The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

**2025-31**

**Satellite Navigation Science and Technology for Africa**

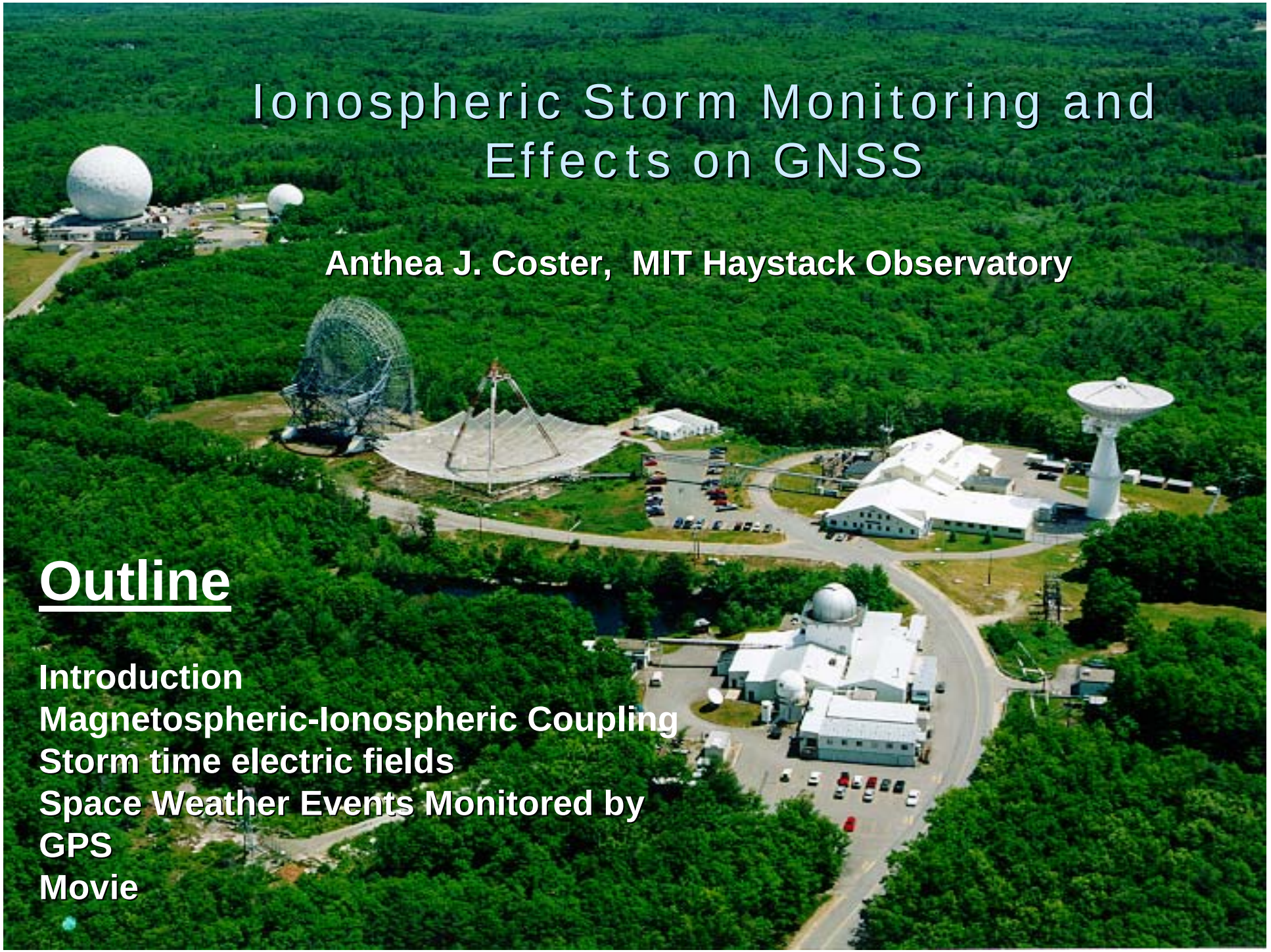
***23 March - 9 April, 2009***

# Ionospheric Storm Monitoring and Effects on GNSS

COSTER Anthea Jane
*M.I.T. - Atmospheric Sciences Group*
*Haystack Observatory, Off Route 40*
*01886 Westford*
*U.S.A.*

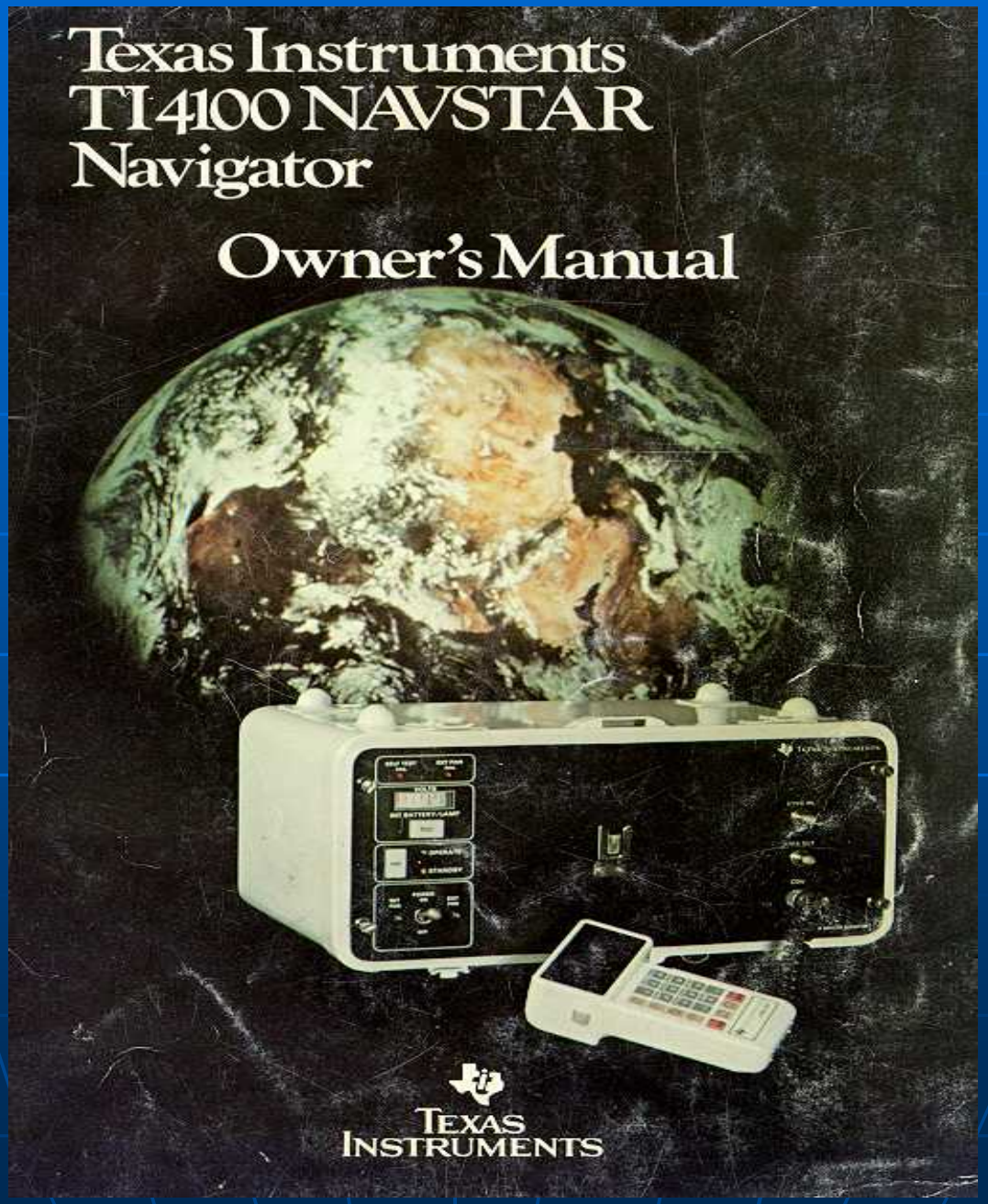
# Ionospheric Storm Monitoring and Effects on GNSS

**Anthea J. Coster, MIT Haystack Observatory**

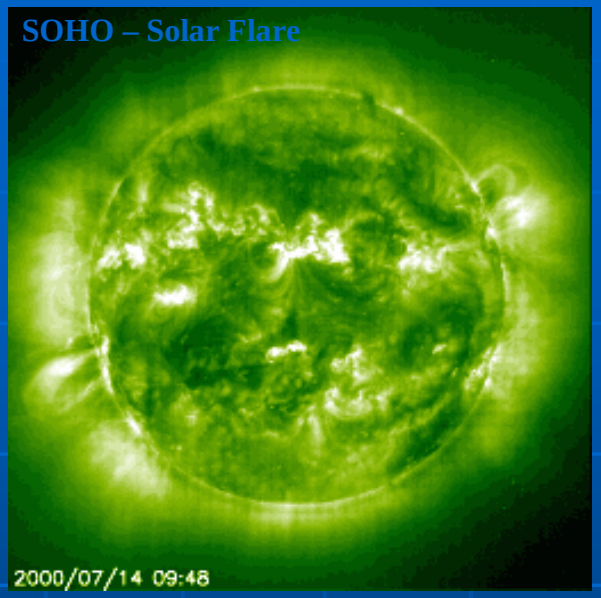


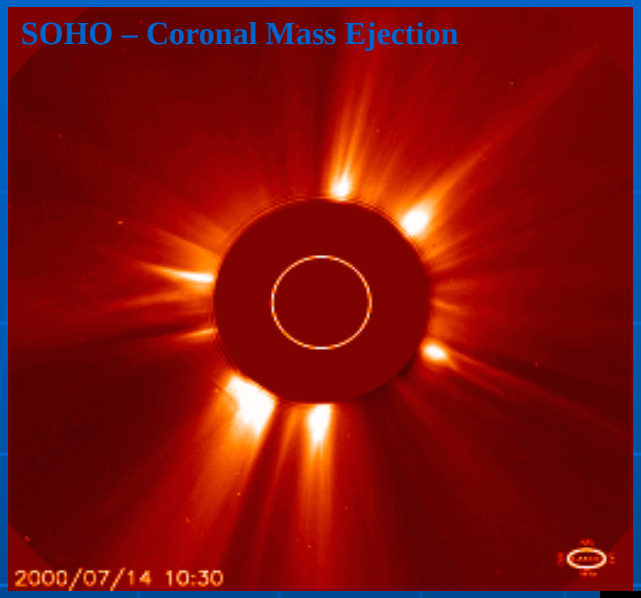
## Outline

**Introduction**
**Magnetospheric-Ionospheric Coupling**
**Storm time electric fields**
**Space Weather Events Monitored by GPS**
**Movie**


