Using CCMC in Education at University of Colorado (and elsewhere)

Delores Knipp

University of Colorado Boulder

Aerospace Engineering

with contributions from

Stefan Eriksson, LASP, Geoff Crowley, ASTRA,

CCMC Staff (Masha, Lutz, Anna)

& 100's of students

HAO NCAR, NRC SWPC, CISM, MURI, USAFA

CU Aerospace Engineering 5335 (and beyond)

- Static Models and Climatology
  - Examples : http://ccmc.gsfc.nasa.gov/modelweb/
  - http://modelweb.gsfc.nasa.gov/models/trap.html
- Archived Runs on Request
  - Exercise(s) under Development
- Future Verification and Validation
  - Plans for MURI data

ASEN 4335 Student Population

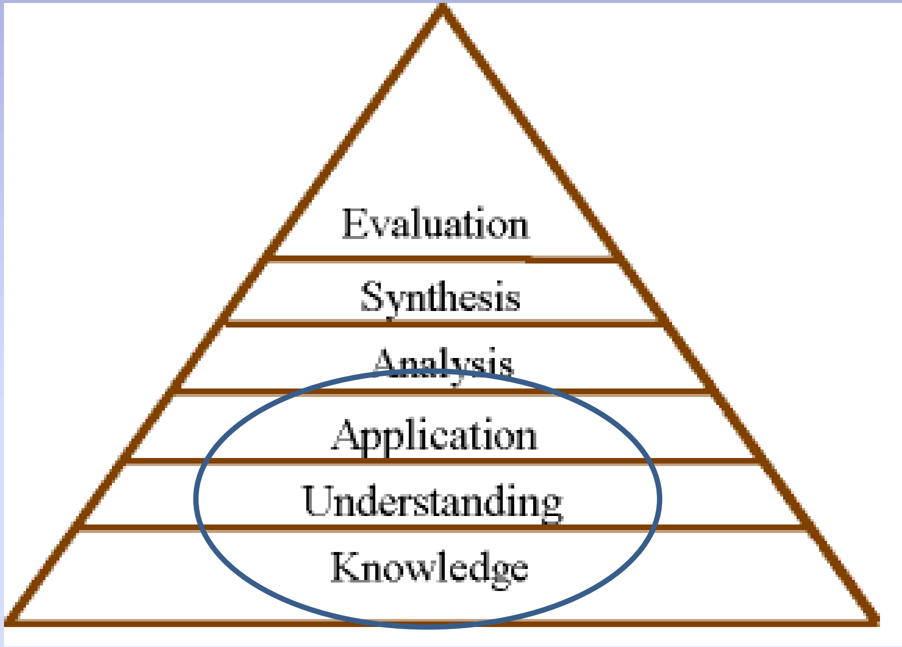
- In-classroom (20)
  - Beginning Graduate Students
  - Advanced Graduate Students
- Distance Students (4)
  - Continuing Ed
  - Pre-Grad Admission
  - Professional Development

Format

- Semester
  - Twice Weekly Lectures, 3 Exams
- Homework (7)
  - Simple Analytical /Empirical Models
    - Units, Order of Magnitude Values,
    - Relevant Parameters, Basic Physics

Teaching and Learning

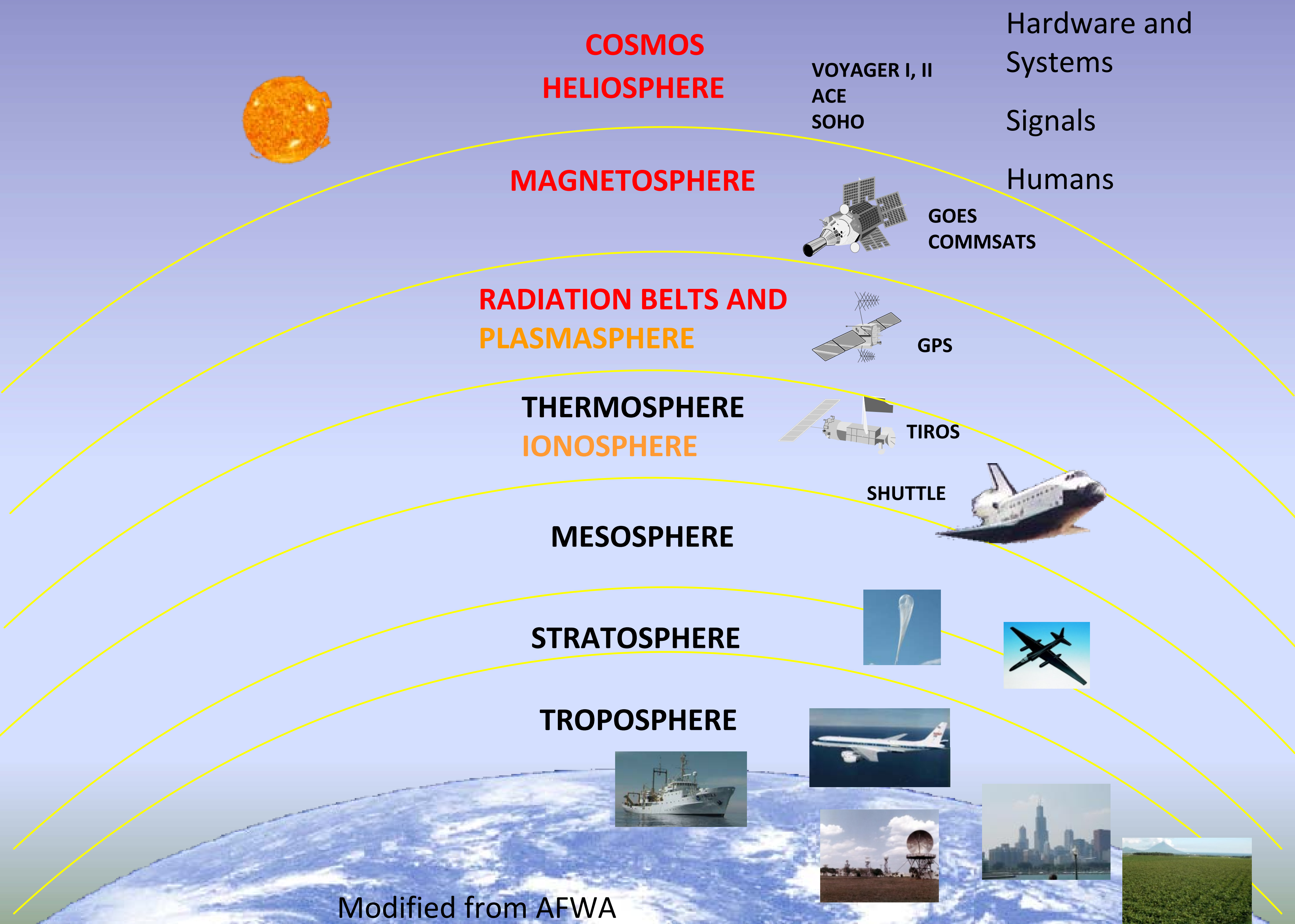
Bloom’s Taxonomy: Educational Psychology



COMPONENTS OF THE SOLAR-TERRESTRIAL SYSTEM

- **A. SUN**
- **B. SOLAR WIND / HELIOSPHERE**
- **C. MAGNETOSPHERE**
  - **Geomagnetic Field**
  - **Radiation Belts**
- **D. THE ATMOSPHERE –**
  - **NEUTRAL ATMOSPHERE**
  - **IONOSPHERE**
- **E. OTHER PLANETS**
- **F. SPACE MISSIONS**

Space Environment



Static Models and Climatology

A. SUN

Radiative Emissions : Analytic Model & SOLAR2000 (HW1)

B. SOLAR WIND / HELIOSPHERE

Developing :
Analytic Model & NOAA SWPC & CCMC

C. MAGNETOSPHERE

Geomagnetic Field& Dynamics

NGDC IGRF & NOAA SWPC (HW4)
Single Particle Motions

Radiation Belts

NASA MODELWEB AE8 AP8
NASA OMNIWEB (HW5)

Radiation Effects

Analytic and Empirical Models (HW6)

D. THE ATMOSPHERE –

NEUTRAL ATMOSPHERE

Scale Height : Analytic and Empirical Models (HW2)

Satellite Drag: NGDC ,
Analytic and Empirical Models
CCMC MSIS-90 (HW7)

IONOSPHERE

Layers Empirical Models and
CCMC International Reference Ionosphere (IRI-2007) (HW3)

E. OTHER PLANETS

F. SPACE MISSIONS

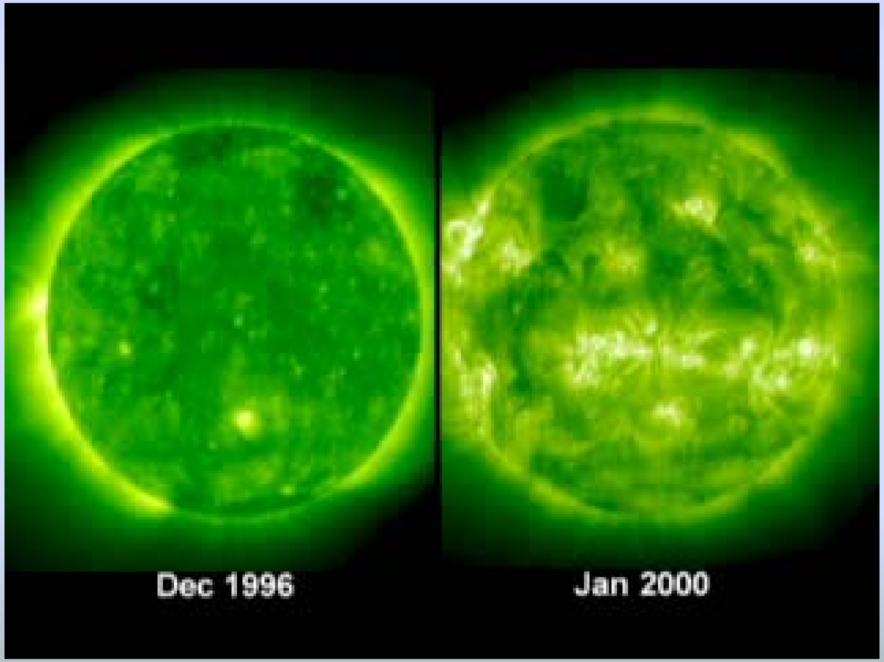
COURSE TOPICS

1. COMPONENTS OF THE SOLAR-TERRESTRIAL SYSTEM

2. ENVIRONMENTAL IMPACT ON SYSTEMS

1. **COMPONENTS OF THE SOLAR-TERRESTRIAL SYSTEM -** The various components of the solar-terrestrial system, and the interactions between them, will be examined in some detail. Essential elements of plasma and fluid physics, magnetohydrodynamics, atomic and molecular structure and spectra are introduced as needed.

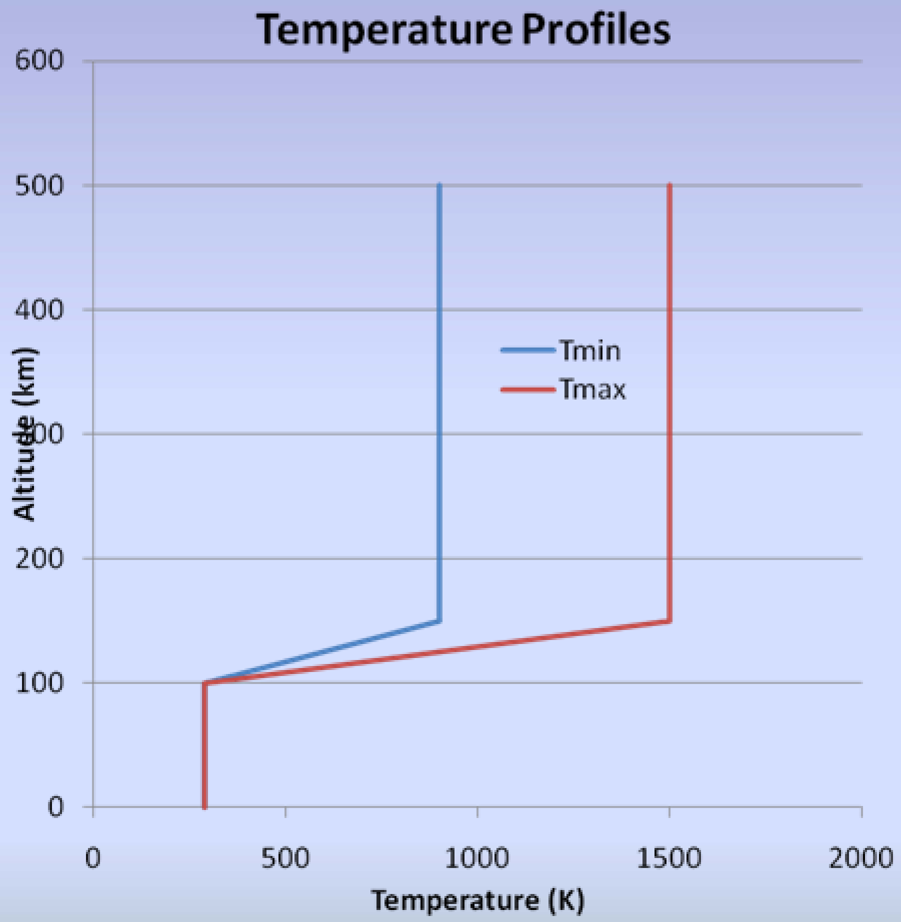
SolarCycleOld SunNew Sun.mpg

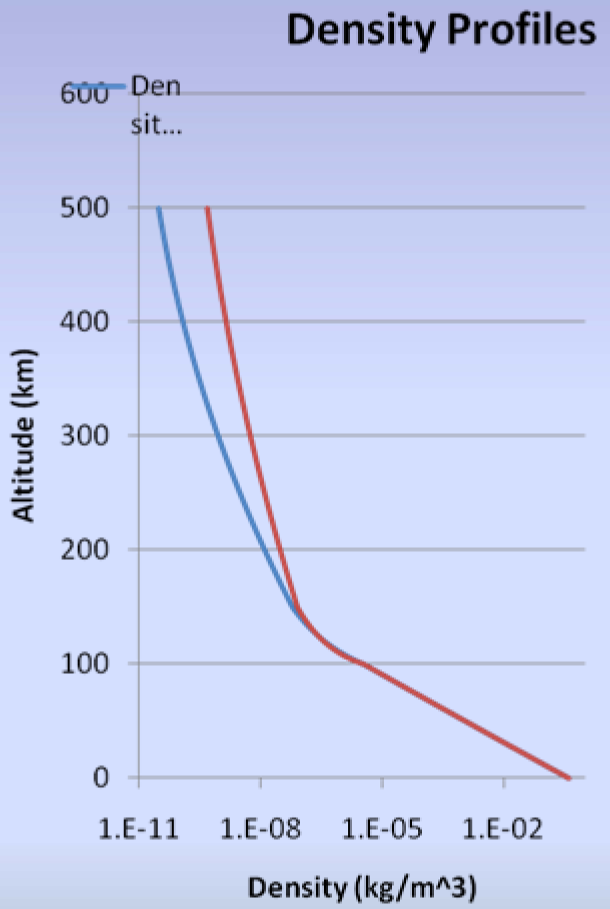


A. THE SUN - Basic structure and components; radio, visible, UV, EUV, and particle emissions; variability; interaction with Earth's neutral upper atmosphere and ionosphere.

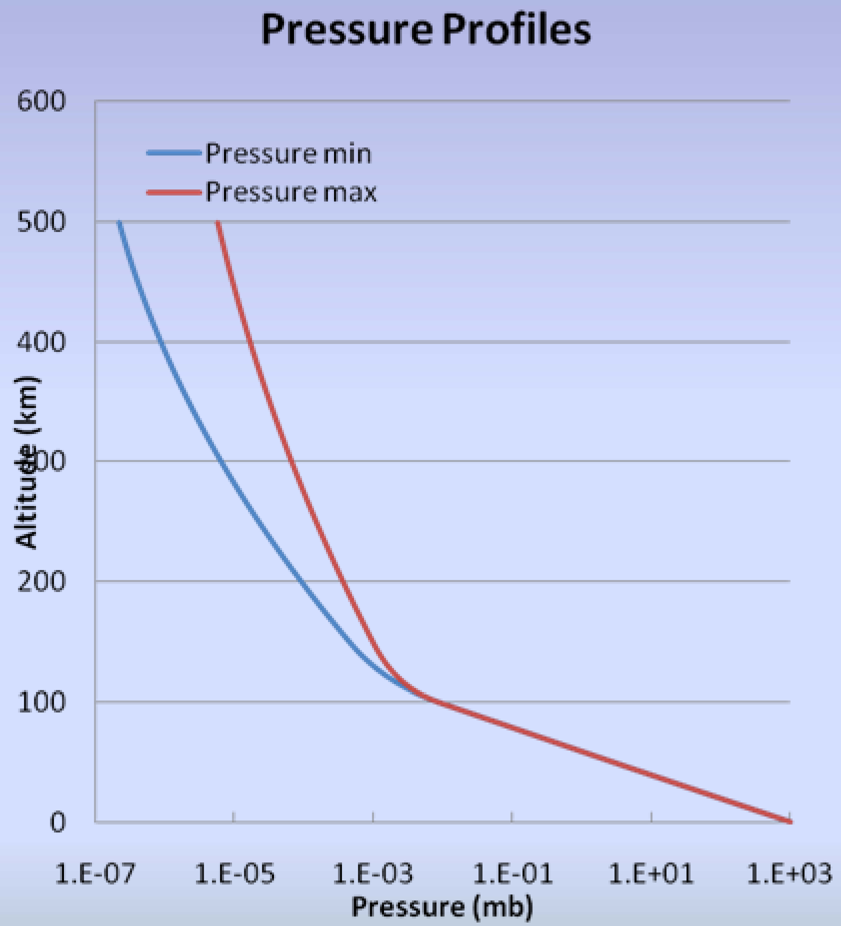
D. THE ATMSOPHERE- Basic origins, properties, and structure; interplanetary magnetic field; interactions with outer regions of the magnetosphere.

