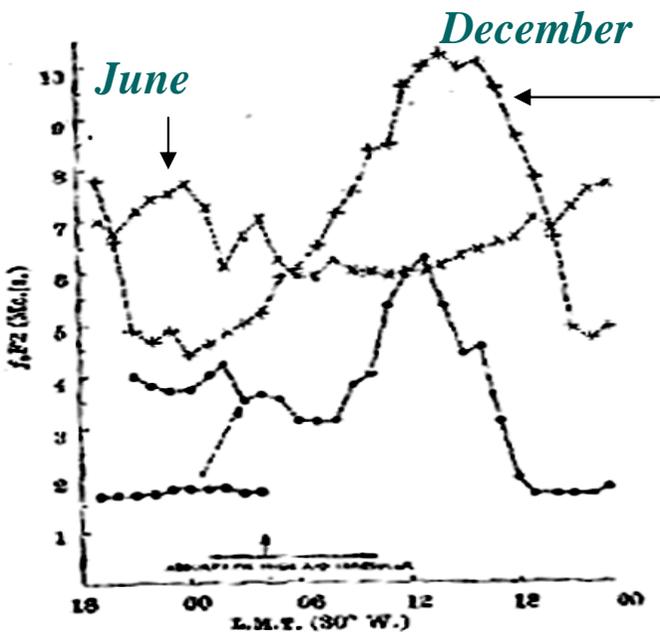
# **Mid-latitude Summer Nighttime Anomaly**

## **Weddell Sea Anomaly**



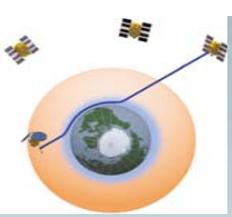
## The Ionospheric Weddell Sea Anomaly

1. Stronger nighttime  $N_e$  than that during daytime
2. Discovered 50 years ahead of renewed observation by COSMIC
3. First glance of its vertical structure by COSMIC!



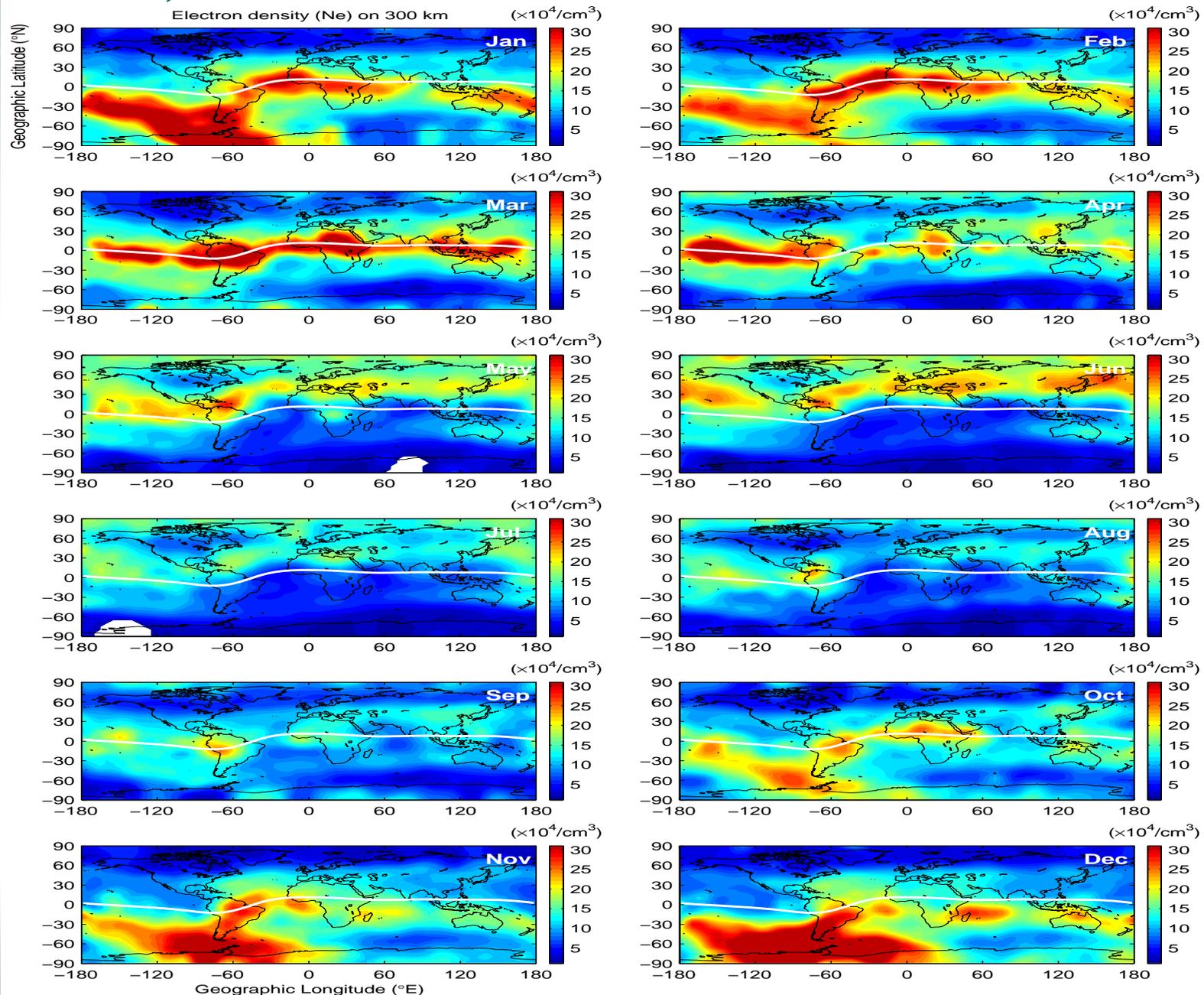
Ionosonde Observation  
 (Bellchambers and Piggott, 1958)

Lin et al., 2009

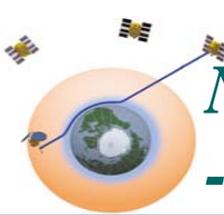


# MSNA is the most significant nighttime ionospheric phenomena

Lin et al., 2010



Ne at 300 km altitude at 24:00 LT



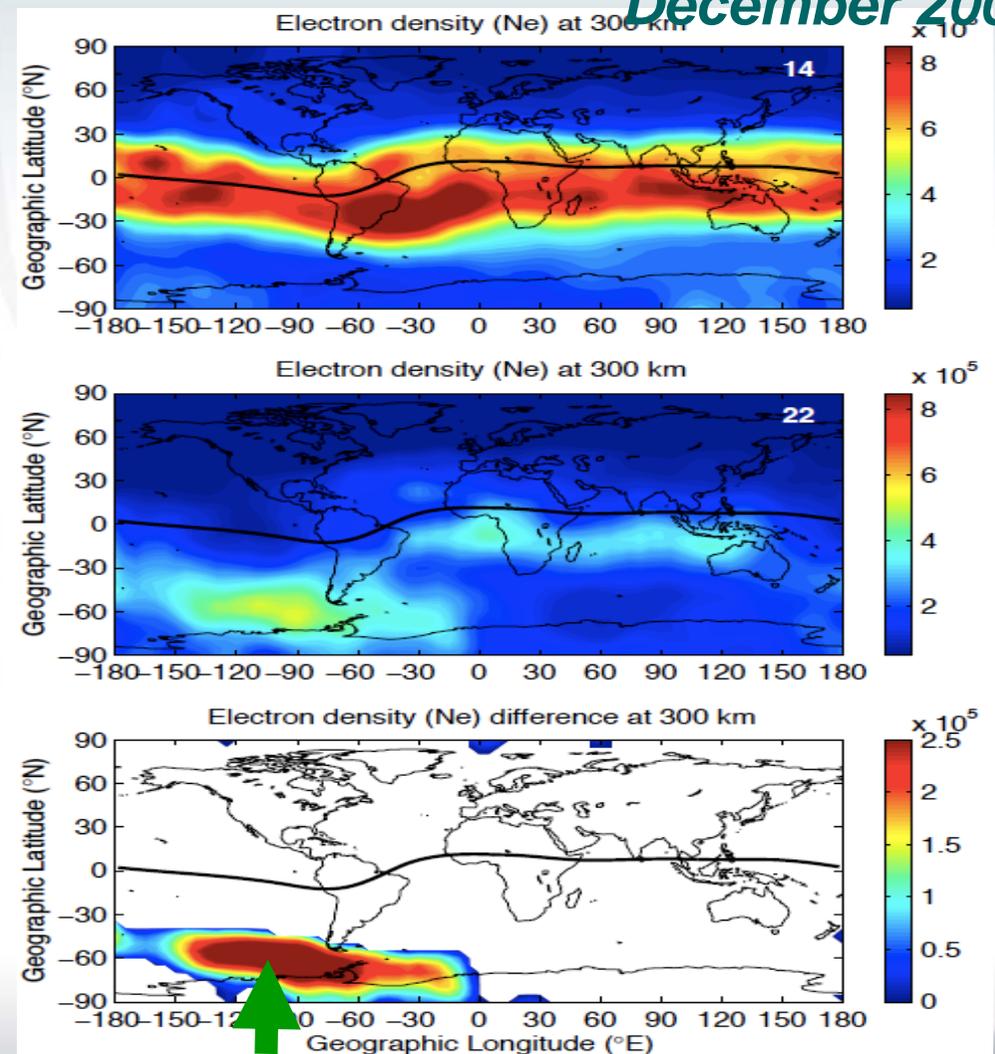
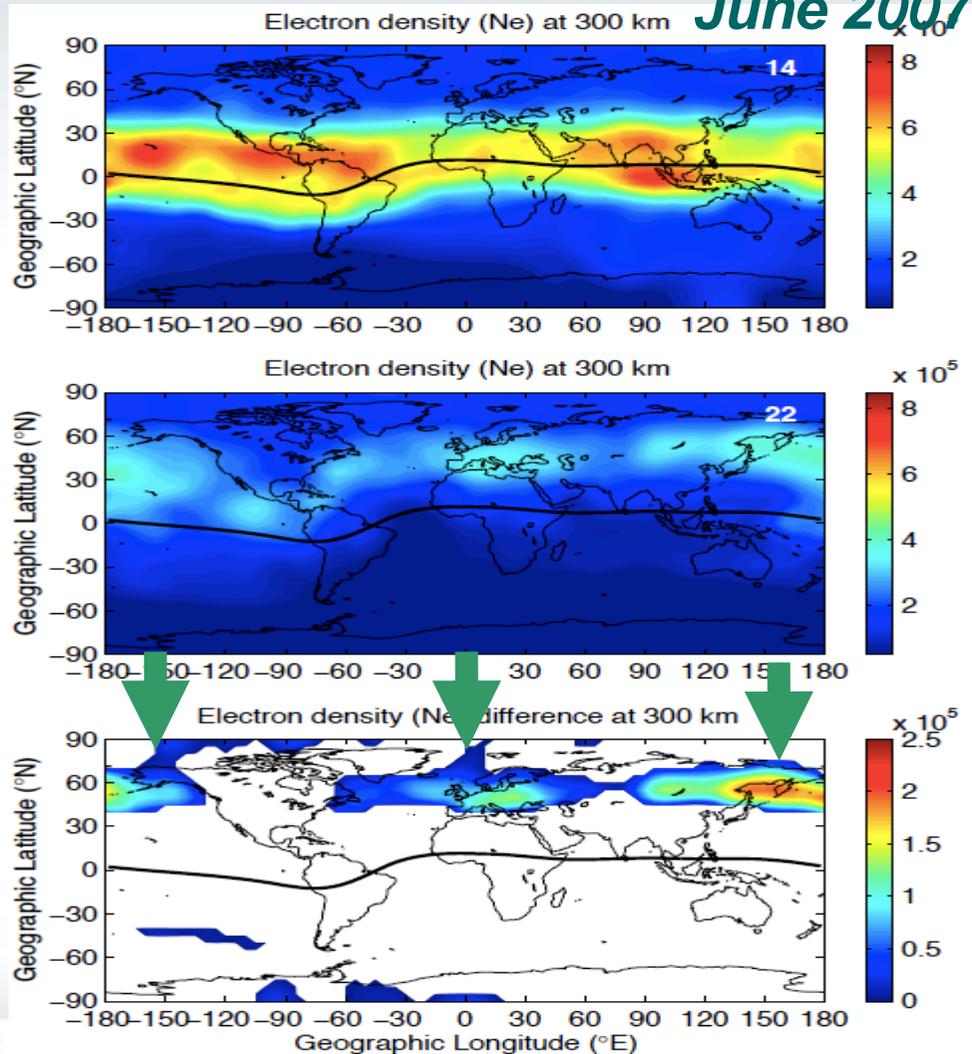
*Not only occurred in the Southern hemisphere but also in the North*  
*- Categorized as the Mid-latitude Summer Nighttime Anomaly (MSNA)*

*$Ne(2200LT) > Ne(1400LT)$*

*- driven by equatorward meridional neutral wind*

**June 2007**

**December 2007**

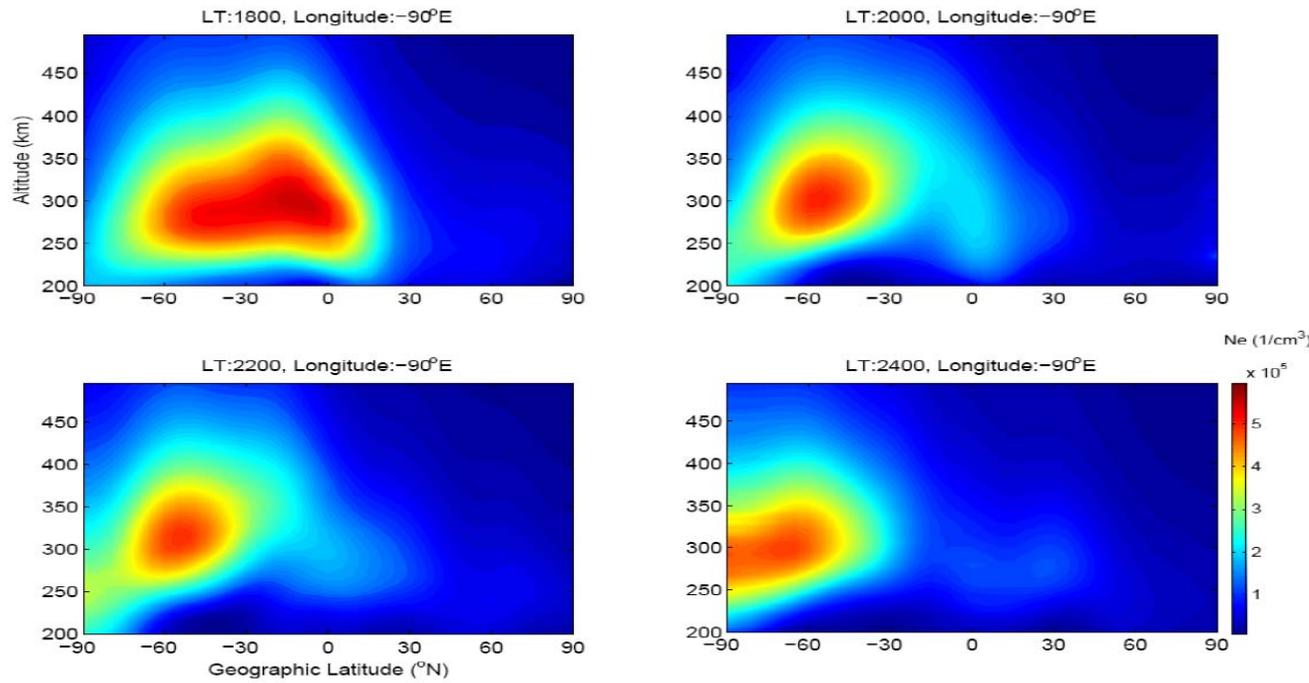


**↑ : equatorward neutral wind**

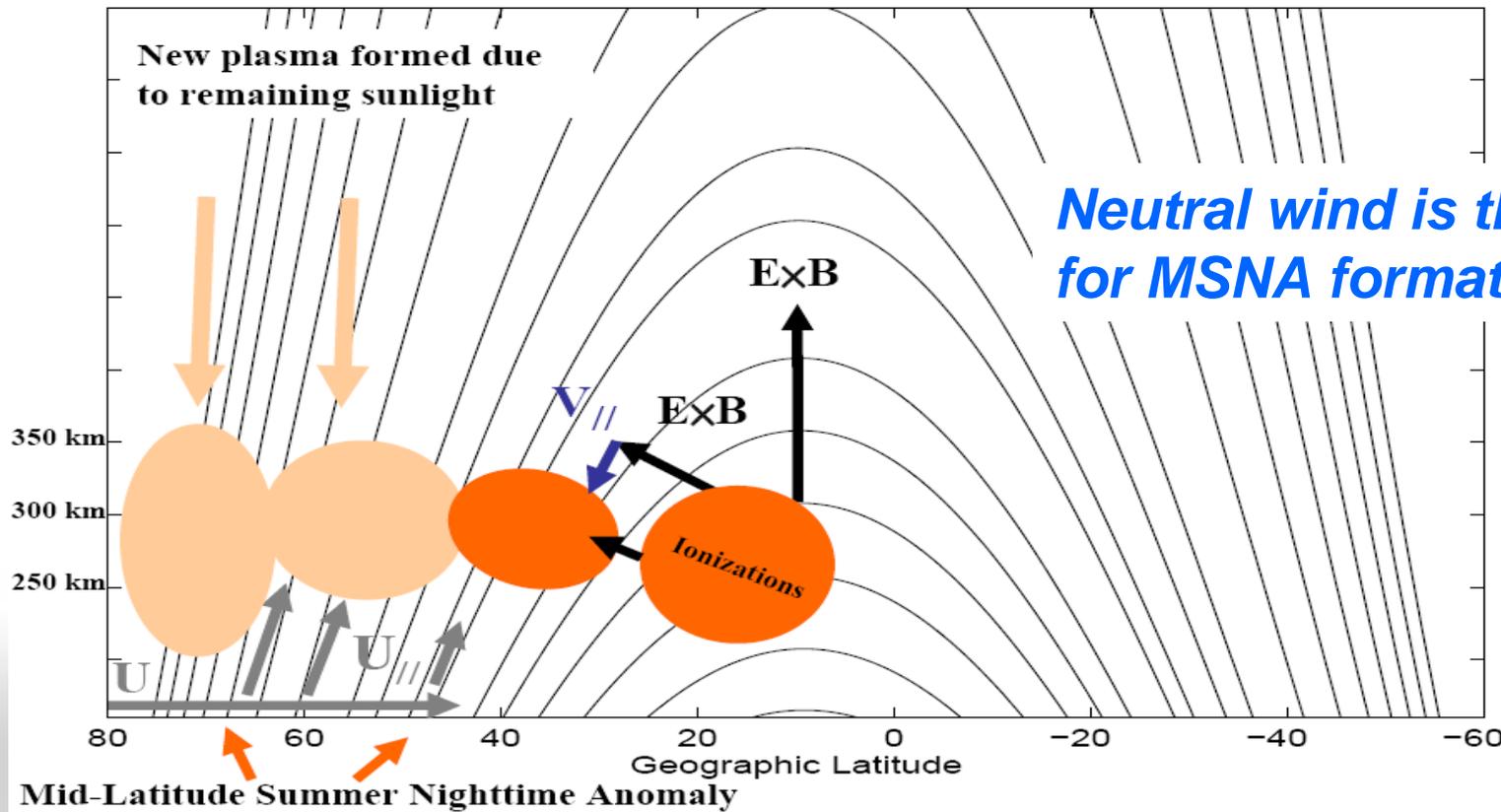
*Lin et al., 2010*



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*Development of the MSNA observed by COSMIC gives clue to disclose the underlying physics!*