Texas Instruments
TI 4100 NAVSTAR
Navigator
Owner's Manual
TEXAS
INSTRUMENTS

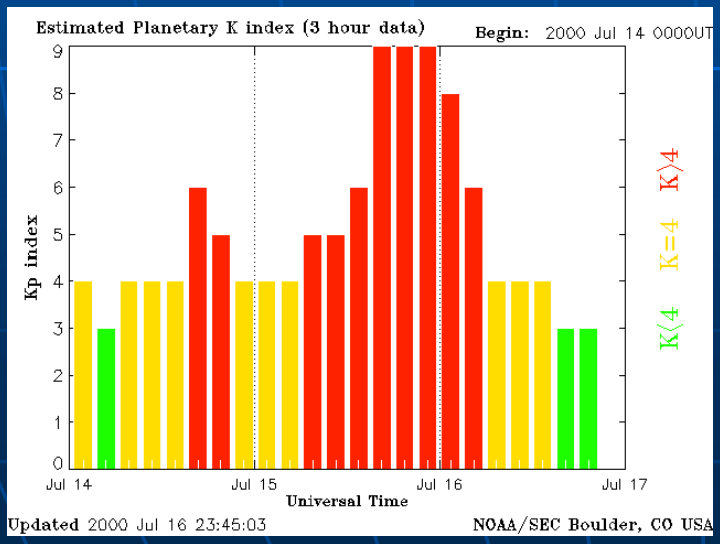
# Solar Flare of 14 July 2000

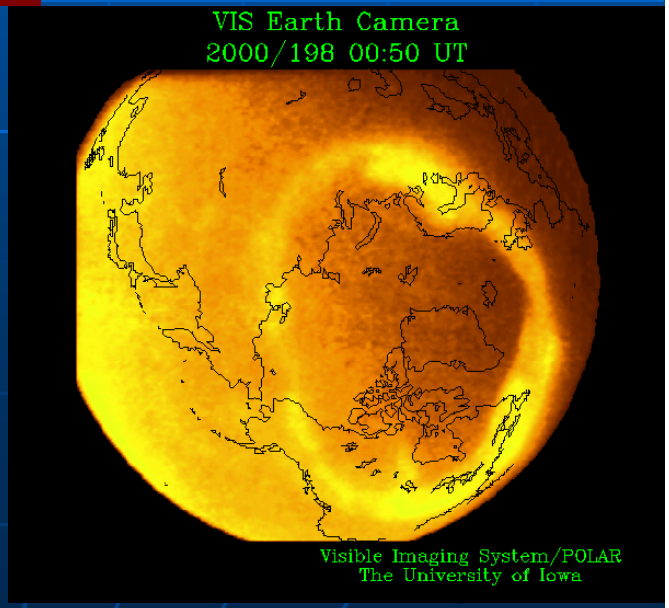


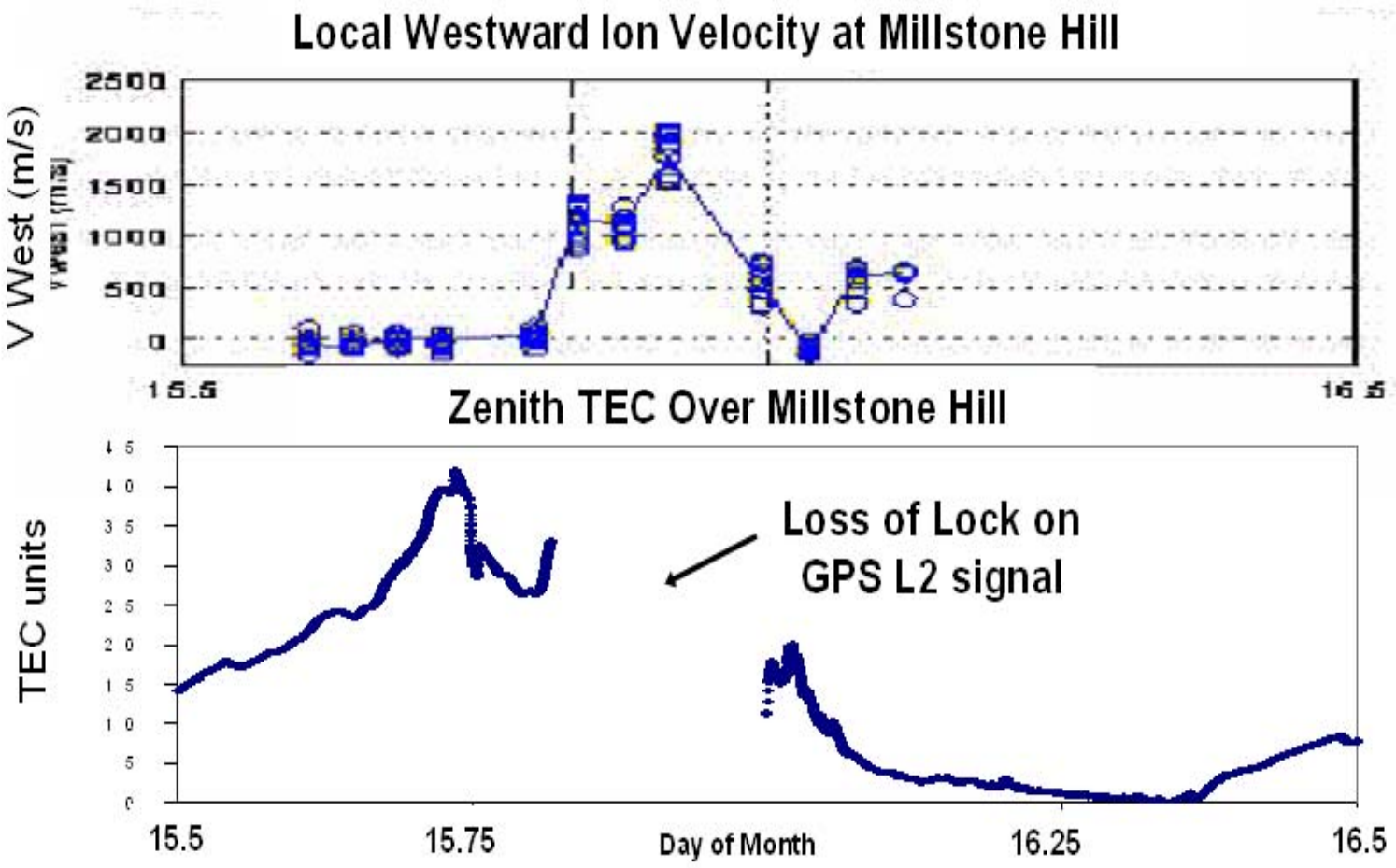

**Solar Flare of 14 July 2000**
**Biggest Solar Storm in Nine Years**

**Caused very large magnetic storm and ionospheric effects**

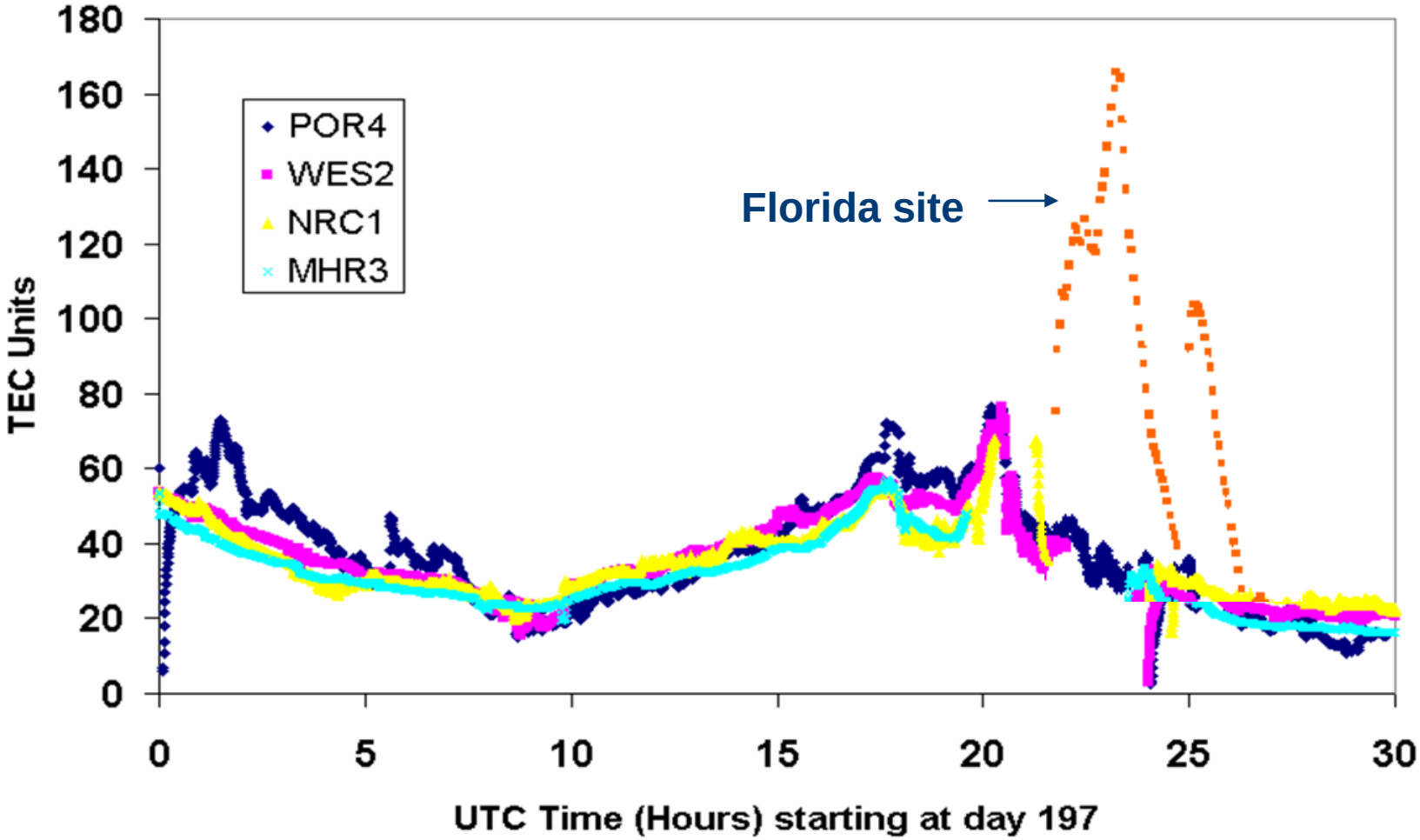


# GPS Loss of Lock at Millstone

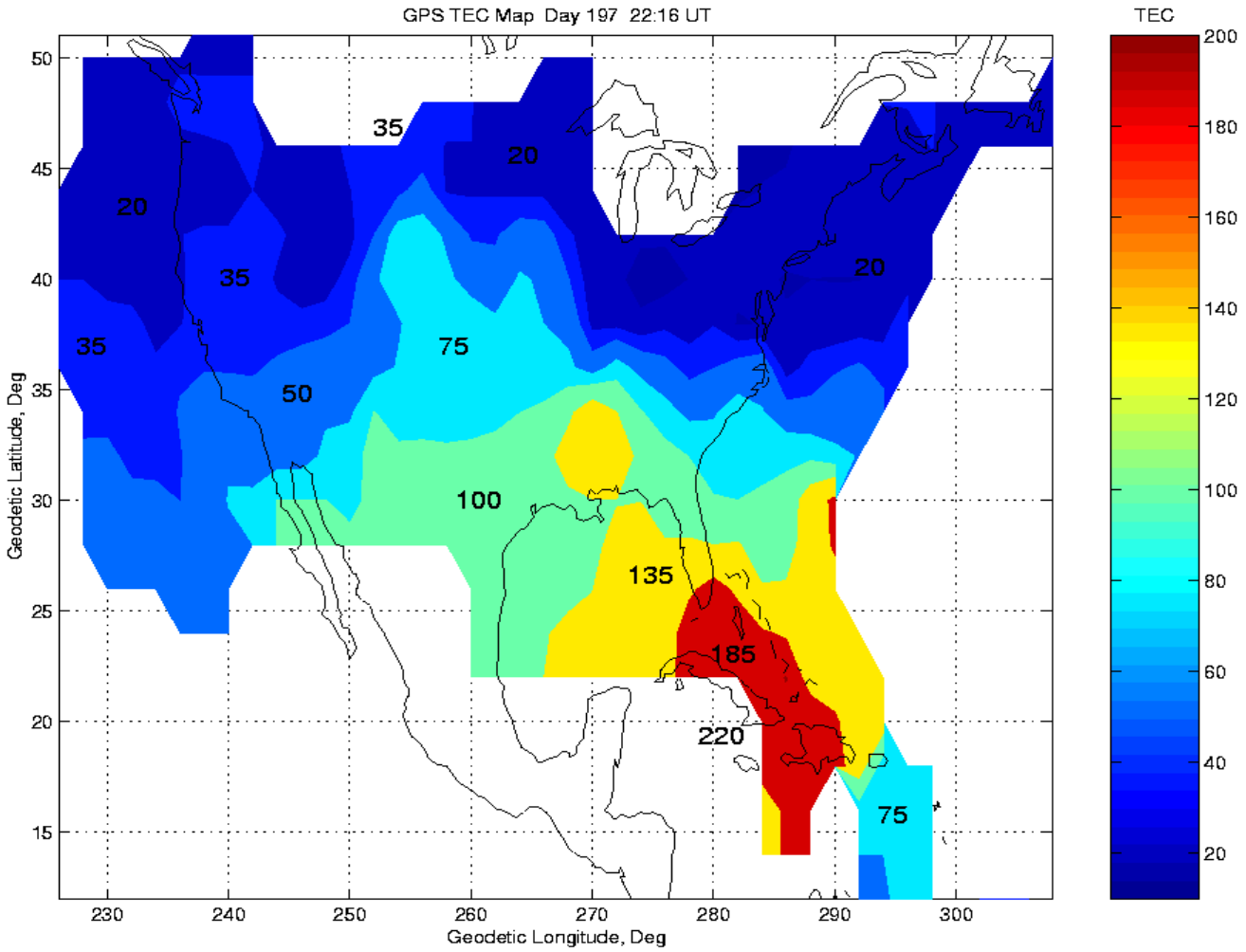


# TEC Disturbances on 15 July 2000



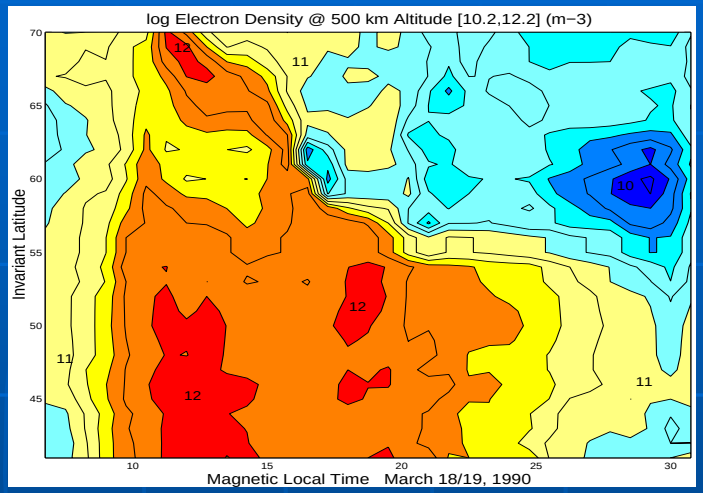