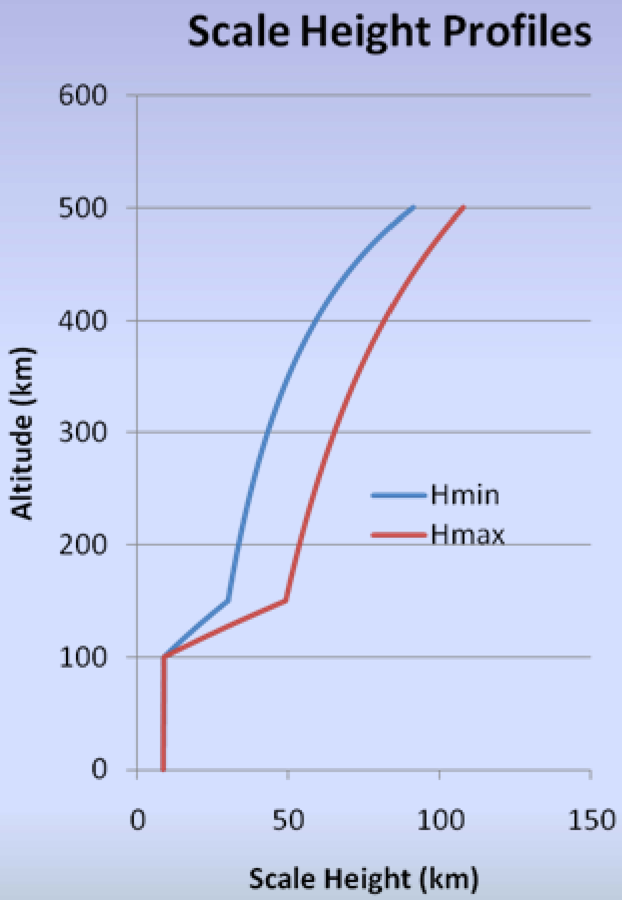
Exponential Atmosphere



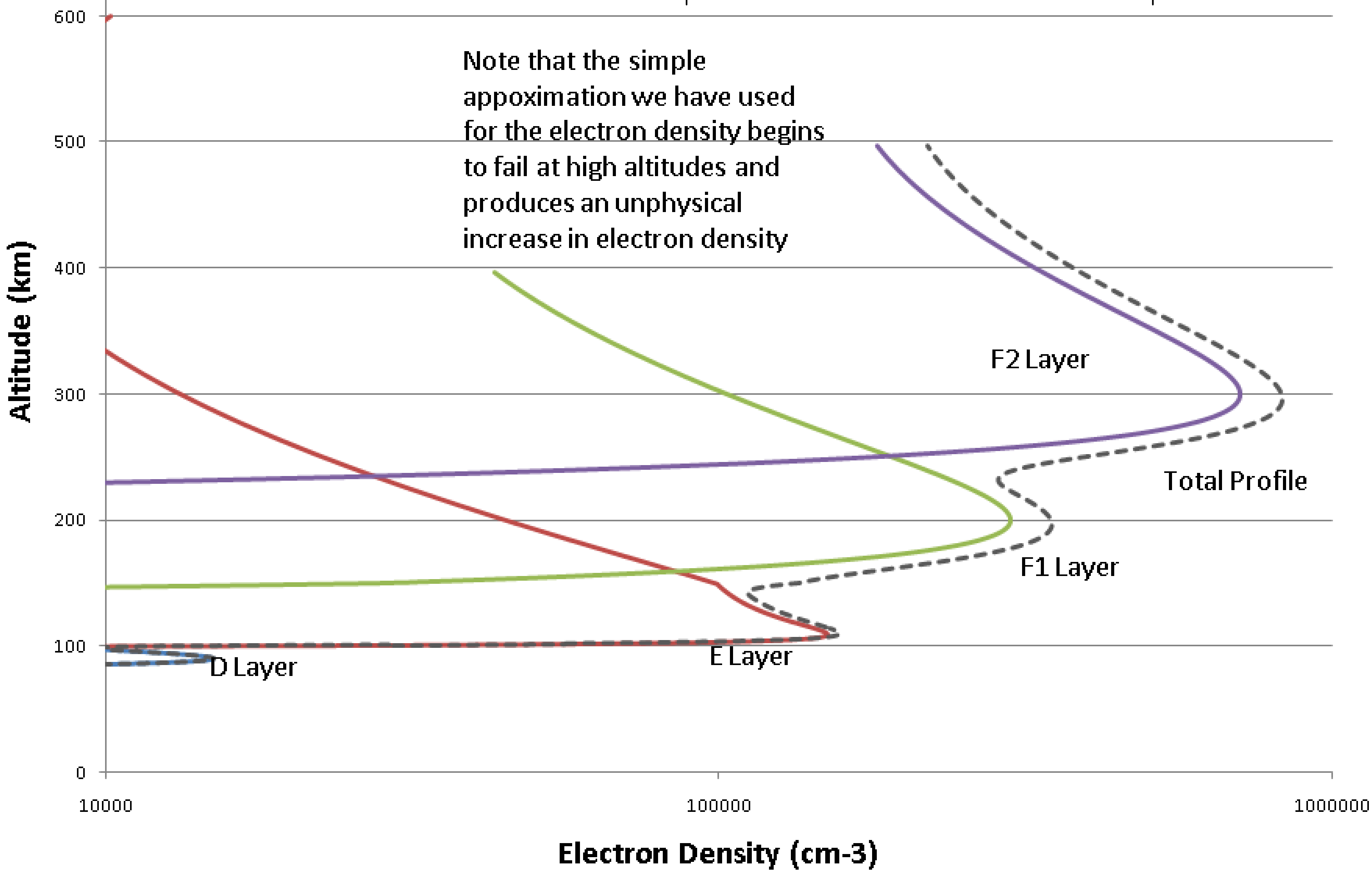


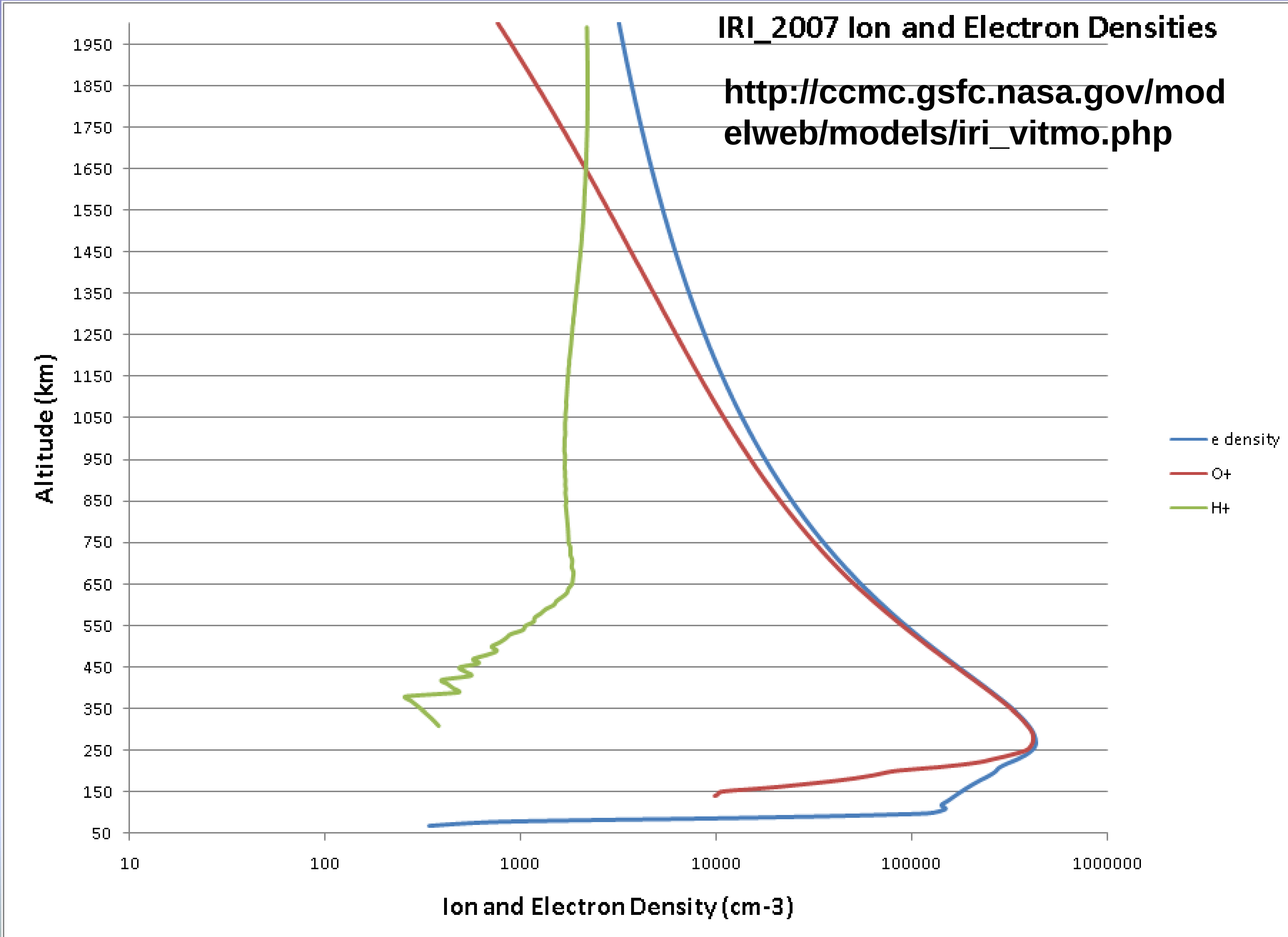
Scale Height





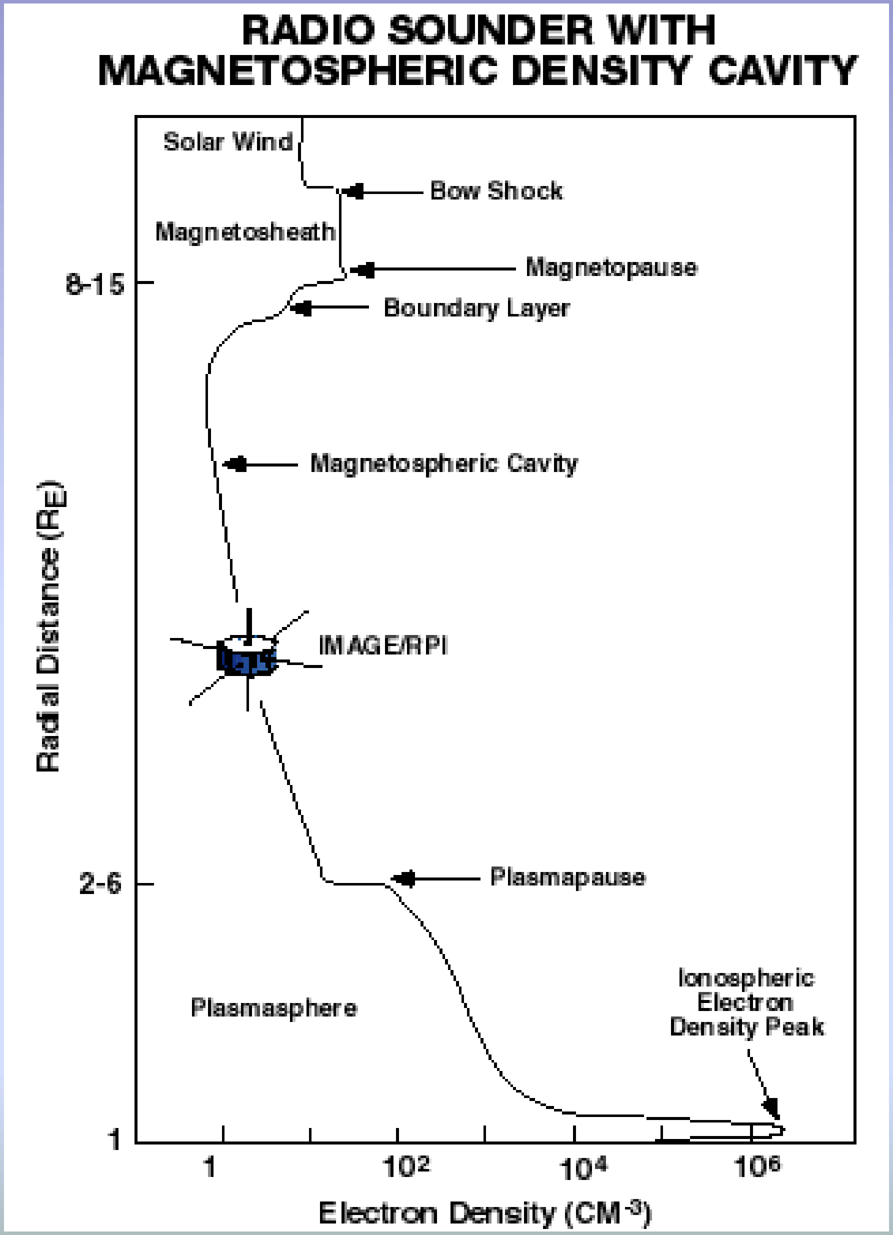
$$n(h) = \sqrt{q^{*}{}_{\max} / \alpha} \;\; \exp\{\frac{1}{2}\left|1 - \frac{h - h^{*}{}_{\max}}{H} - \sec\chi e^{-(h - h^{*}{}_{\max})/H}\right|\}$$





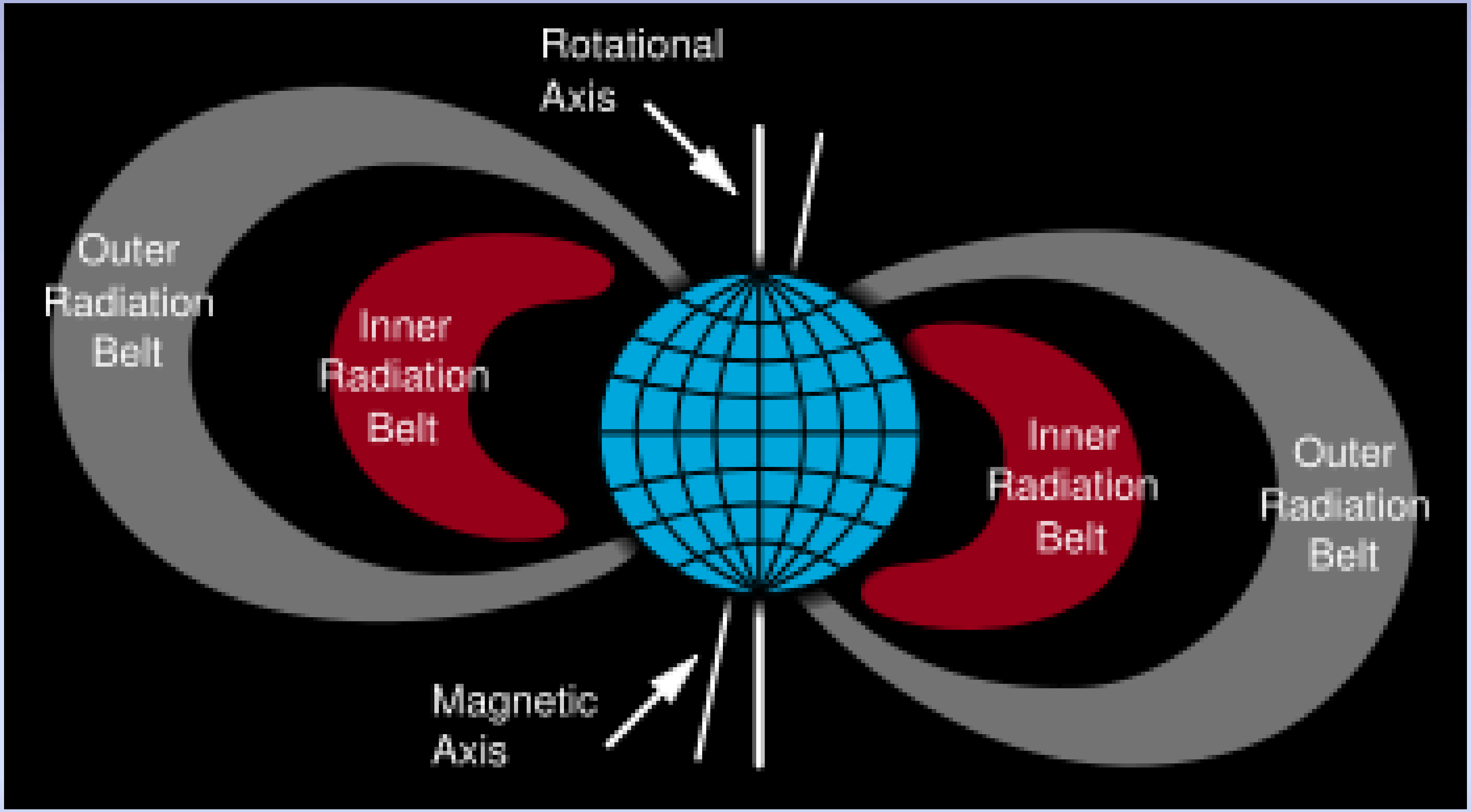
IRI_2007 Ion and Electron Densities
http://ccmc.gsfc.nasa.gov/modelweb/models/iri_vitmo.php
Altitude (km)
1950
1850
1750
1650
1550
1450
1350
1250
1150
1050
950
850
750
650
550
450
350
250
150
50
10
100
1000
10000
100000
1000000
Ion and Electron Density (cm-3)
e density
O+
H+

System Perspective on Electron Density



Courtesy NASA, IMAGE

Radiation Belts and Effects



NASA's *AE-8 and AP-8 radiation belt models*

http://modelweb.gsfc.nasa.gov/models/trap.html .

- Used by satellite designers to estimate mission lifetime particle fluxes

- The input parameters are energy range, L-value and B/Bo where Bo is the magnetic field strength at the magnetic equator (minimum value).

Estimate the flux of electrons in particles/cm^2/MeV between energies of 2 and 3 MeV that would be experienced by a geostationary satellite over the period of one day during solar maximum conditions.