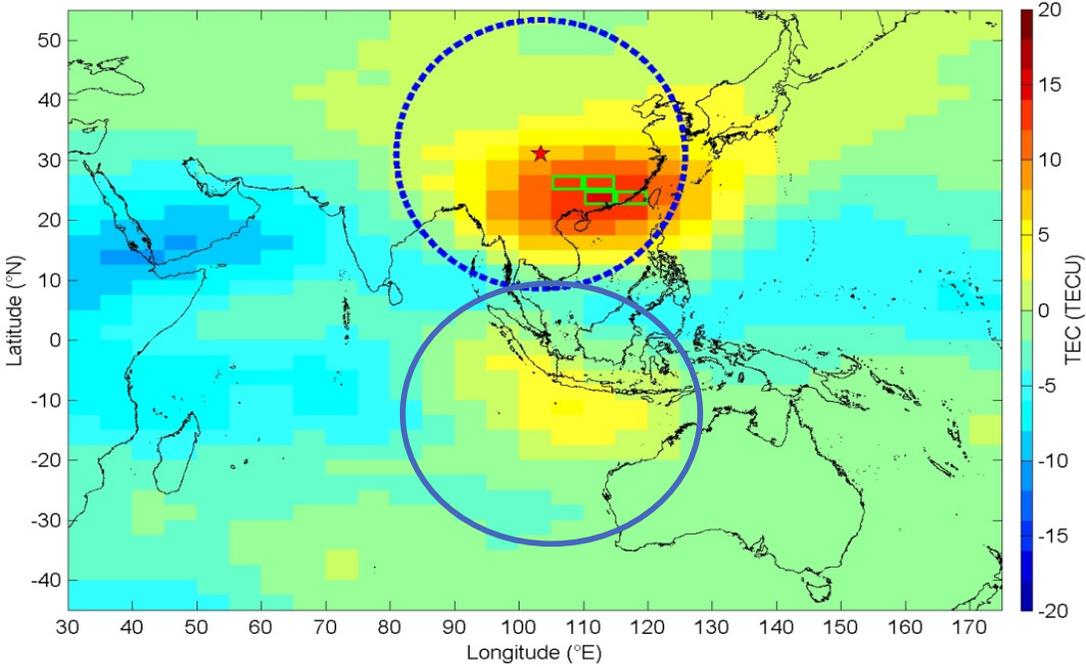


# **Lithosphere-Ionosphere Coupling**

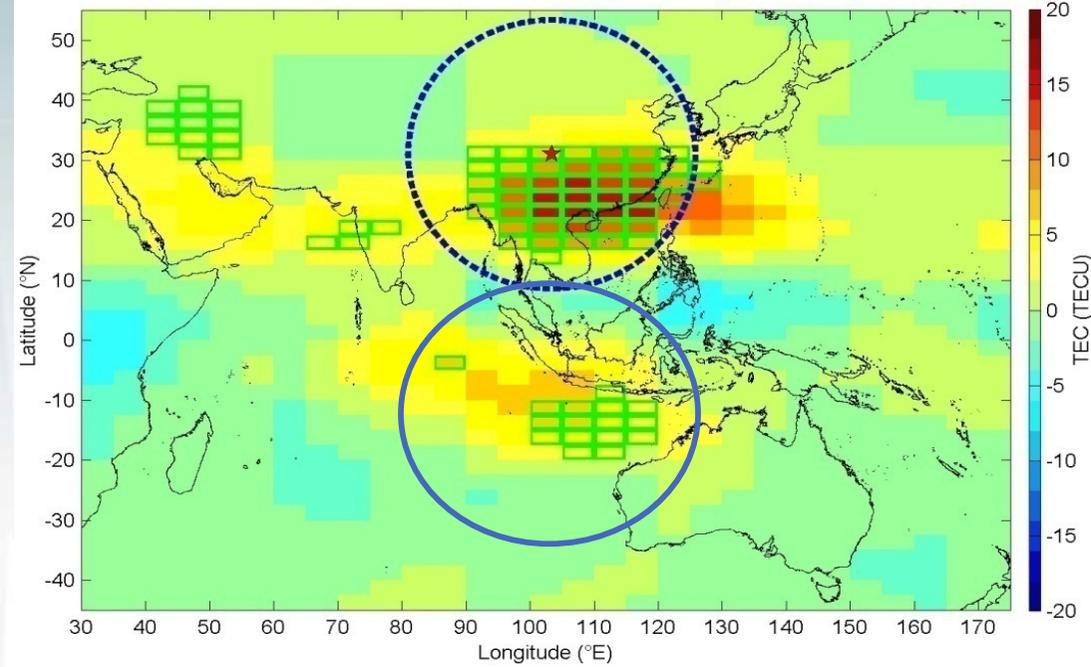
**Ionospheric conjugate effect**

# 2008/5/12 M8.0 Wenchuan Earthquake

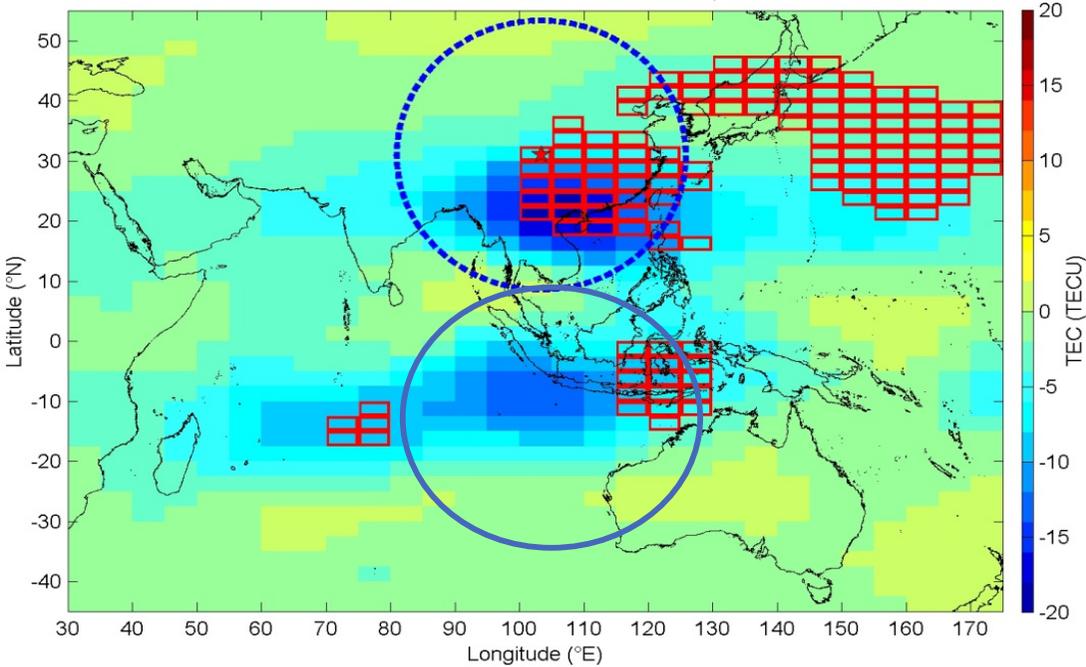
2008 05/09 1000UT Difference LLT Map



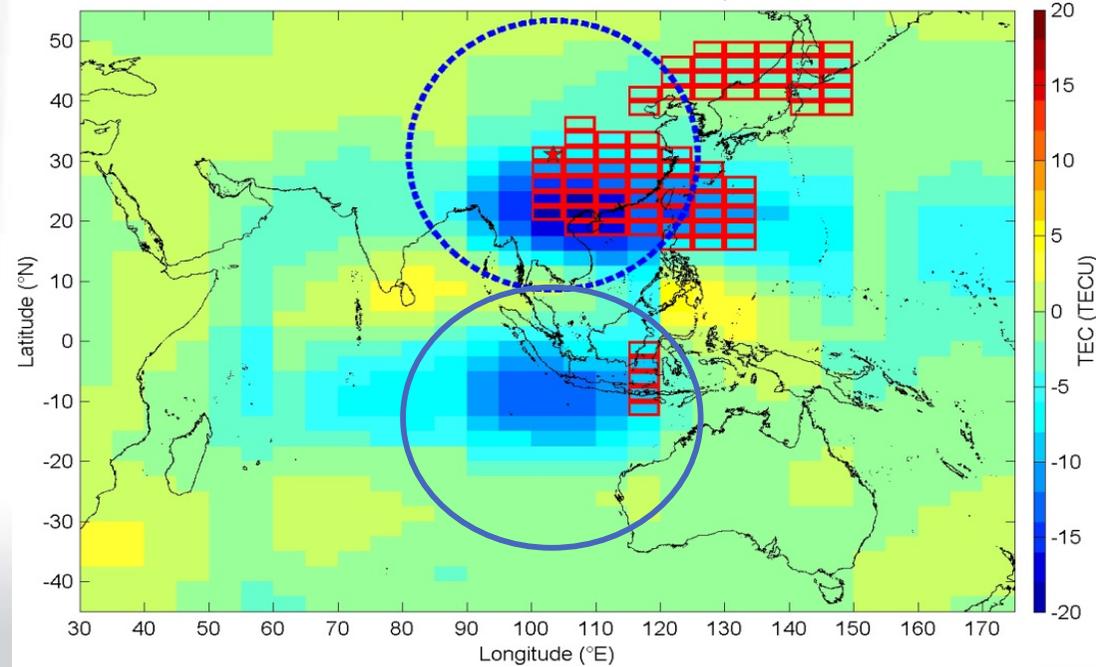
2008 05/09 1700LT Difference LLT Map



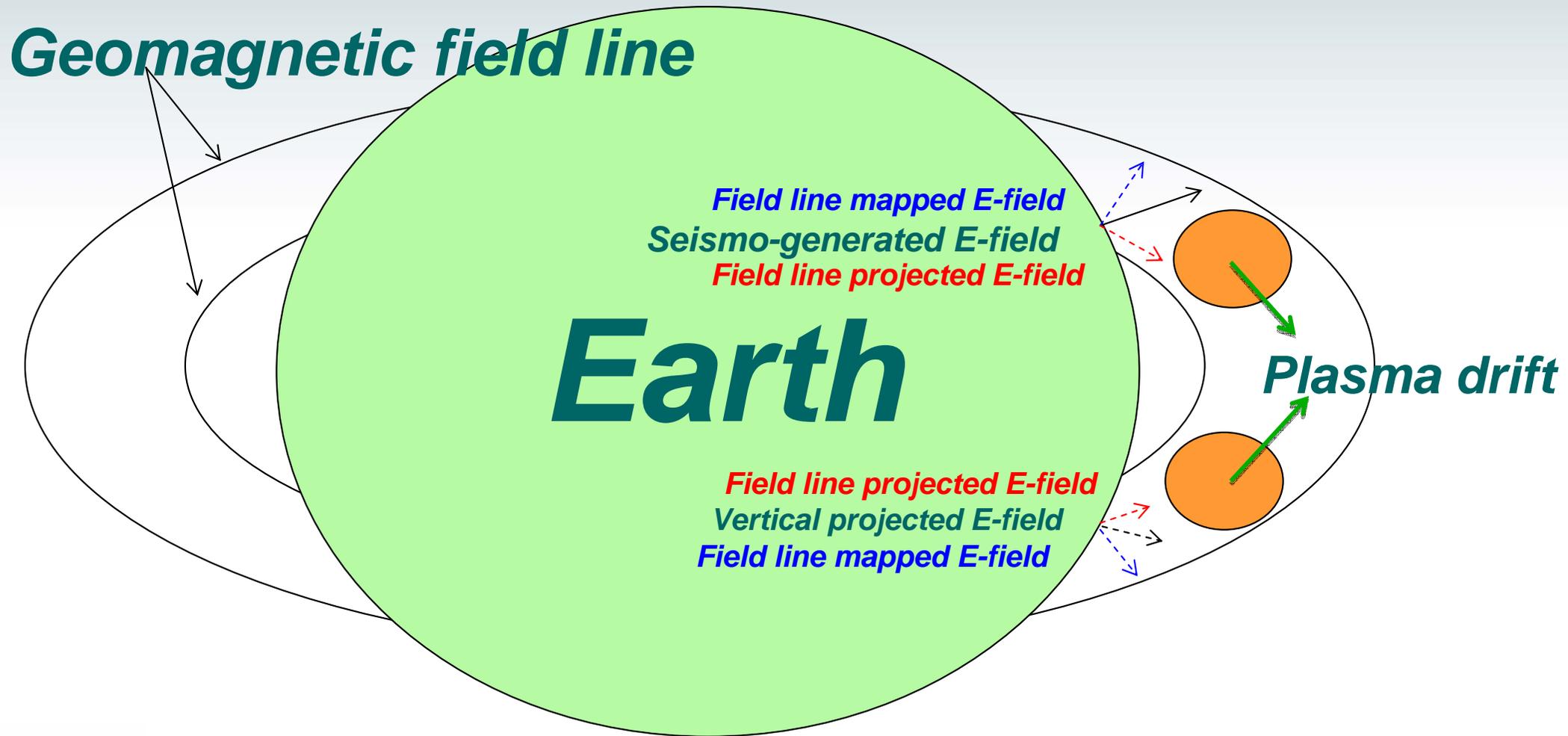
2008 05/06 0800UT Difference LLT Map



2008 05/06 1500LT Difference LLT Map

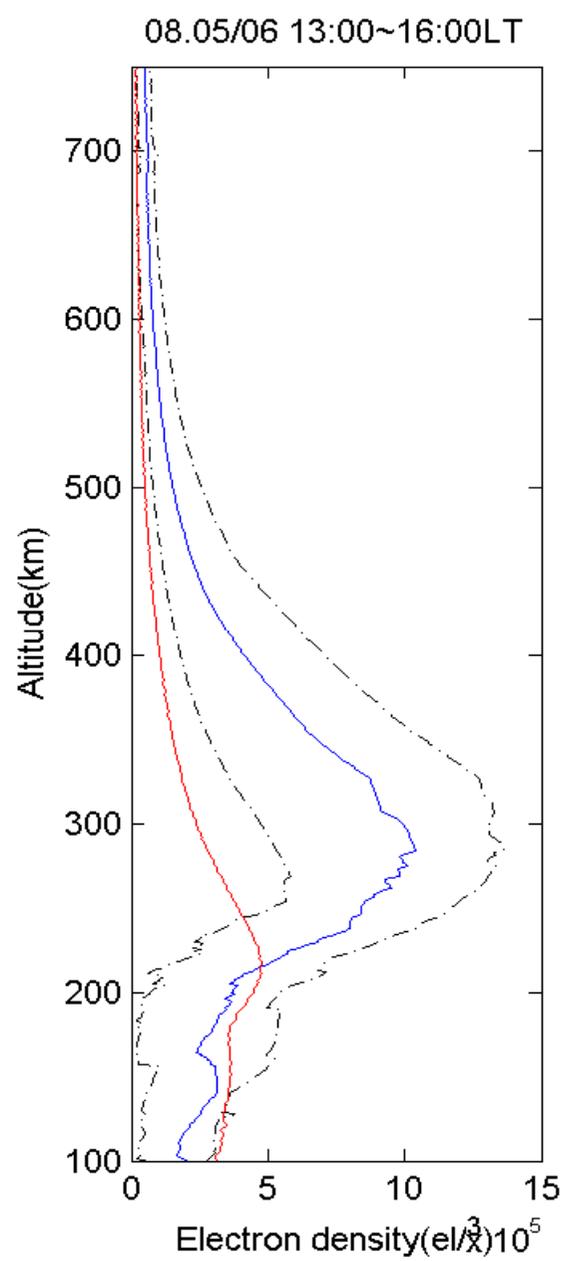


# Seismo-generated E-field

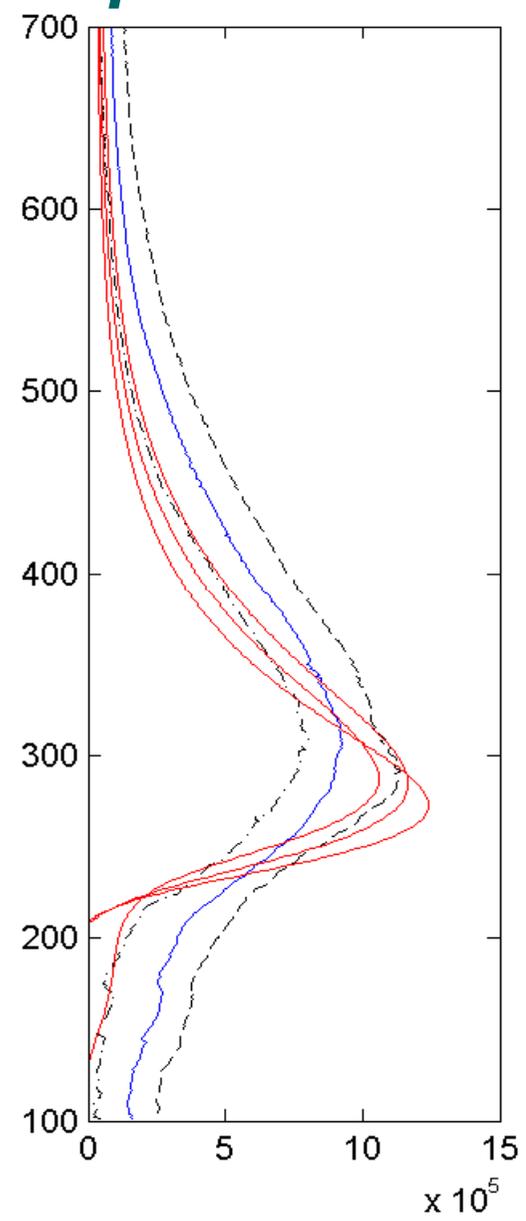


# The 2008/05/06 afternoon 6 days before the Wenchuan Earthquake

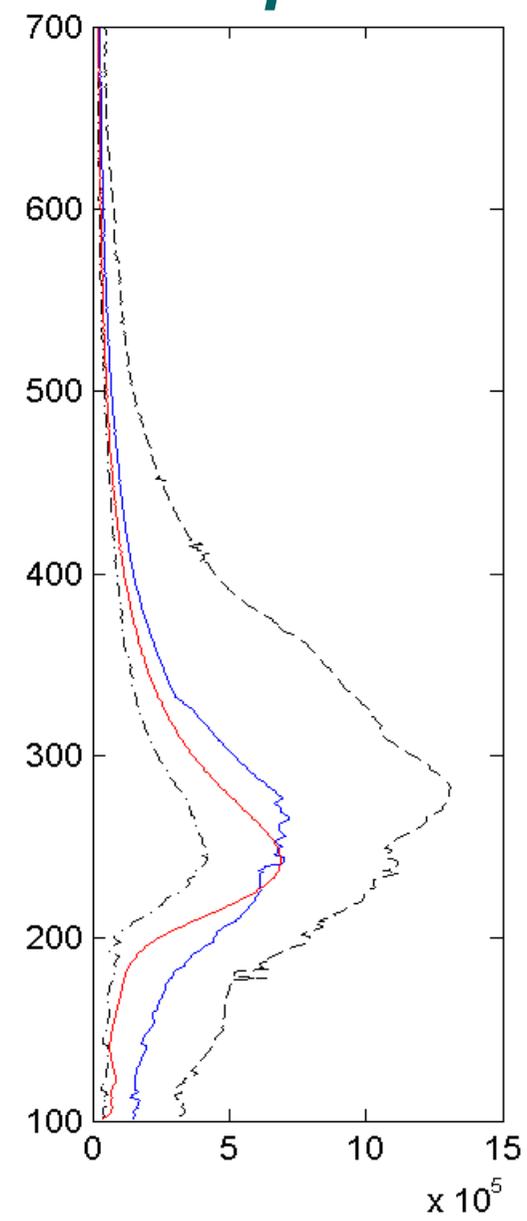
## Epicenter



## Geomagnetic Equator



## Conjugate Point of the Epicenter

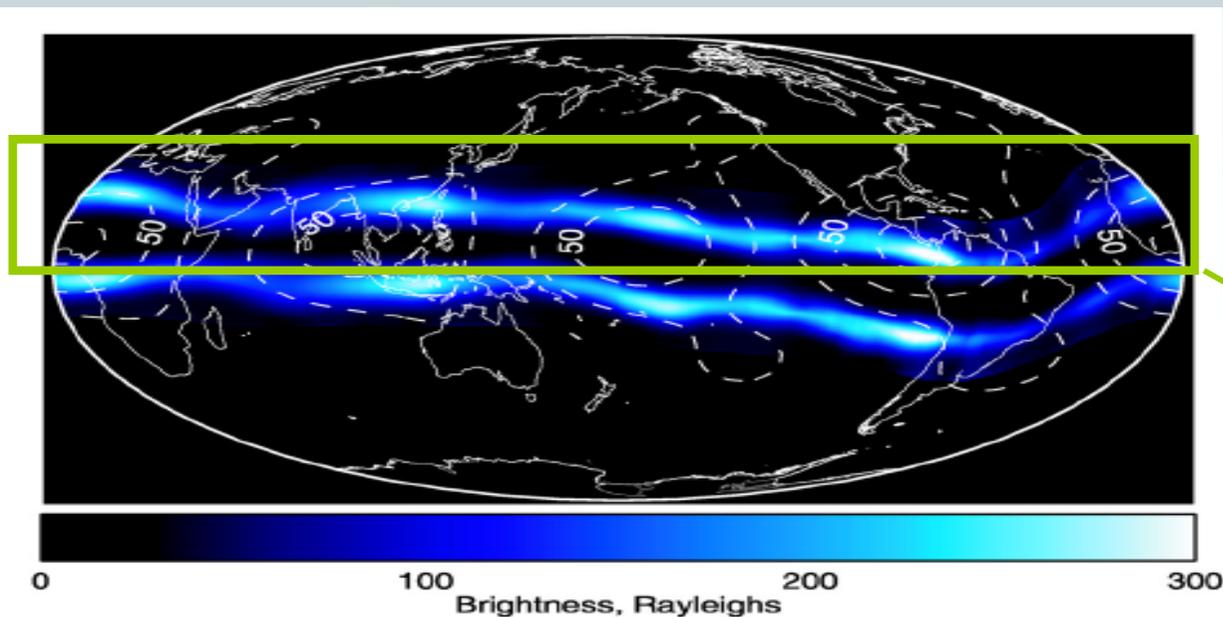


# Troposphere-Ionosphere Link

# Newly discovered ionospheric feature at low-latitude

Recent discovered four-peaked longitudinal structure produced by atmospheric tides :

First reported by Sagawa et al. [2005] and Immel et al. [2006]

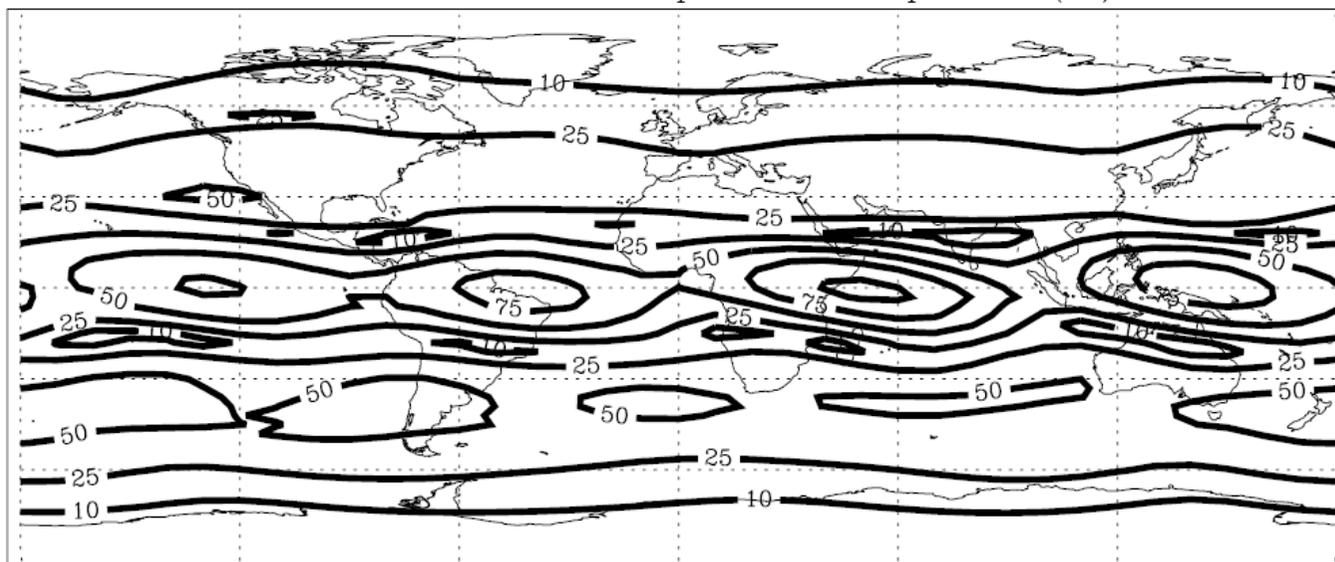


- E3 Nonmigrating tide produced by the latent heat excited by tropospheric water vapors
- Modulating the E-region dynamo and the plasma fountain

Observe the northern hemisphere only

IMAGE FUV observation

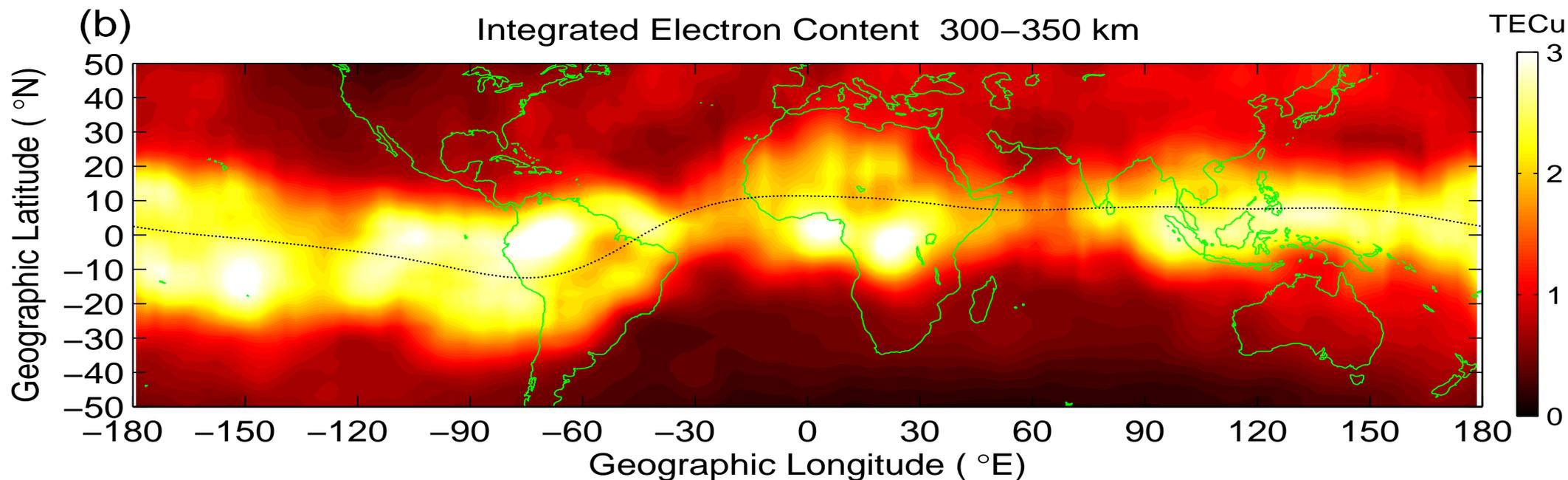
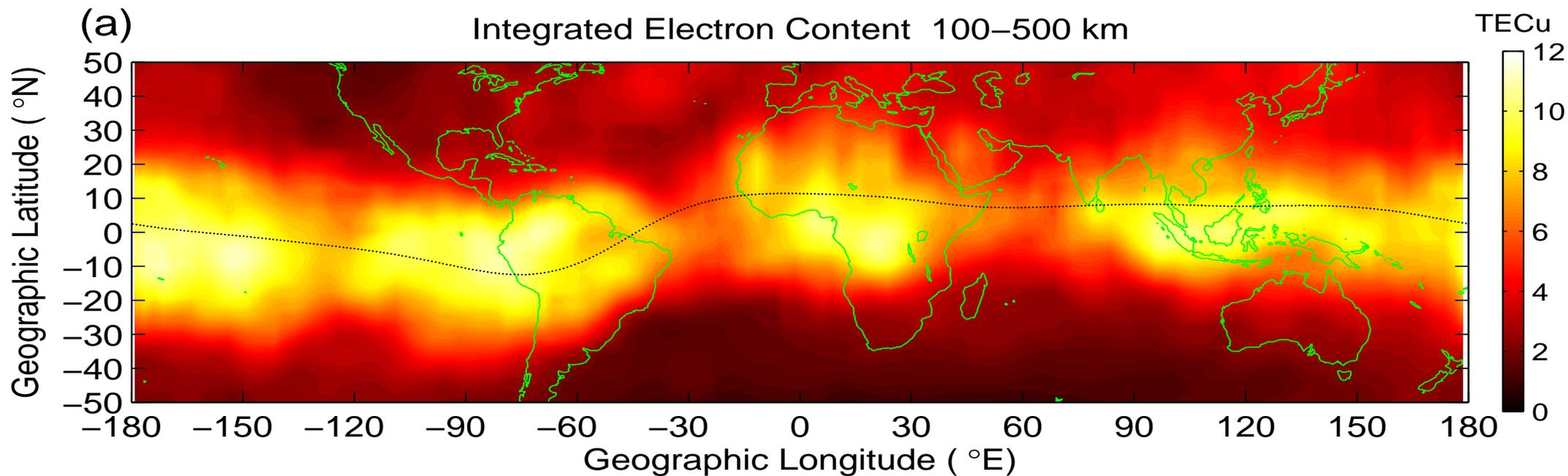
Combined Radiative and Latent Heat Responses at 124 km  
March Semidiurnal Temperature Amplitude (°K)