# GPS Total Electron Content Map

## *Illustration of Storm Enhanced Density*

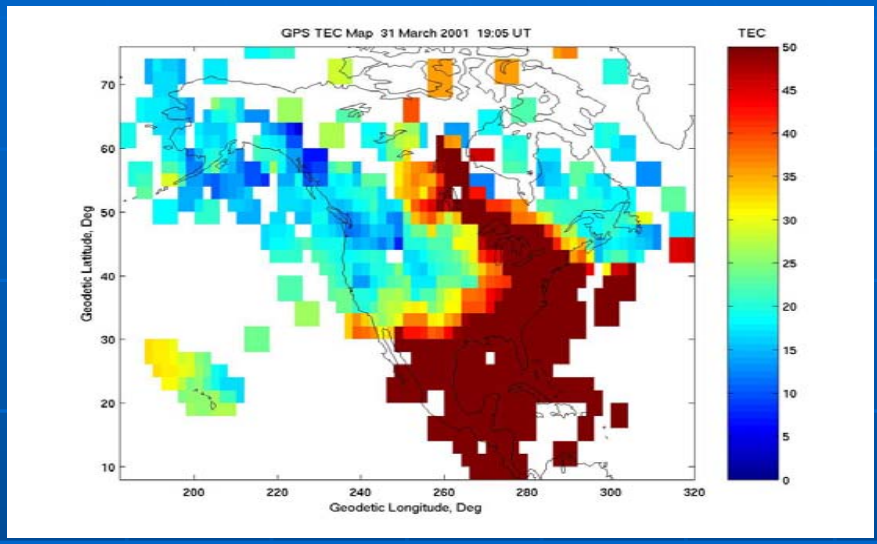


# A Decade Of Storm Enhanced Density

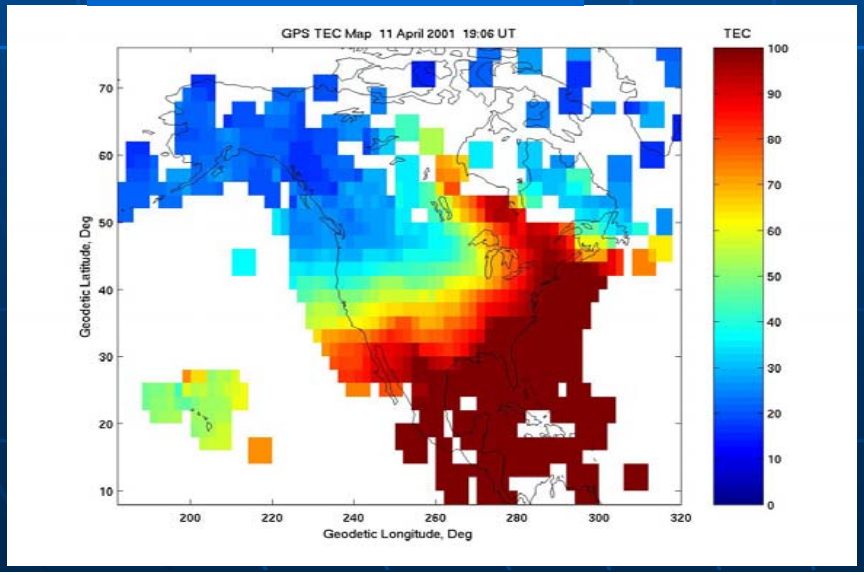
## Day 77, 1990



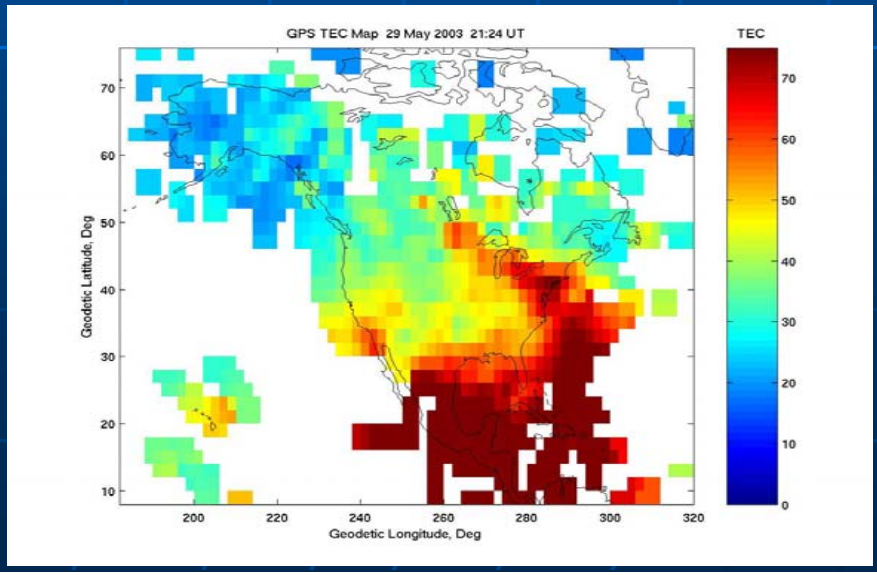

## Day 90, 2001

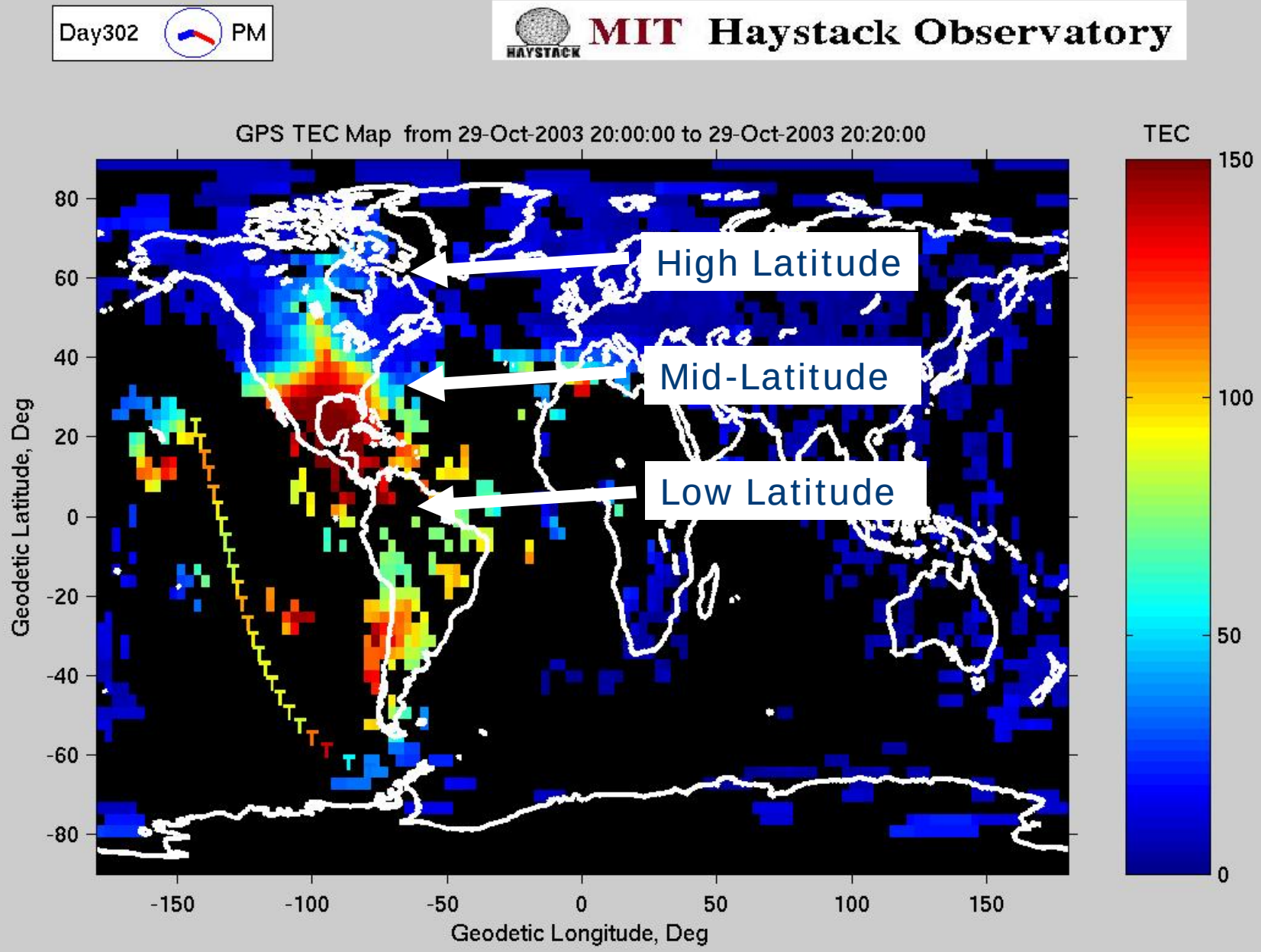



## Day 101, 2001




## Day 149, 2003



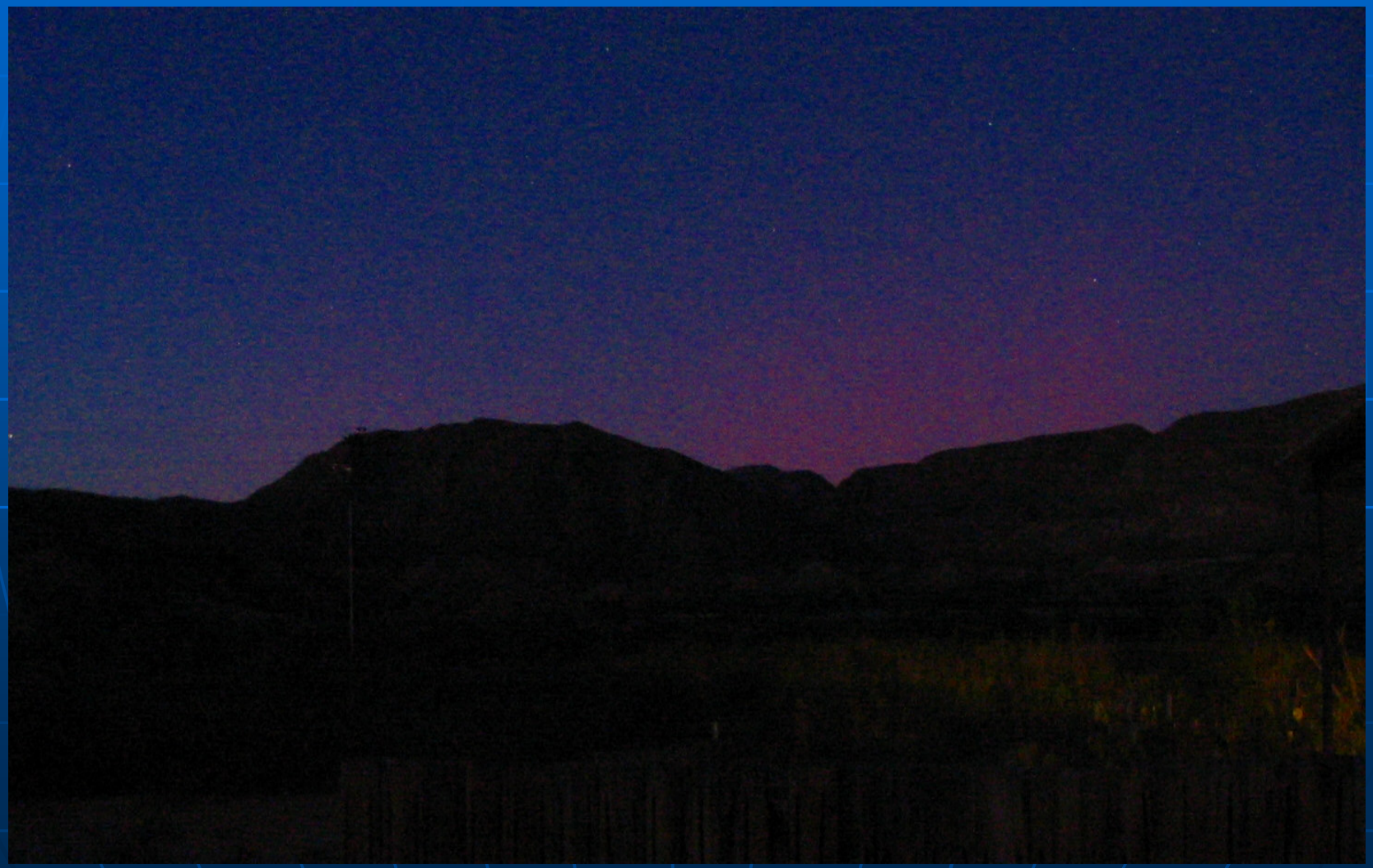

Day302
PM
MIT Haystack Observatory
GPS TEC Map from 29-Oct-2003 20:00:00 to 29-Oct-2003 20:20:00
TEC
150
100
50
0
High Latitude
Mid-Latitude
Low Latitude
Geodetic Latitude, Deg
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
Geodetic Longitude, Deg