AE8MAX / AP8MAX

Model: **AE8MAX** , Energy values: 2,3 L-values: 6.6 B/B0 values: 1
Output fluxes: **Differential** **Results of MODEL calculations:**

differential flux [ELECTRONS/cm*cm*sec*MeV]
L \\ E/MeV   2.00   3.00   0.00   0.00   0.00   0.00   B/B0=   1.00
------\\---
6.60 I   3.62E+04 0.00E+00 0.00E+00 0.00E+00 0.00E+00
-------------------- flux values below 10 are not reliable -----------

Multiply differential flux by 86500 s (in one day)
(3.62×10^4 e^-/cm^2/s/Mev) *(86500 s)*1 Mev = <u>3.13×10^9 e^-/cm^2</u>
****
Model: **AP8MAX** Energy values: 2, 3 L-values: 6.6 B/B0 values: 1
Output fluxes: **Differential Results of MODEL calculations:**

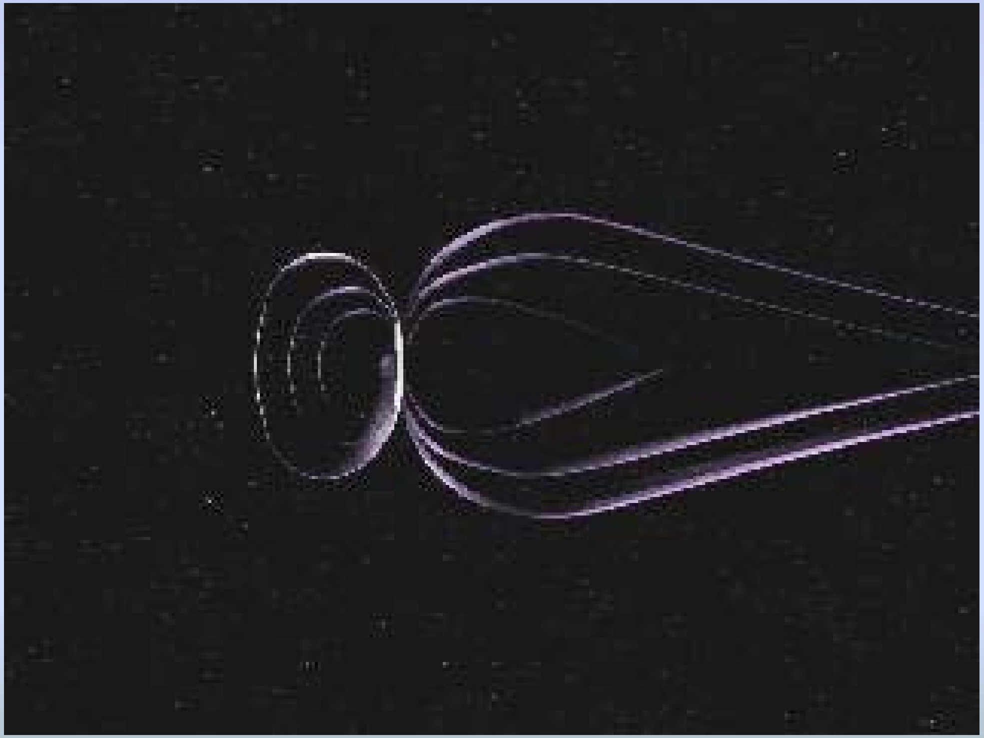
differential flux [PROTONS /cm*cm*sec*MeV]
L \\ E/MeV 2.00   3.00   0.00   0.00   0.00   0.00   B/B0= 1.00
-6.60 I   0.00E+00   0.00E+00   0.00E+00   0.00E+00   0.00E+00
-------------------- flux values below 10 are not reliable -----------
Multiply differential flux by 86500 s (in one day)
(0 protons/cm^2/s/Mev) *(86500 s)*1 Mev = <u>0 protons/cm^2</u>

COURSE TOPICS

C. THE GEOMAGNETIC FIELD - The main field and its origins; magnetic indices; S_q and L variations; magnetic disturbances.

E. THE MAGNETOSPHERE - Bow shock; magnetosheath; magnetospheric currents; plasmasphere; magnetospheric convection; storms and substorms.

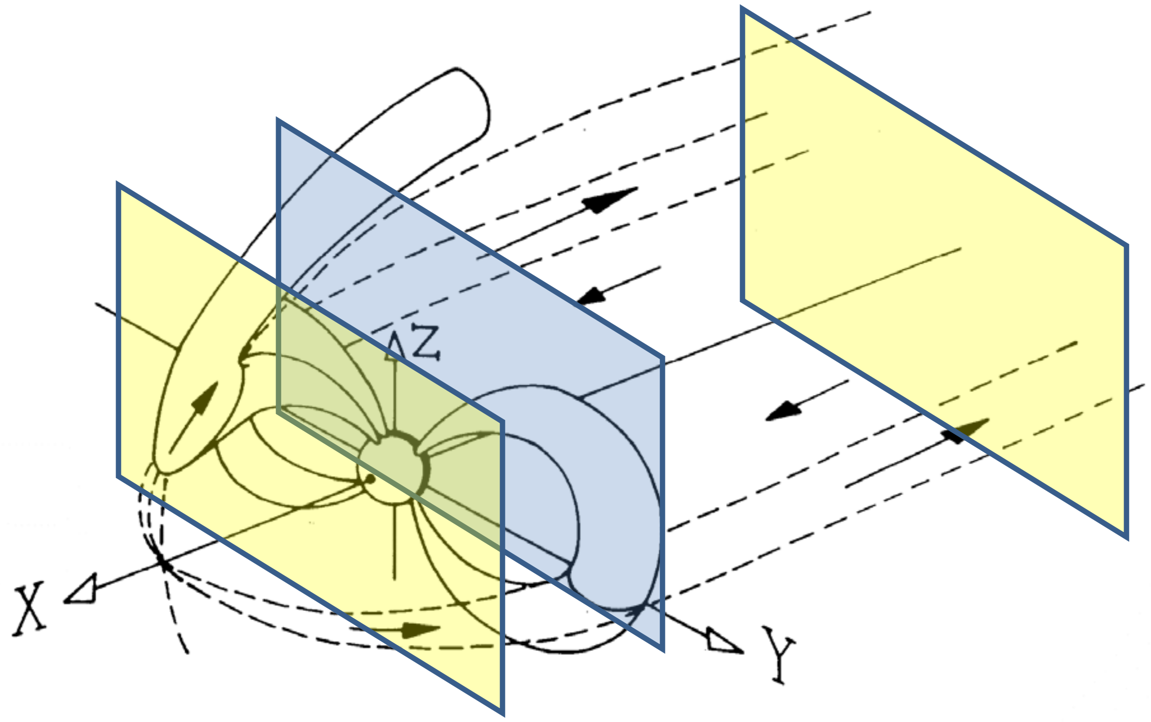
part-reconn-aurora.AVI



Credit: NASA

Runs on Request Output

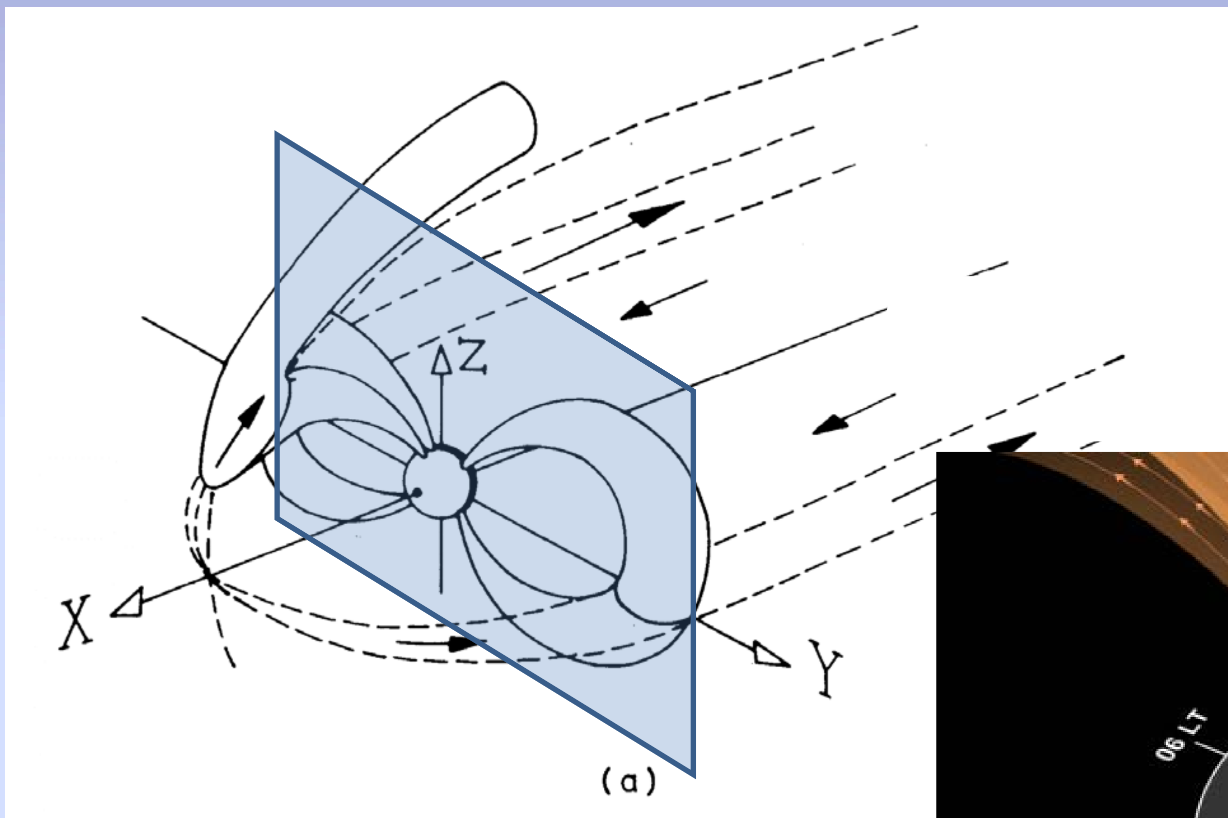
Exercise(s) under Development

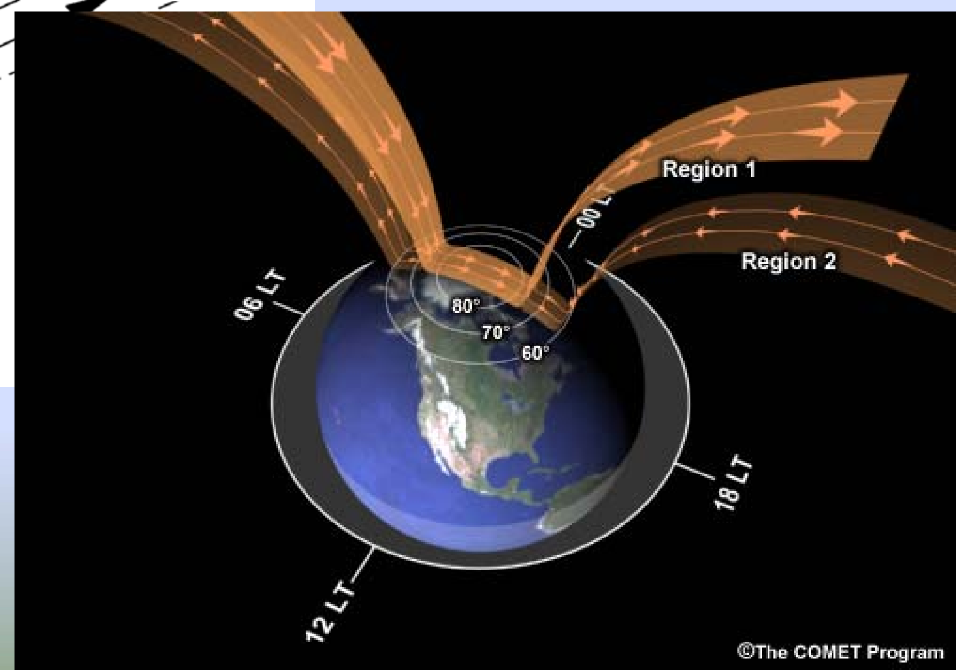


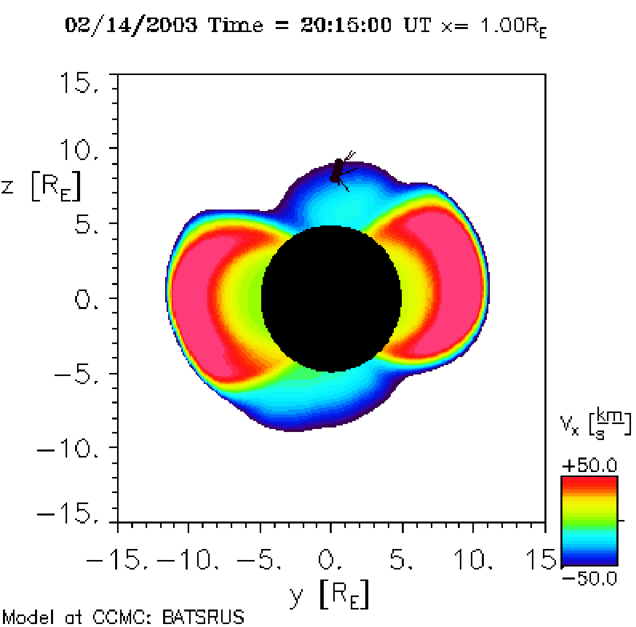
(a)

Runs on Request Output

Exercise(s) under Development

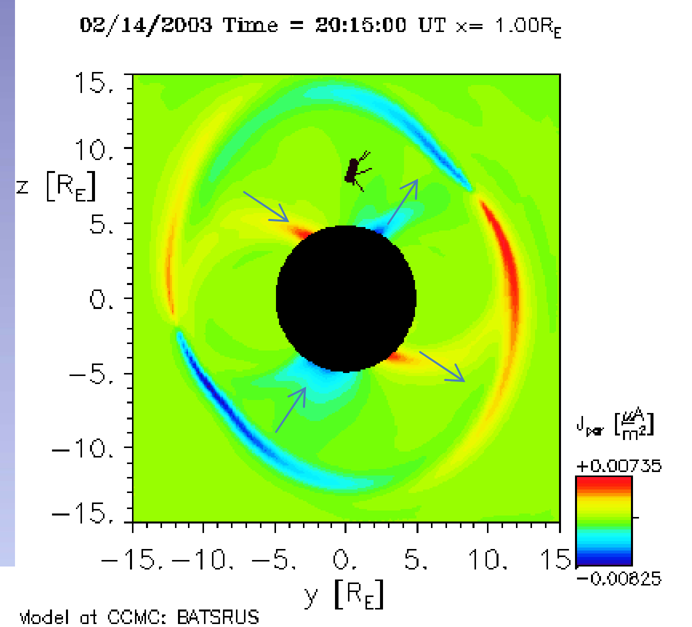






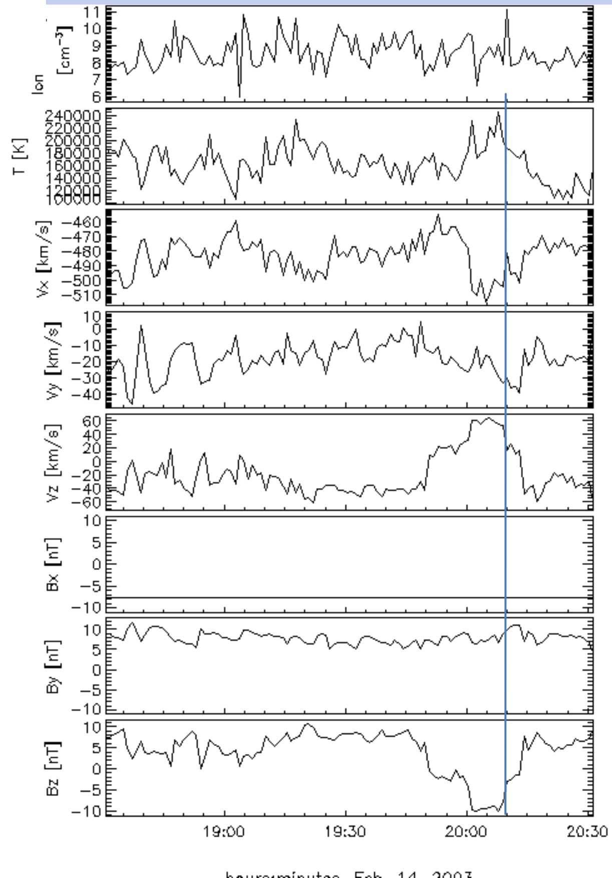
Plasma motion V_x

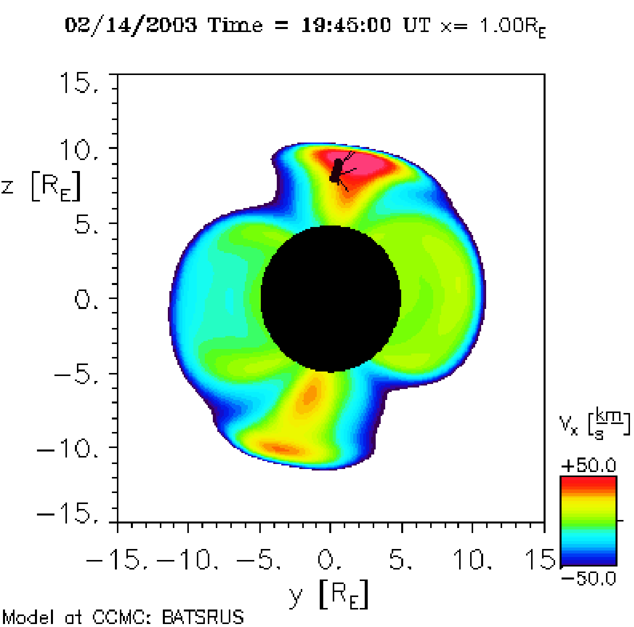
FAC



-During 2015-2020 UT, Vx is tailward over the caps as expected for southward Bz.