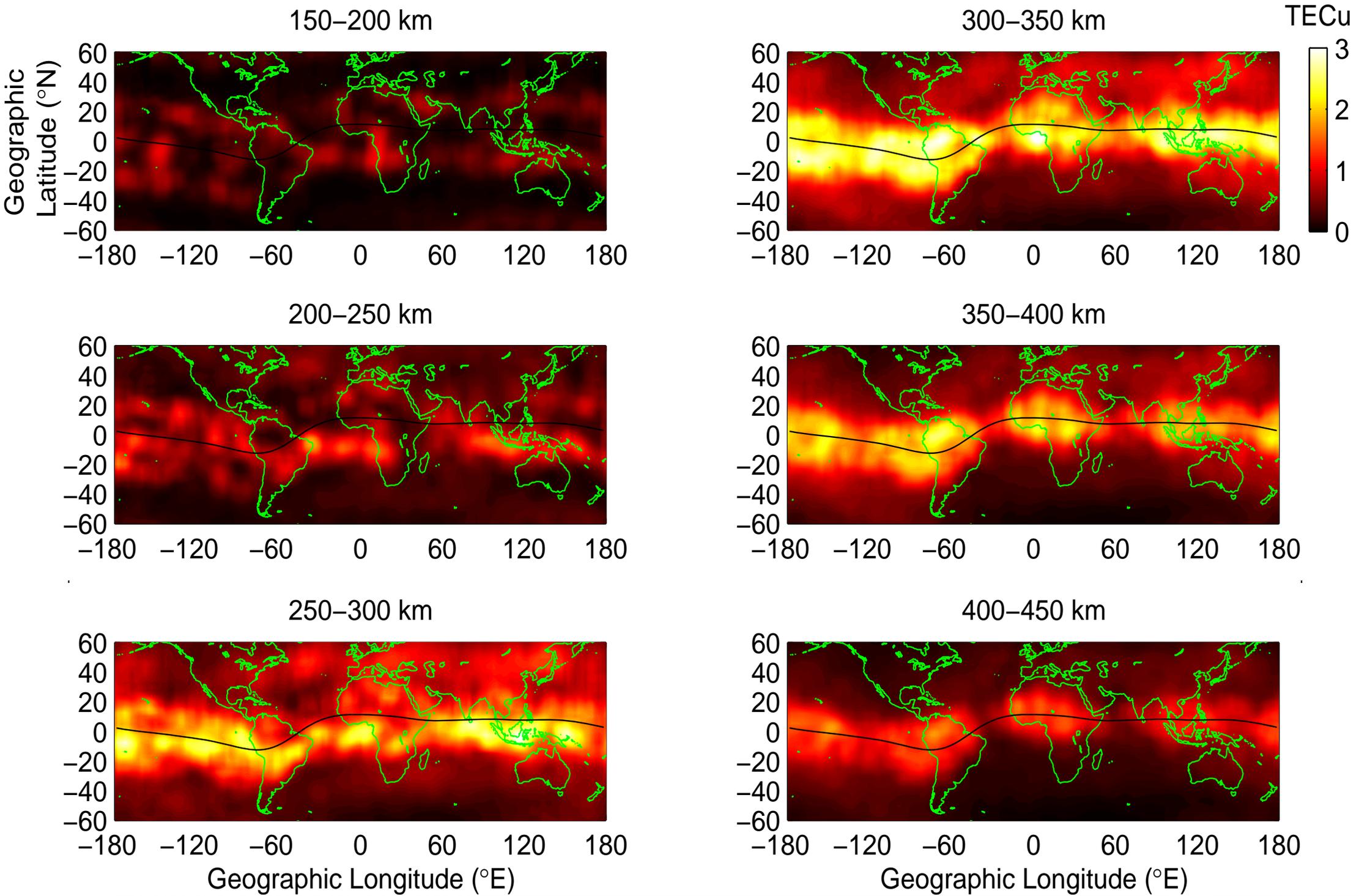


E3 non-migrating tide modeled by  
global scale wave model (GSWM)  
[Hagan and Forbes, JGR, 2002]

# Recent discovered longitudinal structure produced by atmospheric tides :

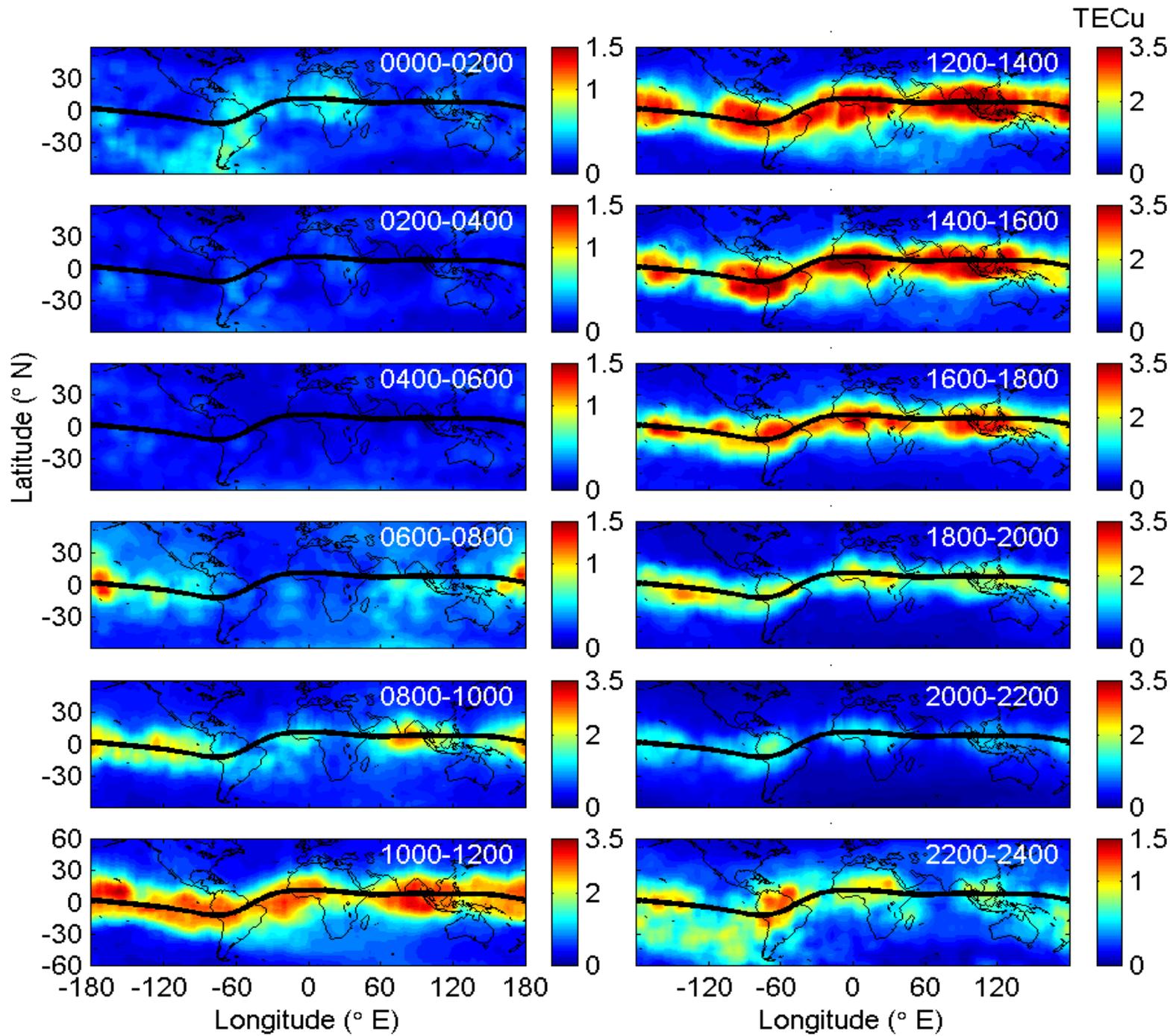
## FORMOSAT-3/COSMIC electron content observations: 2000~2200 LT





# Diurnal variations of the wave-4 structure during Sep.-Oct. 2006

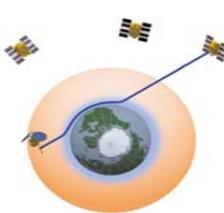
Starting at 08-10 LT, strongest at 14-16LT, subsiding after 22LT



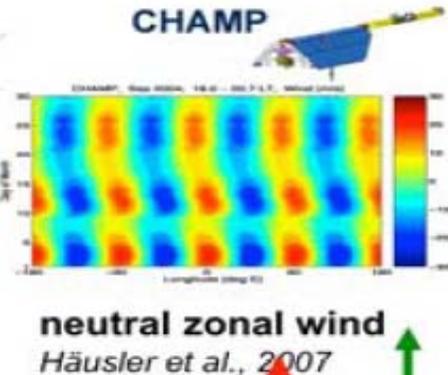
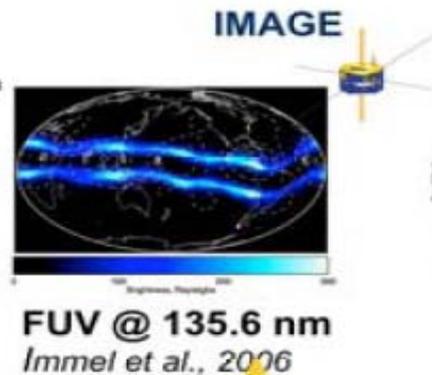
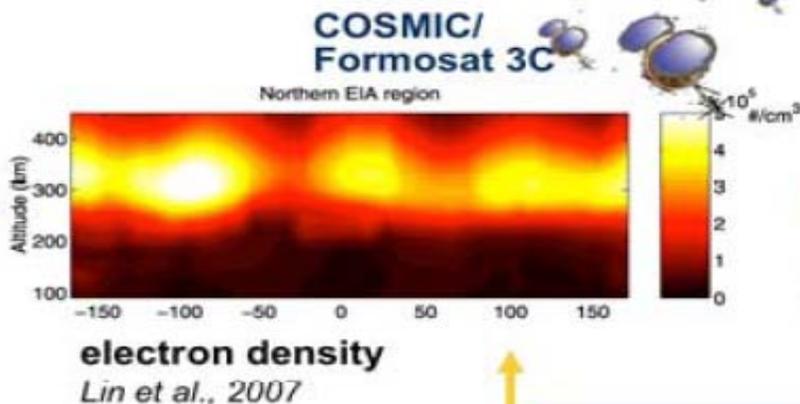


# Coupling from troposphere to ionosphere through atmospheric tides

- CAUSES TG4 Newsletter, Vol. 1, June 2010

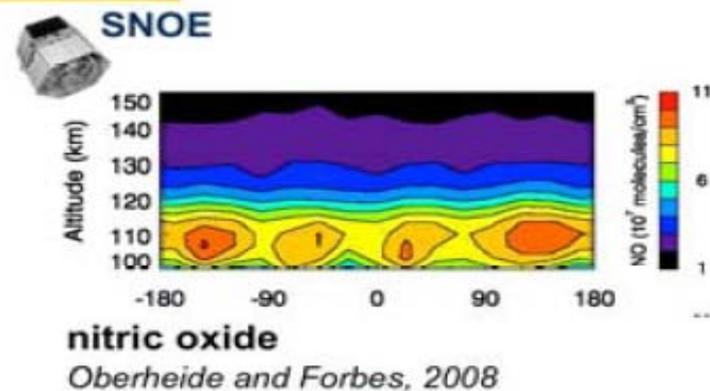
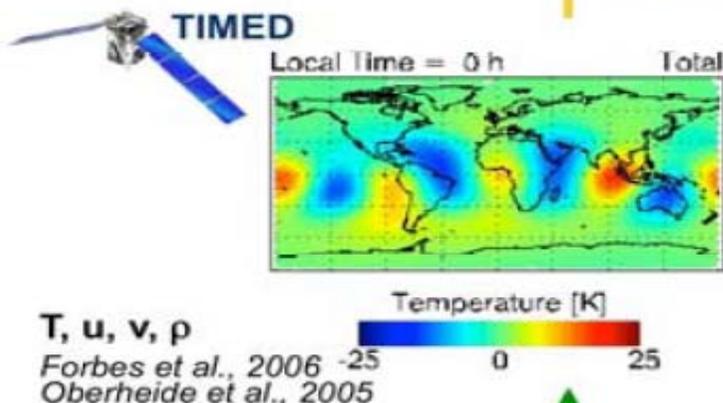


F-region  
(250-450 km)



E-region  
dynamo modulation

MLT/E-region  
(80-140 km)



"wave-4"  $\leftrightarrow$  DE3  
nonmigrating tides

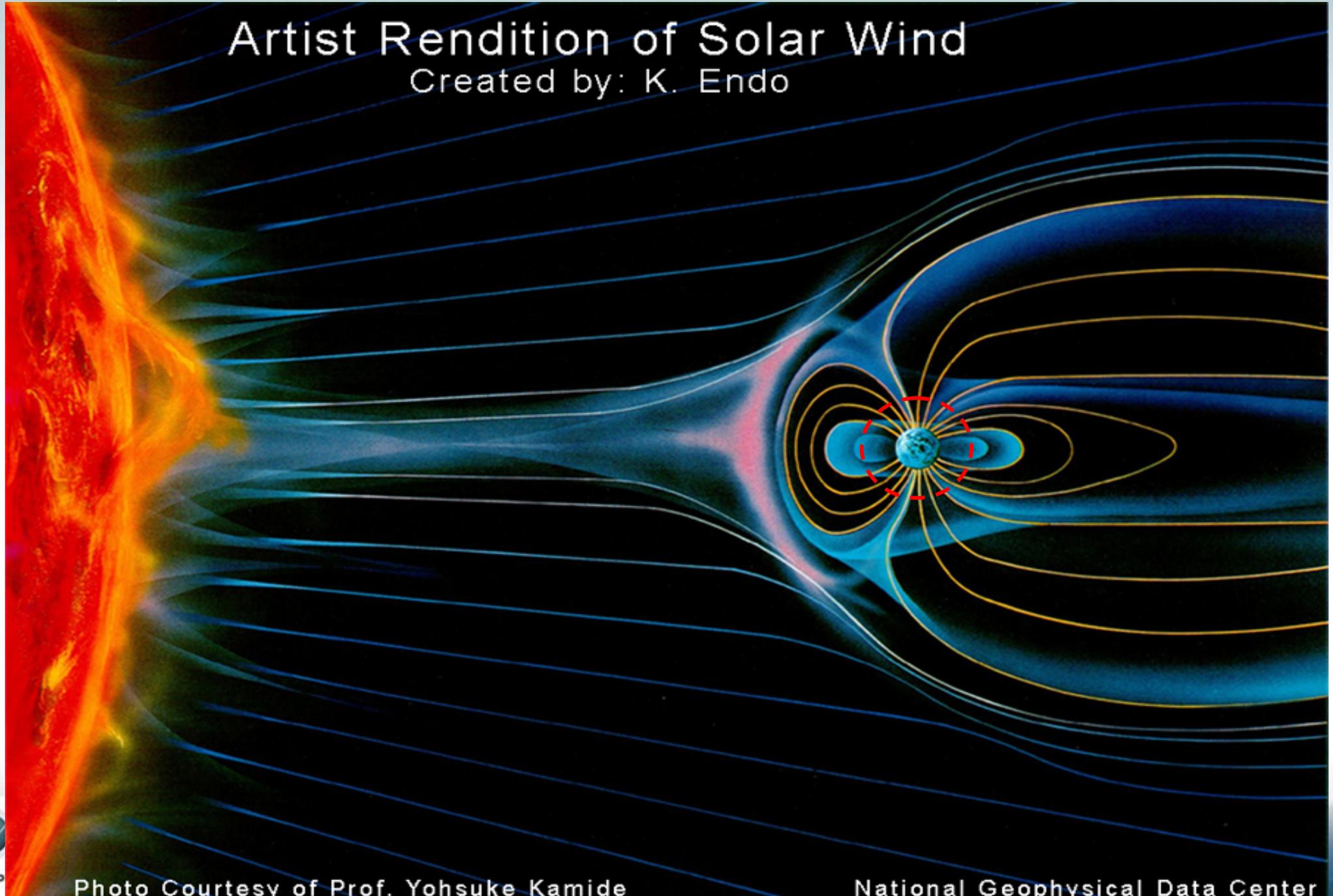
tropical troposphere



# Solar Wind-Ionosphere Effect

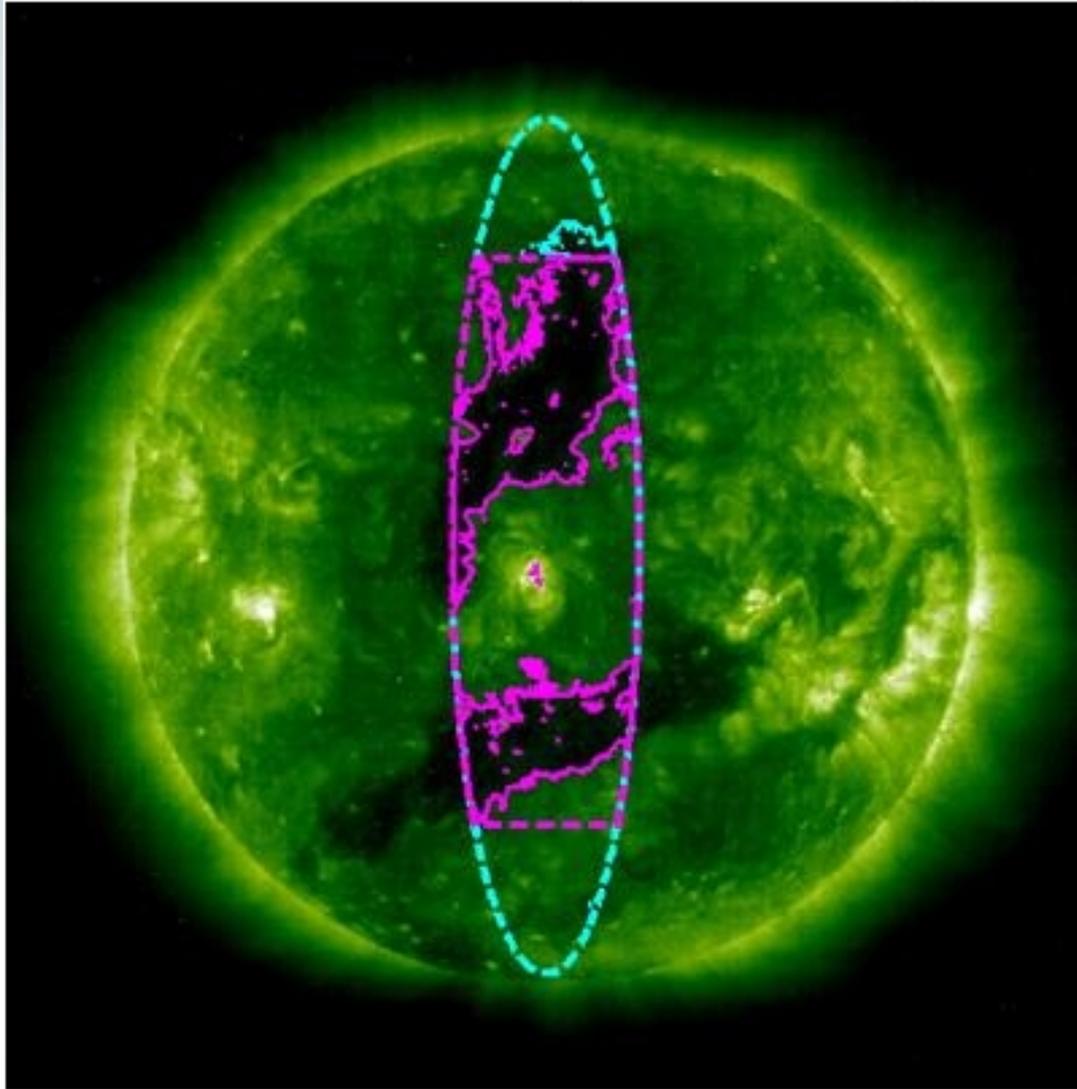
# Solar Terrestrial Environment

Artist Rendition of Solar Wind  
Created by: K. Endo

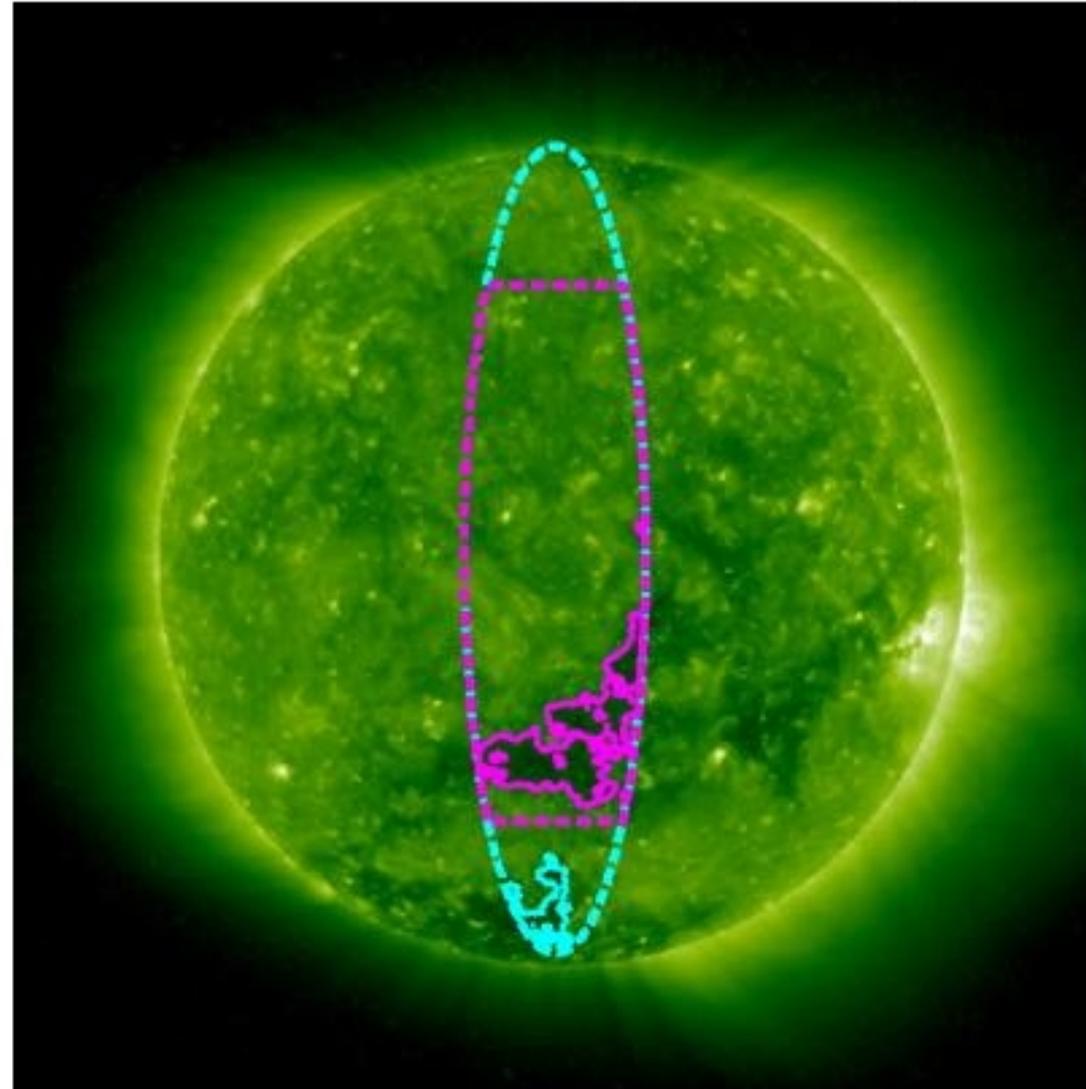


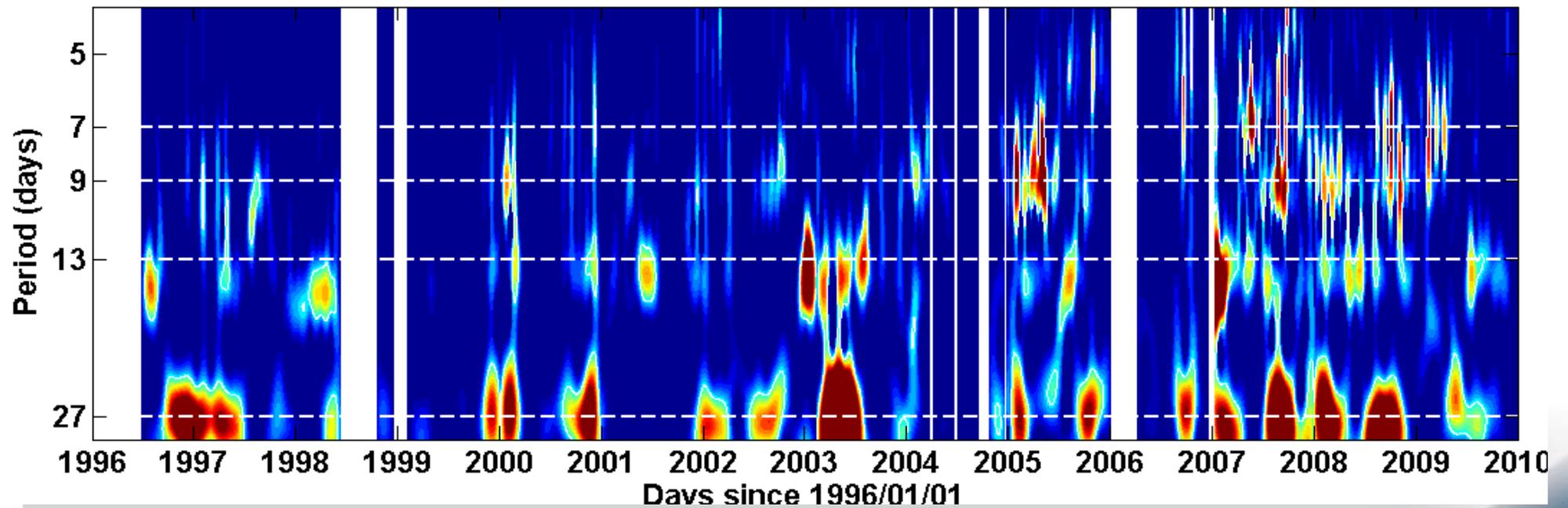
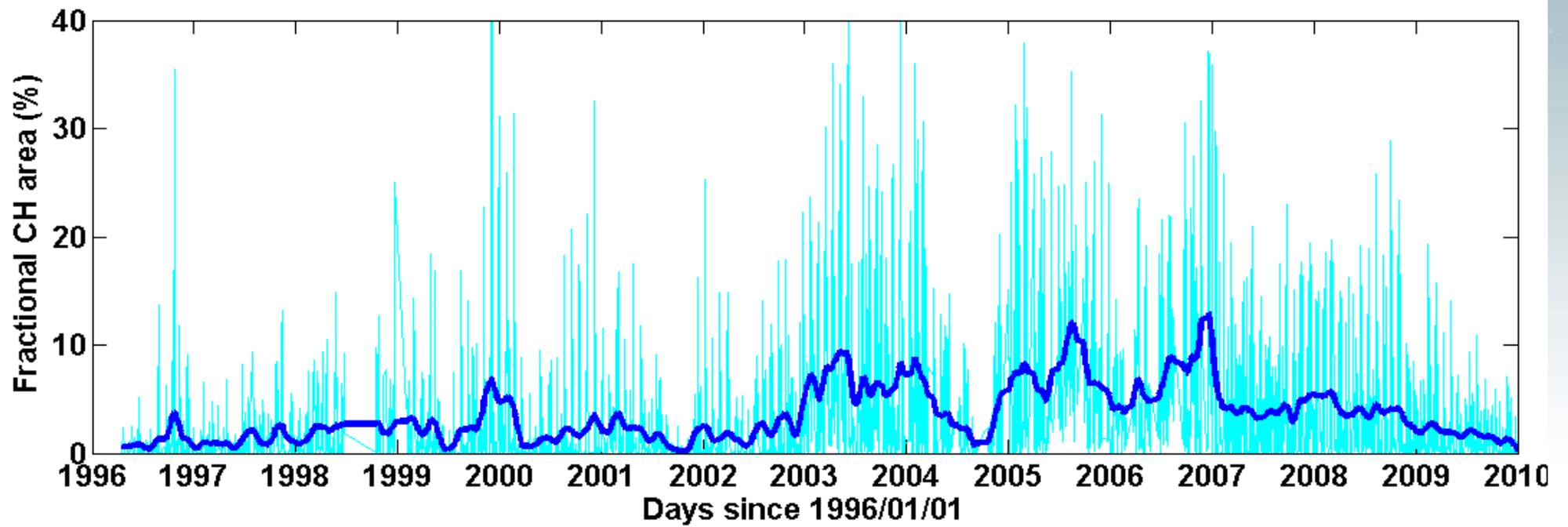
# Coronal Hole