# Aurora in New Brunswick, Canada

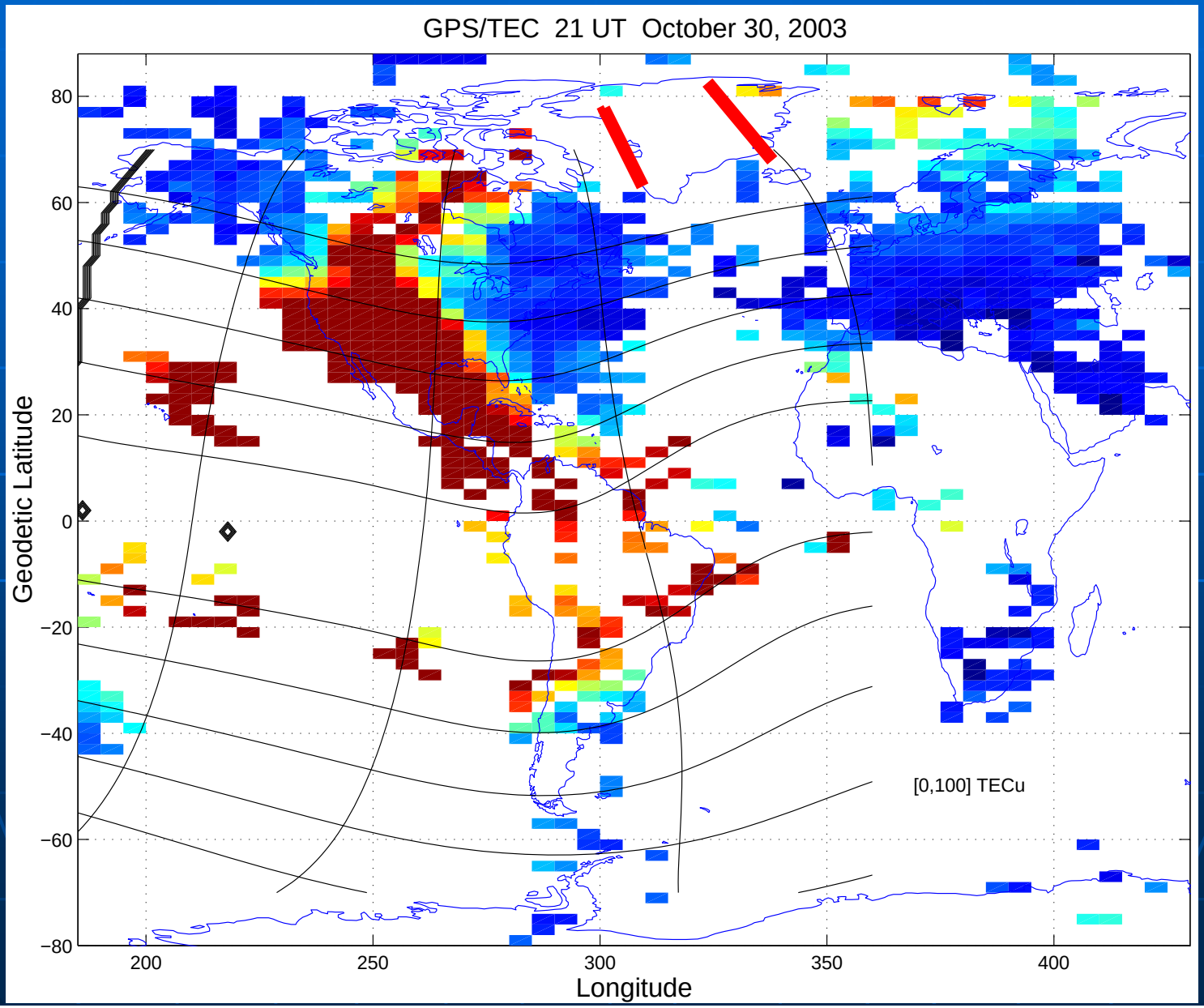
**30 October 2003**

# Aurora as seen in Big Bend, Texas

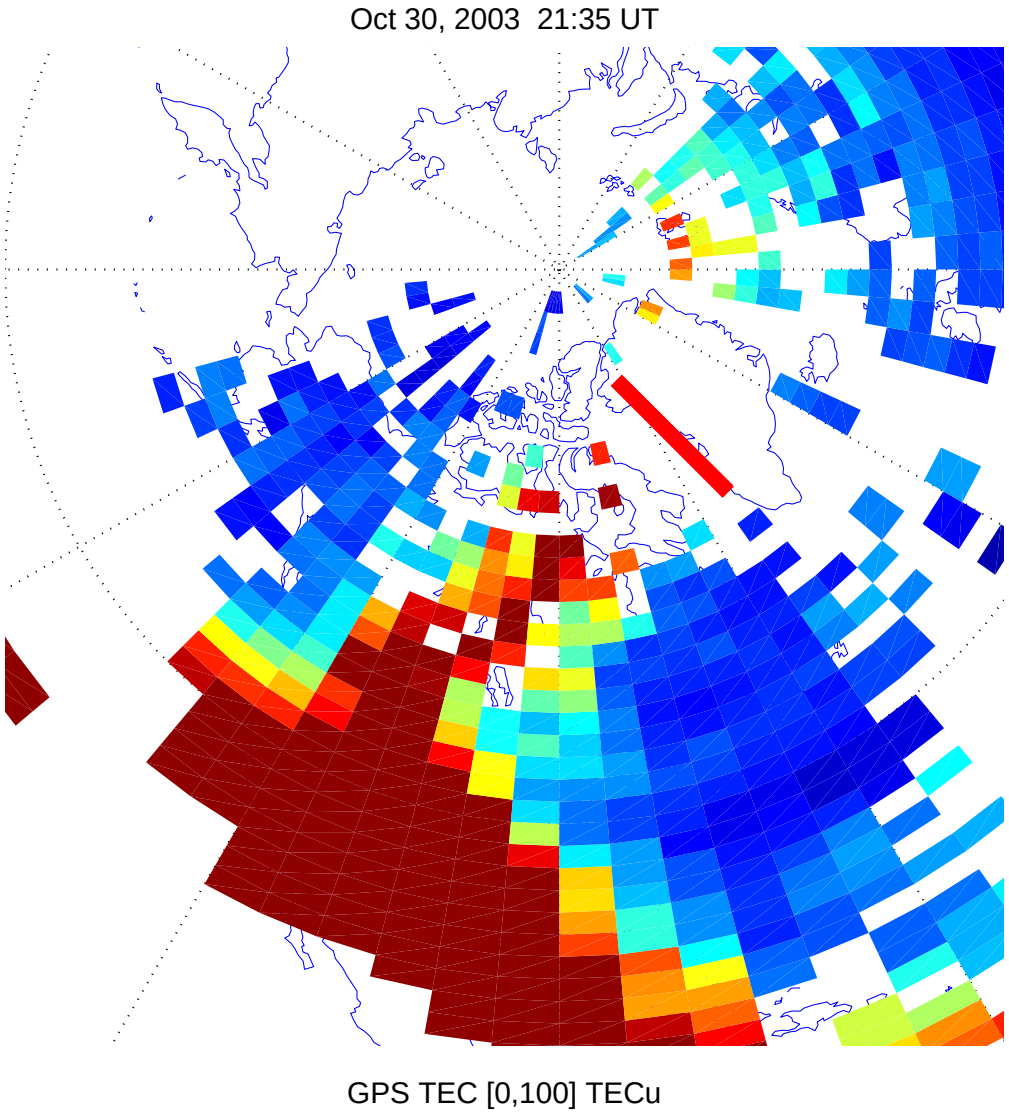
**30 October 2003**



# Oct 30, 2003 21:00 UT
# Plume Appears over Northern Eurpoe

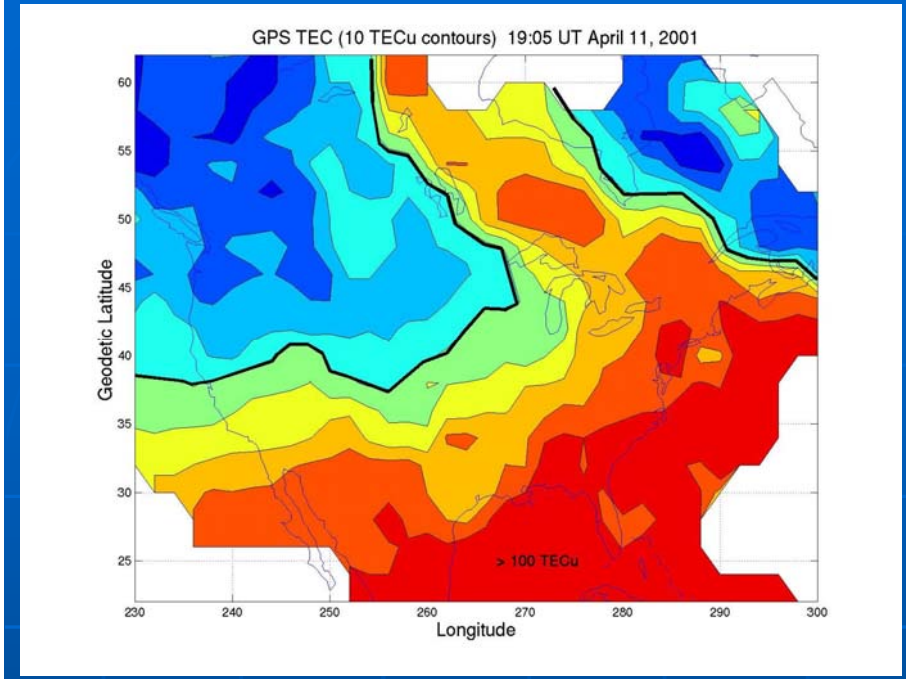


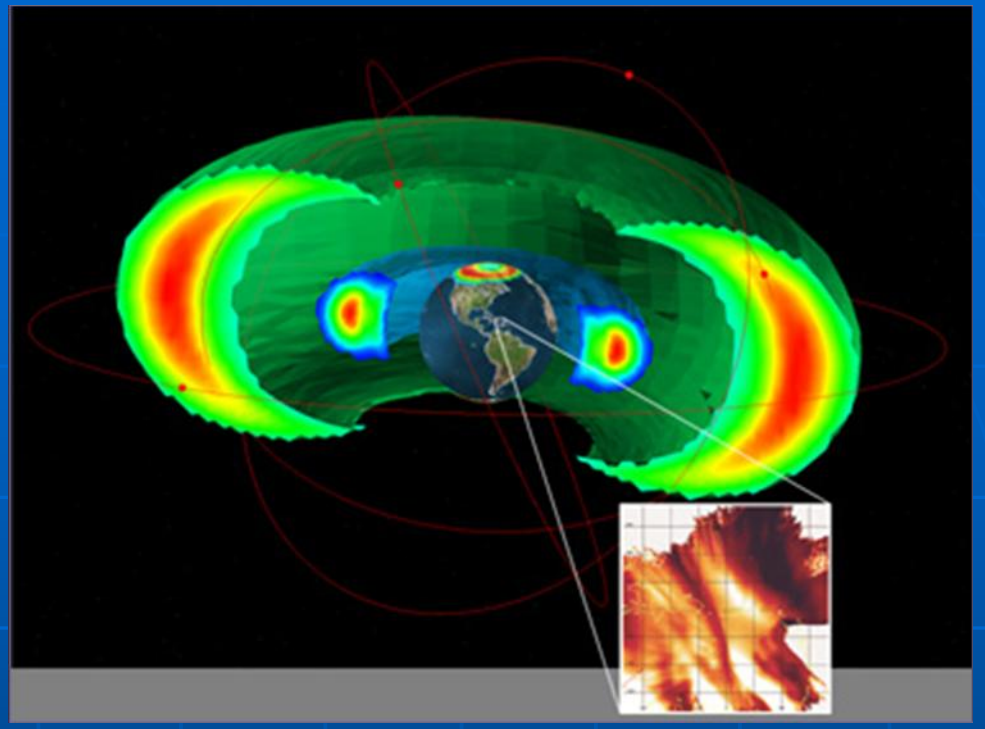
# Oct 30, 2003  21:00 UT
# Plume Appears over Northern Eurpoe



# Outline

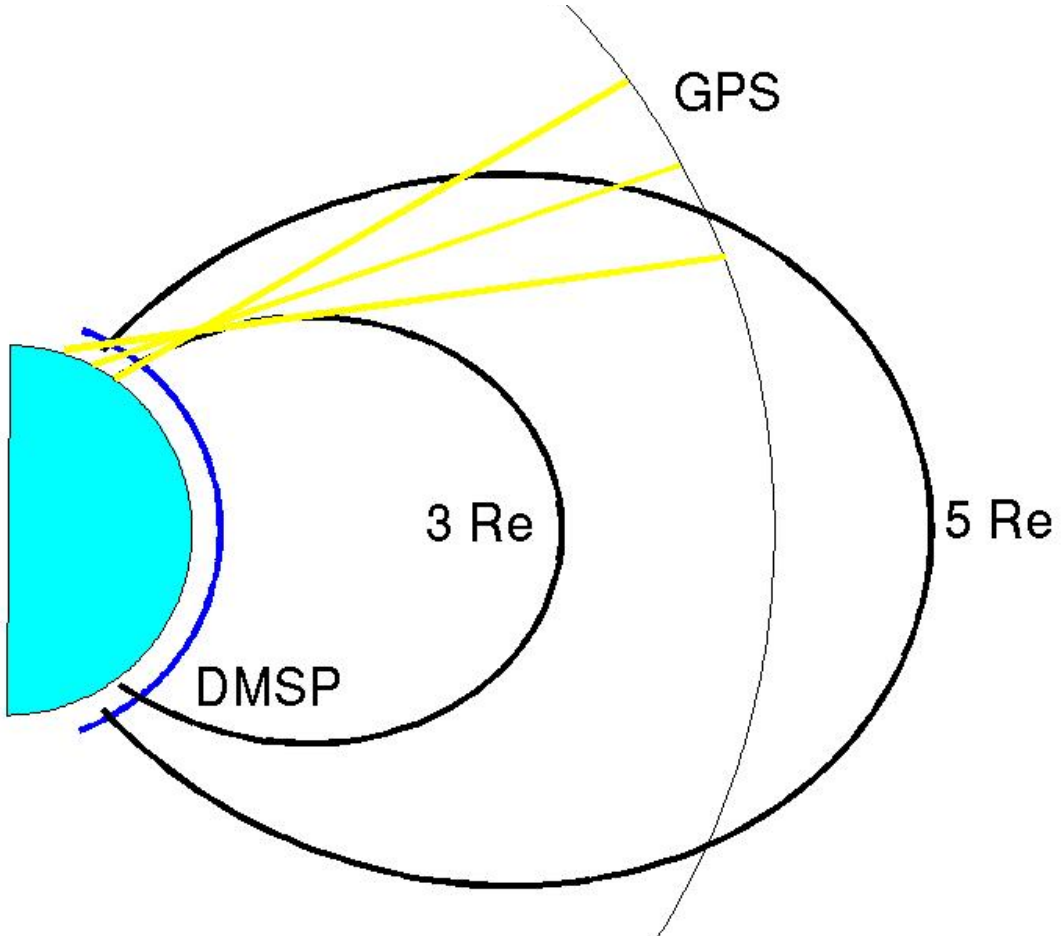
- Introduction
- Magnetospheric-Ionospheric Coupling
- Storm-time Electric Fields
- Monitoring Space Weather Events