Sunward flow at lower latitudes is strong





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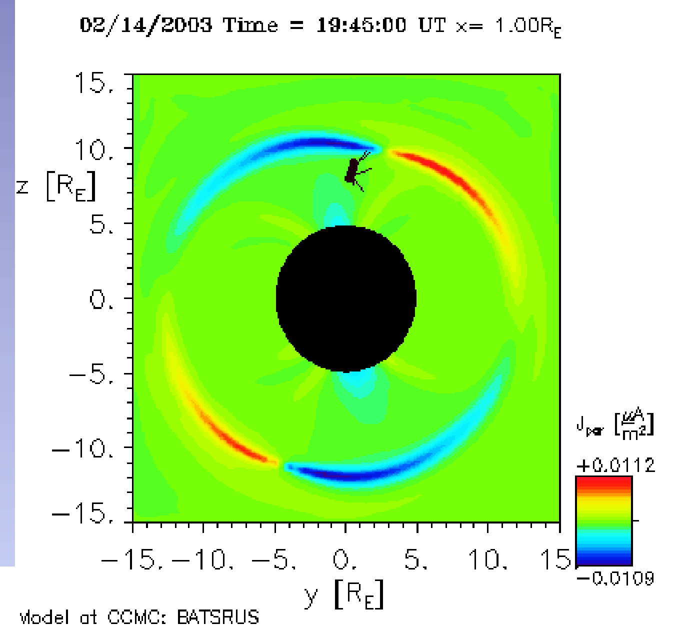
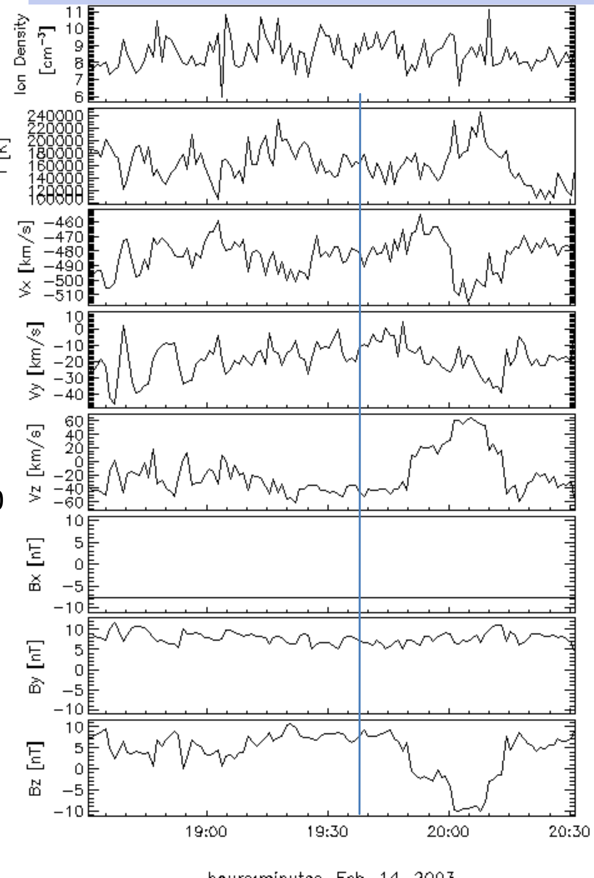




(ACE; at upstream boundary of simulation, no delays)

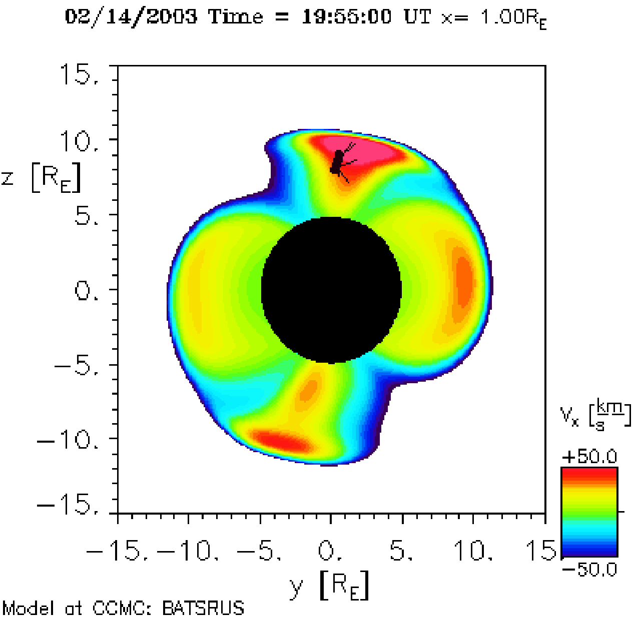
Vx plots at the X=1 RE YZ plane.

The IMF Bz is northward for this event with the exception for a shorter period of southward IMF.

The southward turning occurred just after 1950 UT and at ~2000 UT IMF Bz gets even stronger southward.

The Bz turns northward again during 2010-2015 UT.

-There is a clear sunward Vx flow in both polar cap regions (lobe reconnection in both hemispheres) 1945-2000 UT.
-During 2005-2010 UT there is no flow (Vx=0) in the polar cap.
-During 2015-2020 UT, Vx is tailward over the caps as expected for southward Bz.
-At 2025 UT, a separate sunward flow channel becomes evident near the duskside flank that reaches toward the northern polar cap.
-At 2030 UT, this flow channel has migrated further poleward.



Plasma motion V_x

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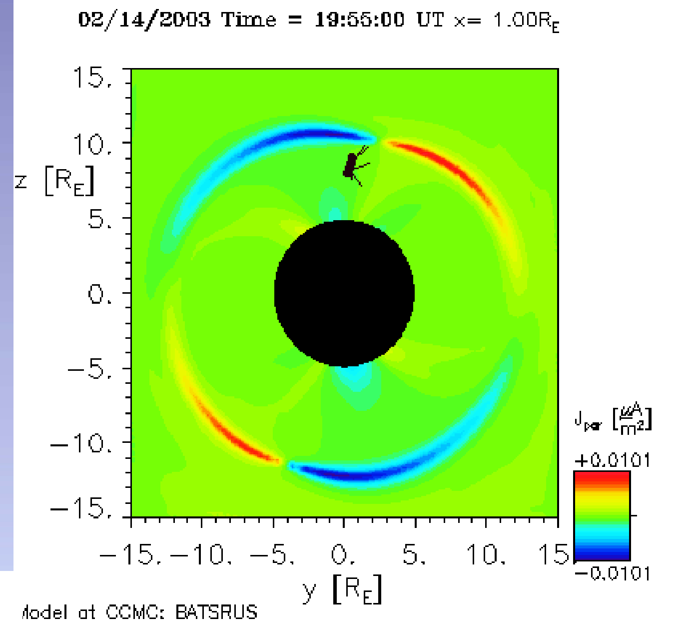

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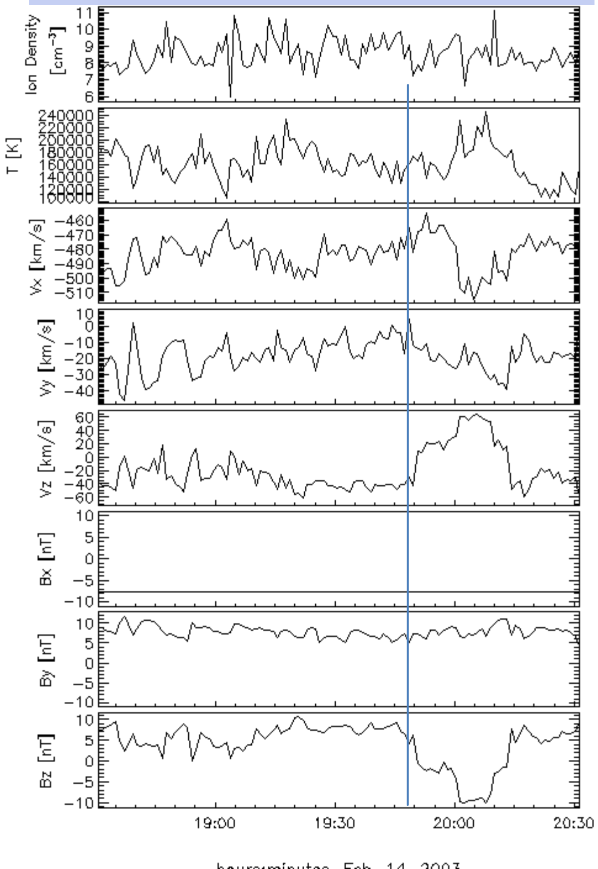

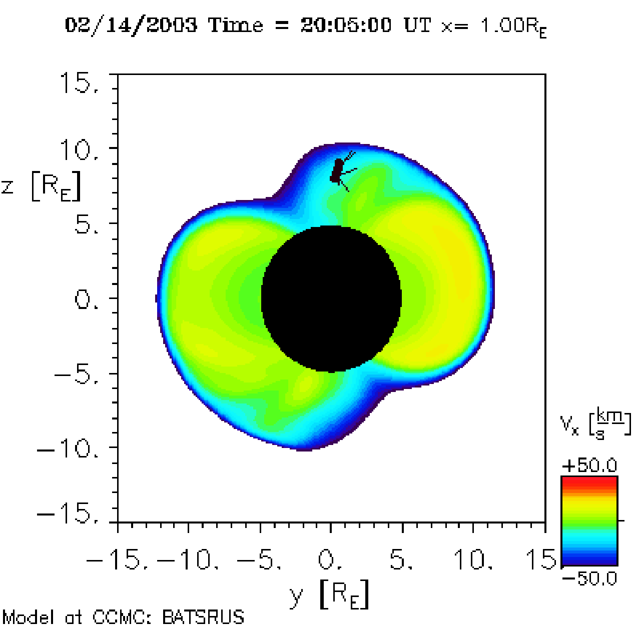

Plasma motion V_x

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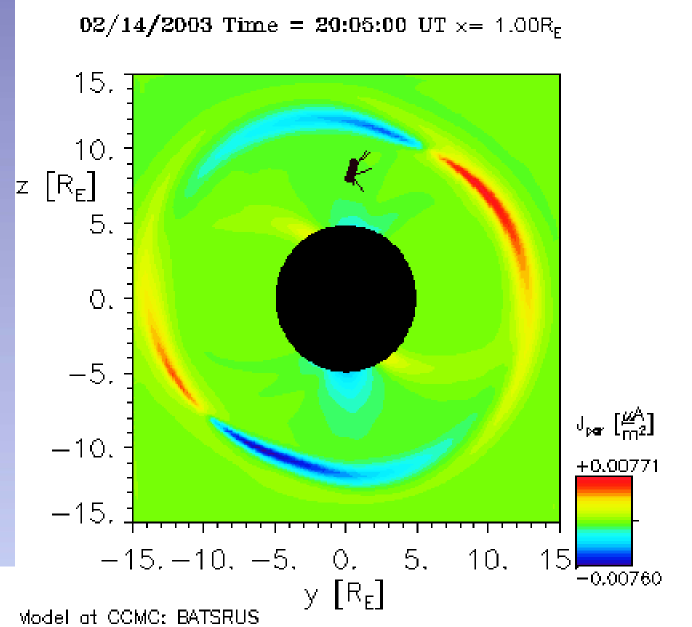
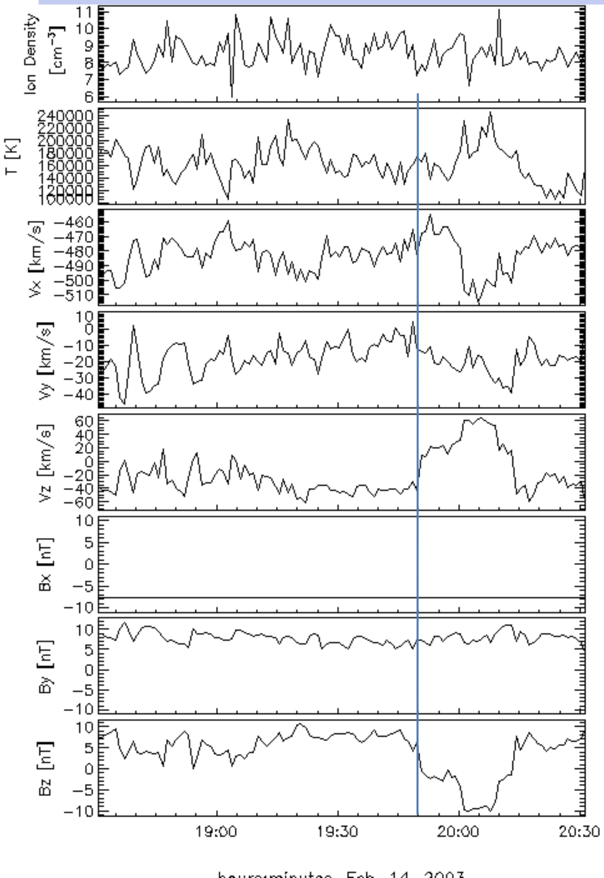
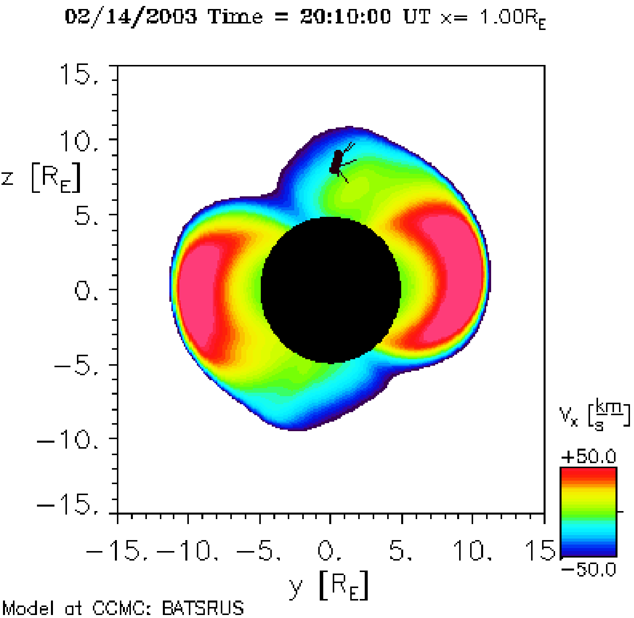




-During 2005-2010 UT there is no flow (Vx=0) in the polar cap.

Sunward flow at lower latitudes strengthens.



Plasma motion V_x

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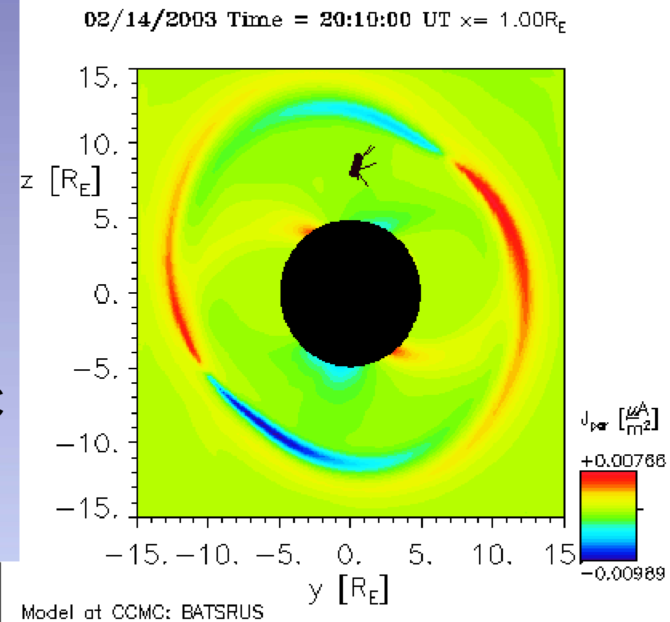

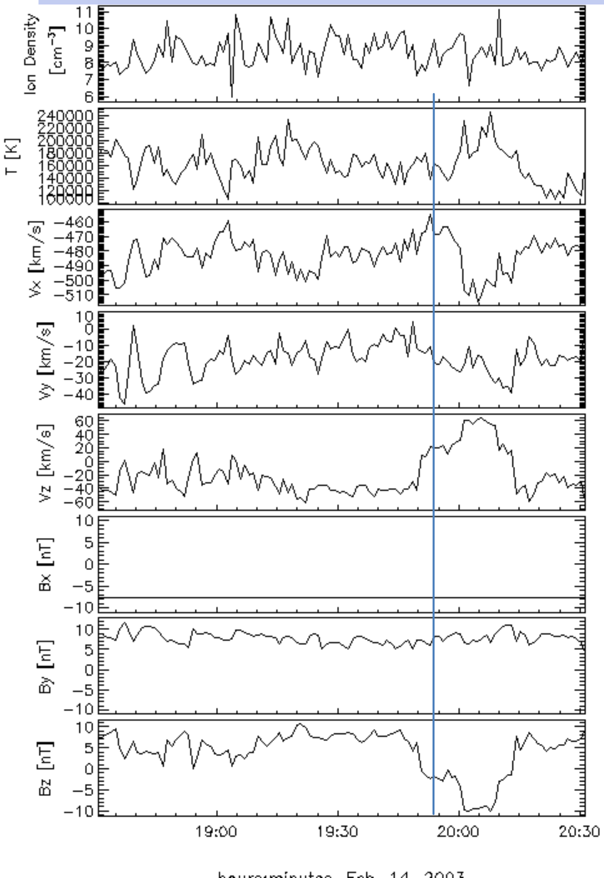

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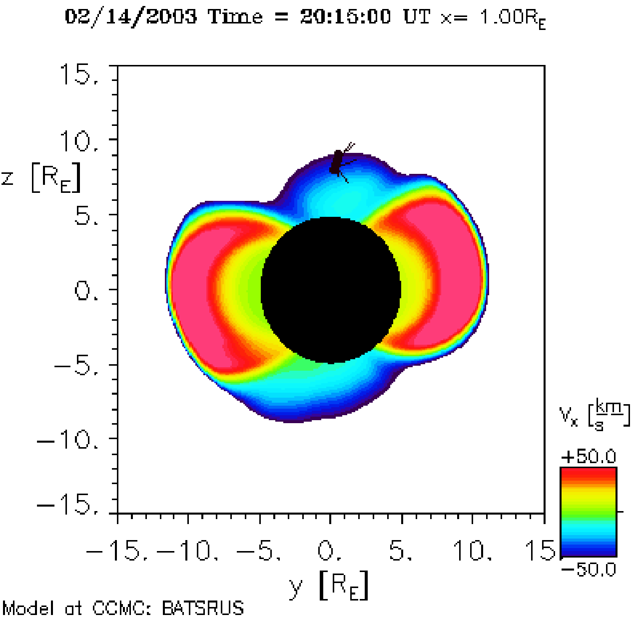