SOHO-EIT (1996 – 2006)



STEREO-EUVI (2007-2010)

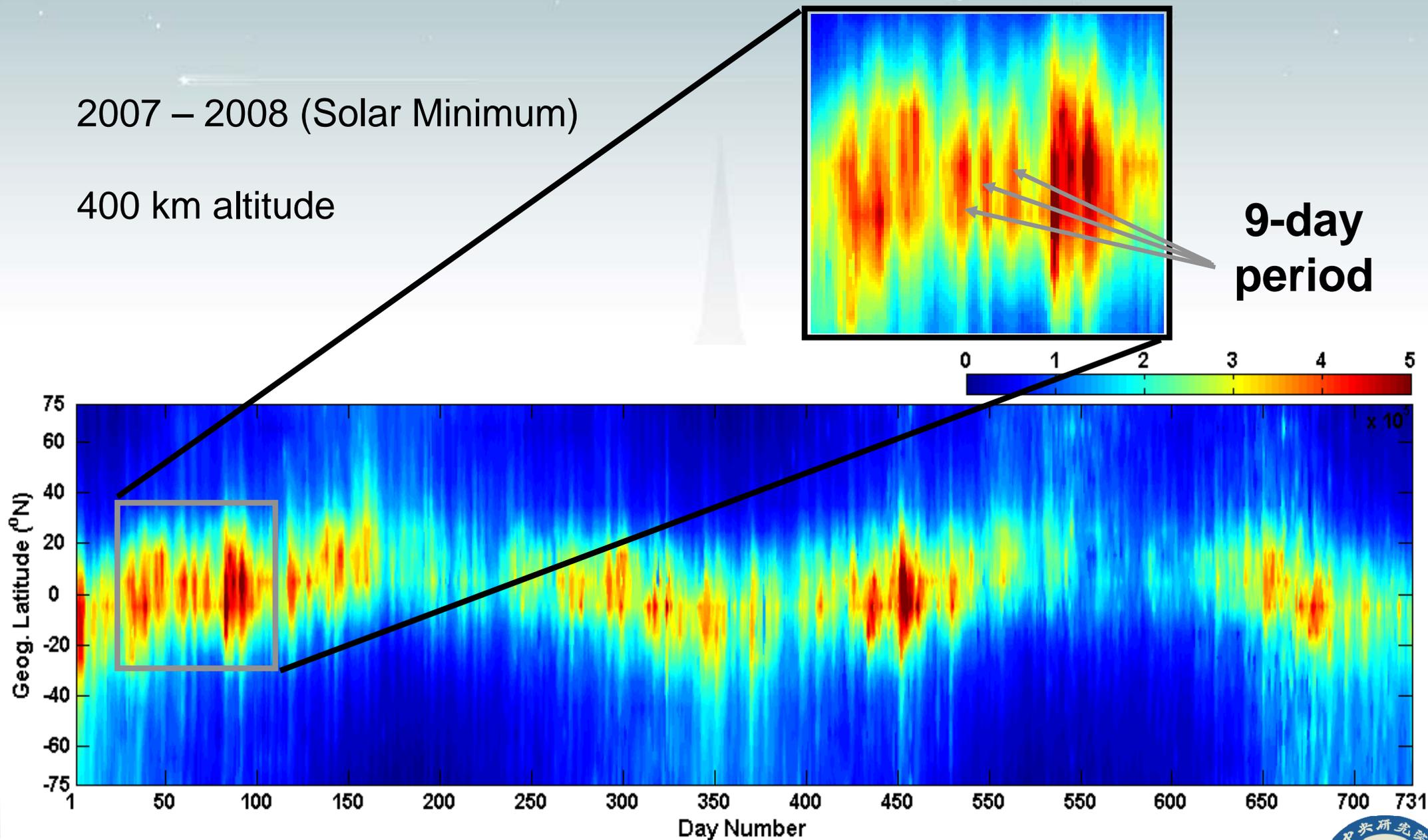


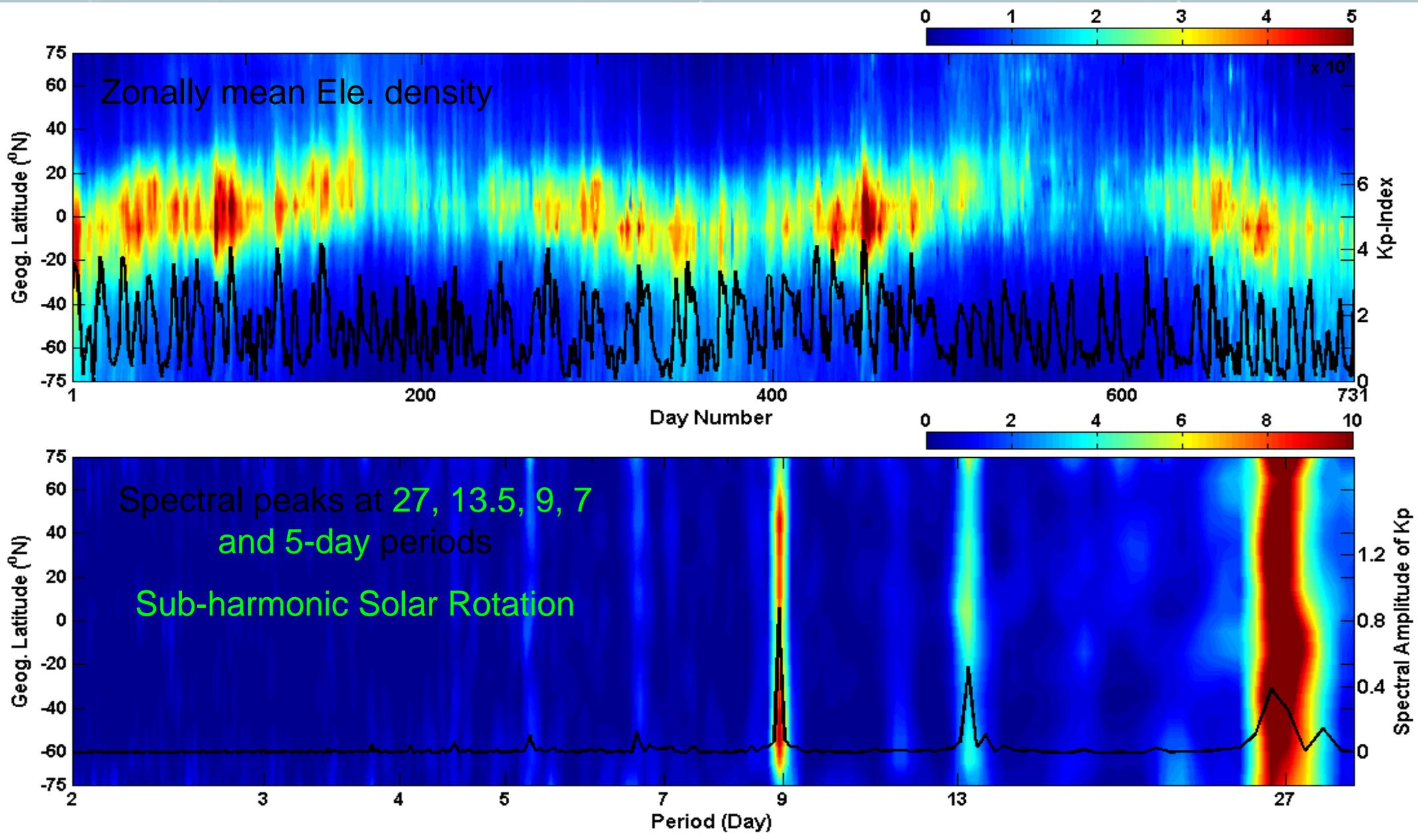


# Daily zonal mean electron density from FORMOSAT-3/COSMIC

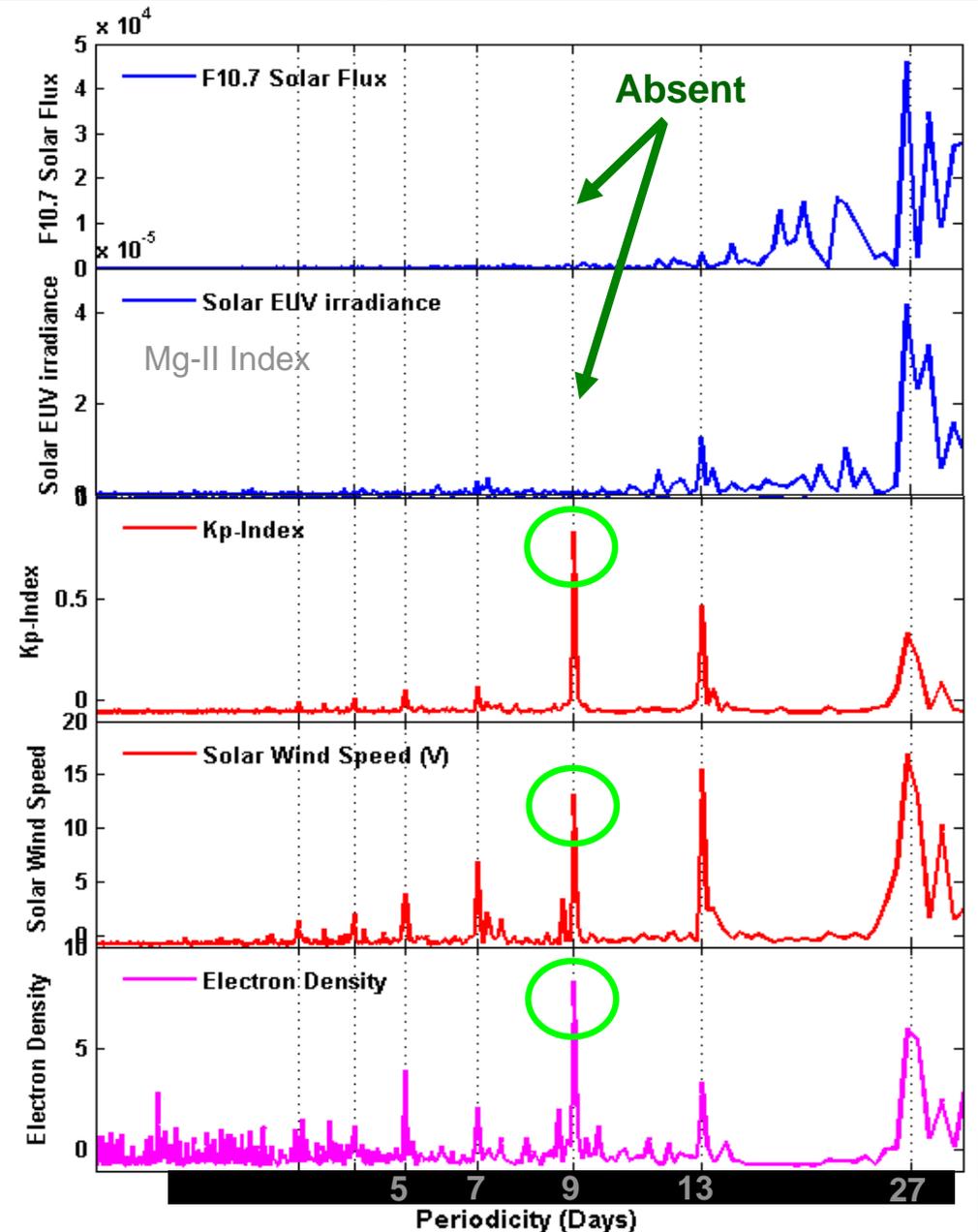
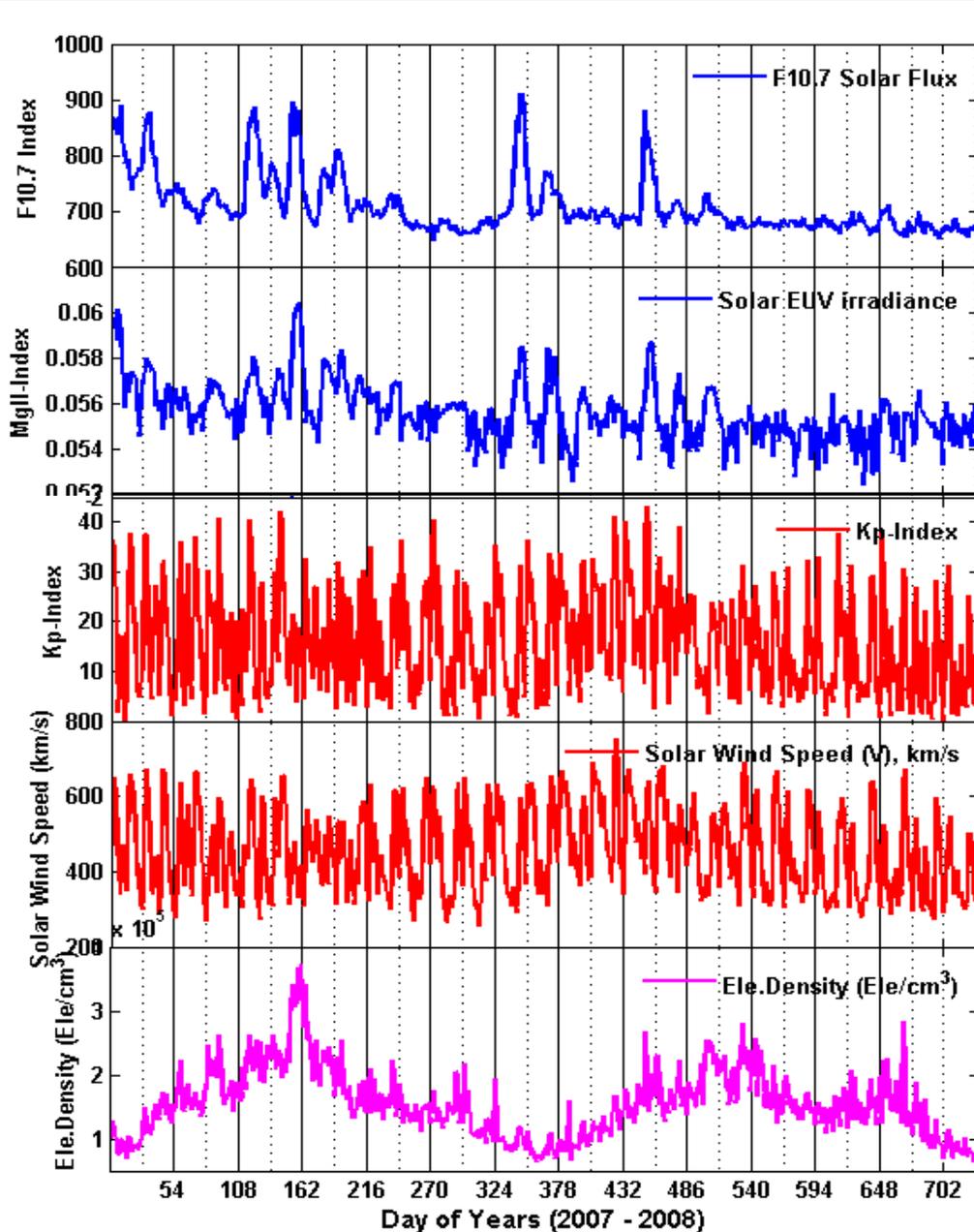
2007 – 2008 (Solar Minimum)