# Magnetosphere
# Ionosphere
# Atmosphere
# Coupling

GPS samples the ionosphere and plasmasphere to an altitude of ~20,000 km




TEC is a measure of integrated density in a 1 $m^2$ column

1 TEC unit = $10^{16}$ electrons $m^{-2}$

# Plasmasphere

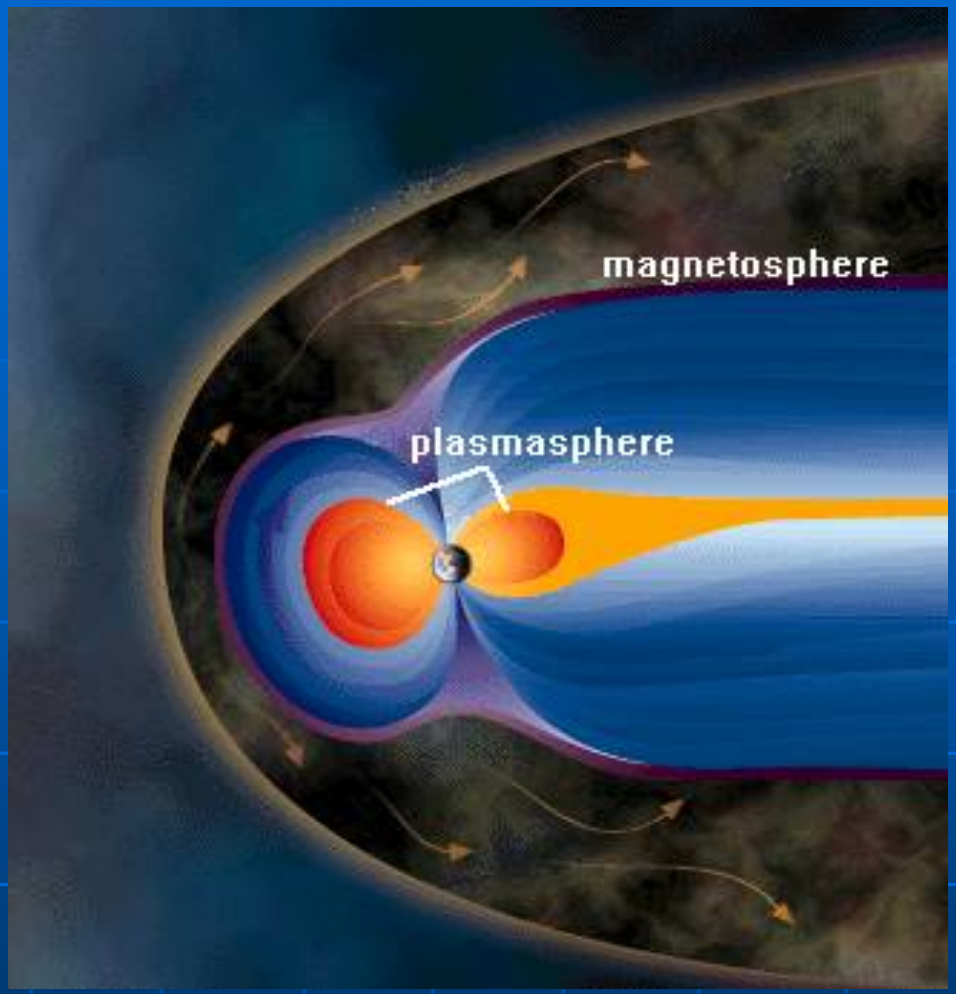
extension of ionosphere and part of the inner magnetosphere.

filled with ionospheric plasma from the mid- and low latitudes

plasma gas pressure is equalized along the entire field line.

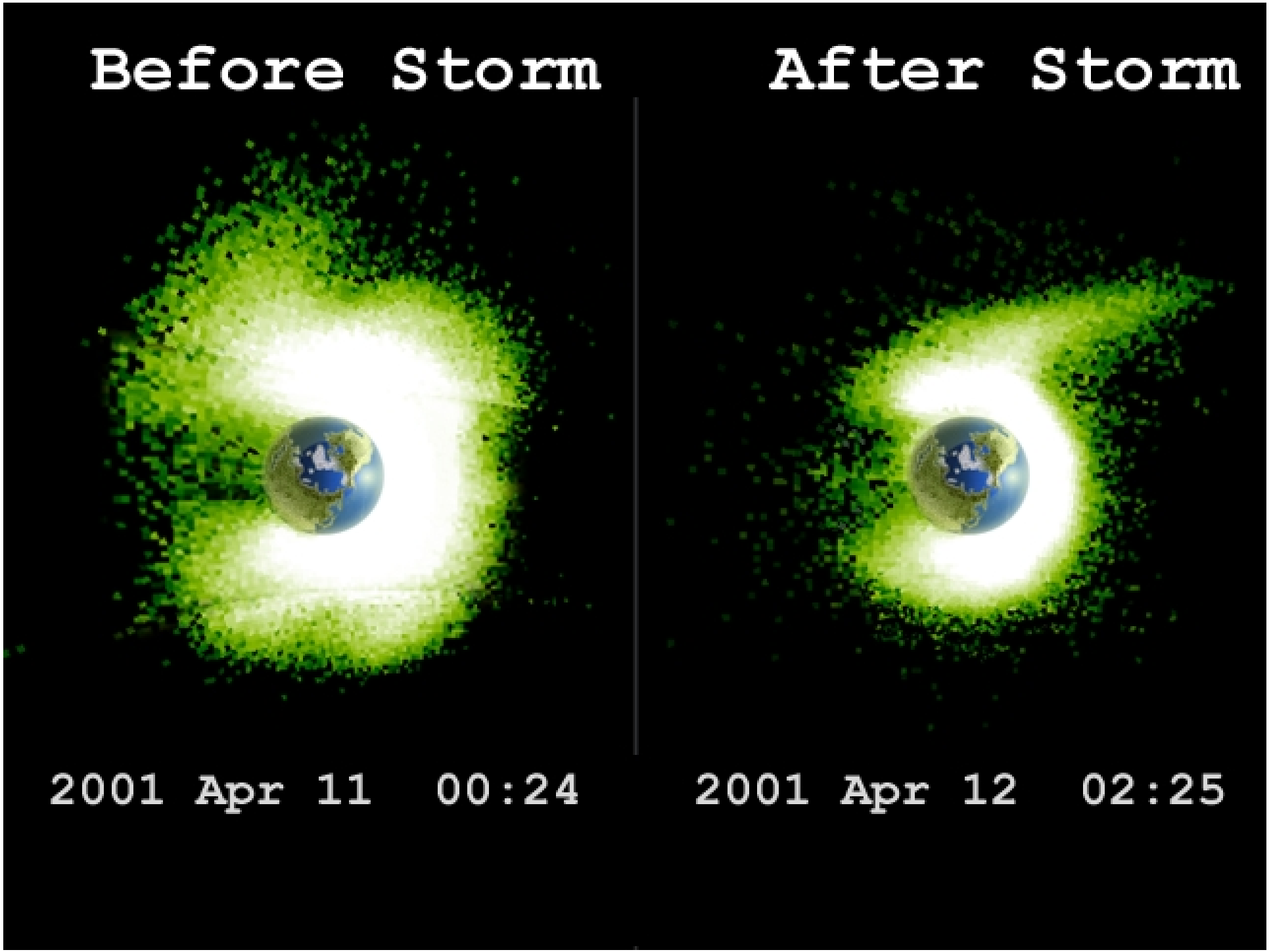
plasma co-rotates with the Earth and its motion is dominated by the geomagnetic field.

Plasma on magnetic field lines associated with higher latitudes (~ above 60 deg. geomagnetic lat.) is convected to the magnetopause




Quiet conditions - plasmapause may extend to ~ 7 Earth radii

Disturbed conditions – plasmapause can contract to ~3 or less Earth radii.


Before Storm
After Storm
2001 Apr 11 00:24
2001 Apr 12 02:25

# Next 5 slides and photograph of Einstein Bagel are from Jan Sojka

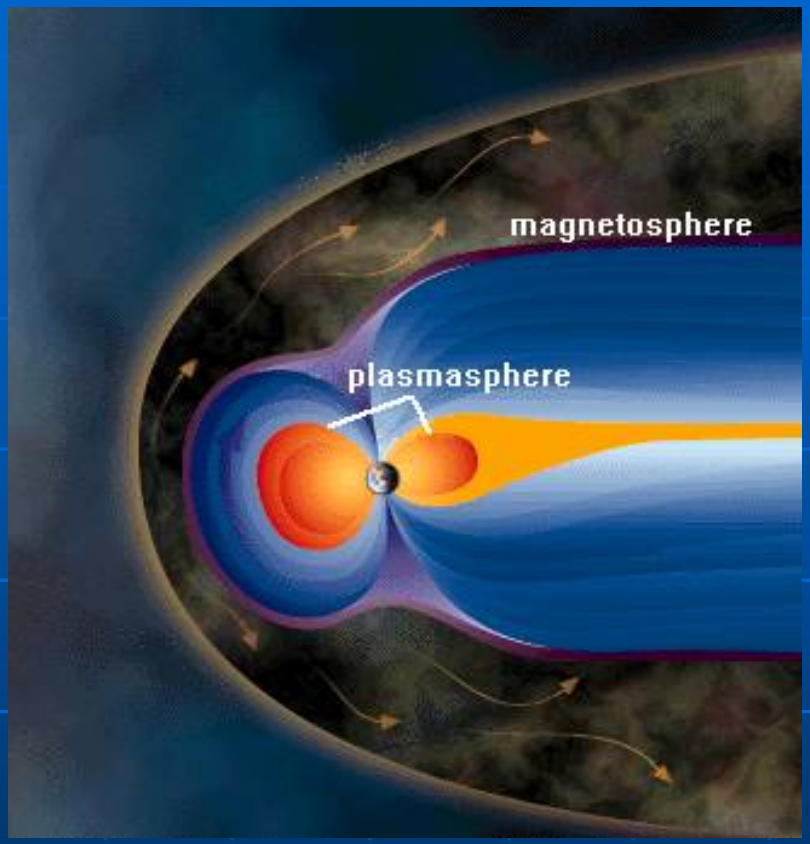
Figure Acknowledgements

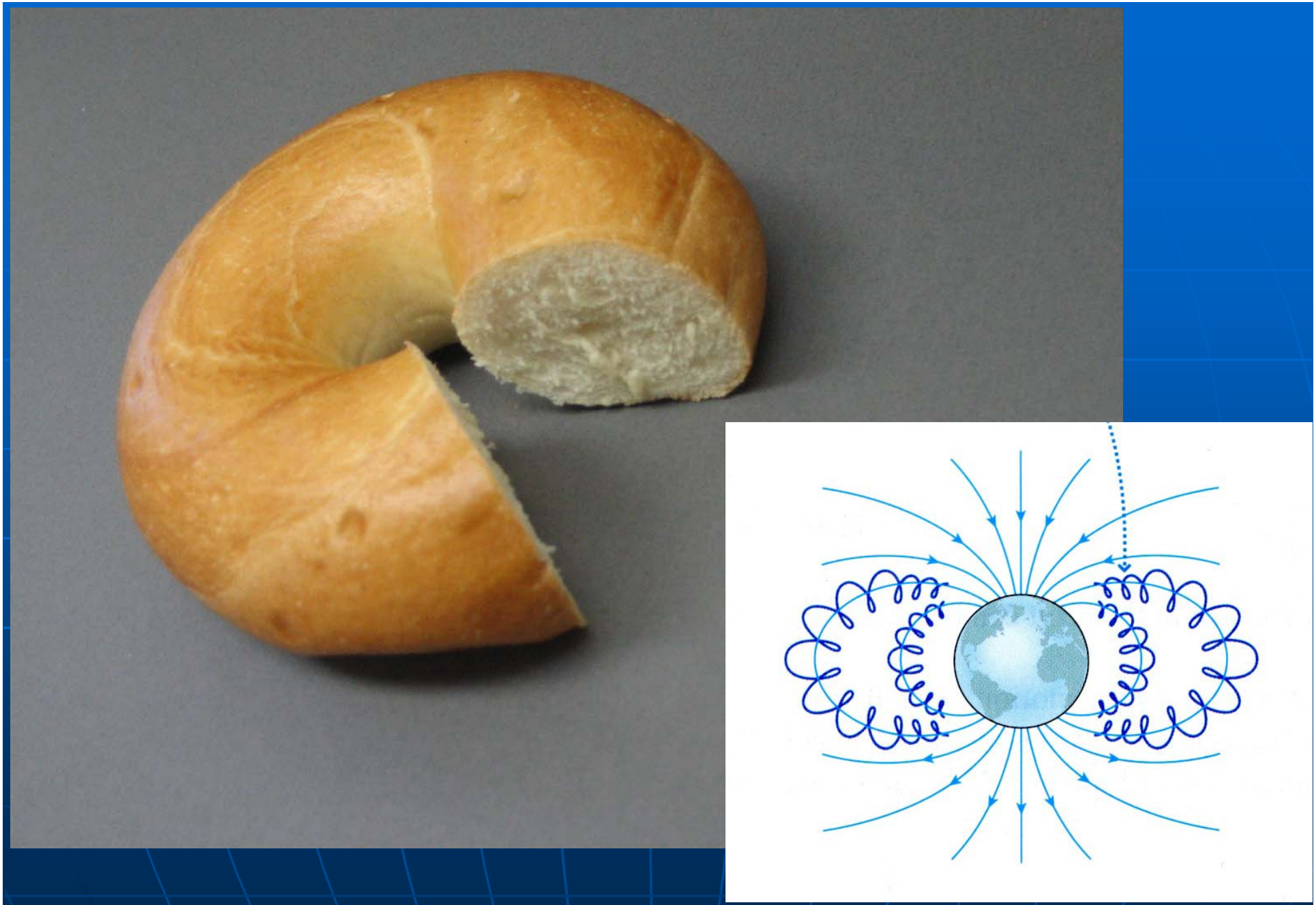
- Book – *Inner Magnetosphere Interactions* (ed. James Burch, Michael Schulz, and Harlan Spence), *Geophysical Monograph*, 159, American Geophysical Union, Washington, DC, 2005.

- Book – *Ionospheres*, R. W. Schunk and A. F. Nagy, Cambridge University Press, U.K., 2000.