Plasma motion V_x

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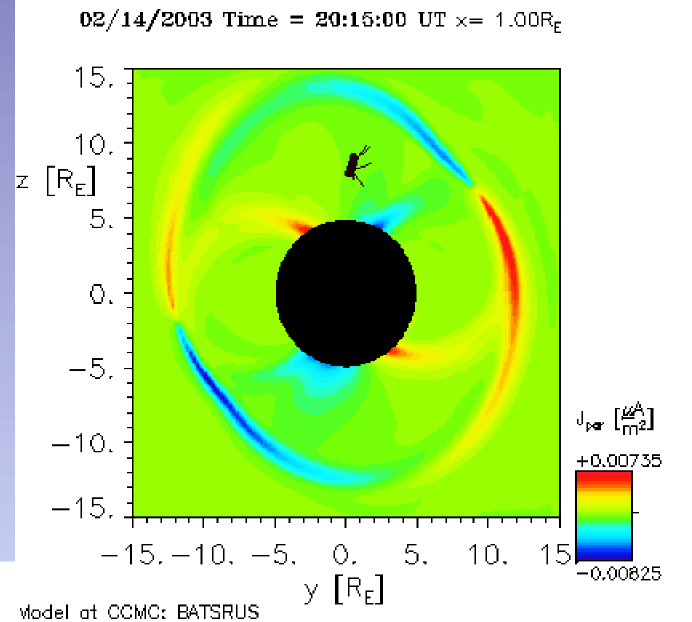

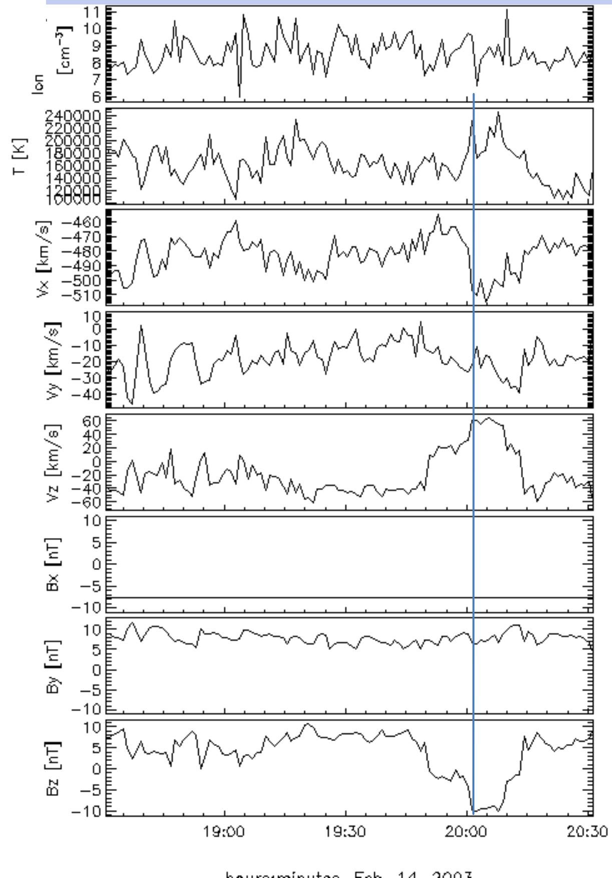

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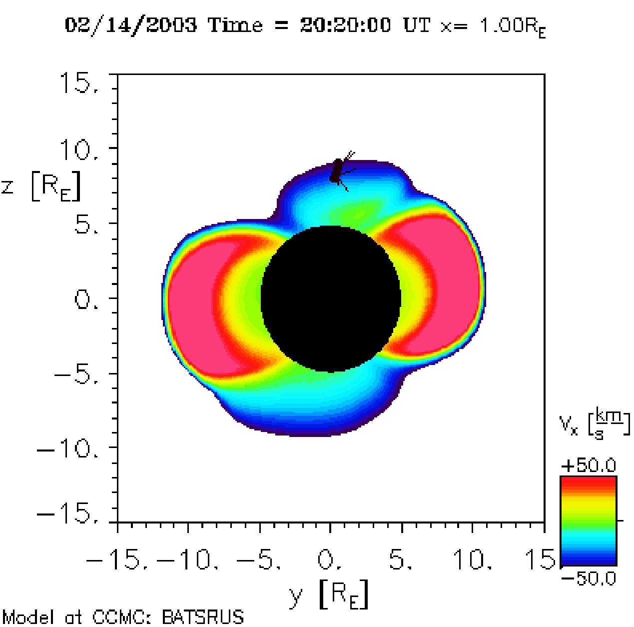
Sunward flow at lower latitudes is strong



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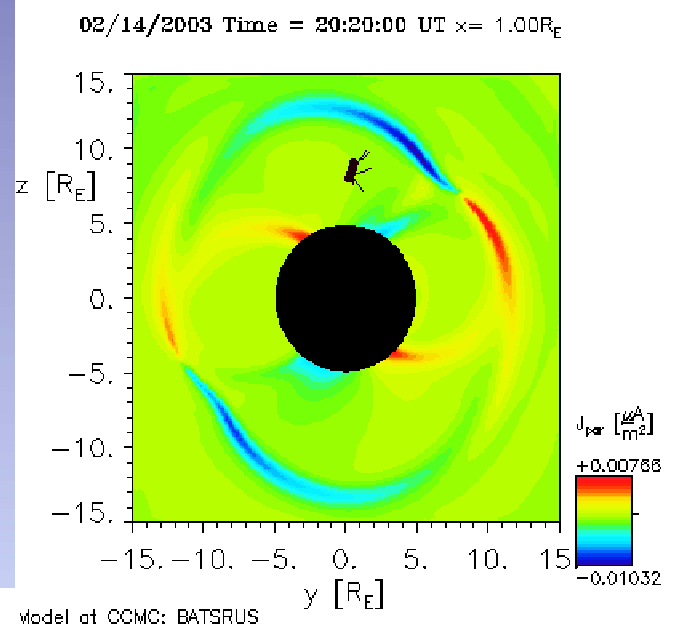

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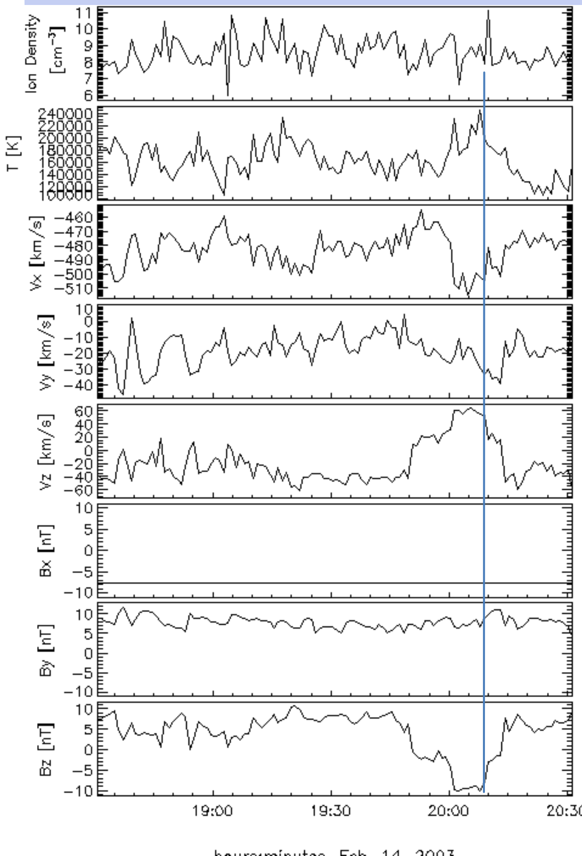

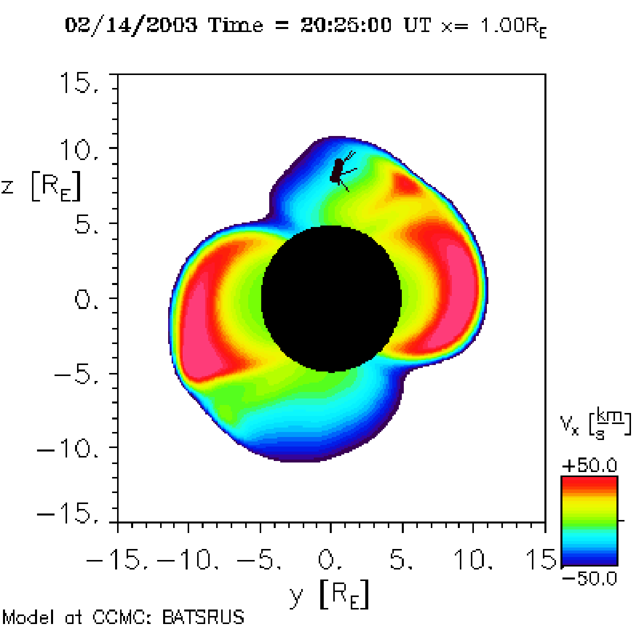

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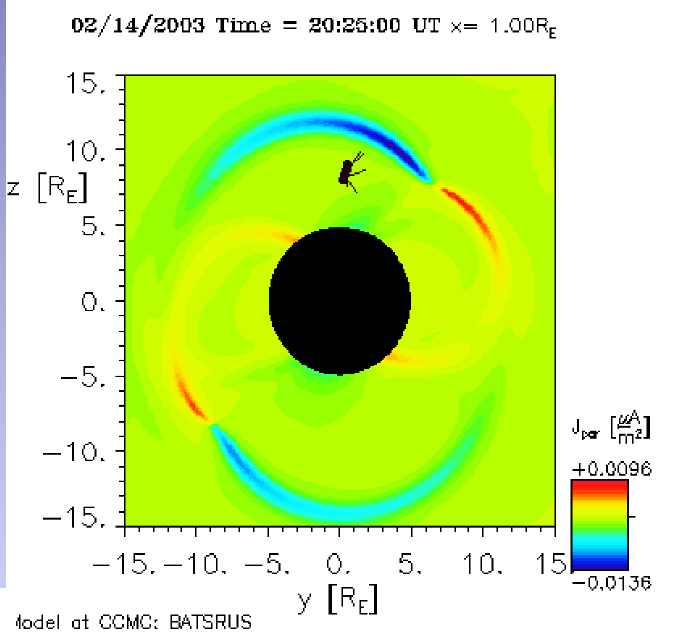

At 2025 UT, a separate sunward flow channel becomes evident near the duskside flank
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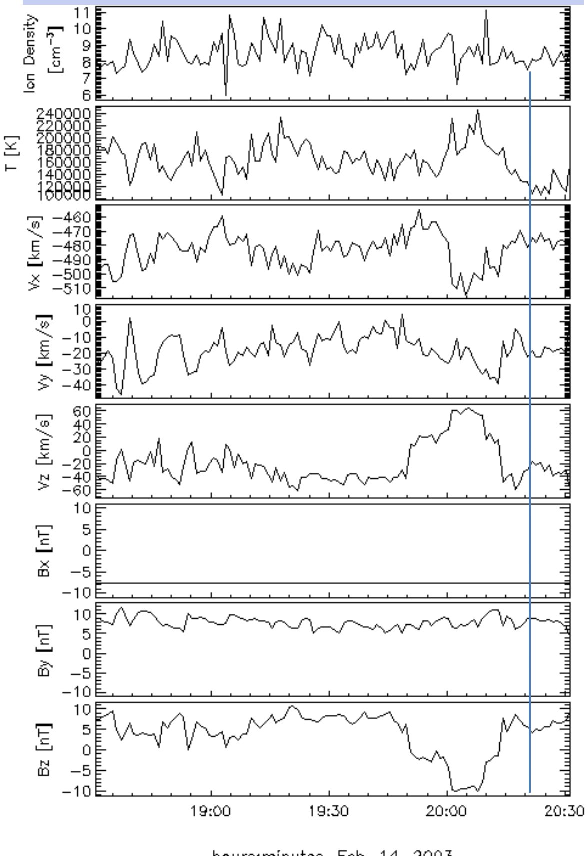
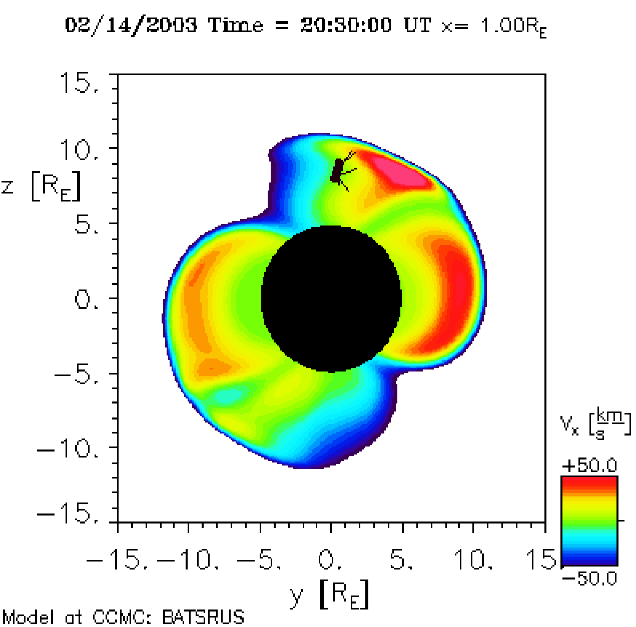
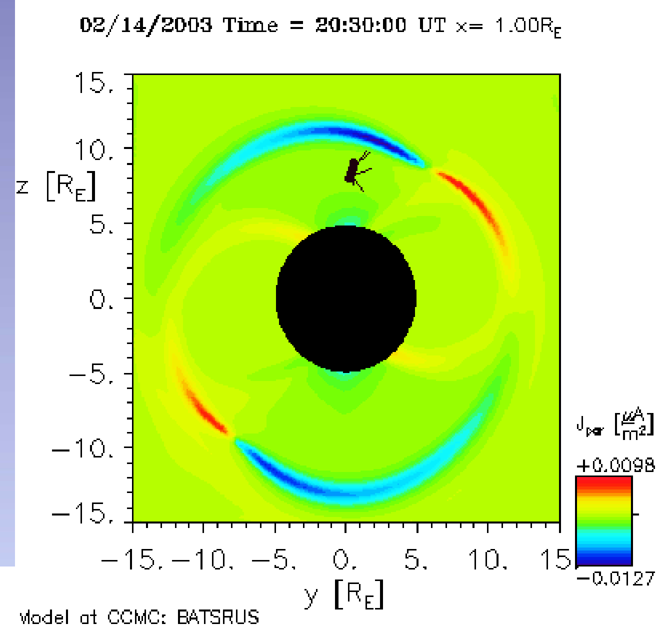
Sunward flow at lower latitudes weakens

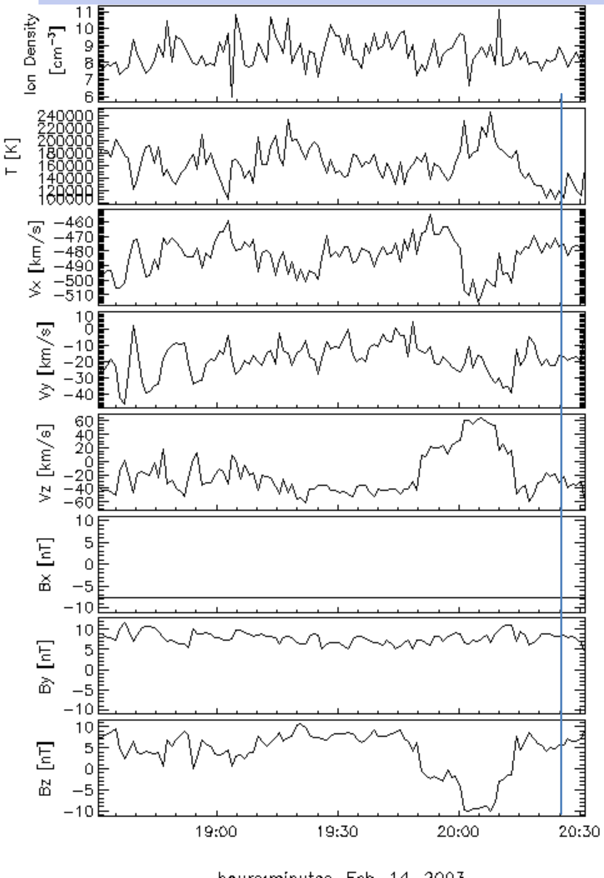




Plasma motion V_x

FAC





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Sunward flow at lower latitudes weakens