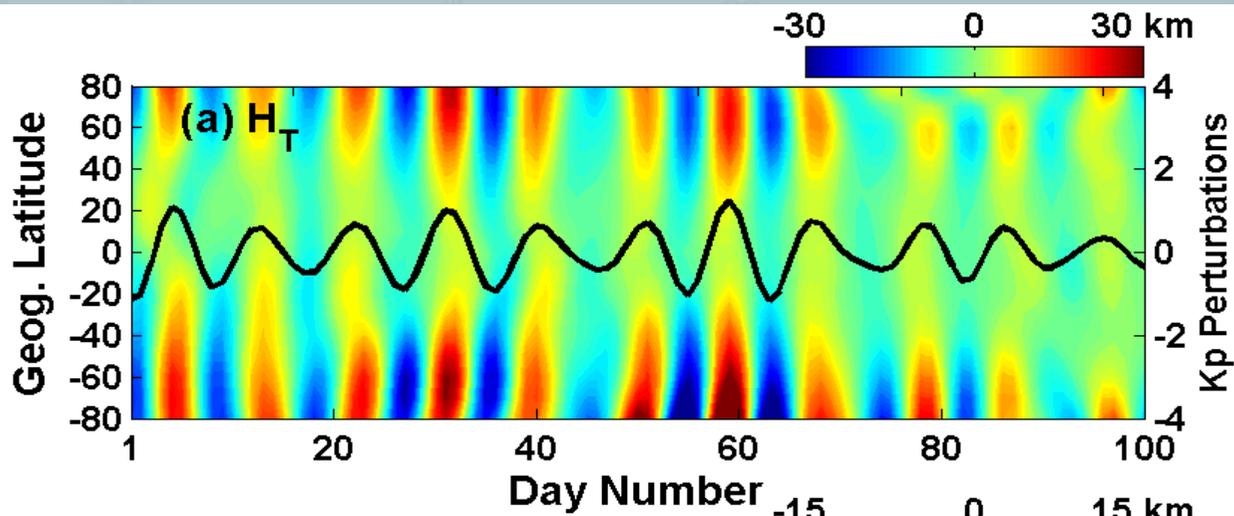
400 km altitude



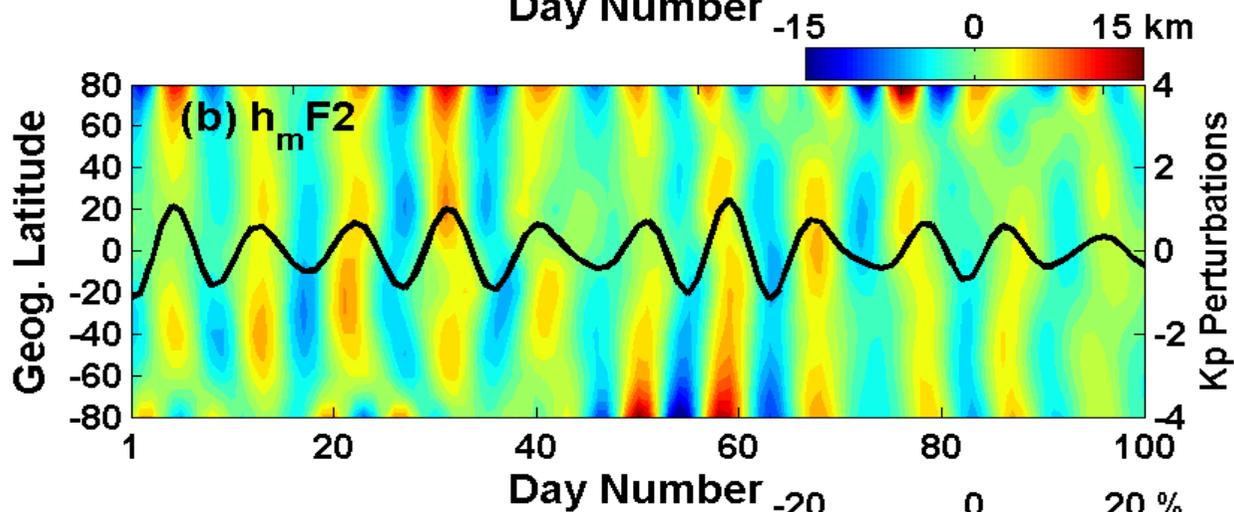


# Spectra of Helio-Geophysical Parameters

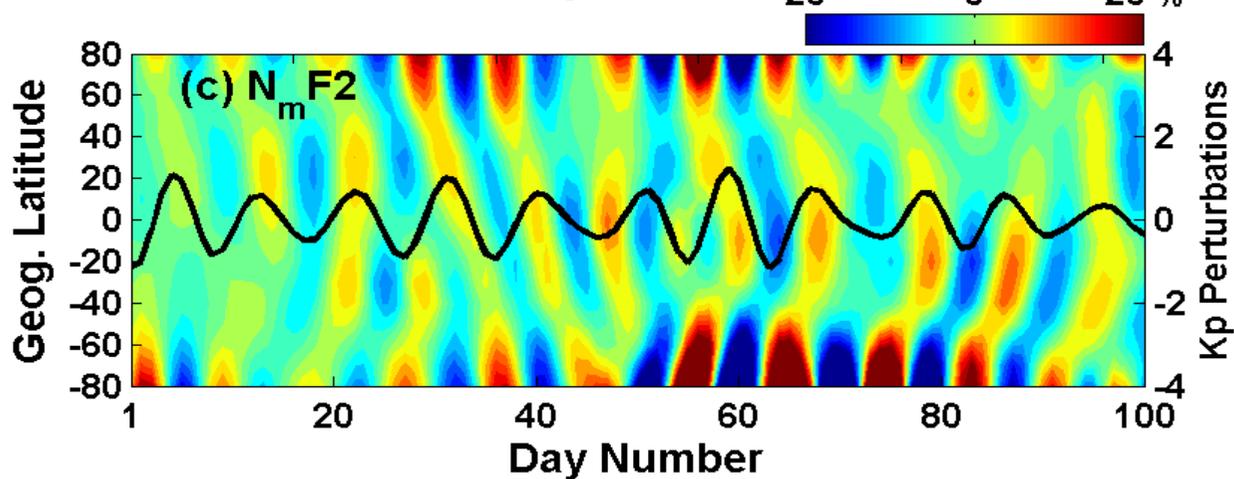




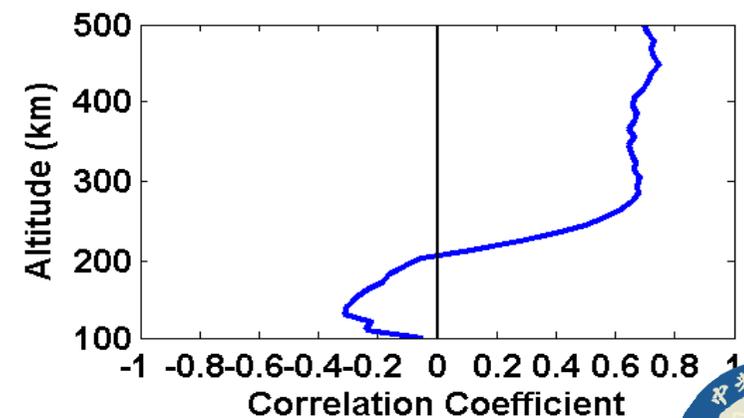
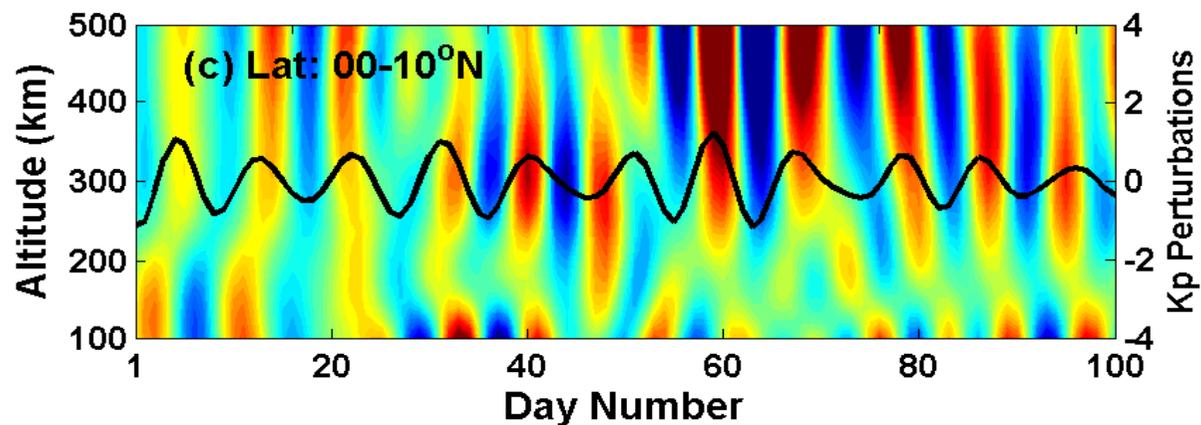
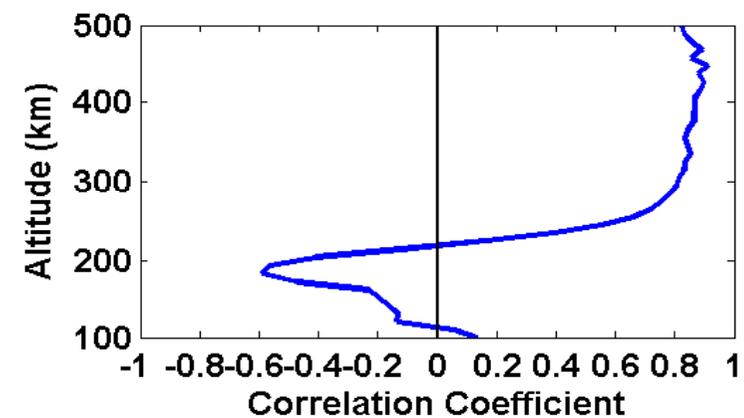
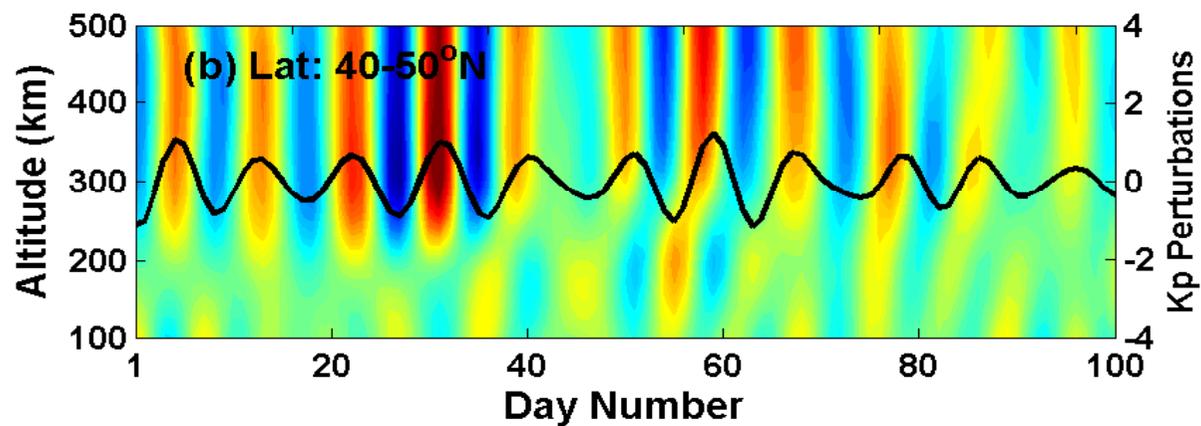
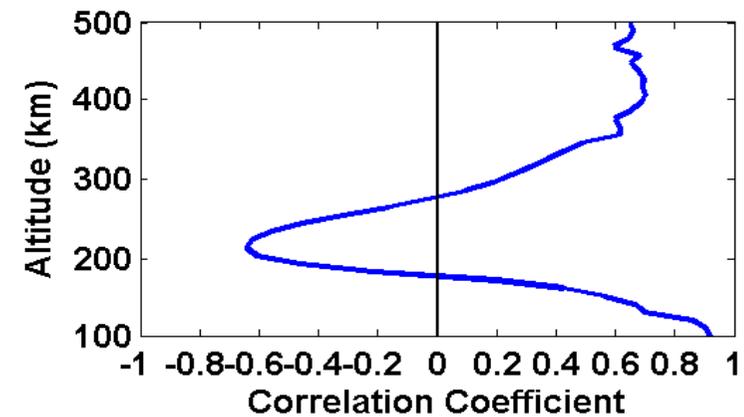
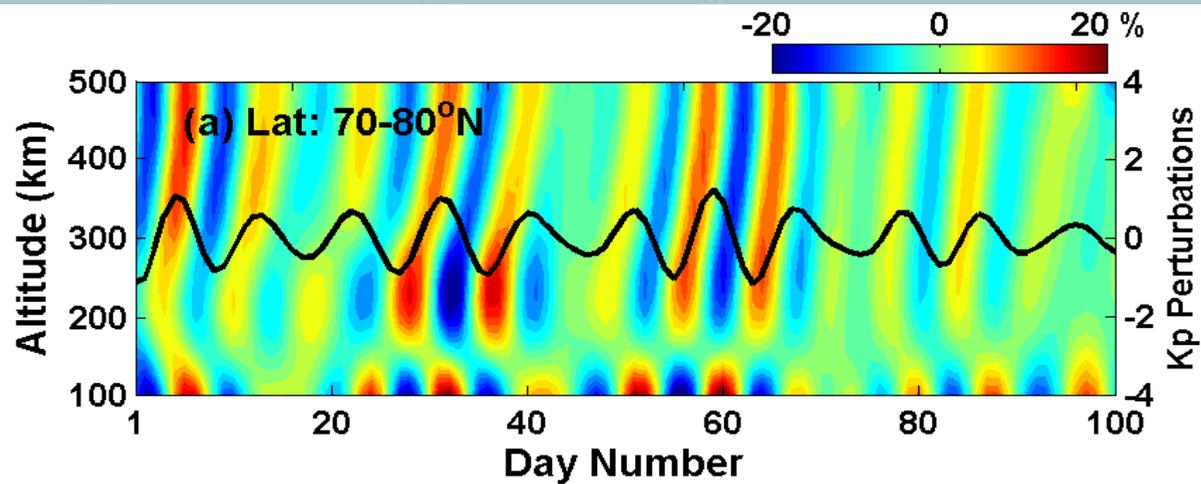
$H_T$  – Scale Height  
More prominent at high-lat

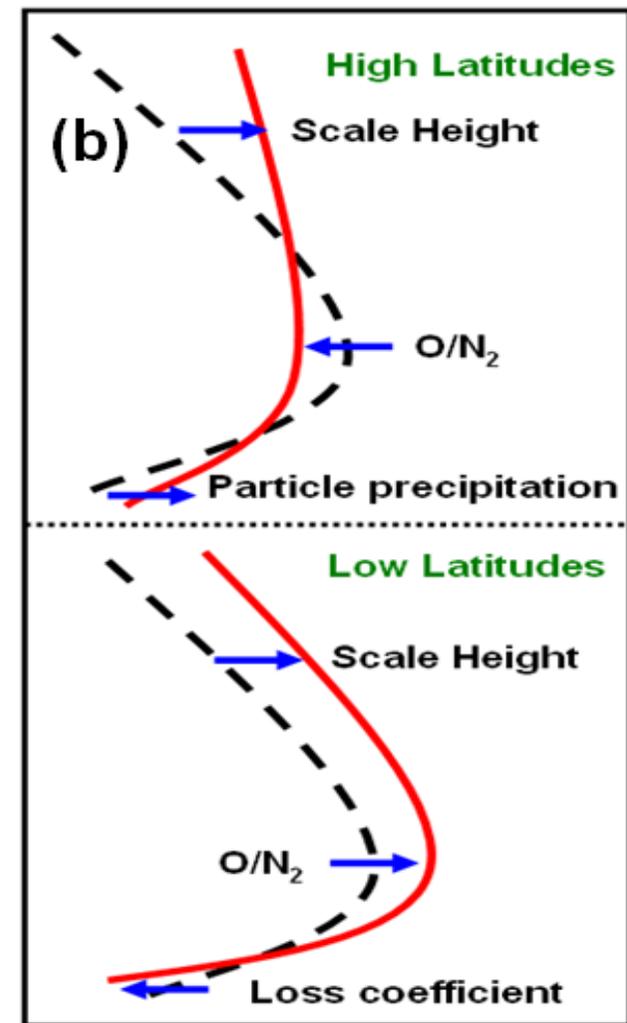
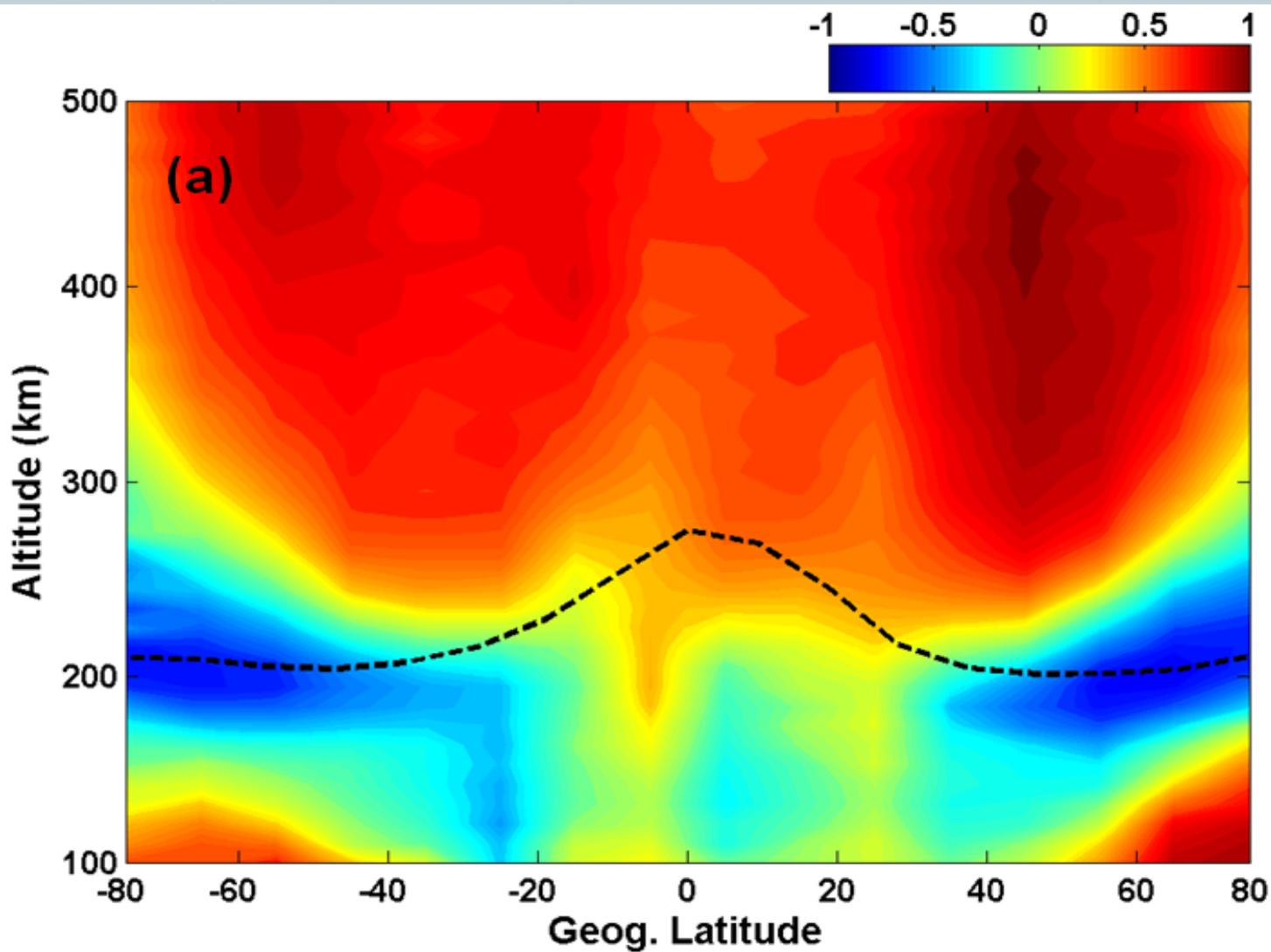


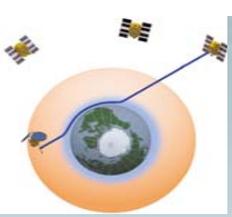
$h_m F2$  – F2 layer peak height  
almost uniform globally



$N_m F2$  – F2 layer peak density  
opposite at high and low latitudes



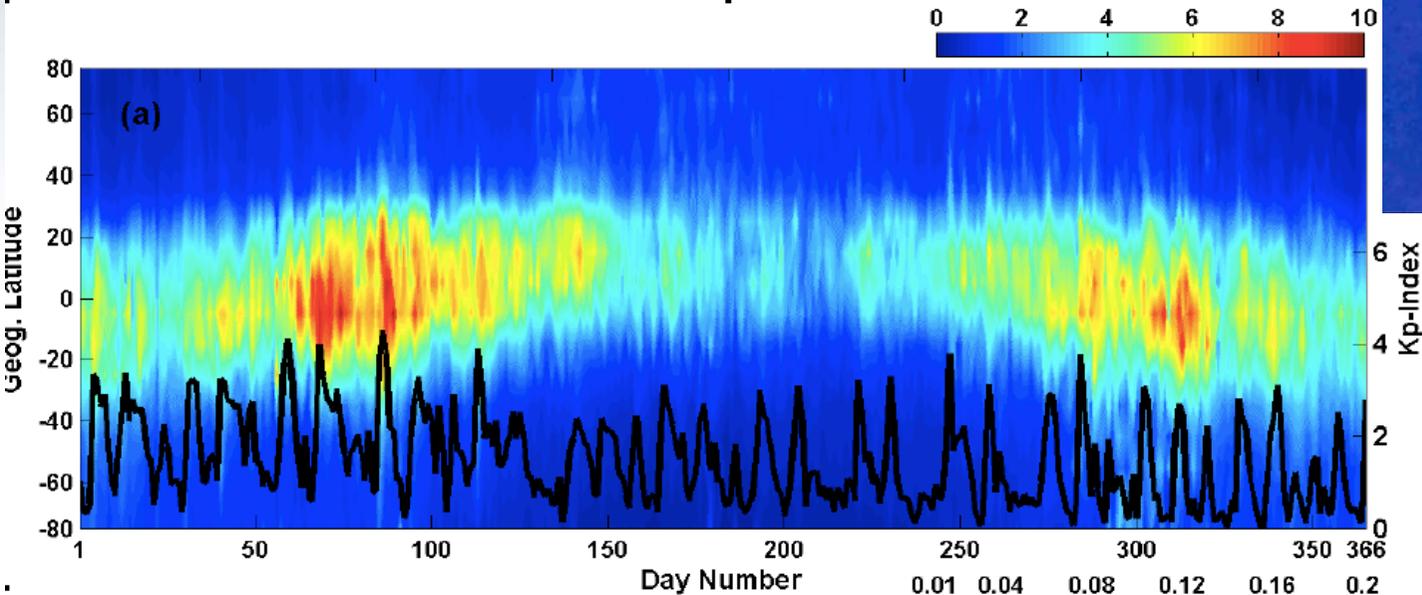
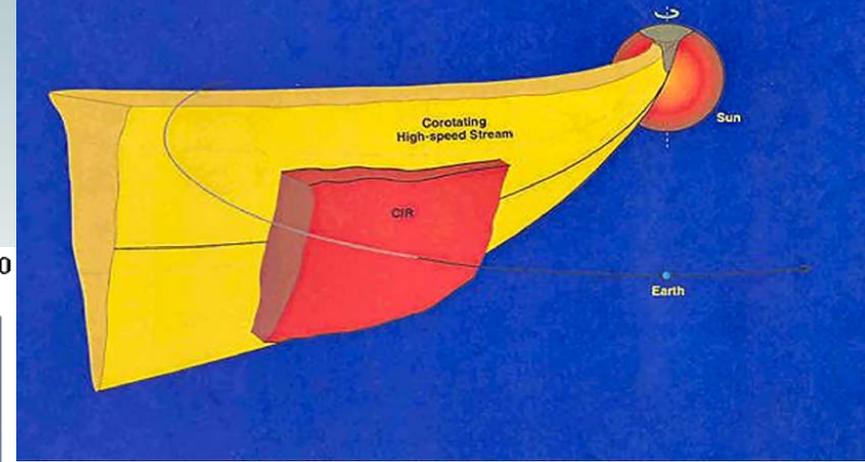




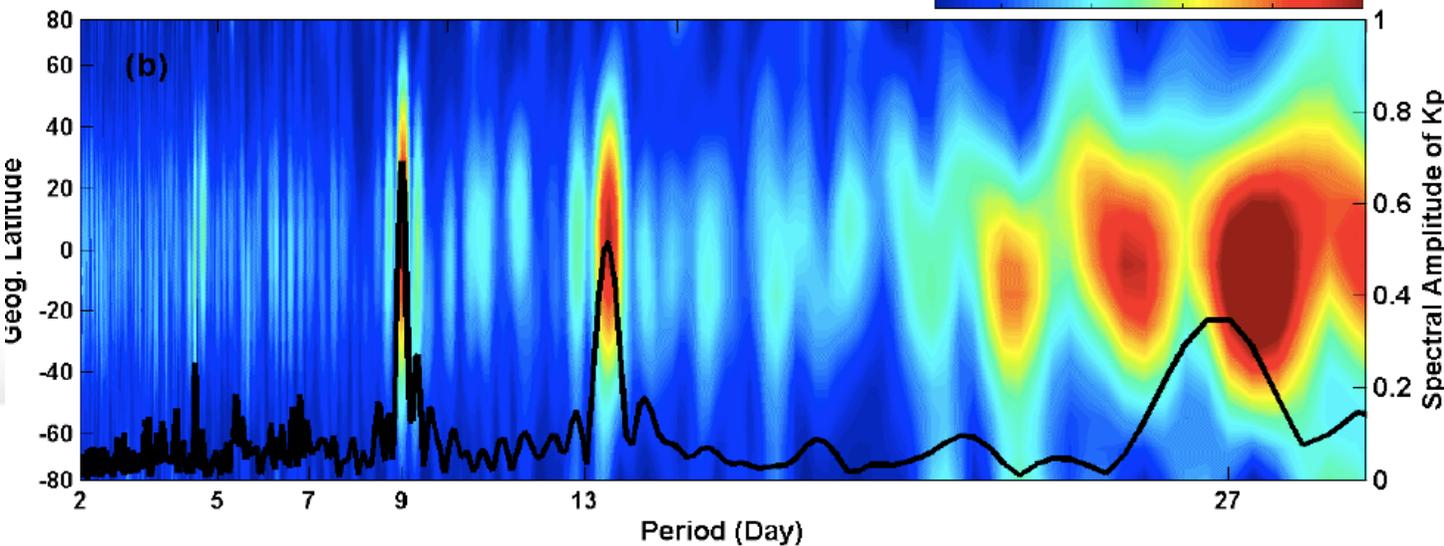
# Forcing of Solar-Wind Origin

*Ionospheric Oscillation due to Periodic Solar Forcing – “Corotating Interaction Region” of the Solar Wind*

*Corotating Interaction Region (CIR)*



*(a) COSMIC observed electron density and Kp during entire year 2008.*



*(a) Spectrum analysis of electron densities and Kp shown in (a) indicating the 9, 13.5, and 27 days ionospheric oscillation.*

*Tulasiram et al., GRL 2010*

# **Ionospheric Solar Eclipse signature**

# 日全蝕 (Eclipse)

## Total Solar Eclipse of 2009 Jul 22

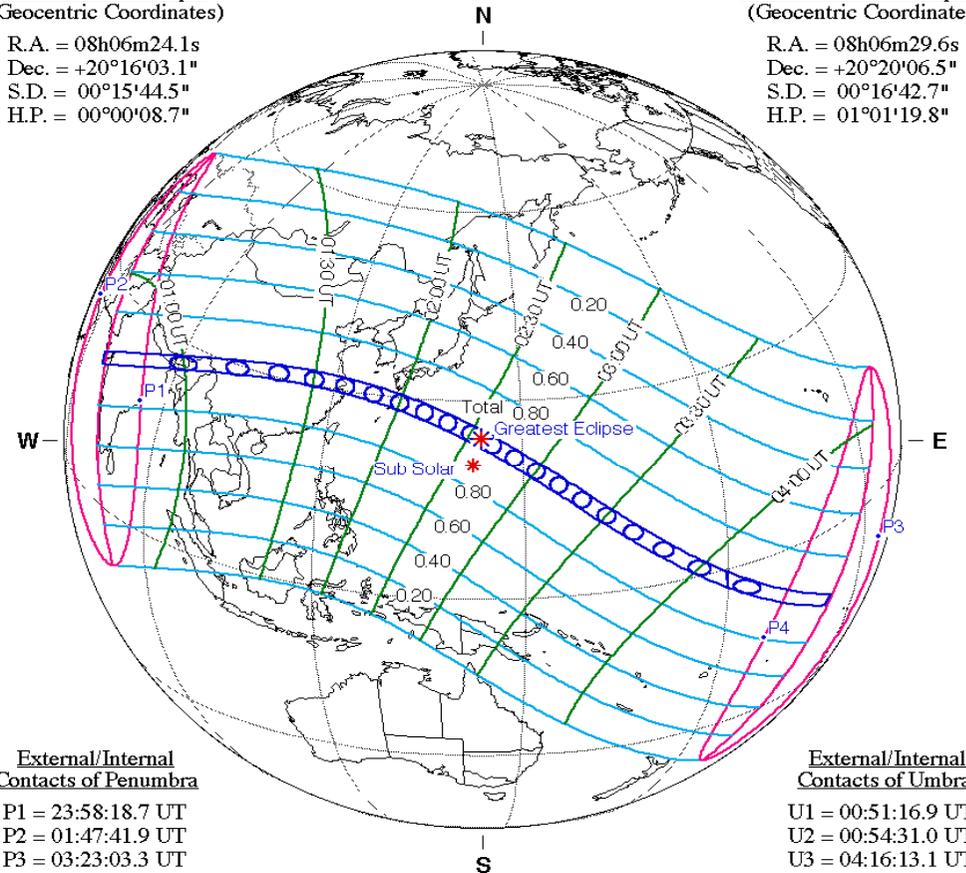
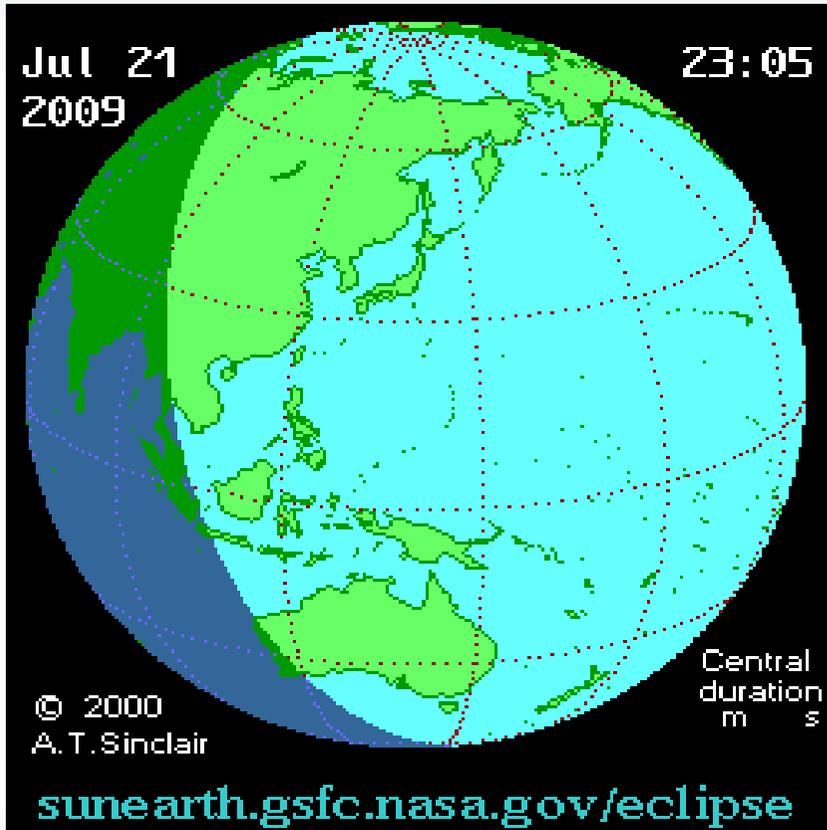
Geocentric Conjunction = 02:33:04.4 UT    J.D. = 2455034.606301  
 Greatest Eclipse = 02:35:21.1 UT    J.D. = 2455034.607884  
 Eclipse Magnitude = 1.0799    Gamma = 0.0696  
 Saros Series = 136    Member = 37 of 71

### Sun at Greatest Eclipse (Geocentric Coordinates)

R.A. = 08h06m24.1s  
 Dec. = +20°16'03.1"  
 S.D. = 00°15'44.5"  
 H.P. = 00°00'08.7"

### Moon at Greatest Eclipse (Geocentric Coordinates)

R.A. = 08h06m29.6s  
 Dec. = +20°20'06.5"  
 S.D. = 00°16'42.7"  
 H.P. = 01°01'19.8"