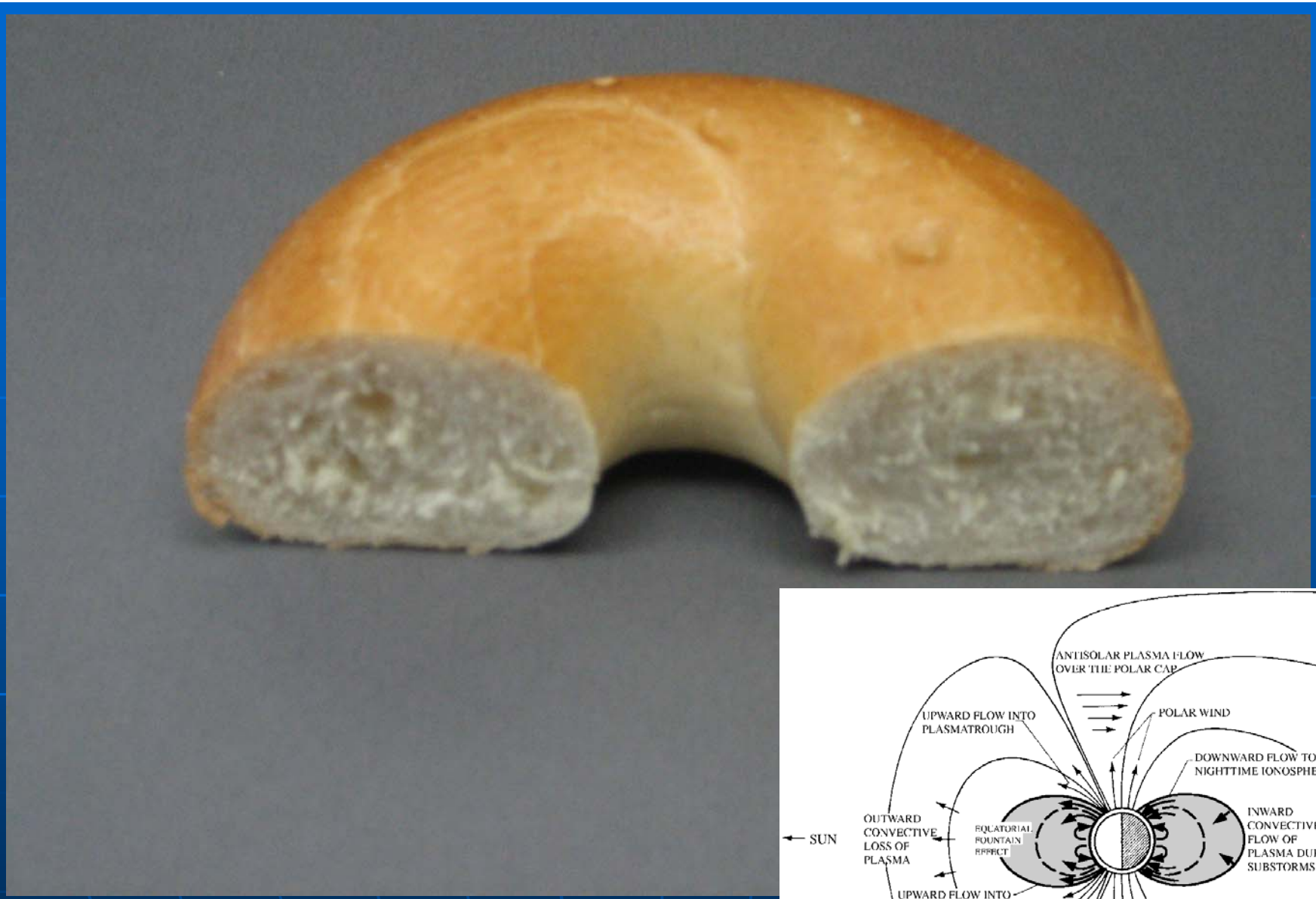
- A standard Introduction to Physics with Calculus text book

# Plasmaspheric Boundary Layer: Plasmapause



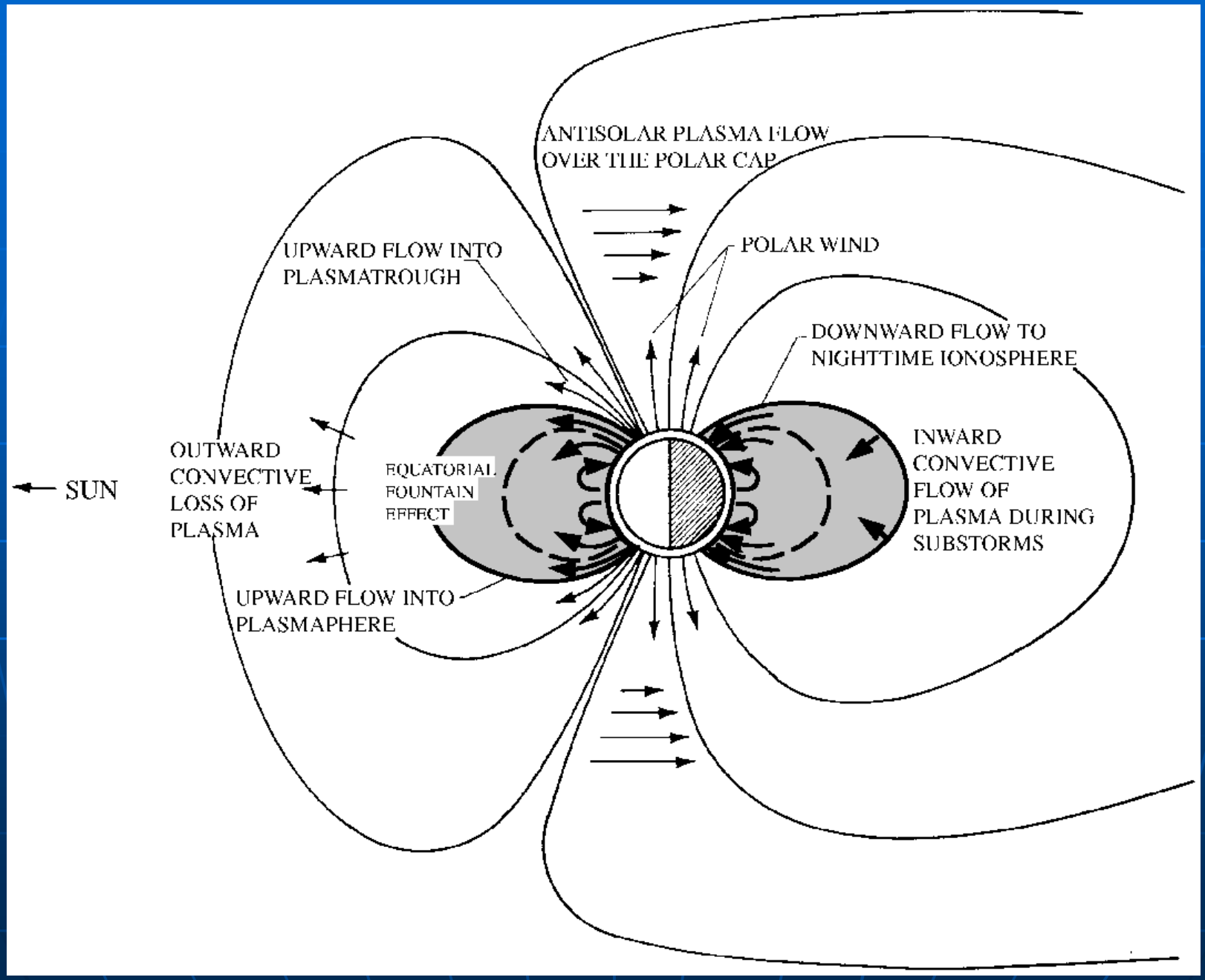



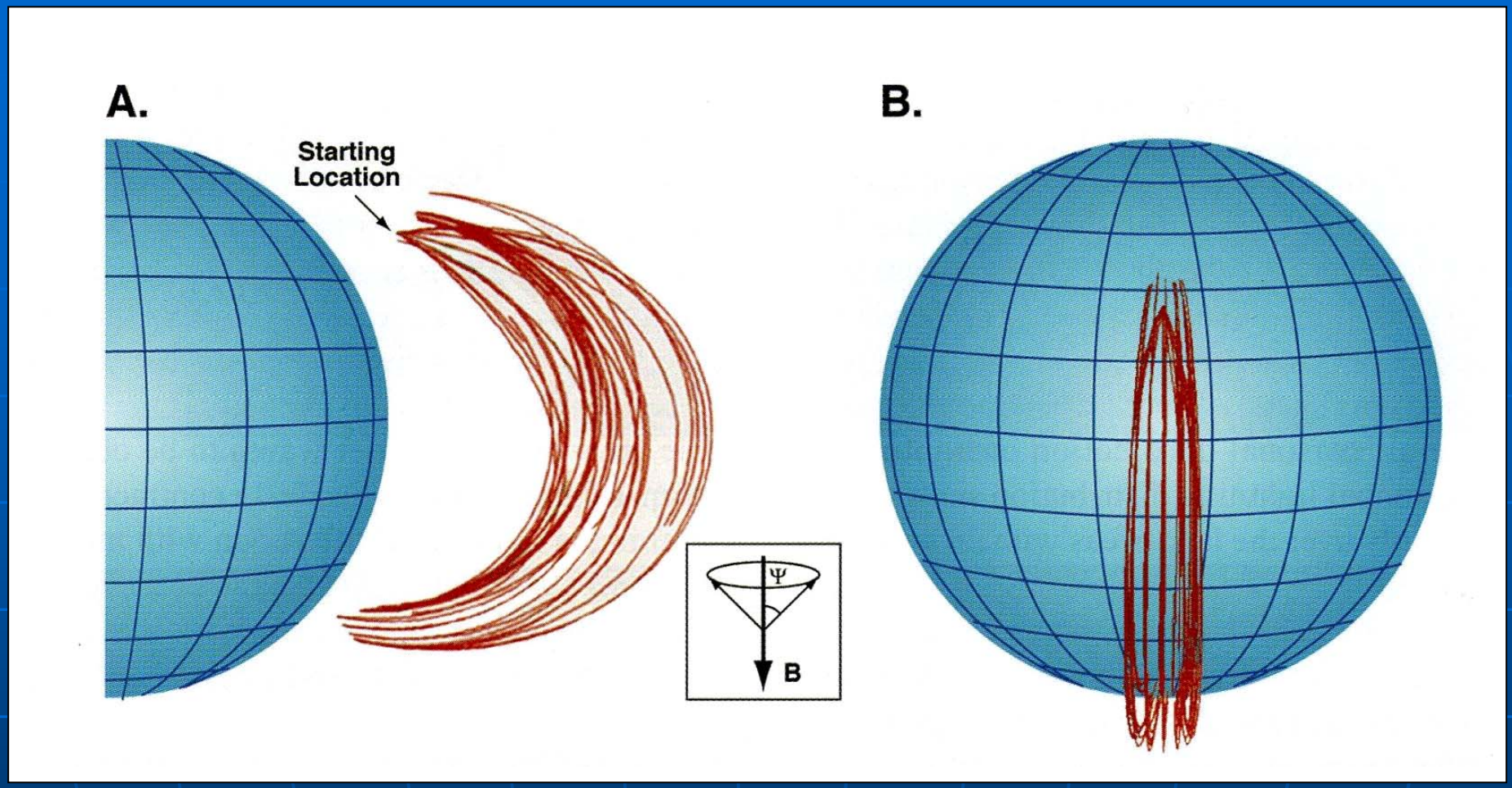
A Dipole Magnetic Field: NOT!





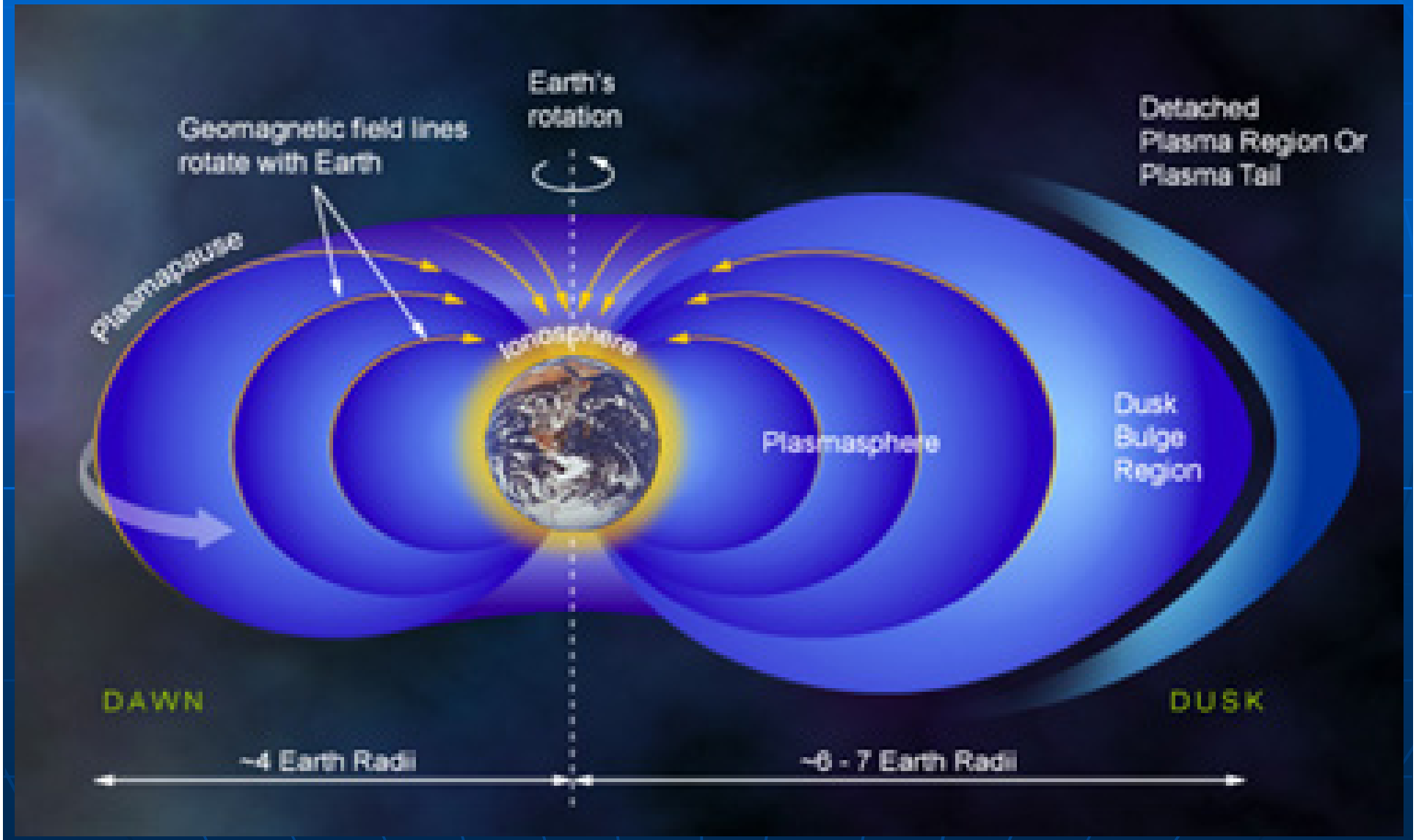

# The Standard Plasmasphere View


ANTISOLAR PLASMA FLOW
OVER THE POLAR CAP
POLAR WIND
UPWARD FLOW INTO
PLASMATROUGH
DOWNWARD FLOW TO
NIGHTTIME IONOSPHERE
SUN
OUTWARD
CONVECTIVE
LOSS OF
PLASMA
EQUATORIAL
FOUNTAIN
EFFECT
INWARD
CONVECTIVE
FLOW OF
PLASMA DURING
SUBSTORMS
UPWARD FLOW INTO
PLASMAPHERE