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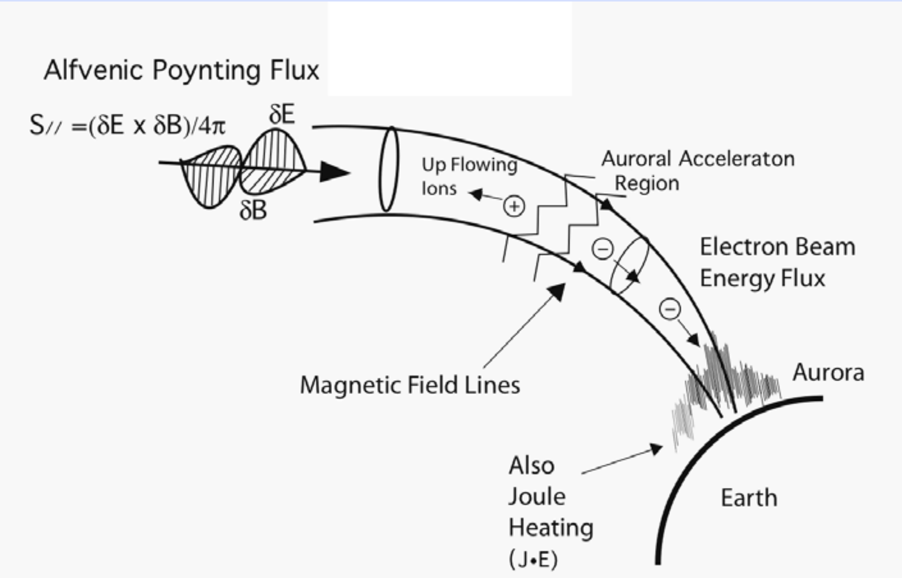
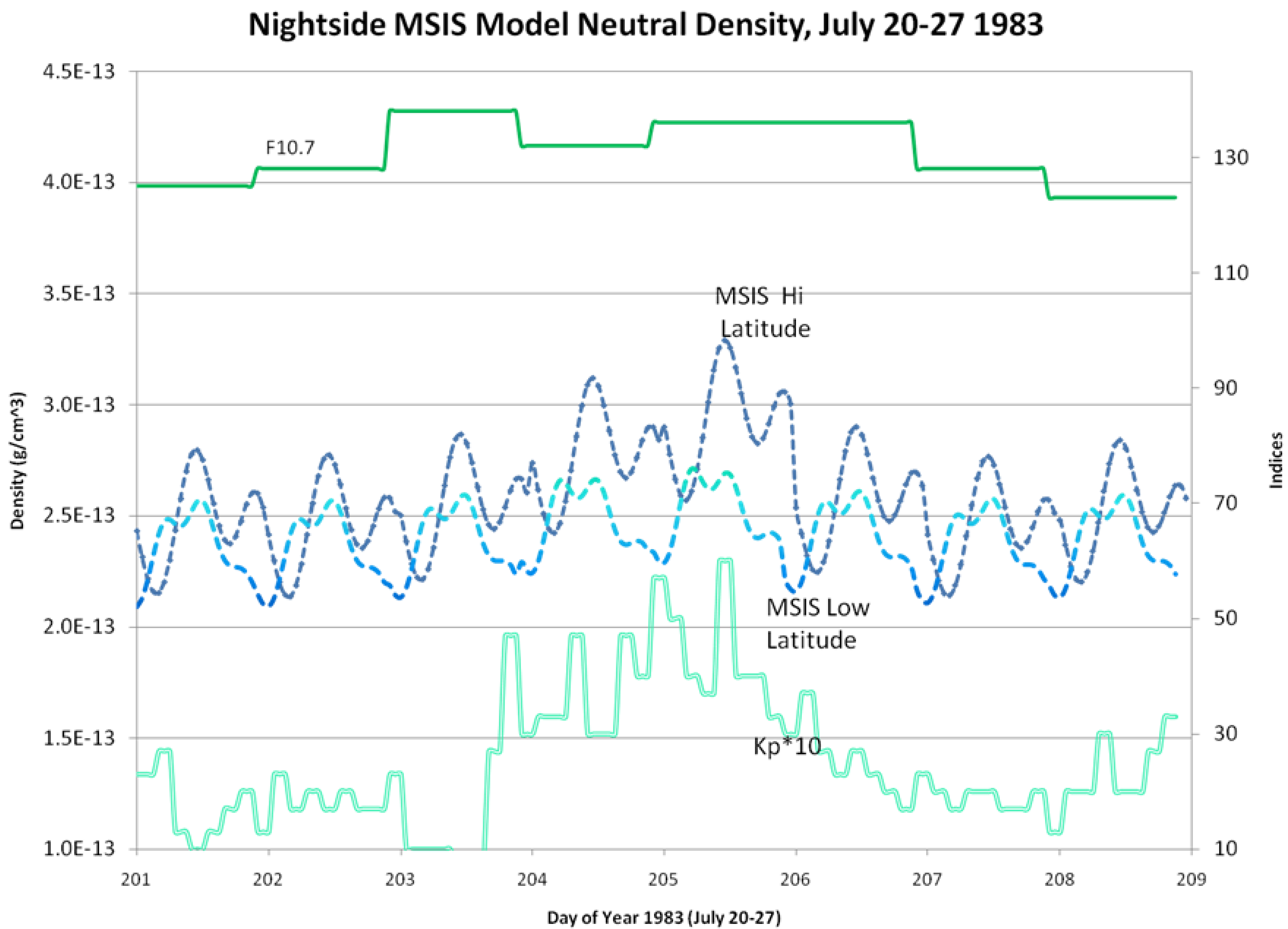
SolarCycleOld SunNew Sun.mpg

A. **THE SUN -** Basic structure and components; radio, visible, UV, EUV, and particle emissions; variability; interaction with Earth's neutral upper atmosphere and ionosphere.

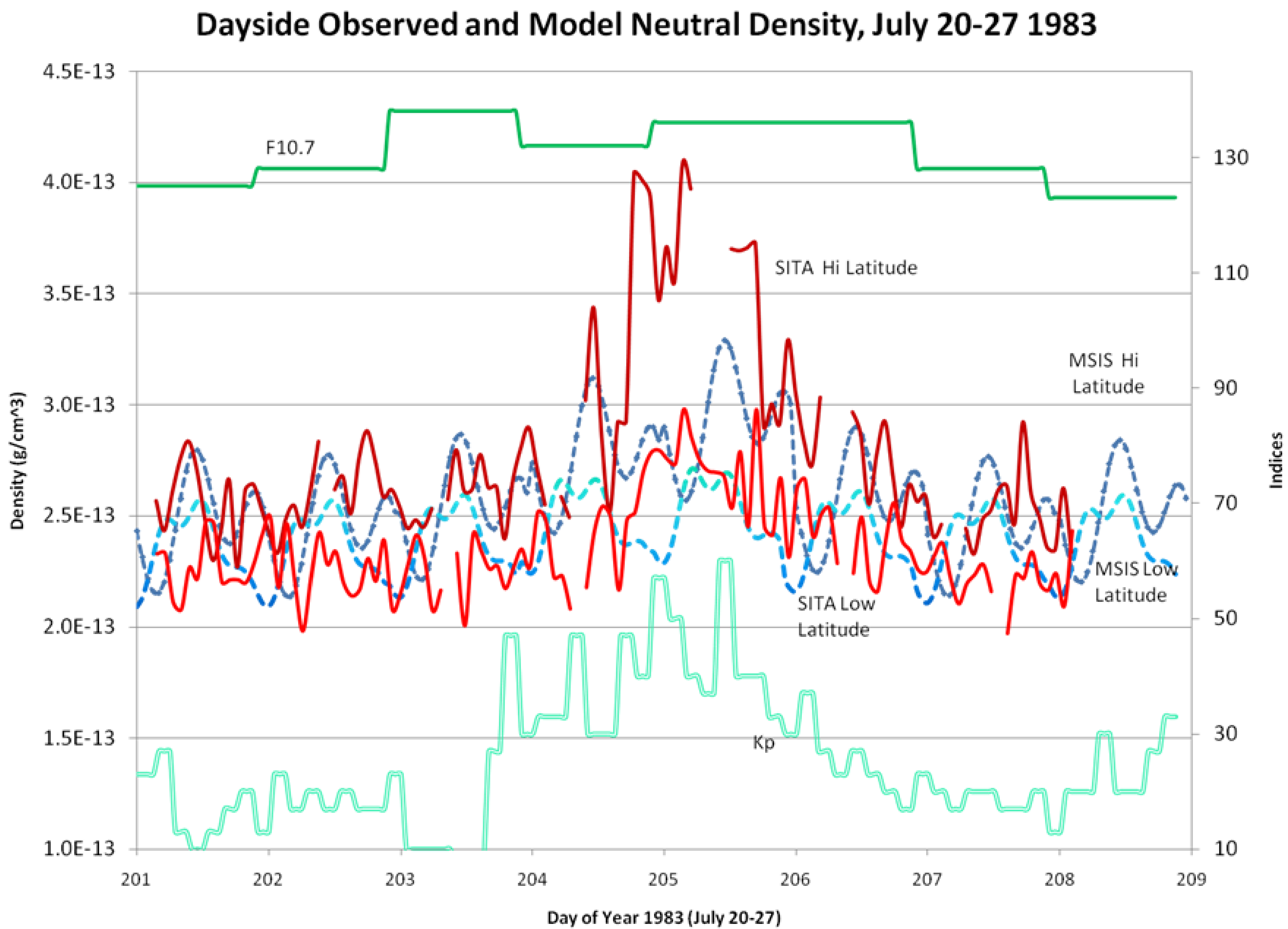
C. **THE MAGNETOSPHERE-** Interactions with ionosphere and thermosphere

D. **THE ATMSOPHERE-** Basic origins, properties, and structure; interplanetary magnetic field; interactions with outer regions of the magnetosphere.





Nightside MSIS Model Neutral Density, July 20-27 1983
4.5E-13
4.0E-13
3.5E-13
3.0E-13
2.5E-13
2.0E-13
1.5E-13
1.0E-13
Density (g/cm^3)
130
110
90
70
50
30
10
Indices
F10.7
MSIS Hi Latitude
MSIS Low Latitude
Kp*10
201
202
203
204
205
206
207
208
209
Day of Year 1983 (July 20-27)


Dayside Observed and Model Neutral Density, July 20-27 1983
4.5E-13
4.0E-13
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3.0E-13
2.5E-13
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130
110
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10
Indices
F10.7
SITA Hi Latitude
MSIS Hi Latitude
MSIS Low Latitude
SITA Low Latitude
Kp
201
202
203
204
205
206
207
208
209
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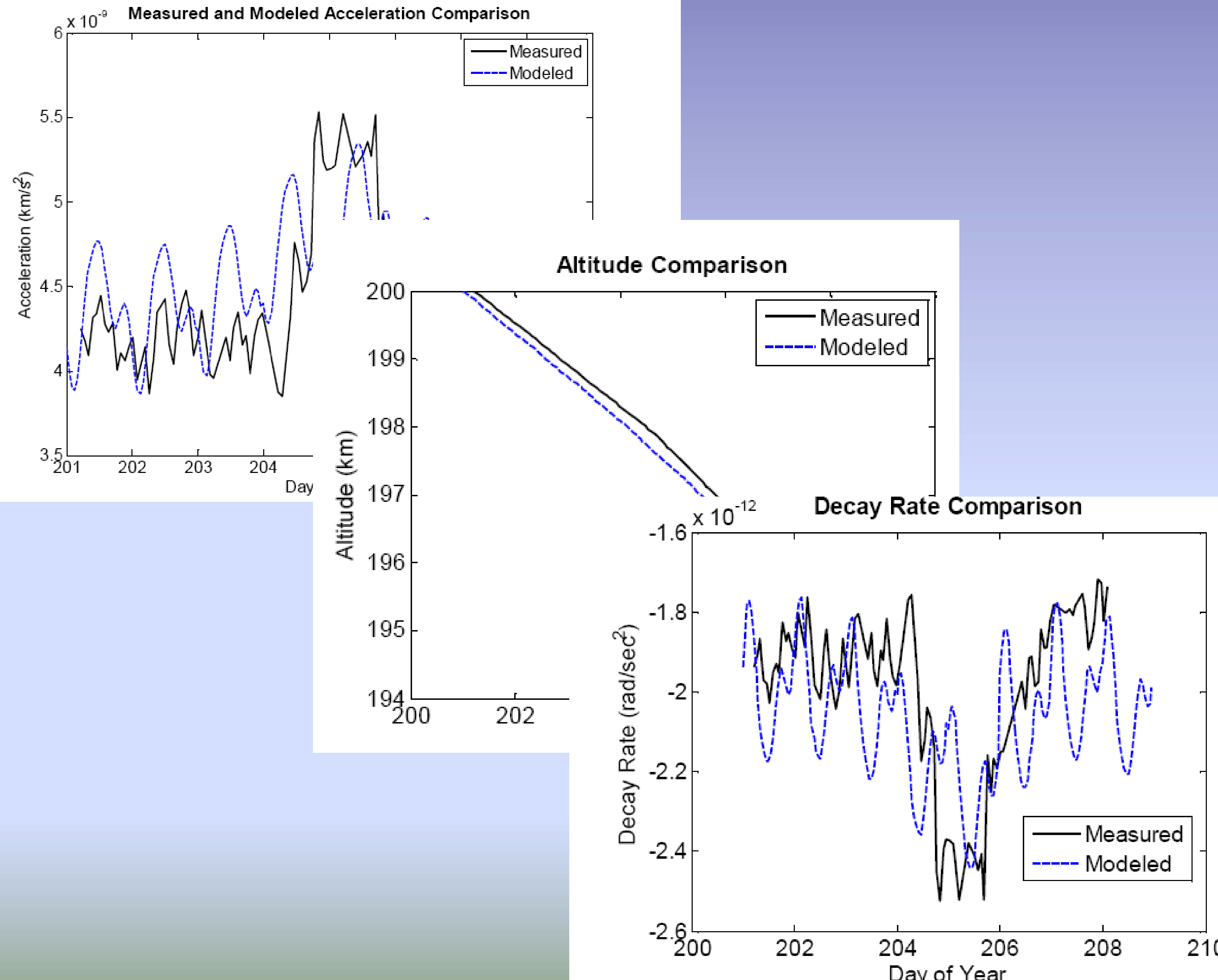
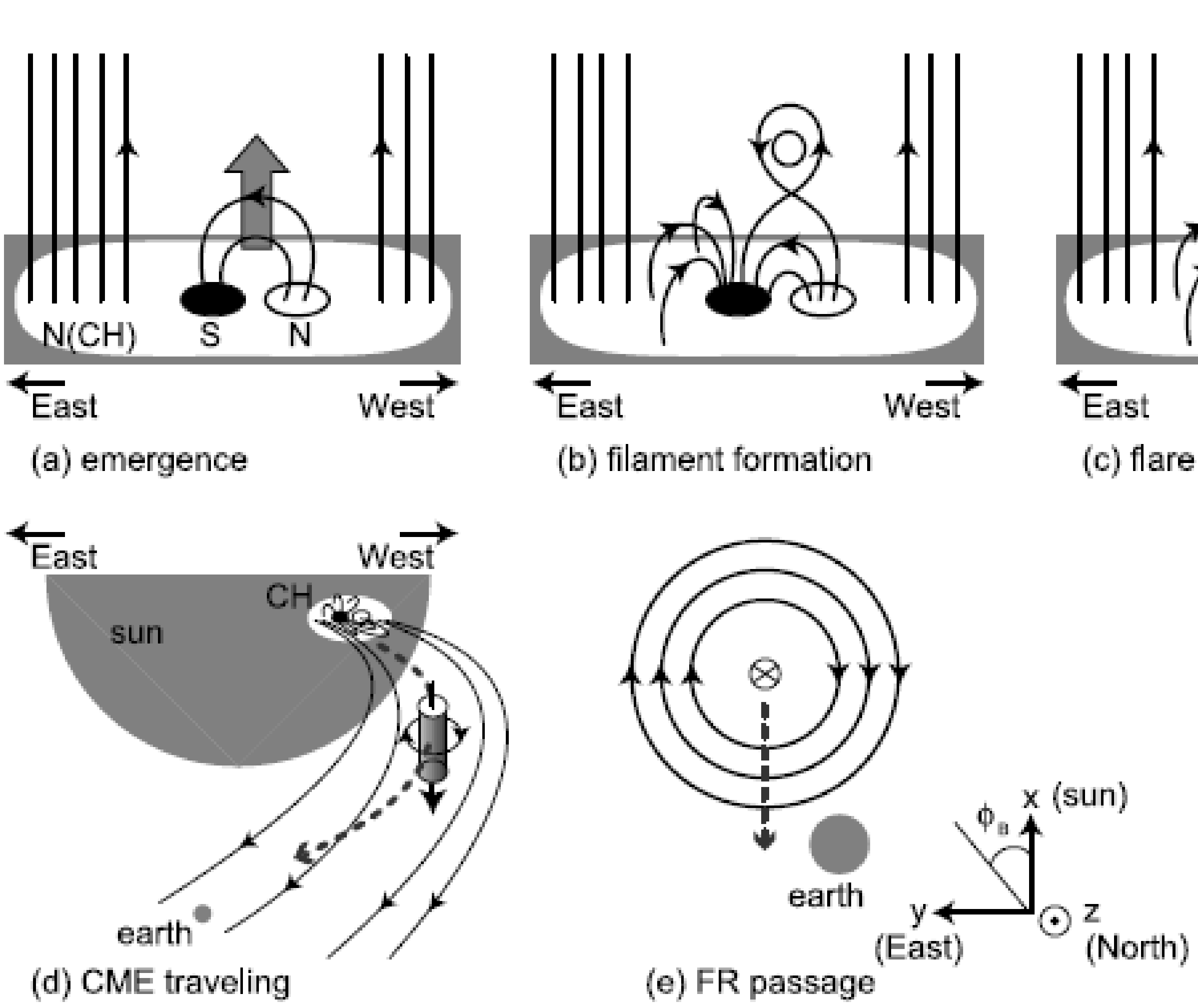

Measured and Modeled Acceleration Comparison
x 10^-9
Acceleration (km/s^2)
Day
Measured
Modeled
Altitude Comparison
Altitude (km)
Measured
Modeled
Decay Rate Comparison
x 10^-12
Decay Rate (rad/sec^2)
Day of Year
Measured
Modeled

Advanced Studies

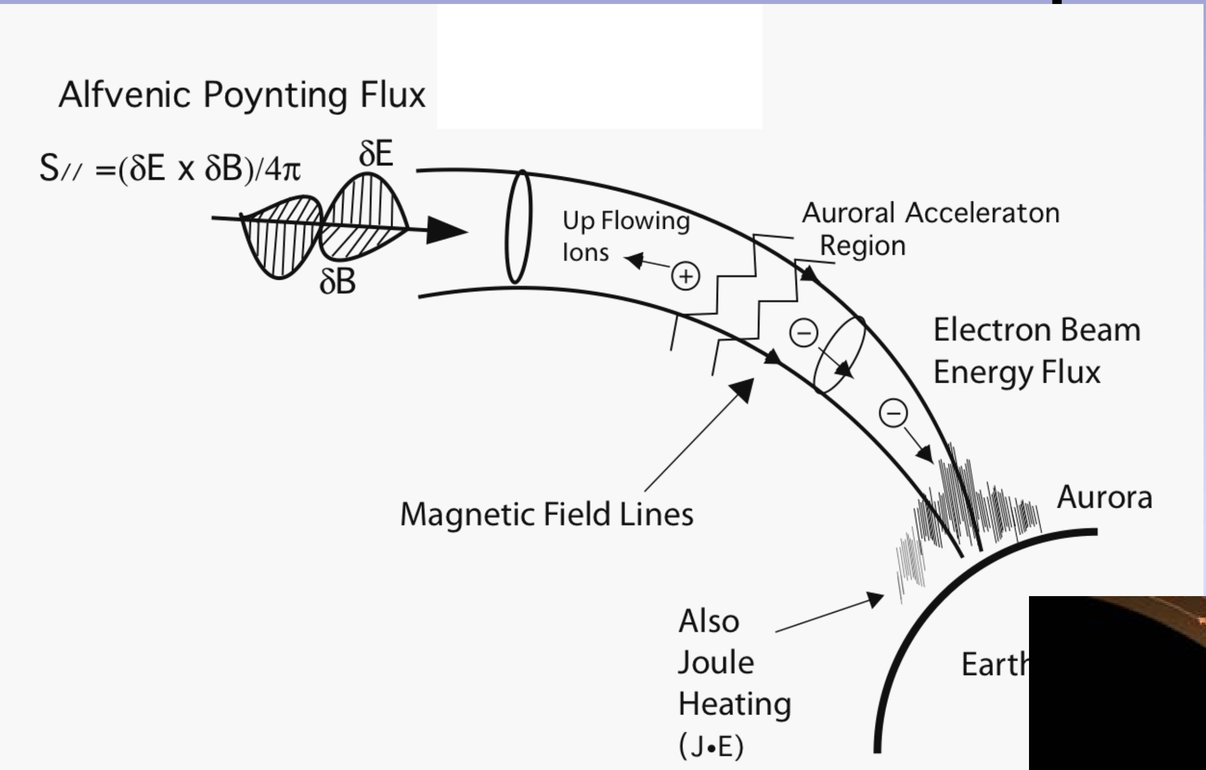
- MS Level Activities
  - AFIT and CU and ???
  - CCMC Calculations
    - Poynting Flux
    - Joule Heat
    - Global
    - Local-Along Track
  - Model Combinations
- Storm Studies
  - NADIR
  - SWARM ??