### External/Internal Contacts of Penumbra

P1 = 23:58:18.7 UT  
 P2 = 01:47:41.9 UT  
 P3 = 03:23:03.3 UT  
 P4 = 05:12:25.1 UT

### External/Internal Contacts of Umbra

U1 = 00:51:16.9 UT  
 U2 = 00:54:31.0 UT  
 U3 = 04:16:13.1 UT  
 U4 = 04:19:26.5 UT

### Ephemeris & Constants

Eph. = Newcomb/ILE  
 $\Delta T = 66.2$  s  
 $k_1 = 0.2724880$   
 $k_2 = 0.2722810$   
 $\Delta b = 0.0''$      $\Delta l = 0.0''$

### Local Circumstances at Greatest Eclipse

Lat. = 24°12.6'N    Sun Alt. = 85.9°  
 Long. = 144°06.4'E    Sun Azm. = 197.6°  
 Path Width = 258.4 km    Duration = 06m38.8s

### Geocentric Libration (Optical + Physical)

$l = 0.66^\circ$   
 $b = -0.09^\circ$   
 $c = 10.53^\circ$

Brown Lun. No. = 1071



F. Espenak, NASA's GSFC - Fri, Jul 2,  
[sunearth.gsfc.nasa.gov/eclipse/eclipse.html](http://sunearth.gsfc.nasa.gov/eclipse/eclipse.html)



NATIONAL SPACE ORGANIZATION

FORMOSAT-3 PROFILES ON 22 JUL 2009  
GREEN RED BLUE 231 181 26

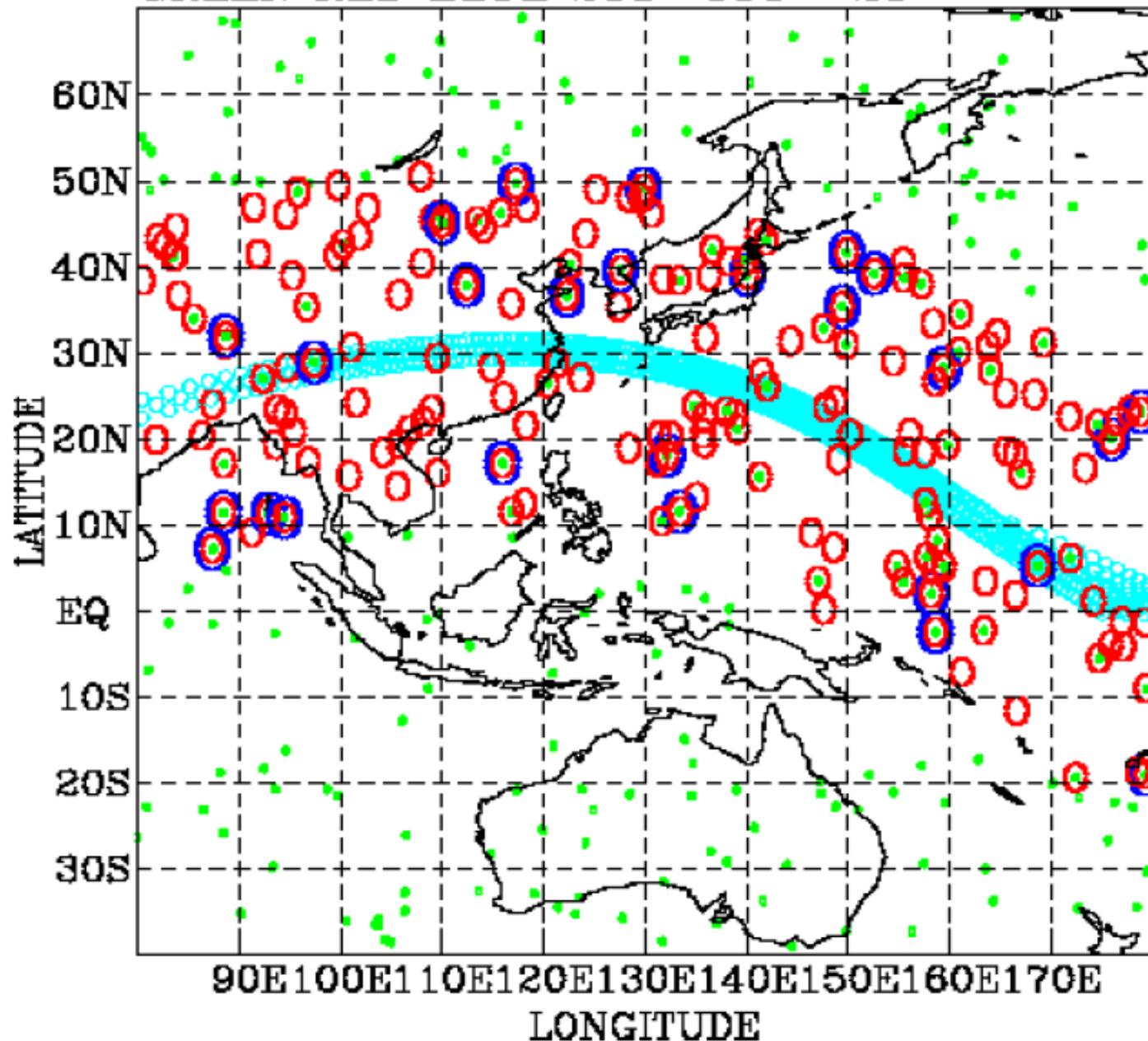


Figure 1. Spatial distribution of FS3/C GPS RO profiles (green dots, red, and blue circles) and path of the total eclipse (sky-blue circles) on 22 July 2009

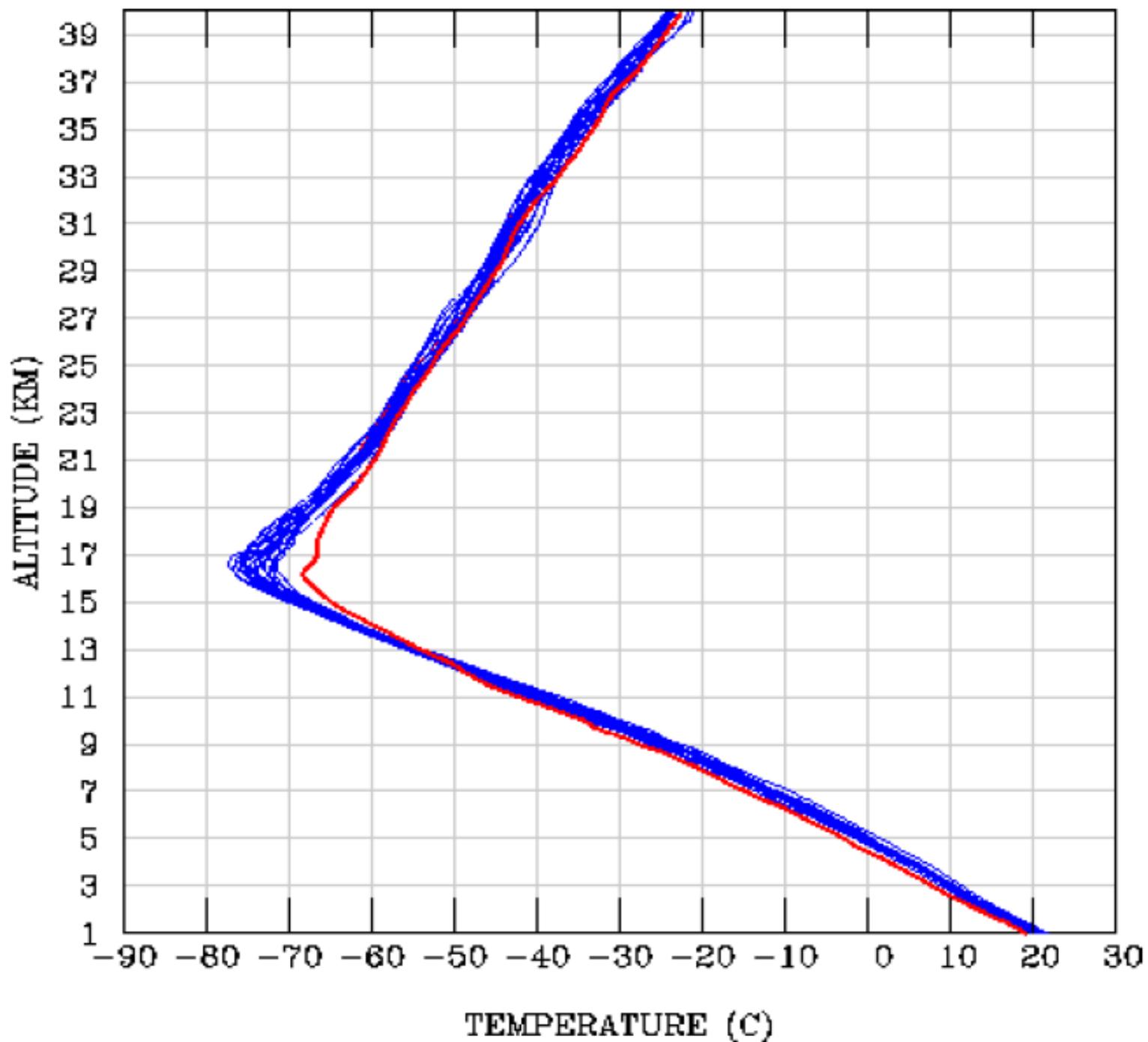


Figure 2. Profiles of temperatures from FS3/C on 22 July 2009 (red curve), and each days of 12 July-21 July, and 23 July-1 August 2009 (blue curves).

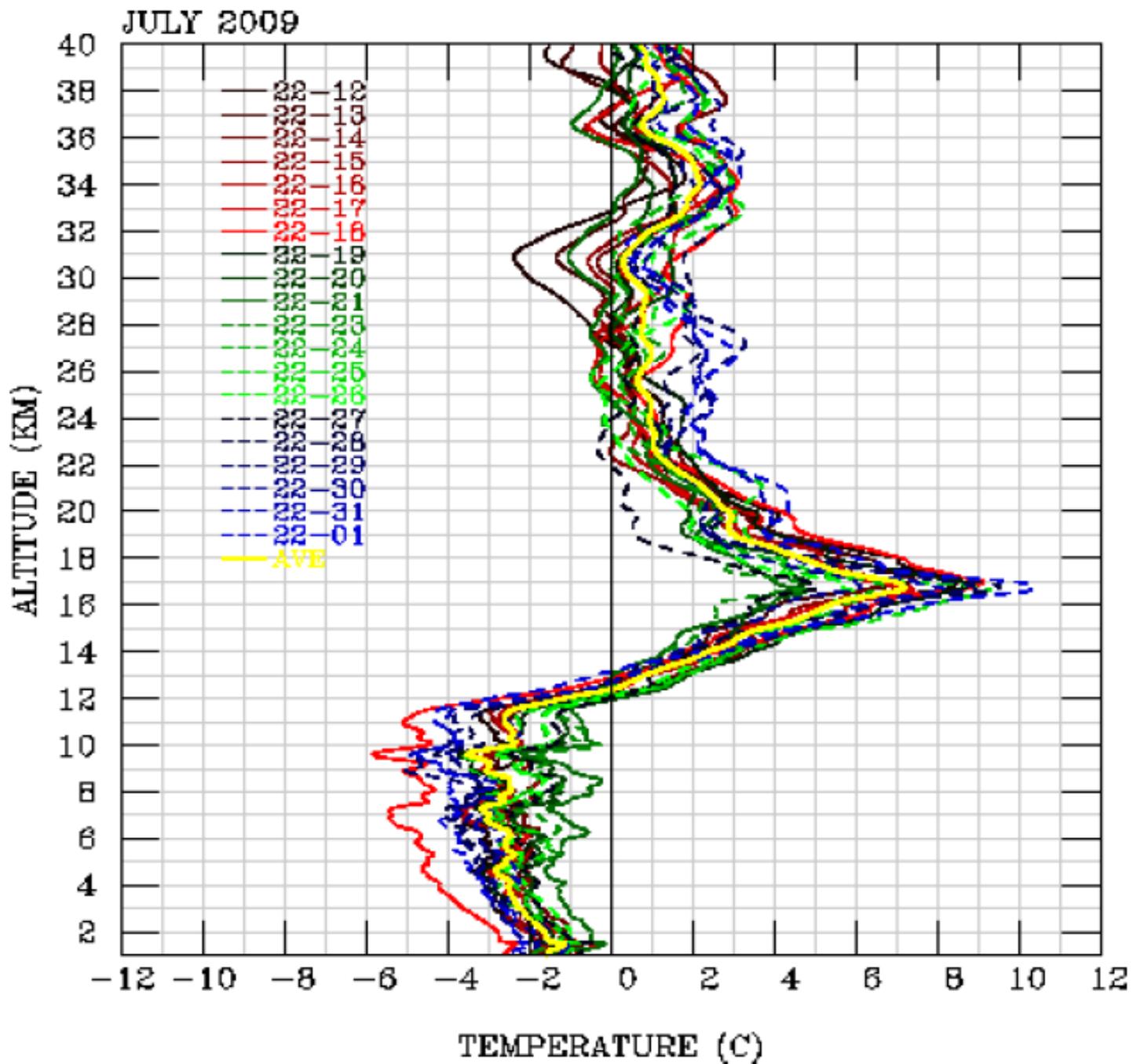


Figure 3(a) Profiles of temperature differences between 22 July 2009 (the eclipse day) and each day of 12 July-21 July, and 23 July-1 August 2009, respectively. Mean profile of temperature differences is shown in yellow curve.

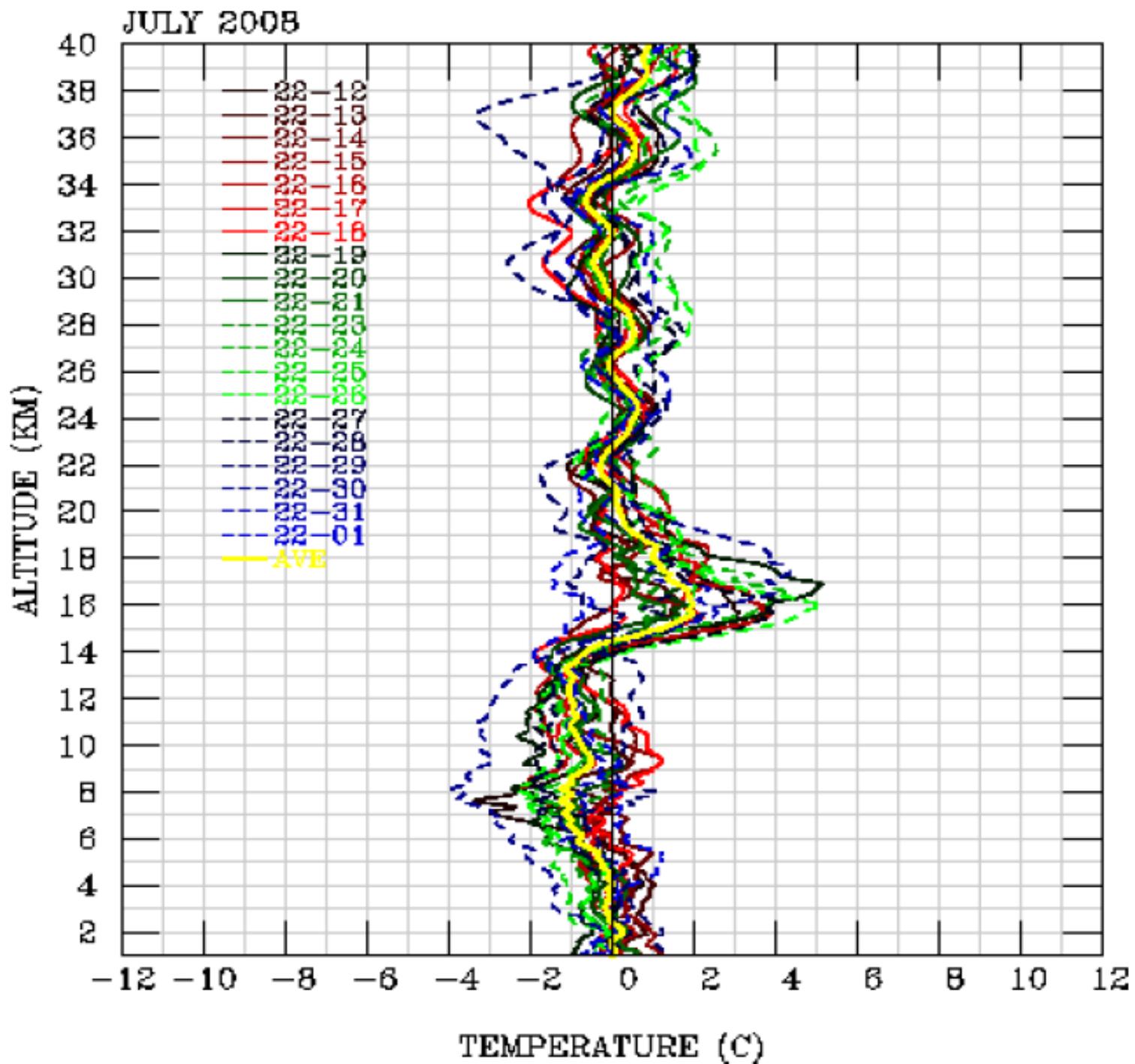
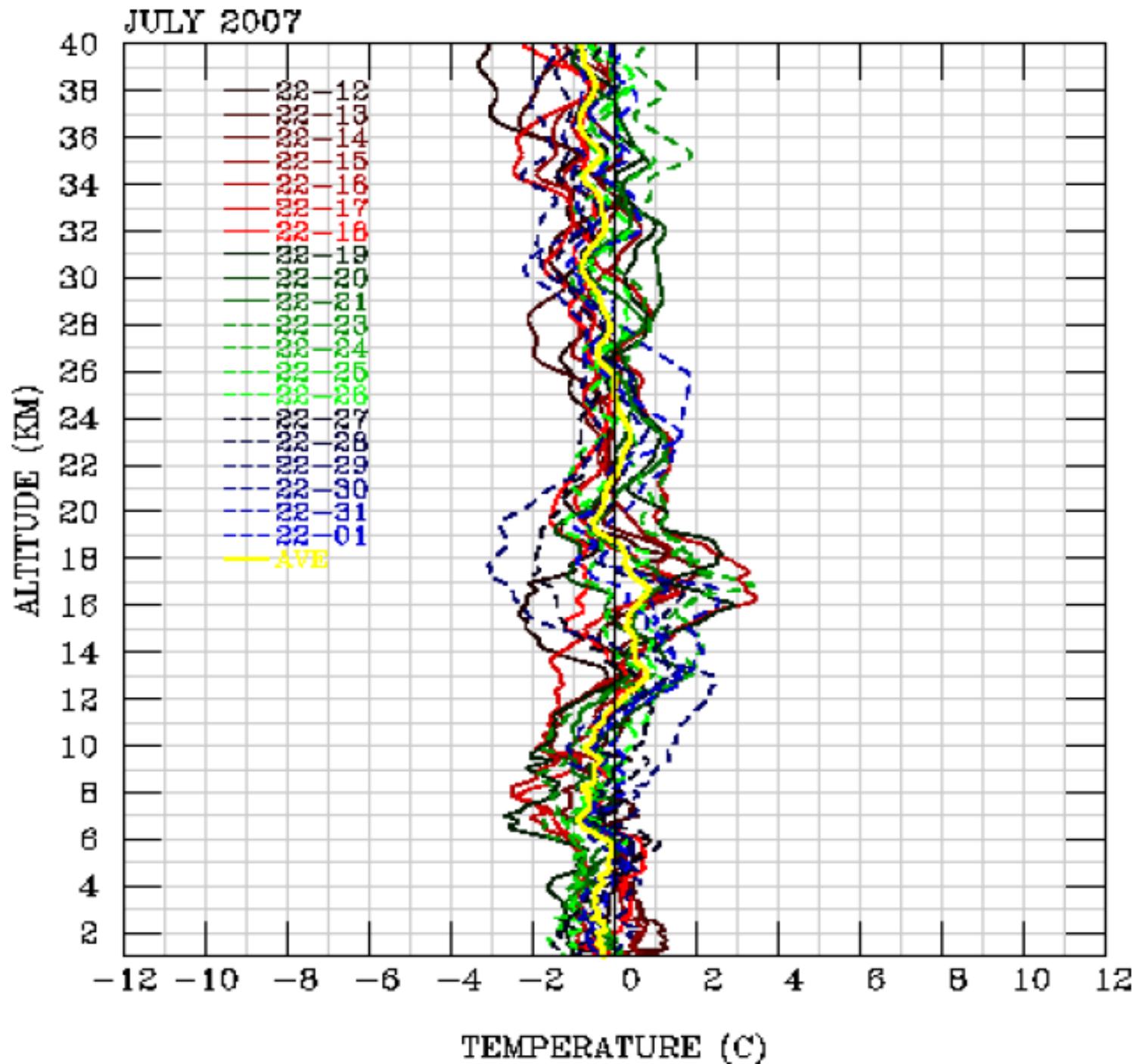
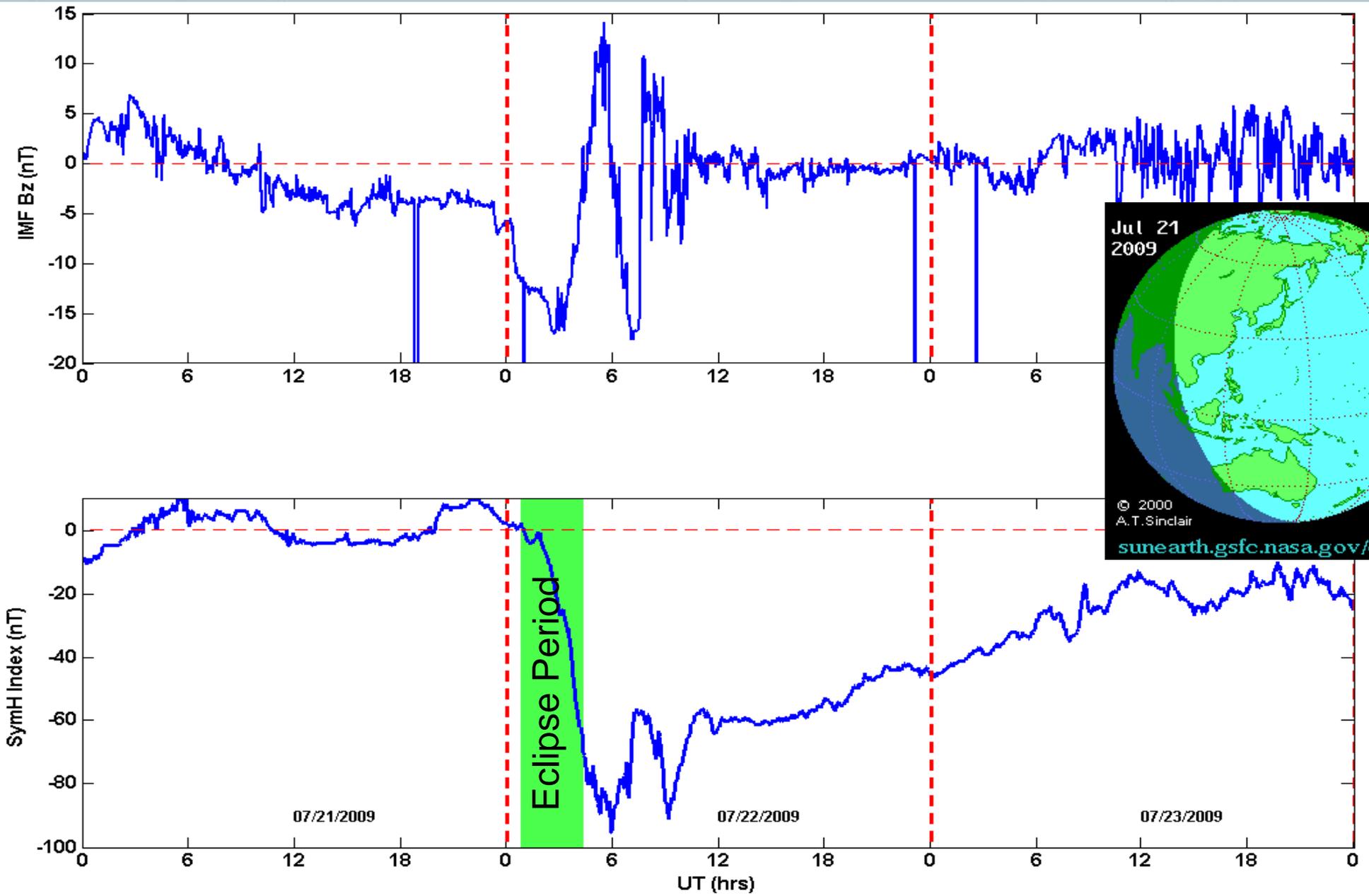


Figure 3(b) The same as in Figure 3(a) but for 2008.



NATIONAL Figure 3(c). The same as in Figure 3(a) but for 2007.