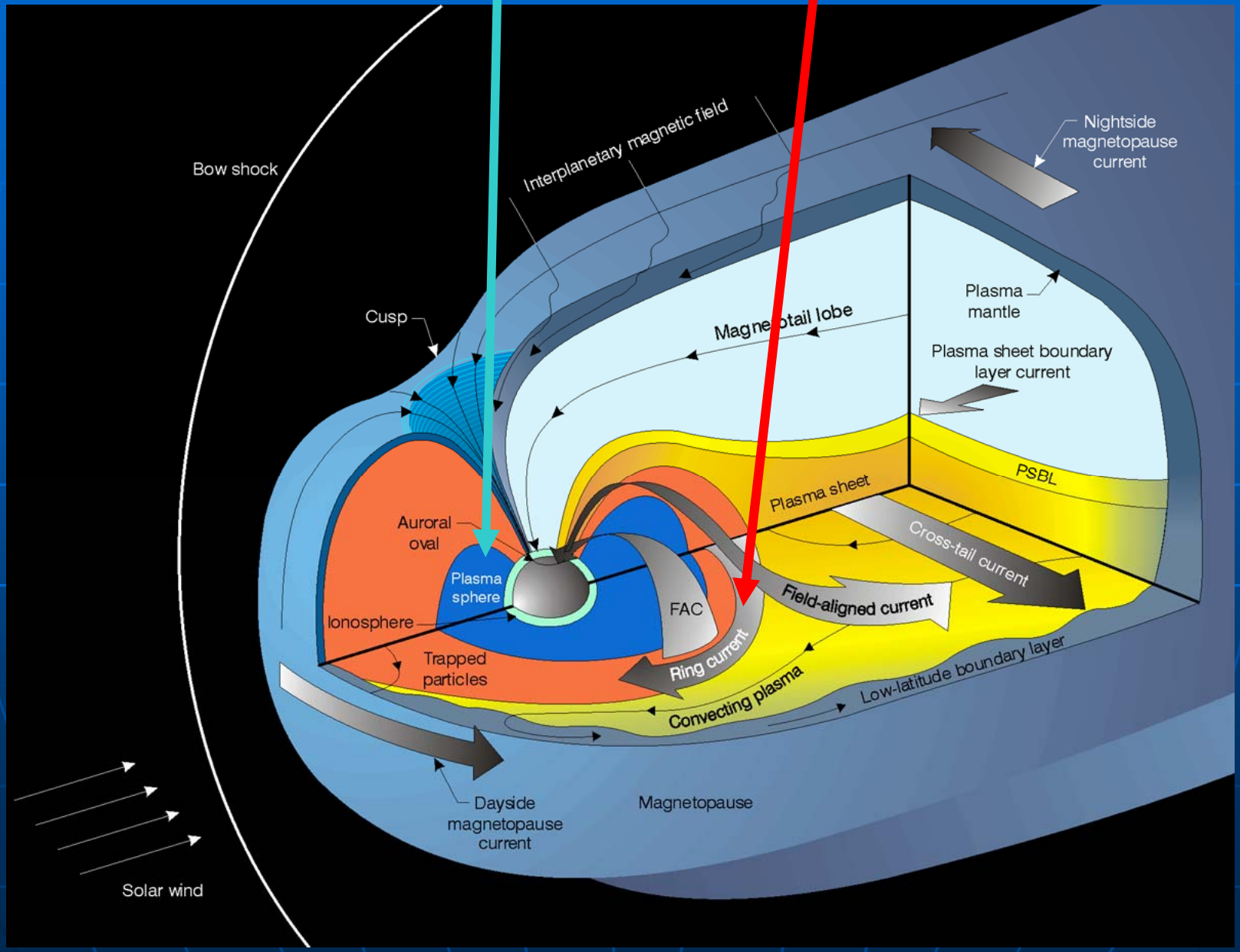



At the boundary layer and in the plasmasphere the cold plasma Interacts with hot plasma: radiation belts and the ring current. These hot particles are guided by a “changing” magnetic fields. The cold boundary layer also has a “hot outer zone” that has a rich ion composition.  Did I mention E&M waves…..