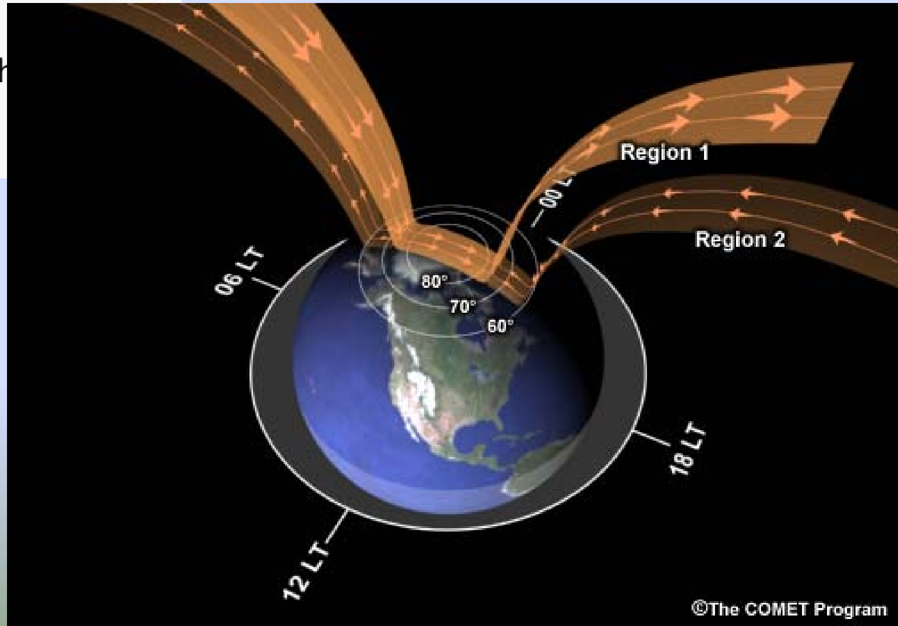
Flux rope within a coronal hole

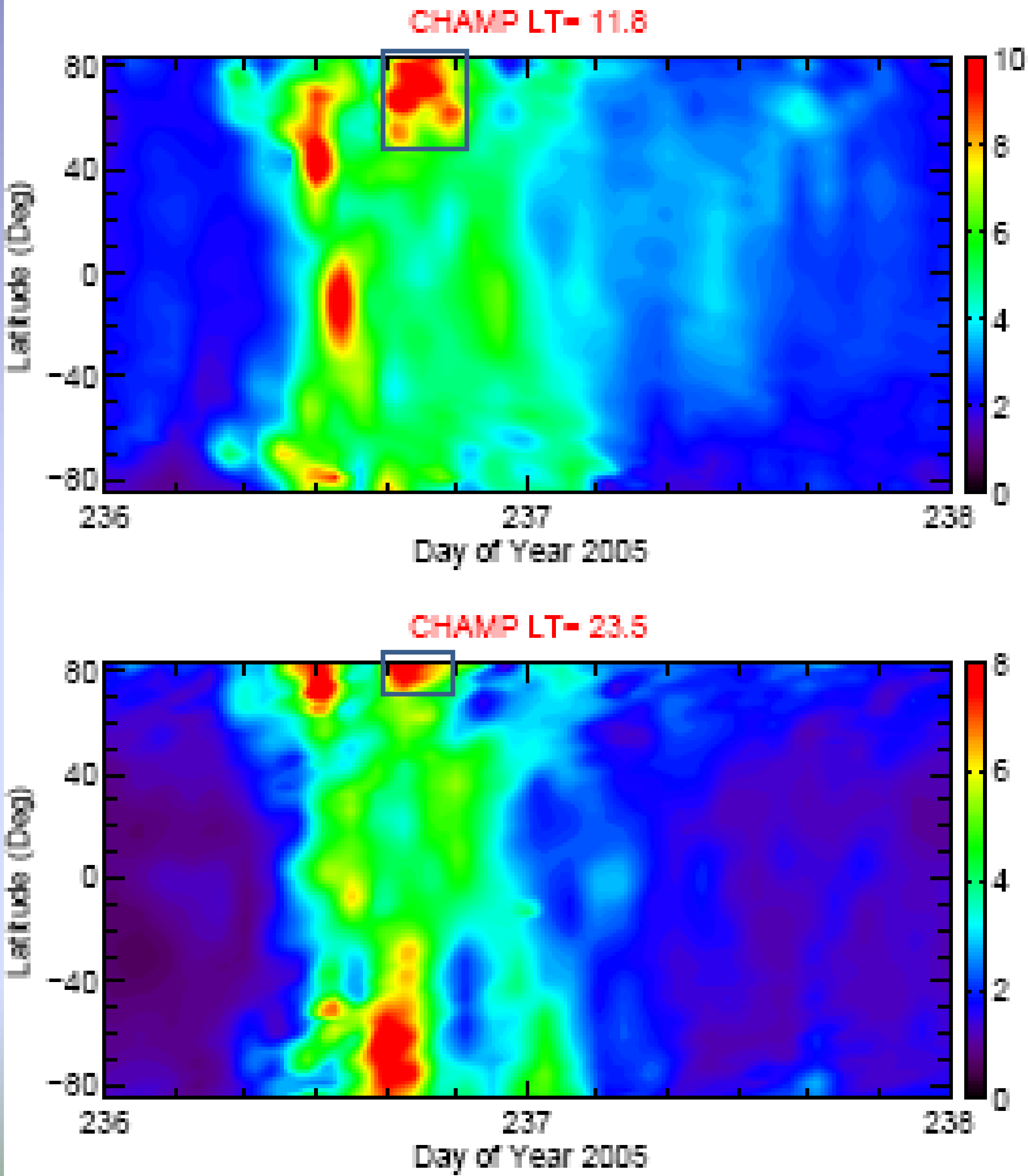


Asai et al. 2009

MIT Coupling

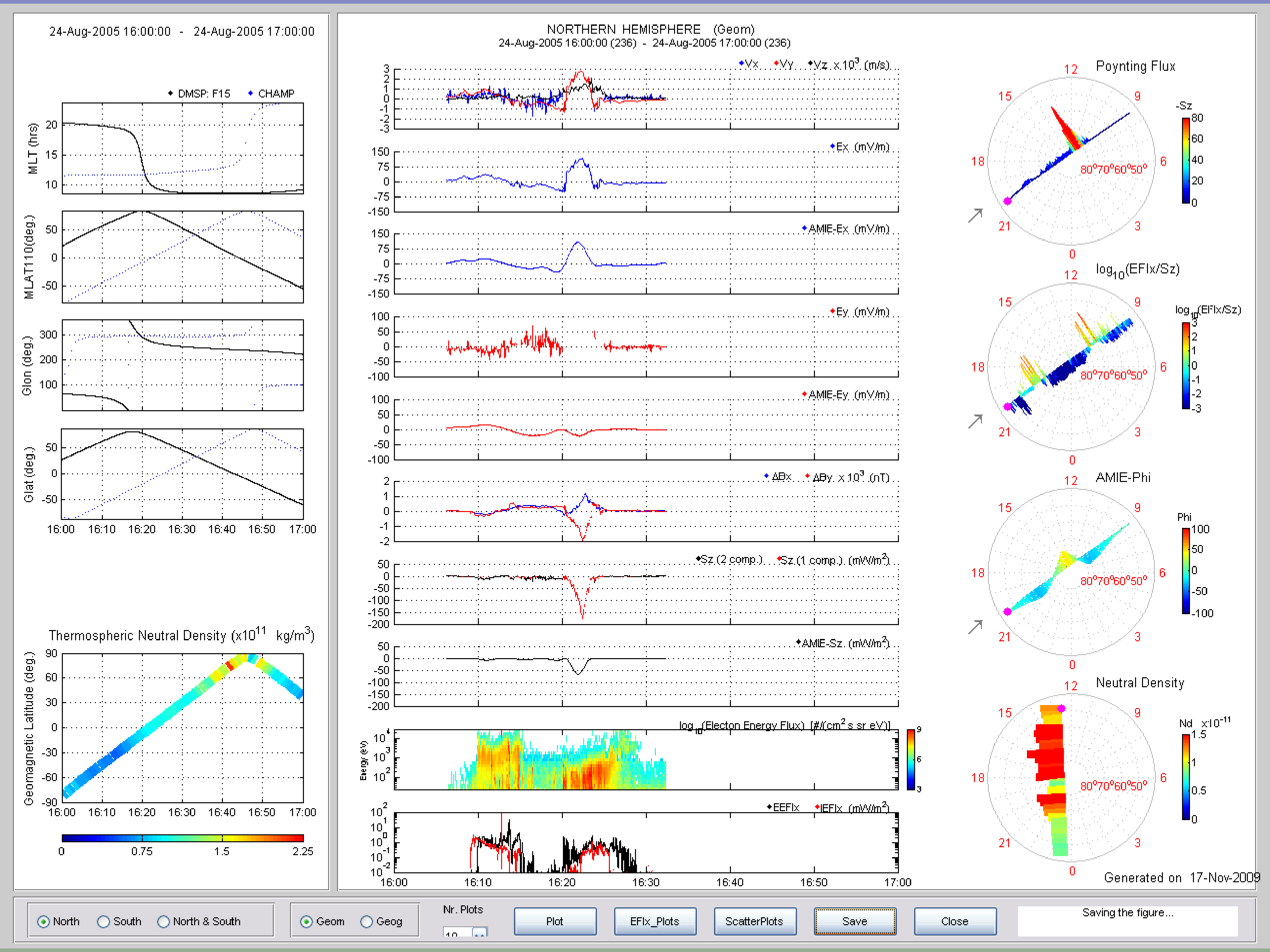


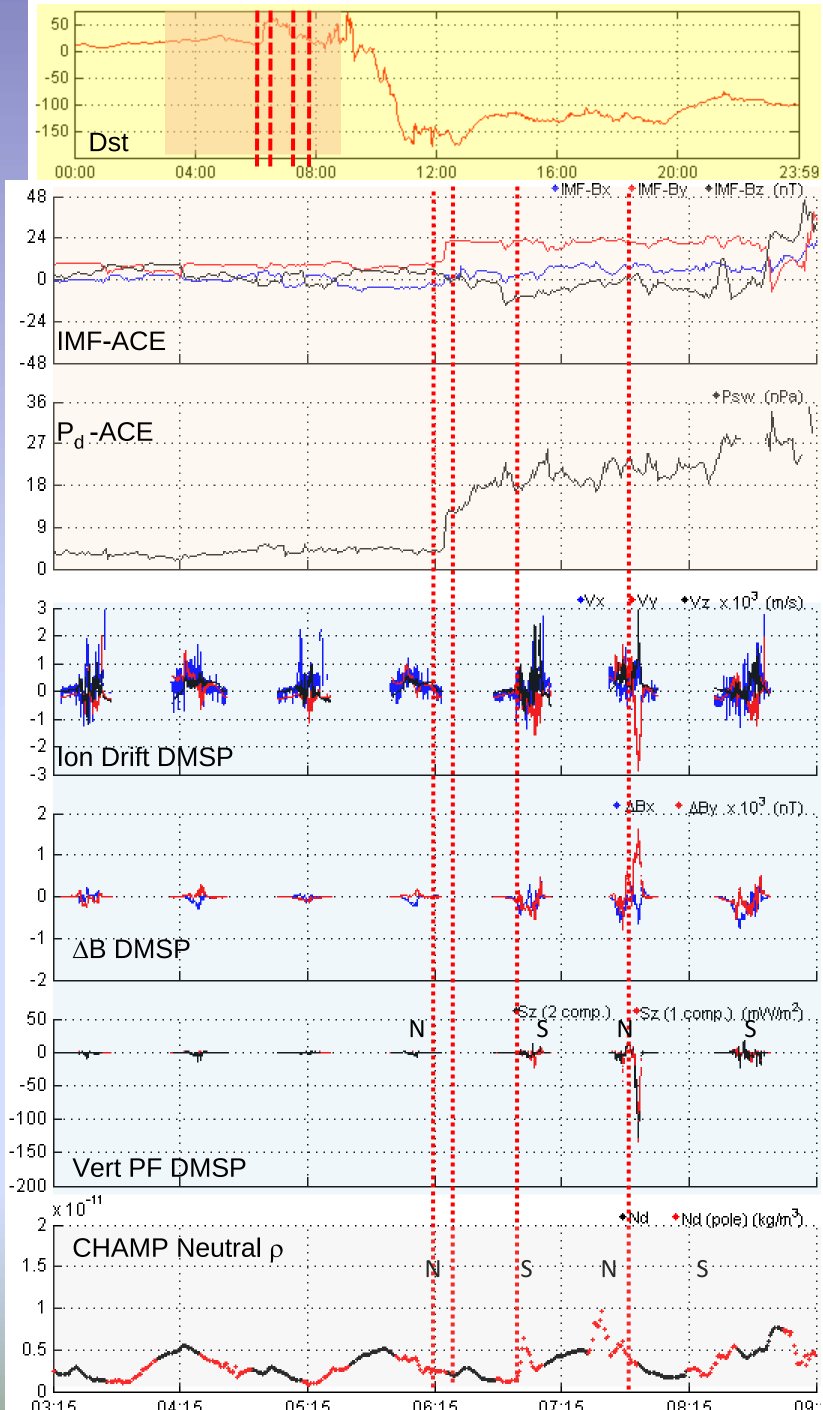


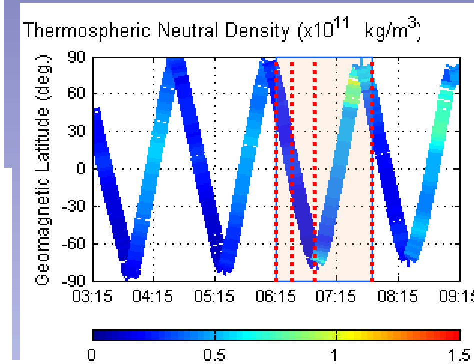


x 10^{-12} kg/m^3

x 10^{-12} kg/m^3


24-Aug-2005 16:00:00 - 24-Aug-2005 17:00:00
DMSP: F15
CHAMP
MLT (hrs)
MLAT110(deg.)
Glon (deg.)
Glat (deg.)
Thermospheric Neutral Density (x10^11 kg/m^3)
Geomagnetic Latitude (deg.)
NORTHERN HEMISPHERE (Geom)
24-Aug-2005 16:00:00 (236) - 24-Aug-2005 17:00:00 (236)
Vx Vy Vz x 10^3 (m/s)
Ex (mV/m)
AMIE-Ex (mV/m)
Ey (mV/m)
AMIE-Ey (mV/m)
ΔBx ΔBy x 10^3 (nT)
Sz (2 comp.) Sz (1 comp.) (mW/m^2)
AMIE-Sz (mW/m^2)
log10(Electon Energy Flux) [#/(cm^2 s sr eV)]
Energy (eV)
EEFlx IEFlx (mW/m^2)
Poynting Flux
-Sz
log10(EFlx/Sz)
AMIE-Phi
Phi
Neutral Density
Nd x10^-11
Generated on 17-Nov-2009
North
South
North & South
Geom
Geog
Nr. Plots
Plot
EFlx_Plots
ScatterPlots
Save
Close
Saving the figure...