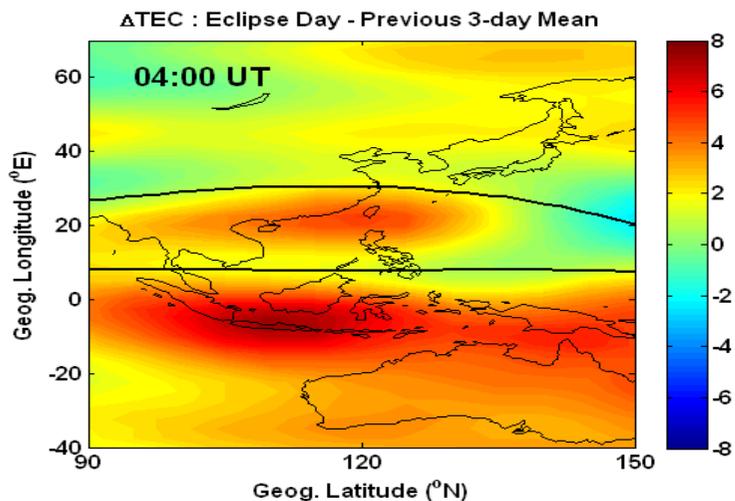
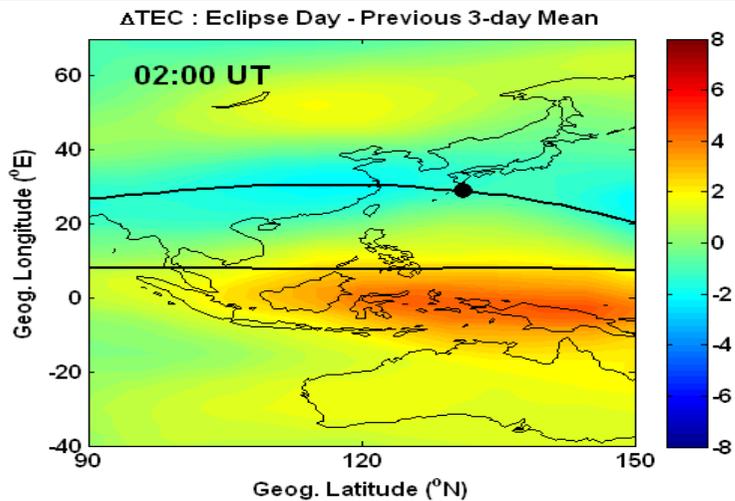
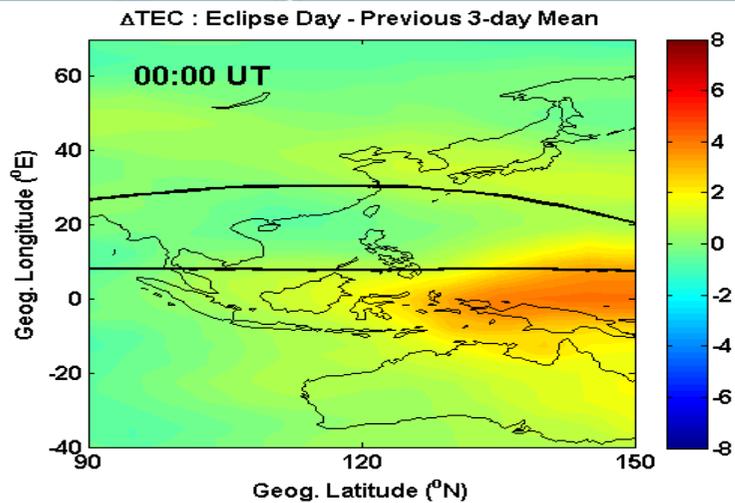
# 22<sup>nd</sup> July 2009 – Geo-magnetic Storm & Solar Eclipse Event



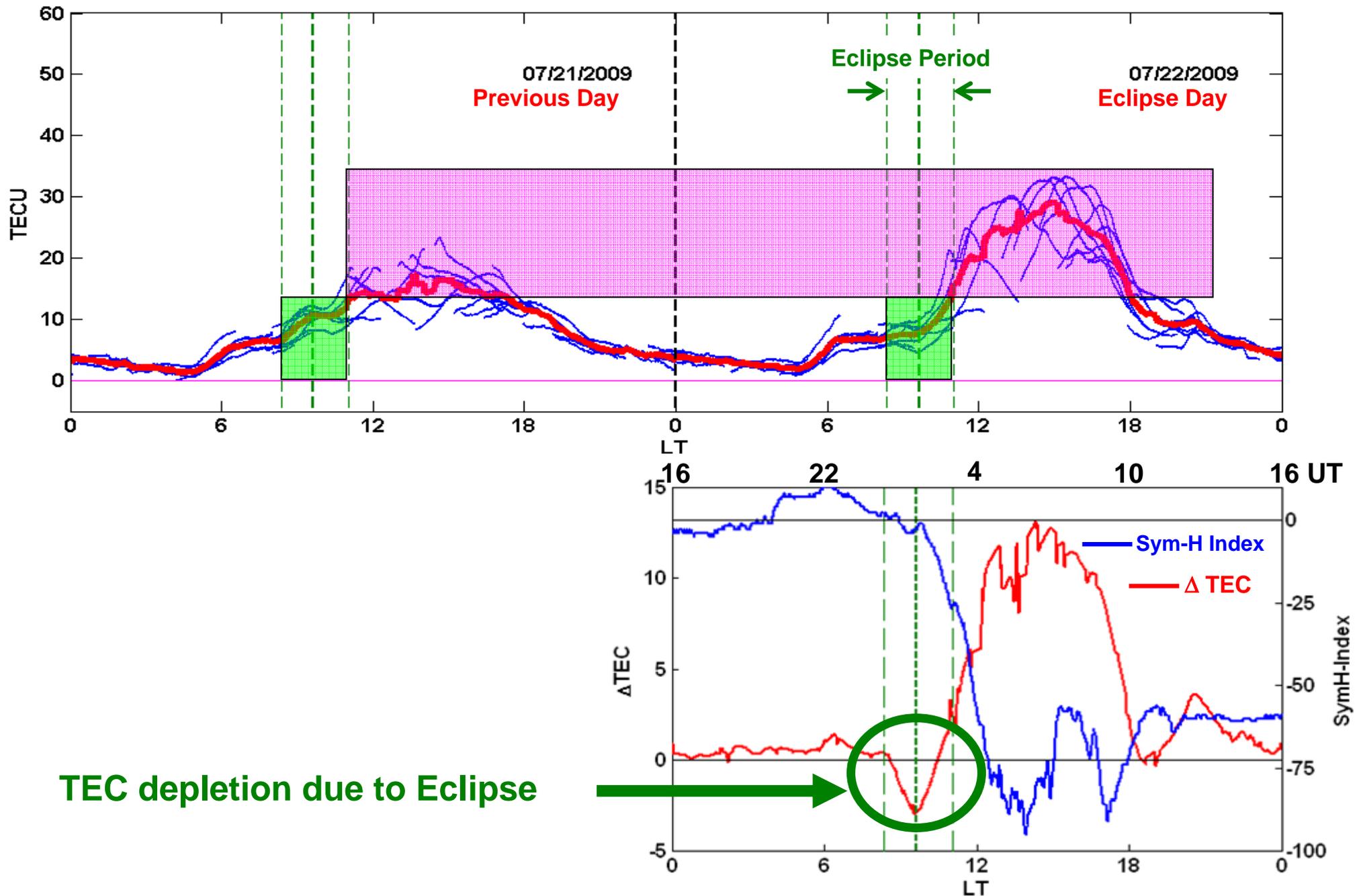
**Pre-Eclipse Period**  
Sun-lit region exhibits positive response

**Eclipse Period**  
Sun-lit region exhibits positive response  
Eclipse region exhibits a depletion in TEC

**Post Eclipse Period**  
Sun-lit region exhibits positive response  
TEC depletion is recovering



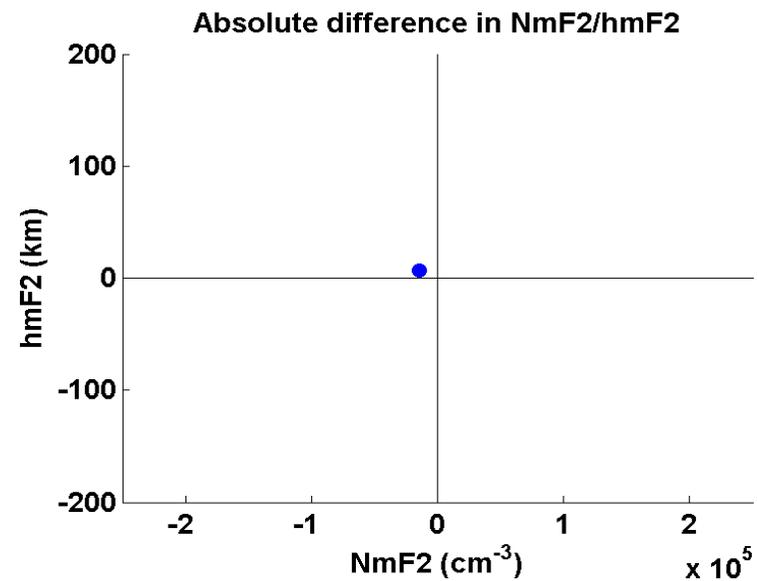
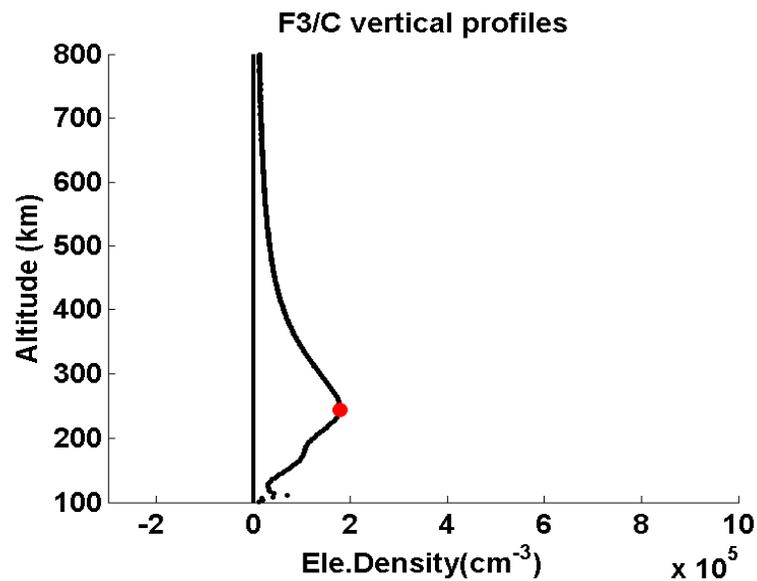
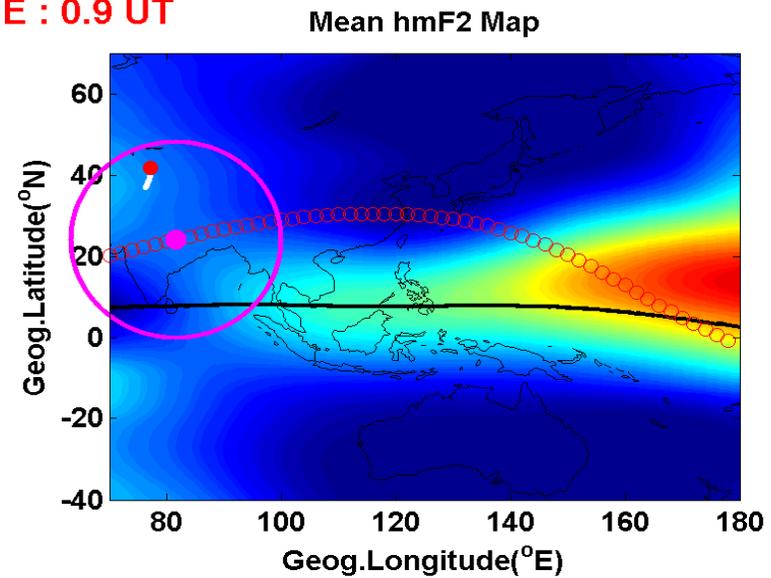
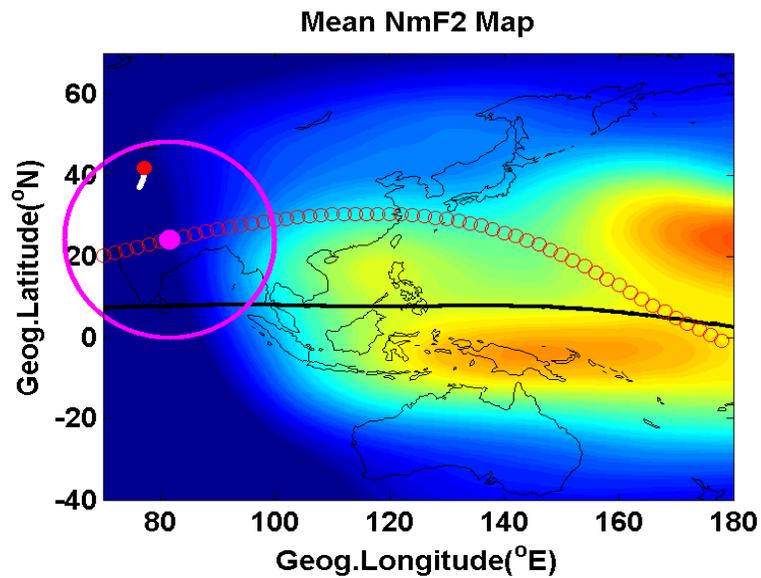
# GPS-TEC response over Chung-Li (24.91°N, 121.24°E)



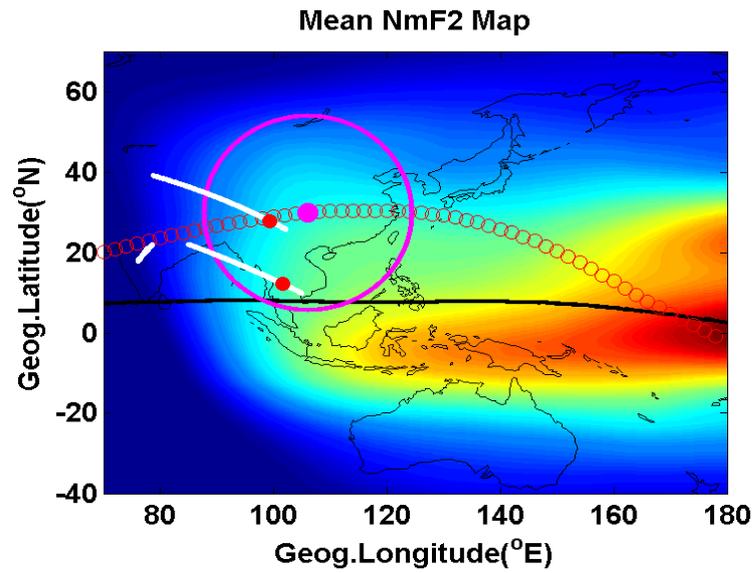
TEC depletion due to Eclipse

# Formosat-3/COSMIC Observations during Eclipse

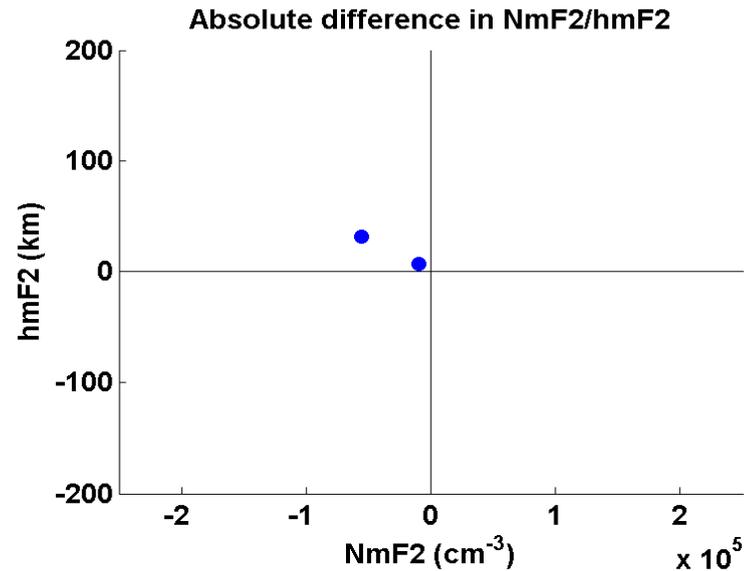
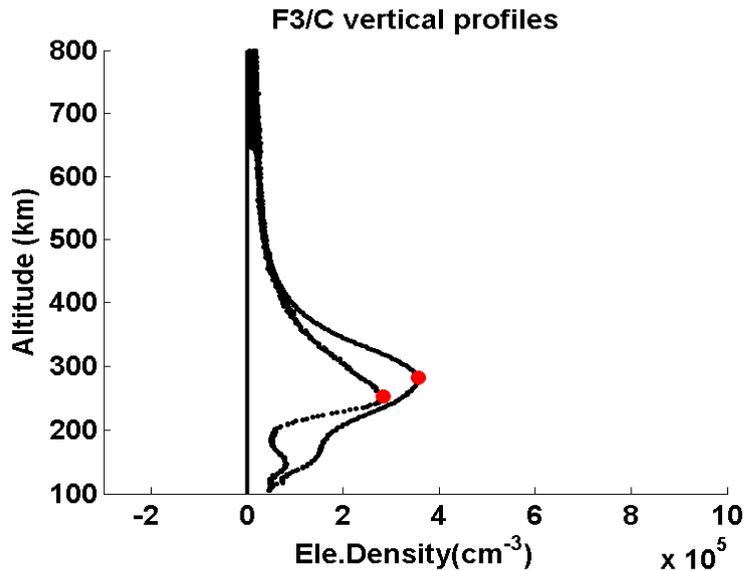
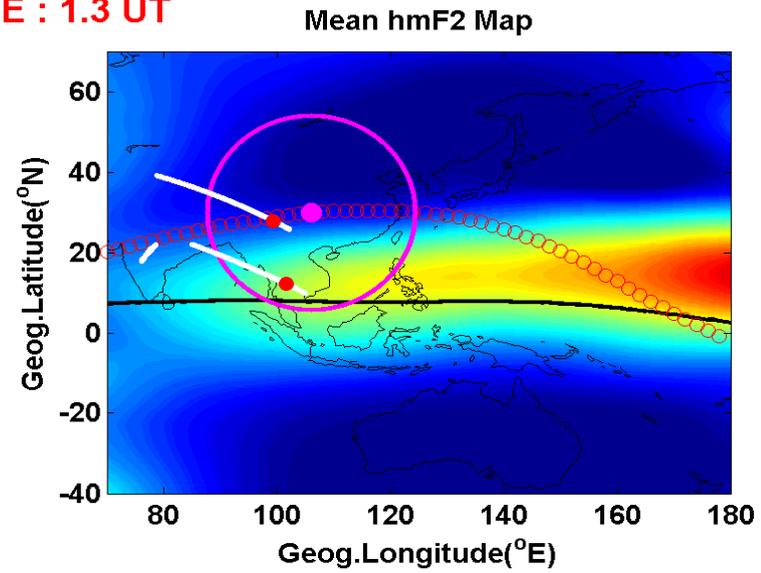
TIME : 0.9 UT



# Formosat-3/COSMIC Observations during Eclipse



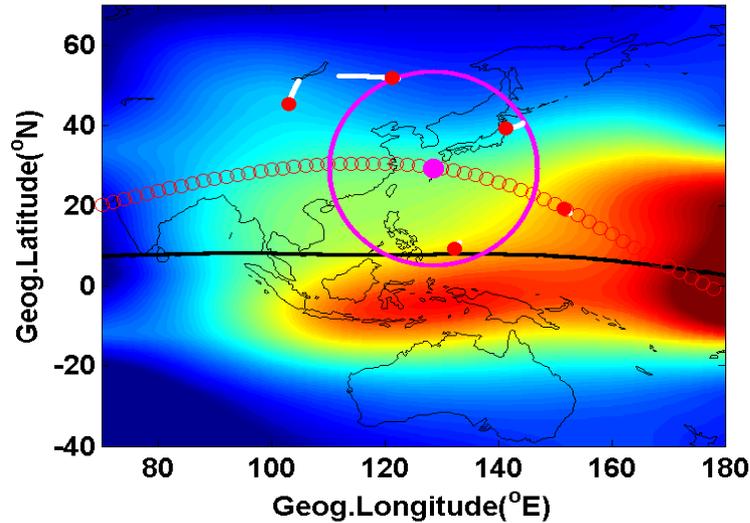
TIME : 1.3 UT



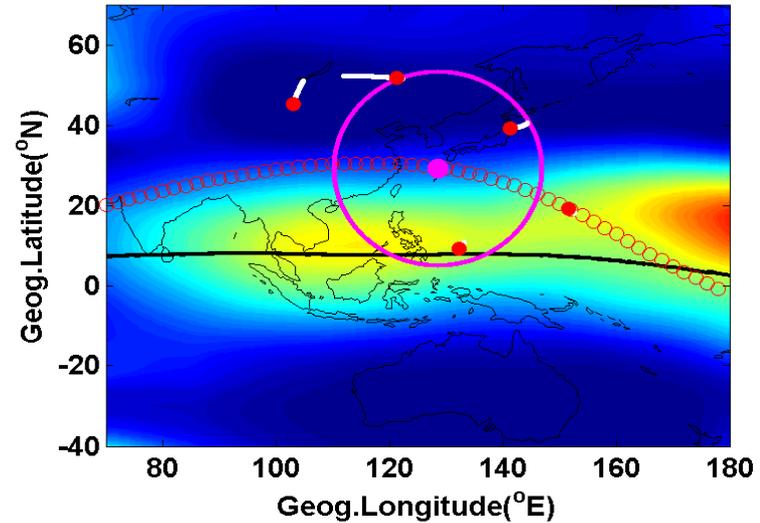
# Formosat-3/COSMIC Observations during Eclipse

TIME : 1.9 UT

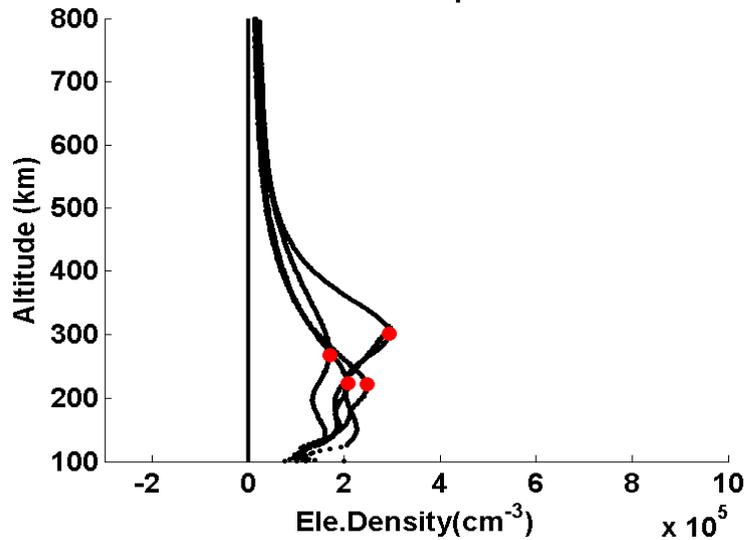
Mean NmF2 Map



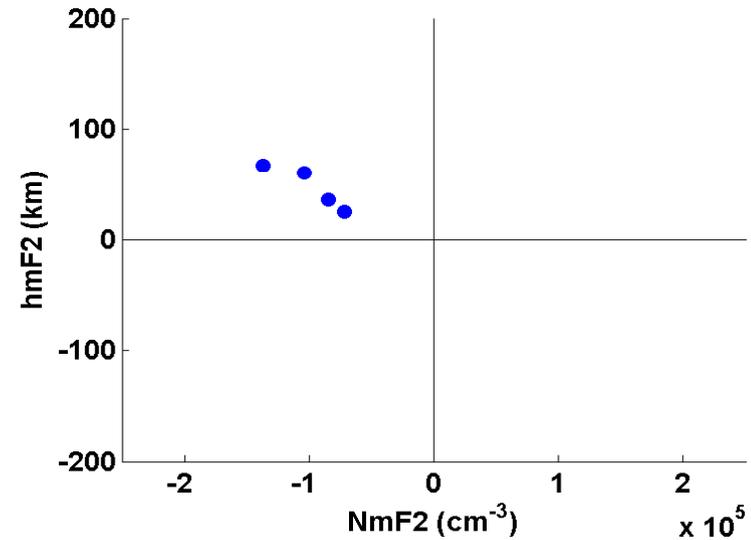
Mean hmF2 Map



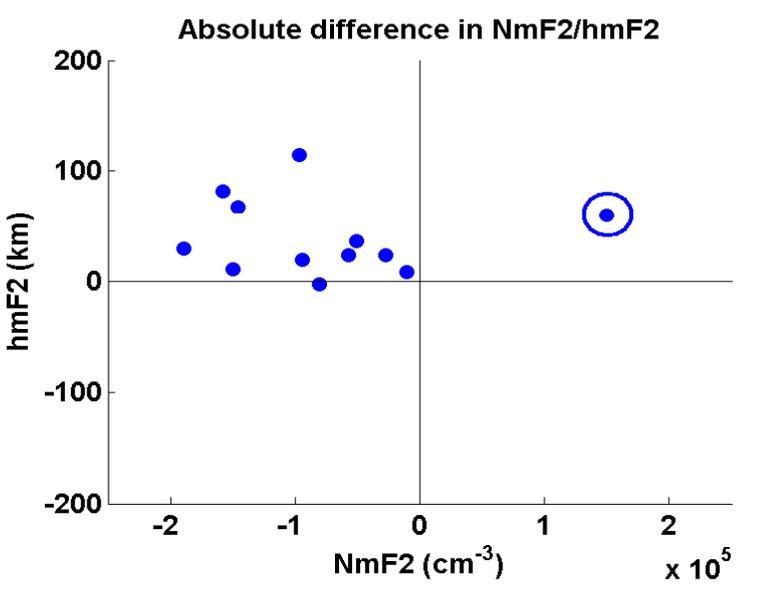
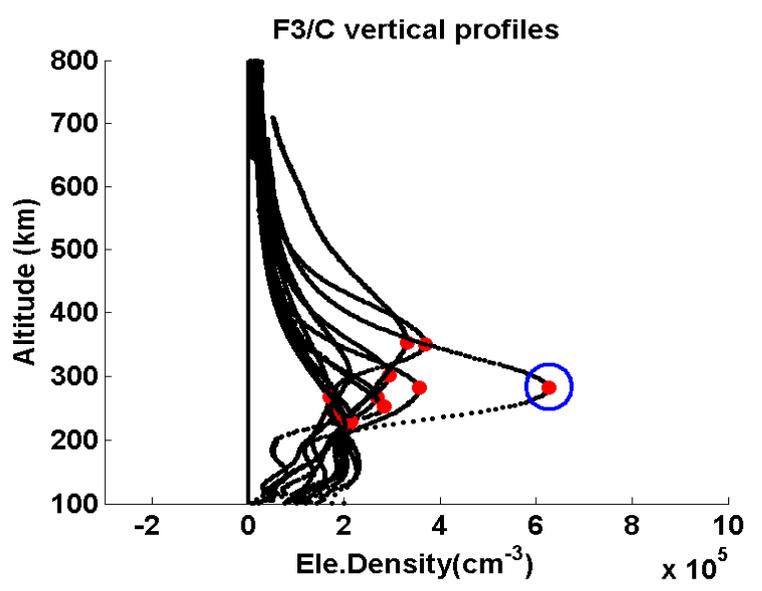
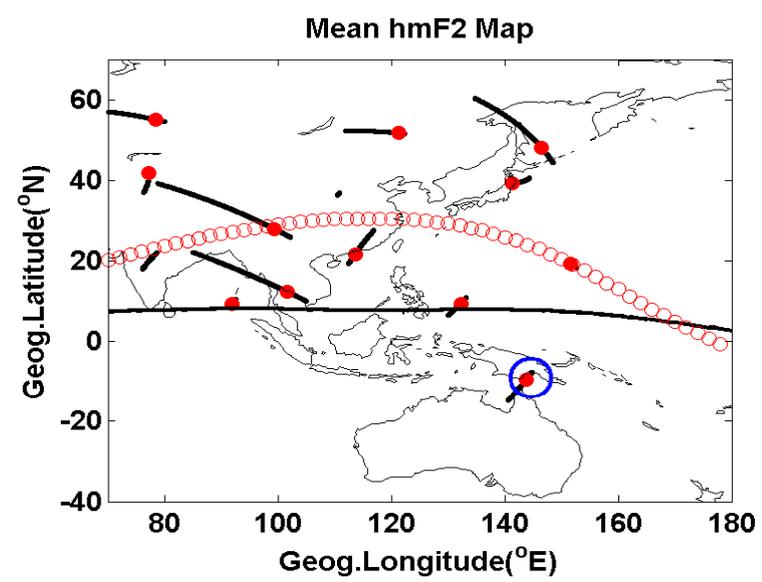
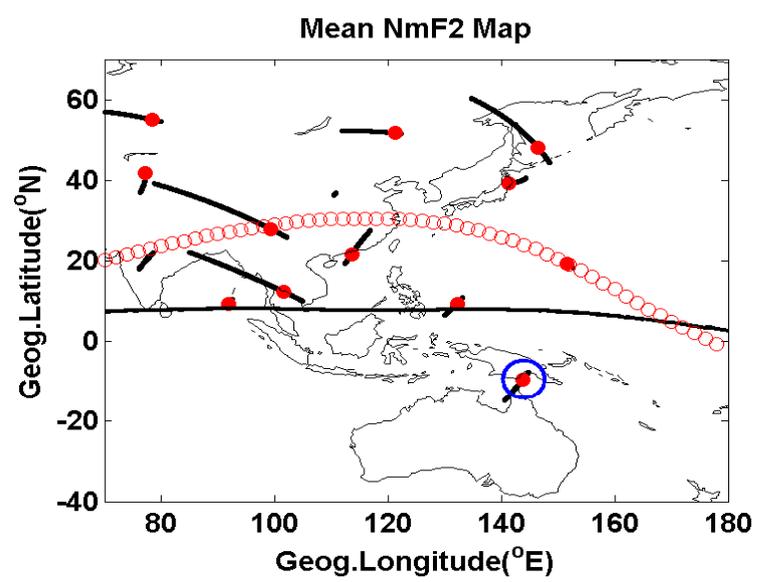
F3/C vertical profiles



Absolute difference in NmF2/hmF2

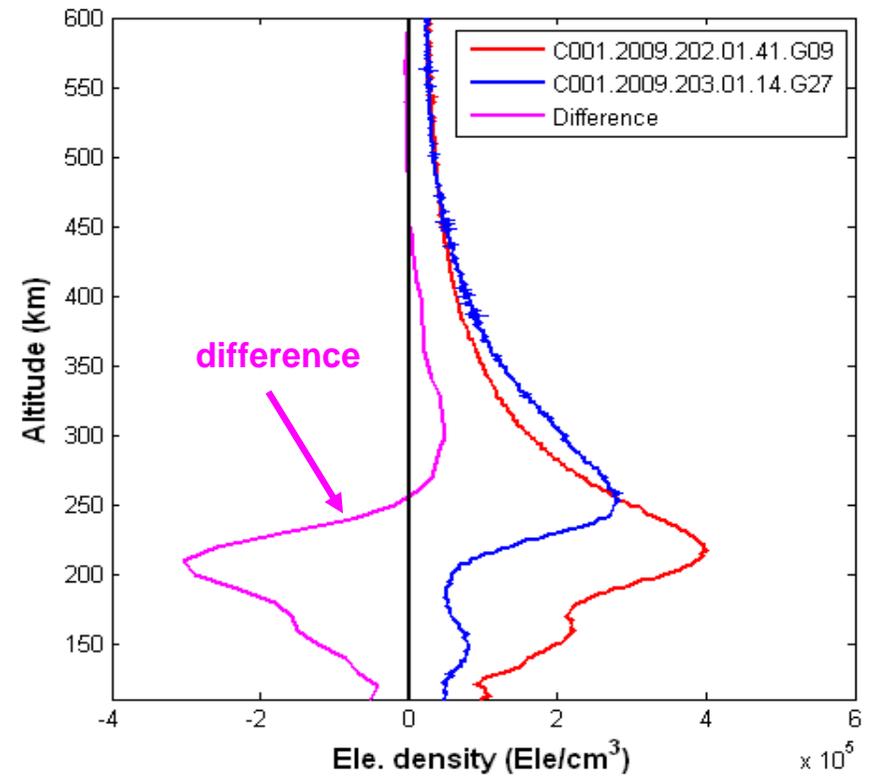
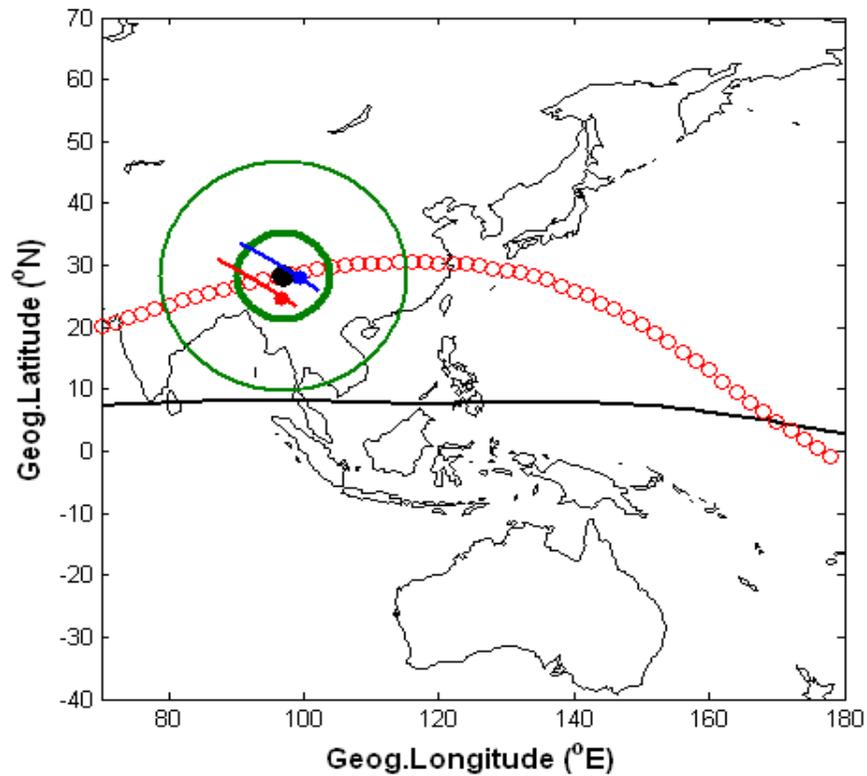


# All F3/C soundings within the 20 - 100% of Eclipse



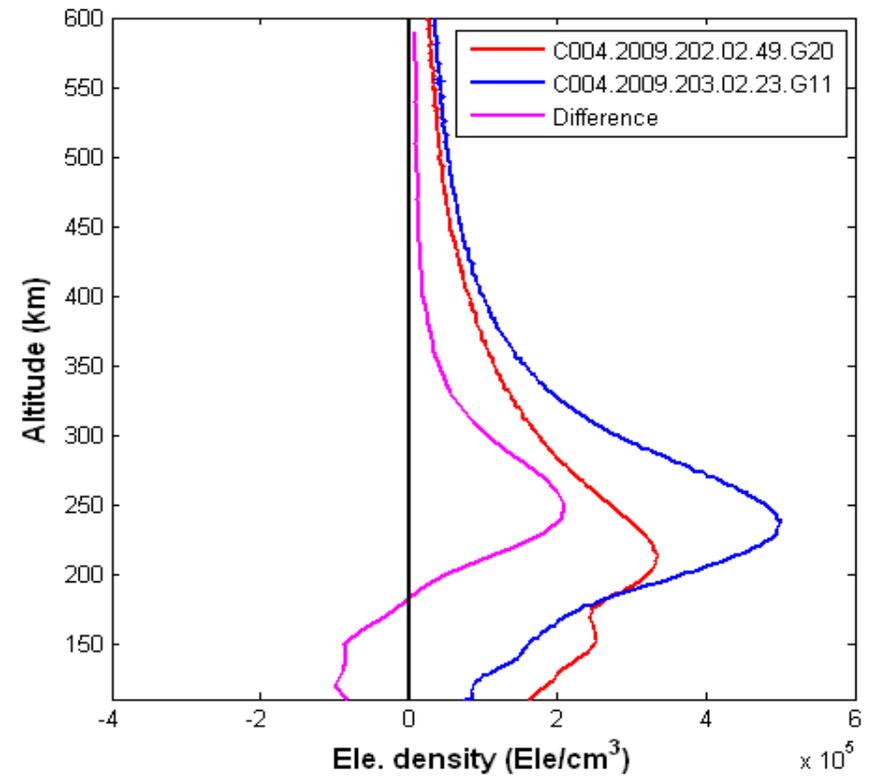
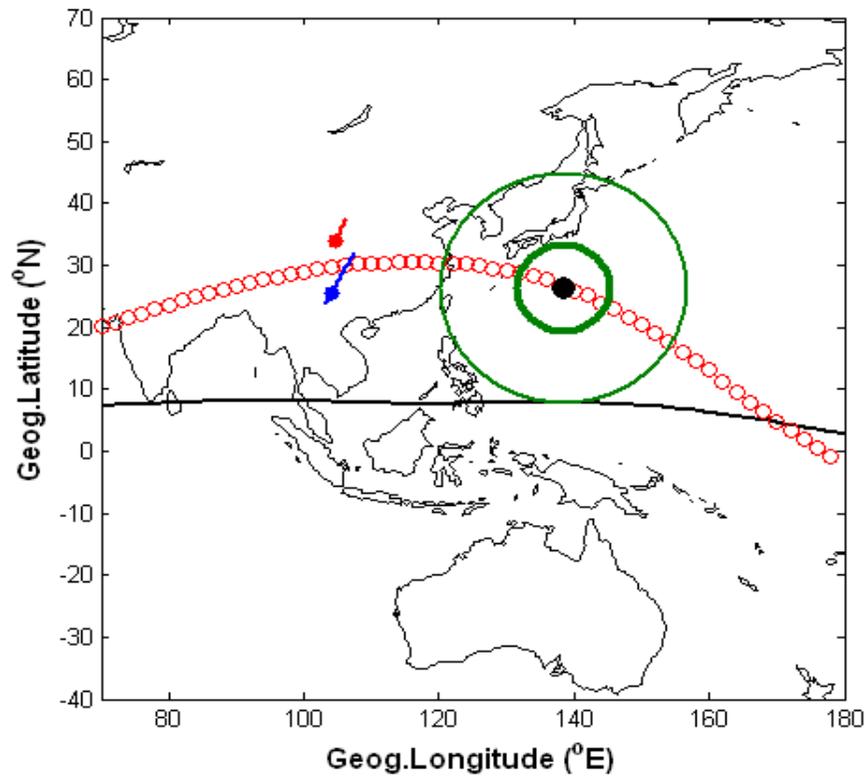
# Formosat-3/COSMIC Observations at nearby locations on 21<sup>st</sup> and 22<sup>nd</sup> July

At totality of Eclipse



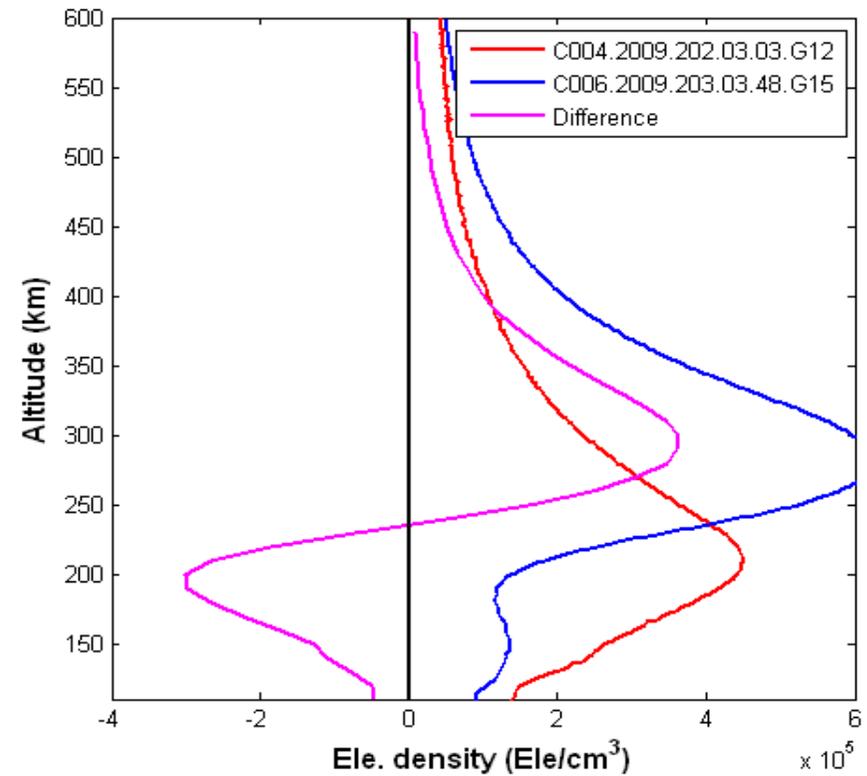
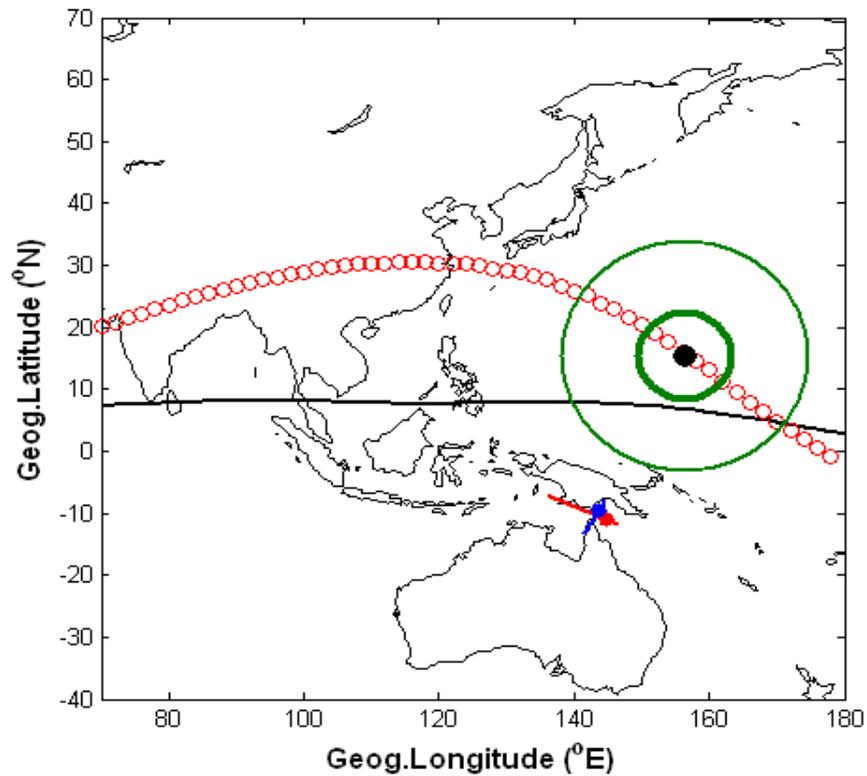
# Formosat-3/COSMIC Observations at nearby locations on 21<sup>st</sup> and 22<sup>nd</sup> July

After 1 hour of Totality



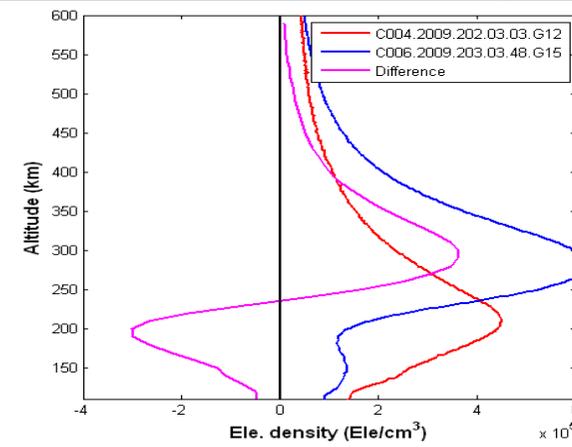
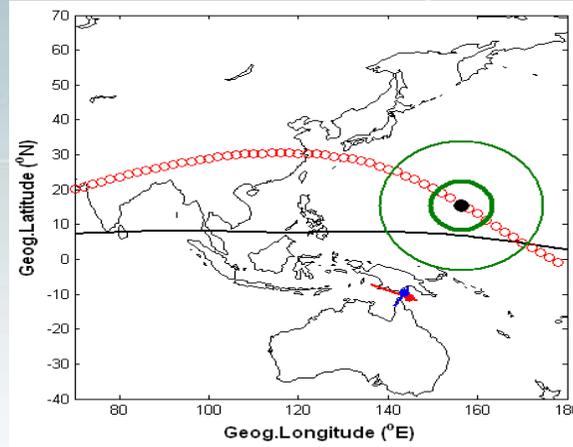
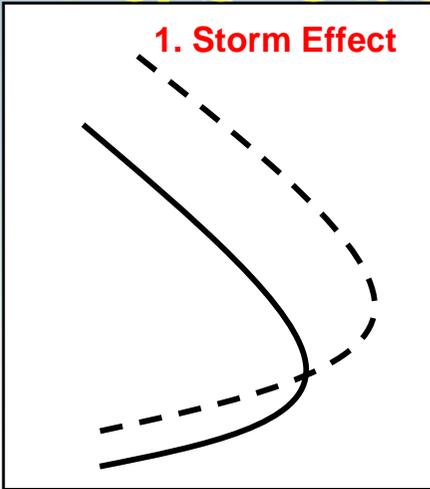
# Formosat-3 Observations at nearby locations on 21<sup>st</sup> and 22<sup>nd</sup> July

## Response to Storm without Eclipse



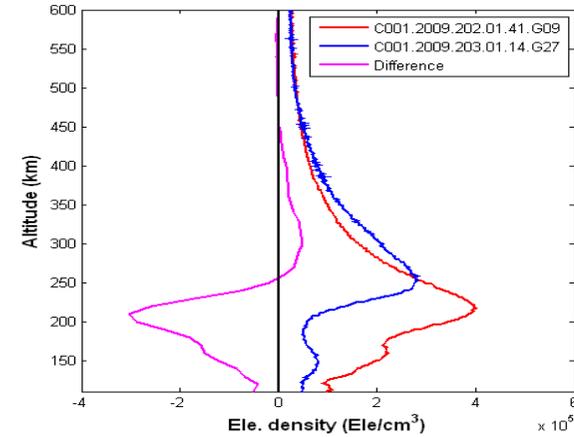
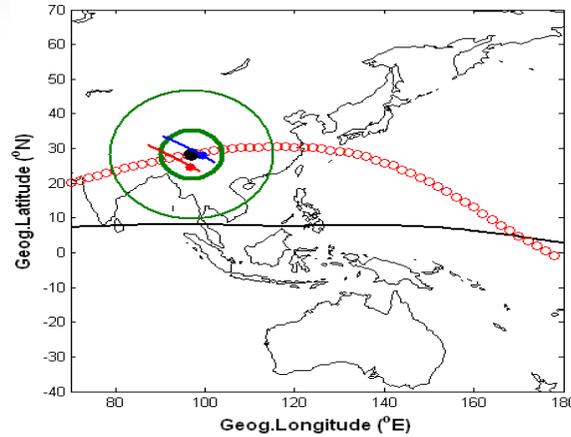
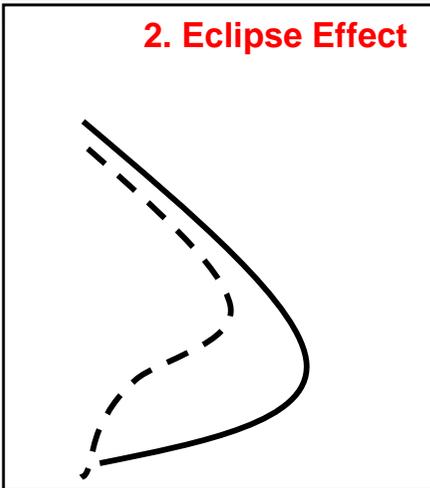
# F3/C Observations of Storm + Eclipse Effect

## 1. Storm Effect



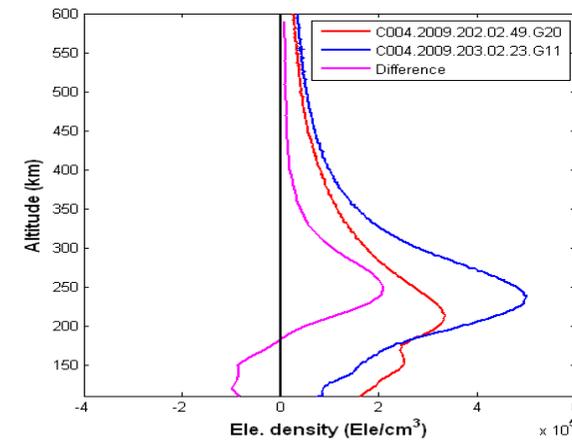
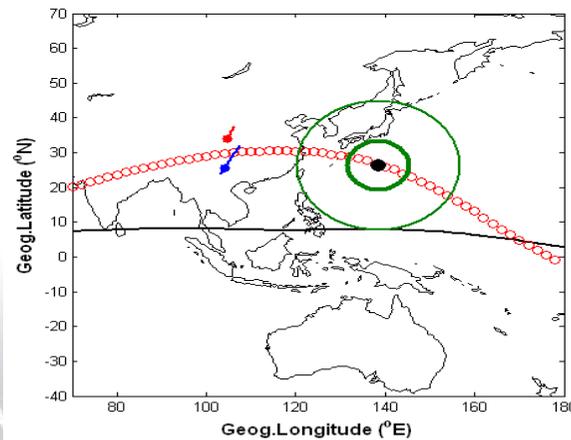
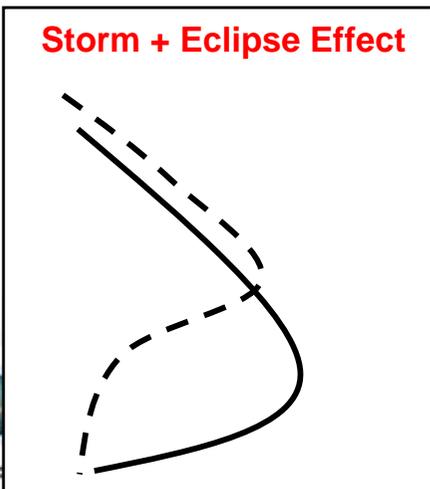
Storm without Eclipse

## 2. Eclipse Effect



At totality of Eclipse

## Storm + Eclipse Effect



1 hr after the Eclipse pass

# Conclusion

- FORMOSAT-3/COSMIC radio occultation GOX is useful to investigate the ionospheric electron density structure and dynamics of the EIA, MT, and MSNA, and find PDB.
- The F3/C is useful to study ionospheric responses to various coupling processes in the solar-terrestrial system.

敬請批評指教 Thank you!!!

太空及遙測研究中心

太空所 ISS