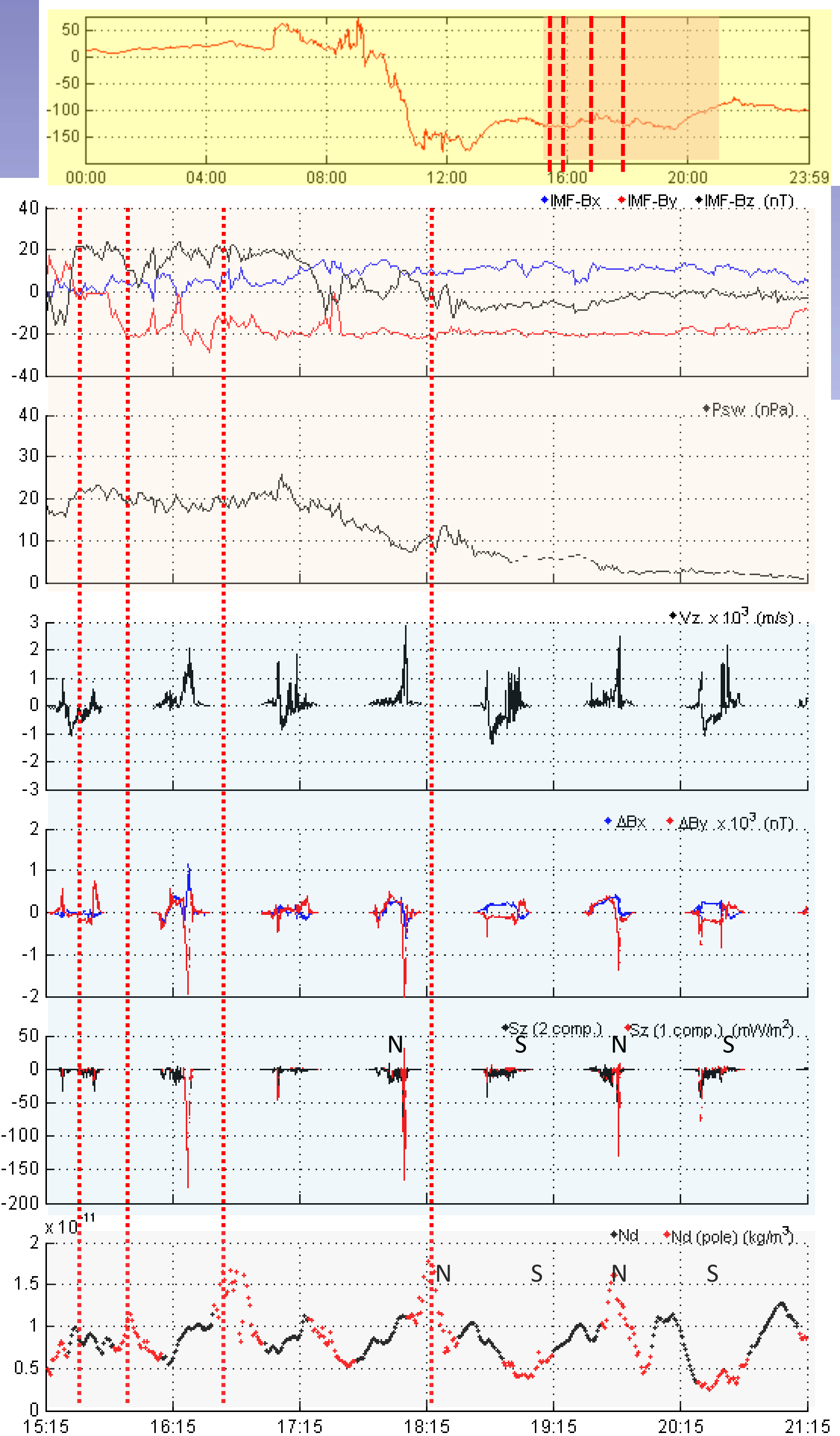


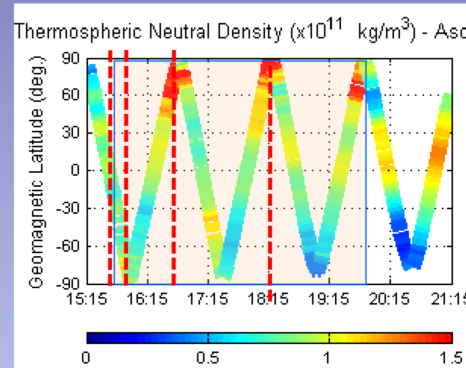


Aug 24 2005 0315-0915 UT

IMF pre-shock and shock

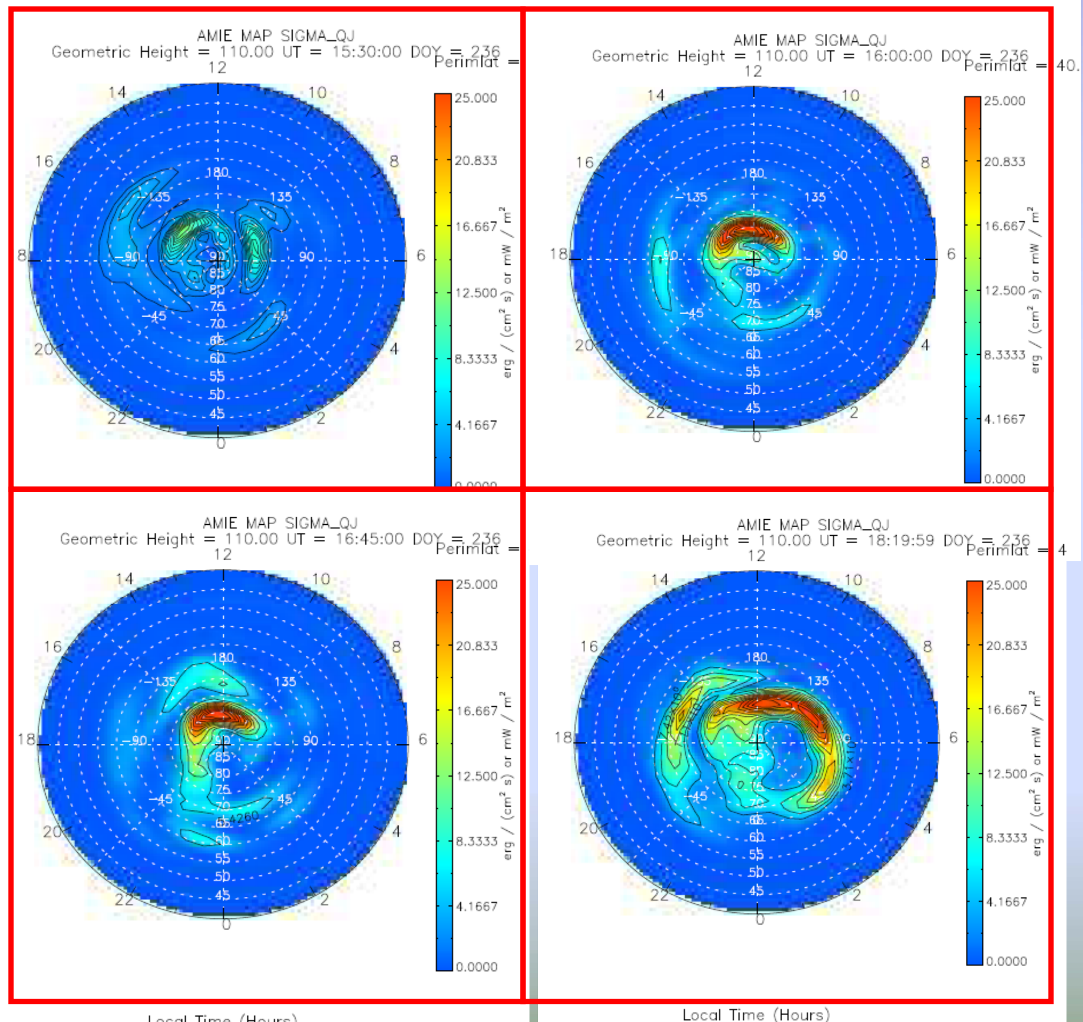
Pre Storm , Sudden Impulse, and Initial Phase





Aug 24 2005 1515-2115 UT

Transient



Summary

- CU Aerospace Environment Course
  - Technically savvy, novice students
  - Very engaged provided with right motivation
- CCMC Model Web Provides Access to
  - Static Models
    - Reinforce basic physics, Specify climatology
    - order of magnitude values, units ,etc
- CCMC Runs on Request

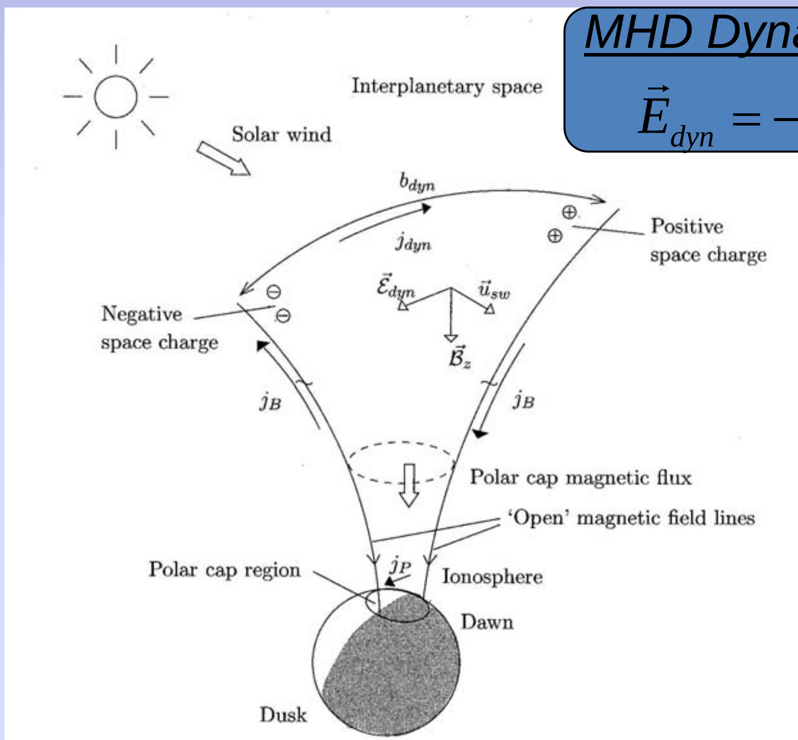
  Visualize time varying, complex, 3-D systems

  Verification and Validation Projects

Huge “Thank You” to CCMC Staff!

Region-1 Current System

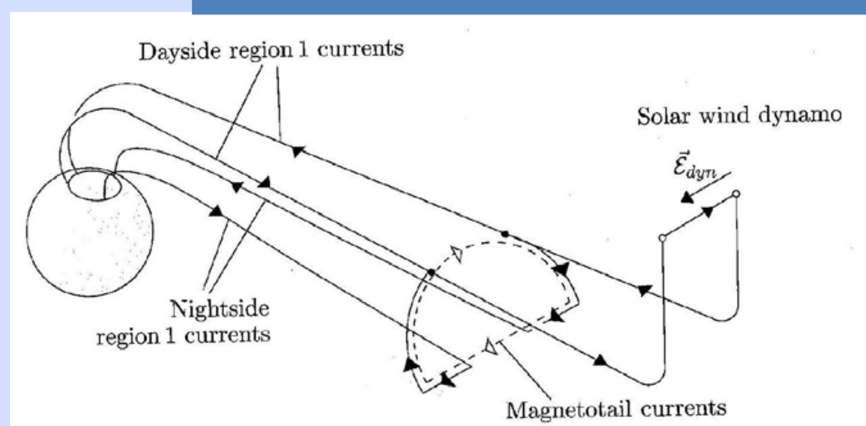
The magnetic field lines are highly conducting, and so it is natural that the magnetosphere seeks some closure of current through an ionospheric route. In fact, the so-called Region 1 currents are necessary if we are to require the polar ionosphere to convect with the magnetic field lines:



MHD Dynamo

$$\vec{E}_{dyn} = -\vec{U}_{sw} \times \vec{B}$$

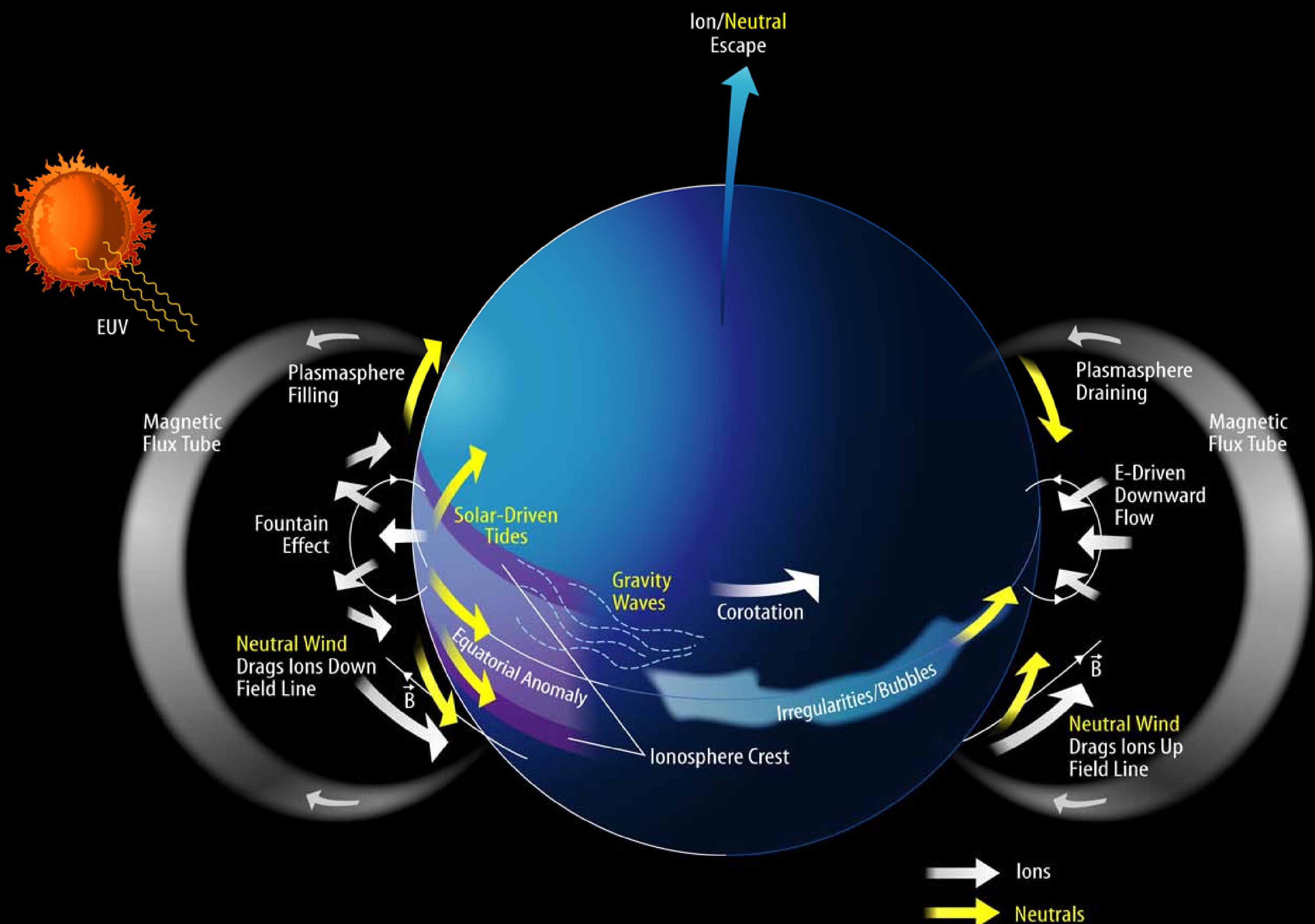
Region 1 Configuration



$$\text{MHD Generator} \Rightarrow \; J \cdot E < 0$$

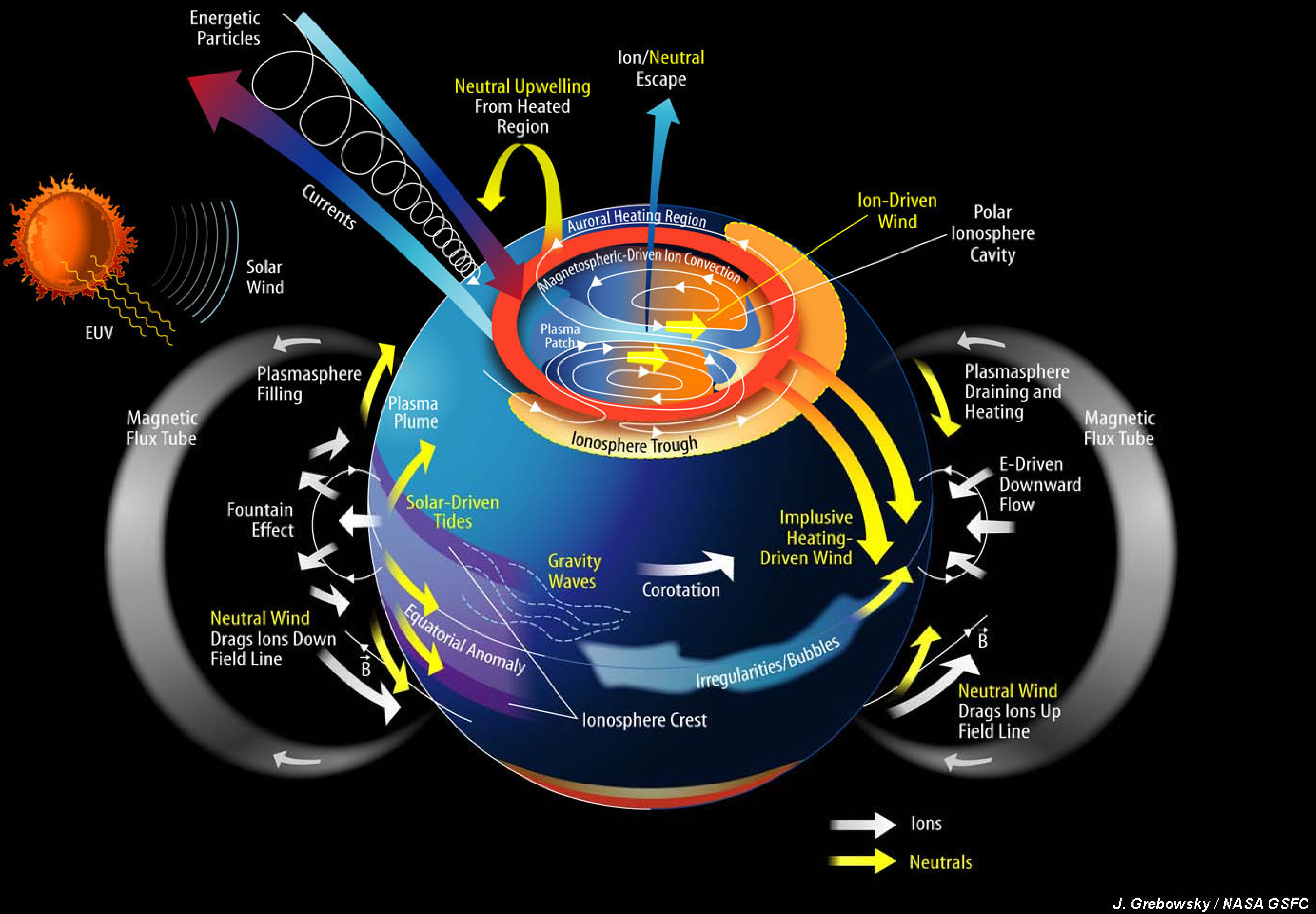
From Prolss, 2004

Addition of Earth's Magnetic Field



J. Grebowsky / NASA GSFC

Addition of Solar Wind And IMF



ddition of Geomagnetic Storms