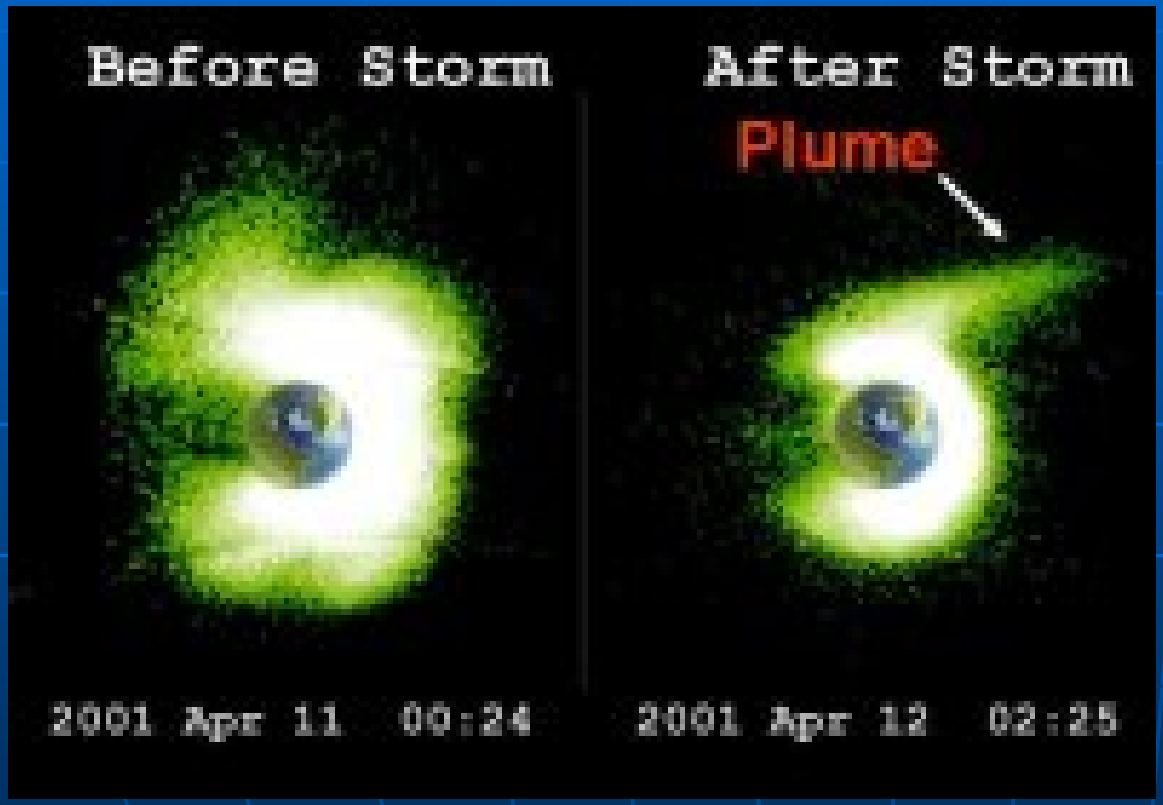
# Plasmasphere

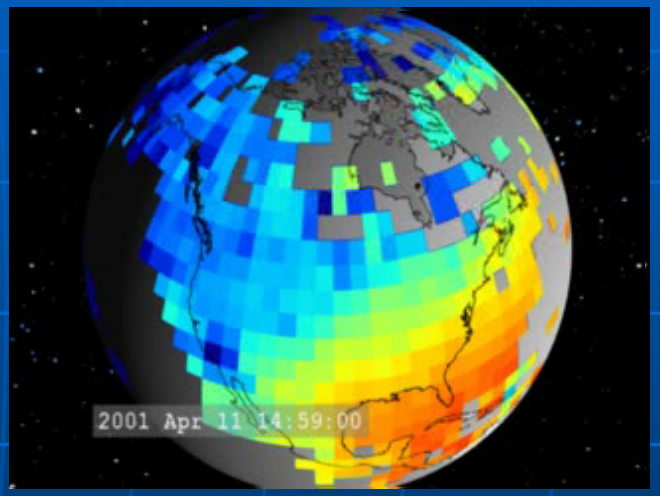


# Plasmasphere & Ring Current

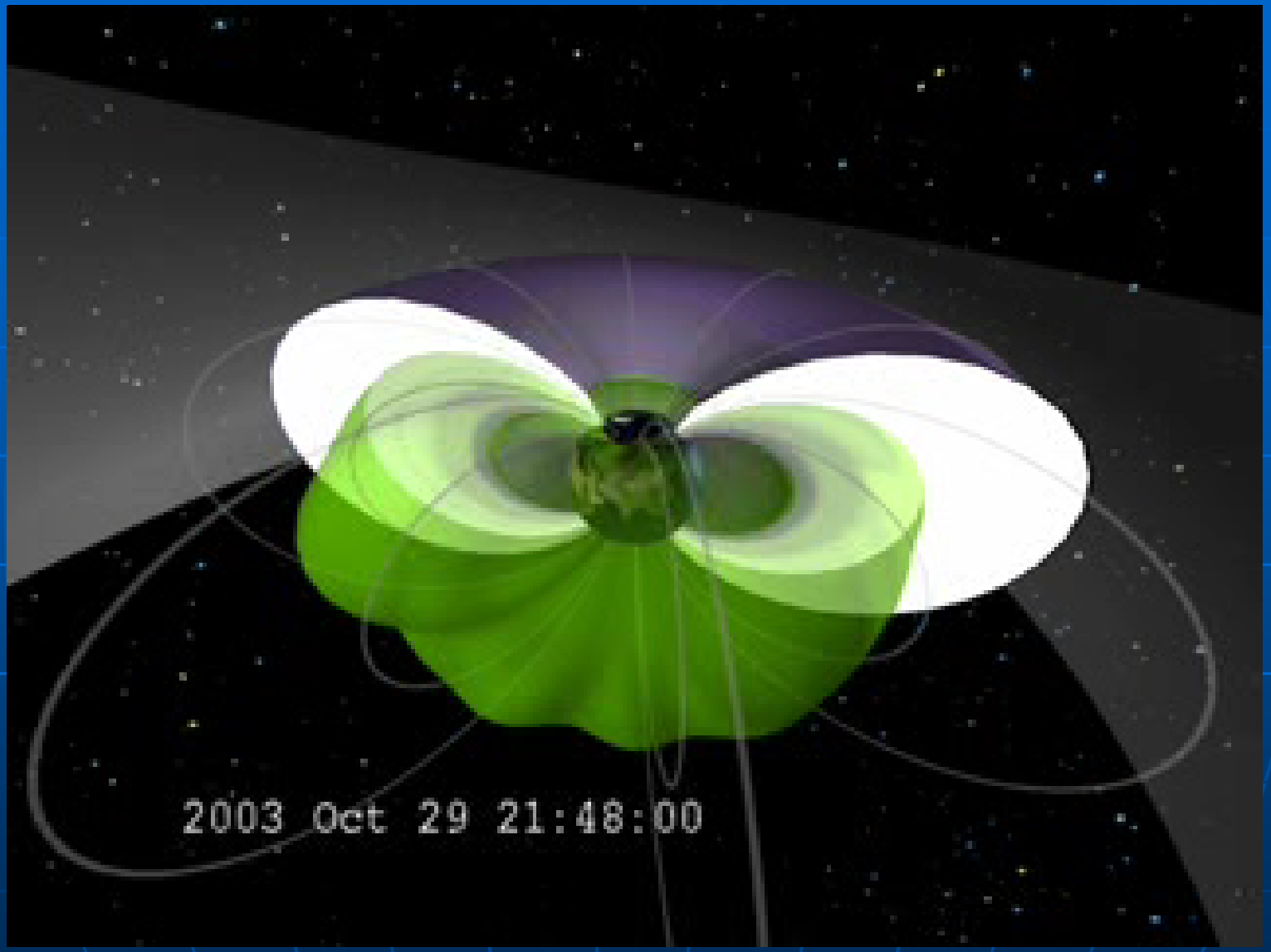


# IMAGE Data of Plasmasphere

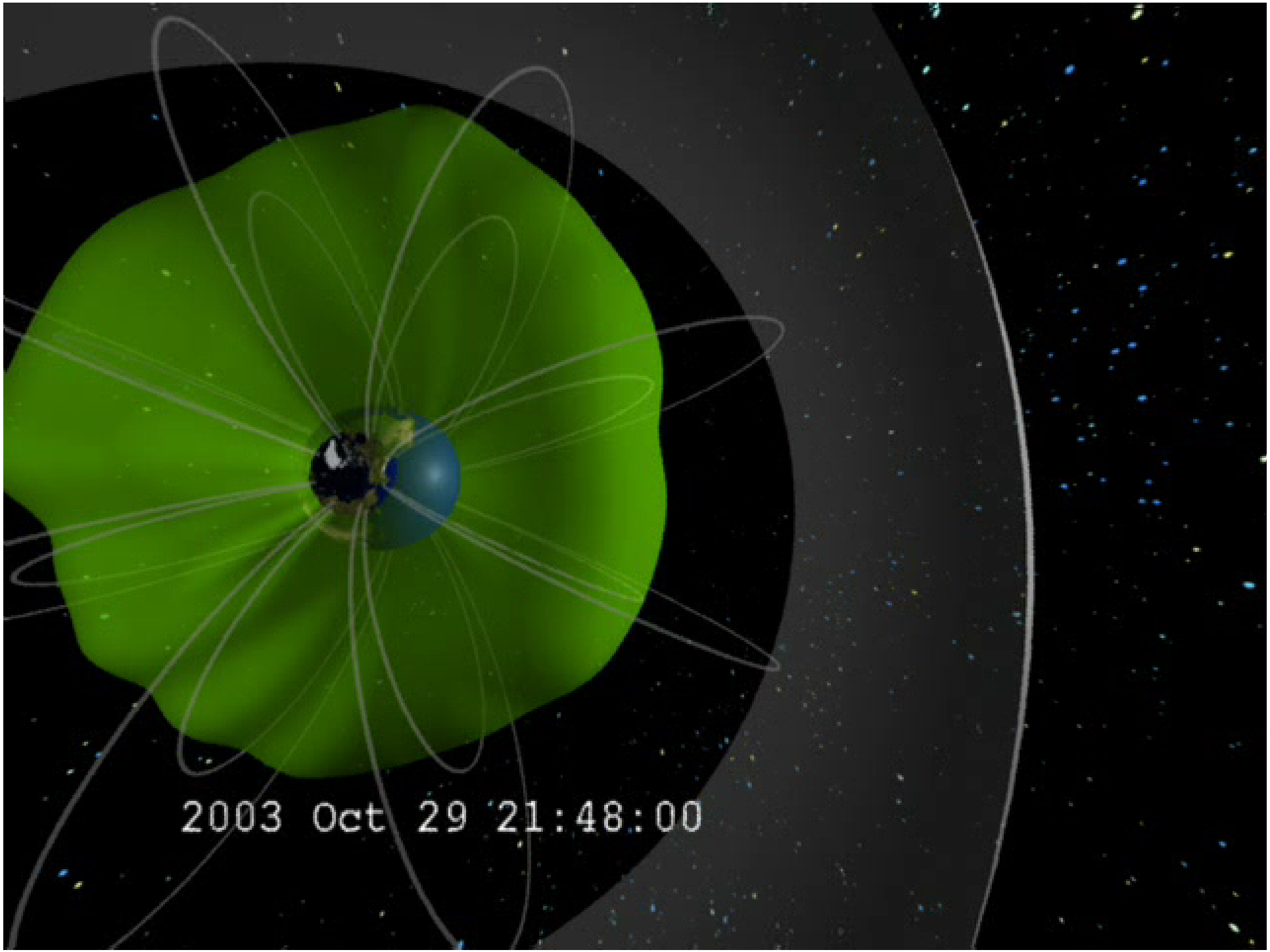



movie




movie


2003 Oct 29 21:48:00

# Outline

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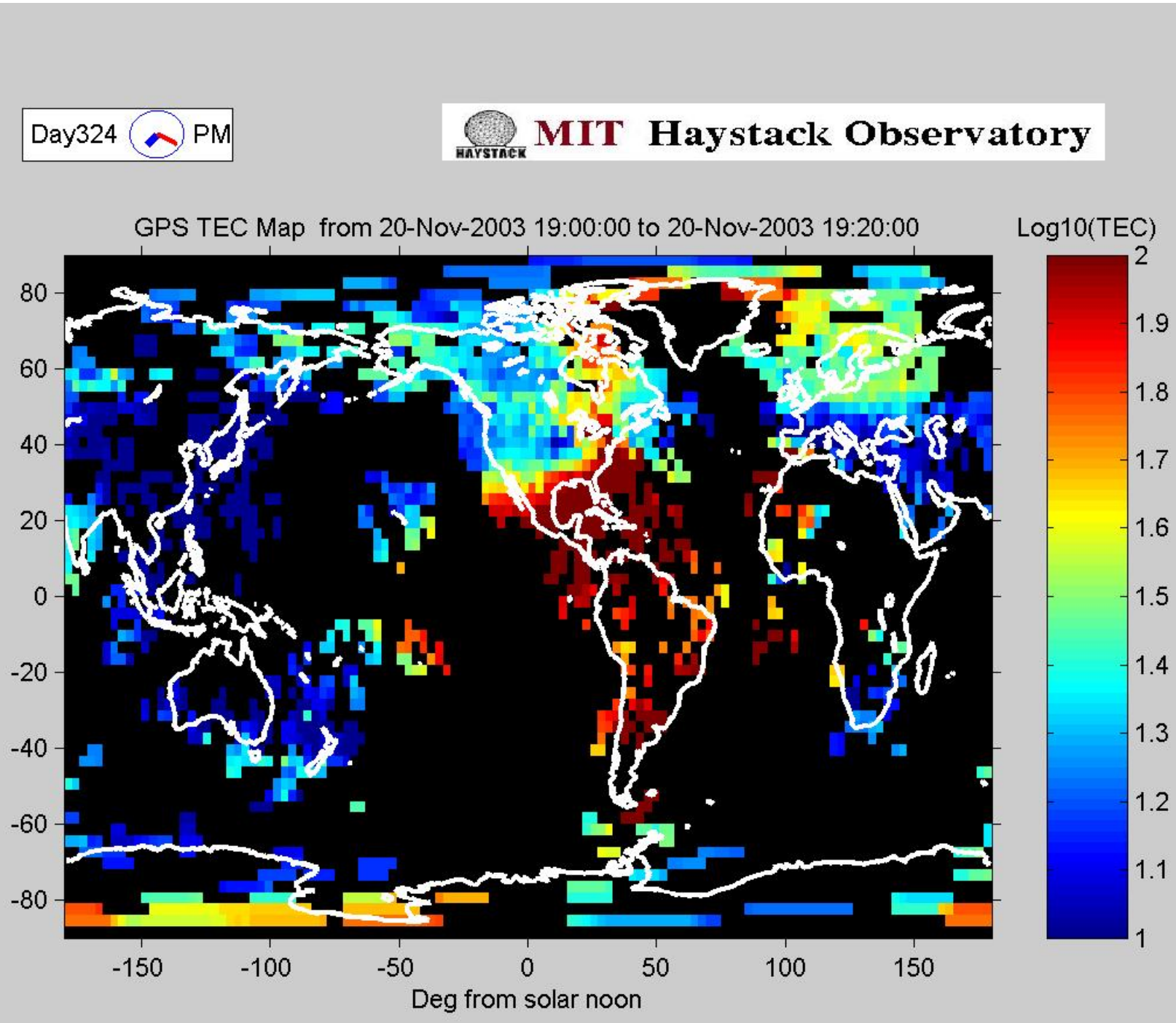
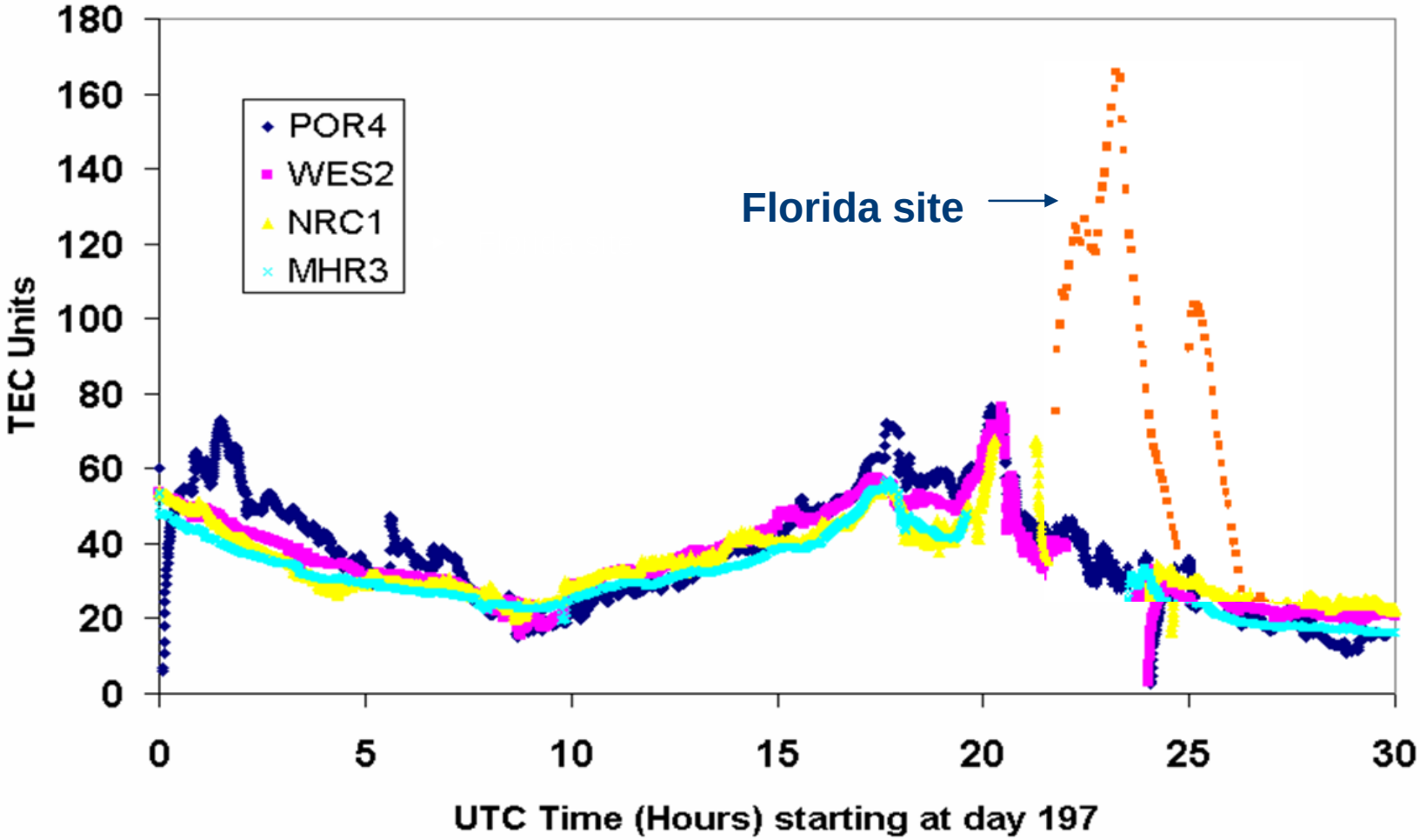
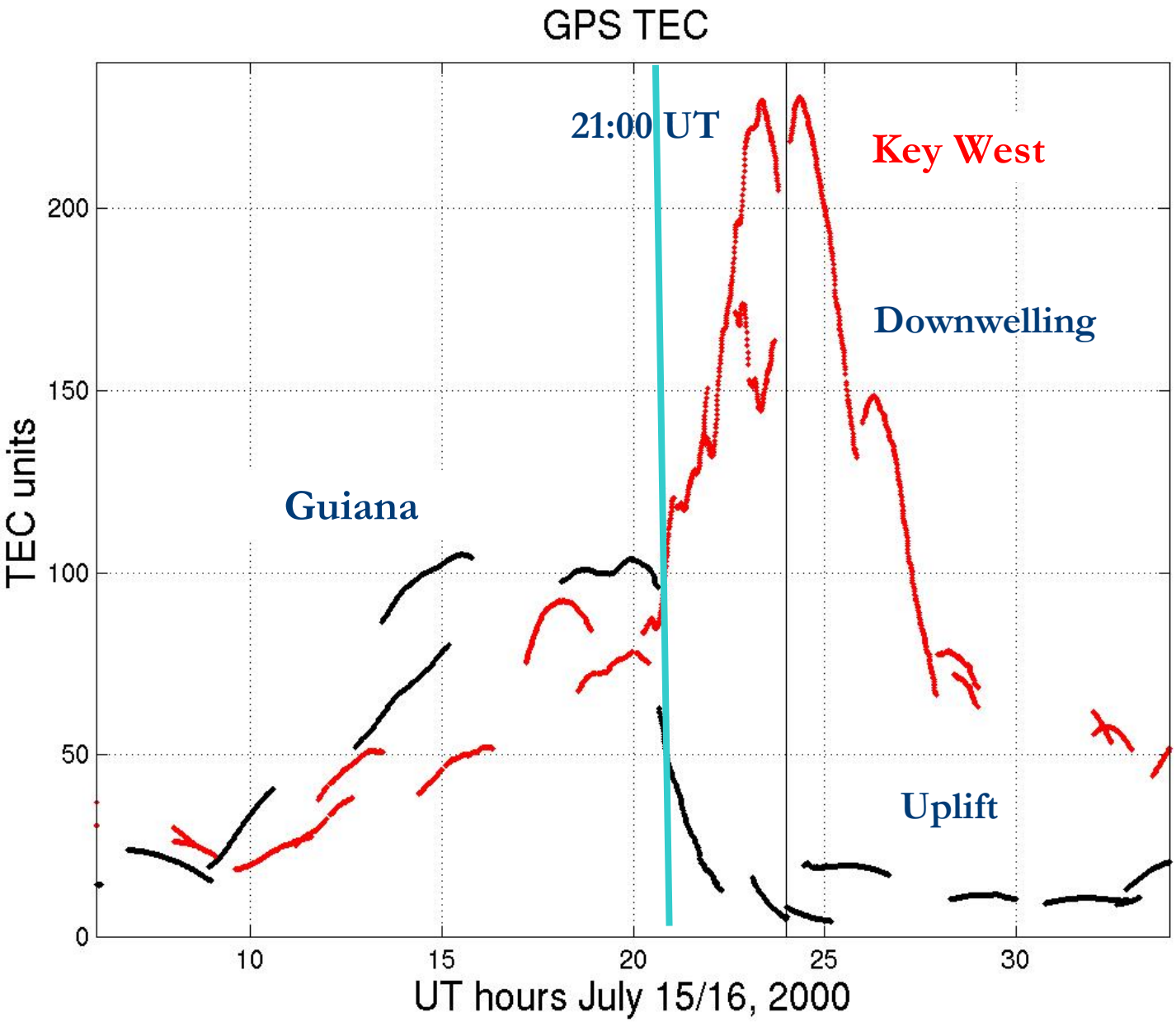
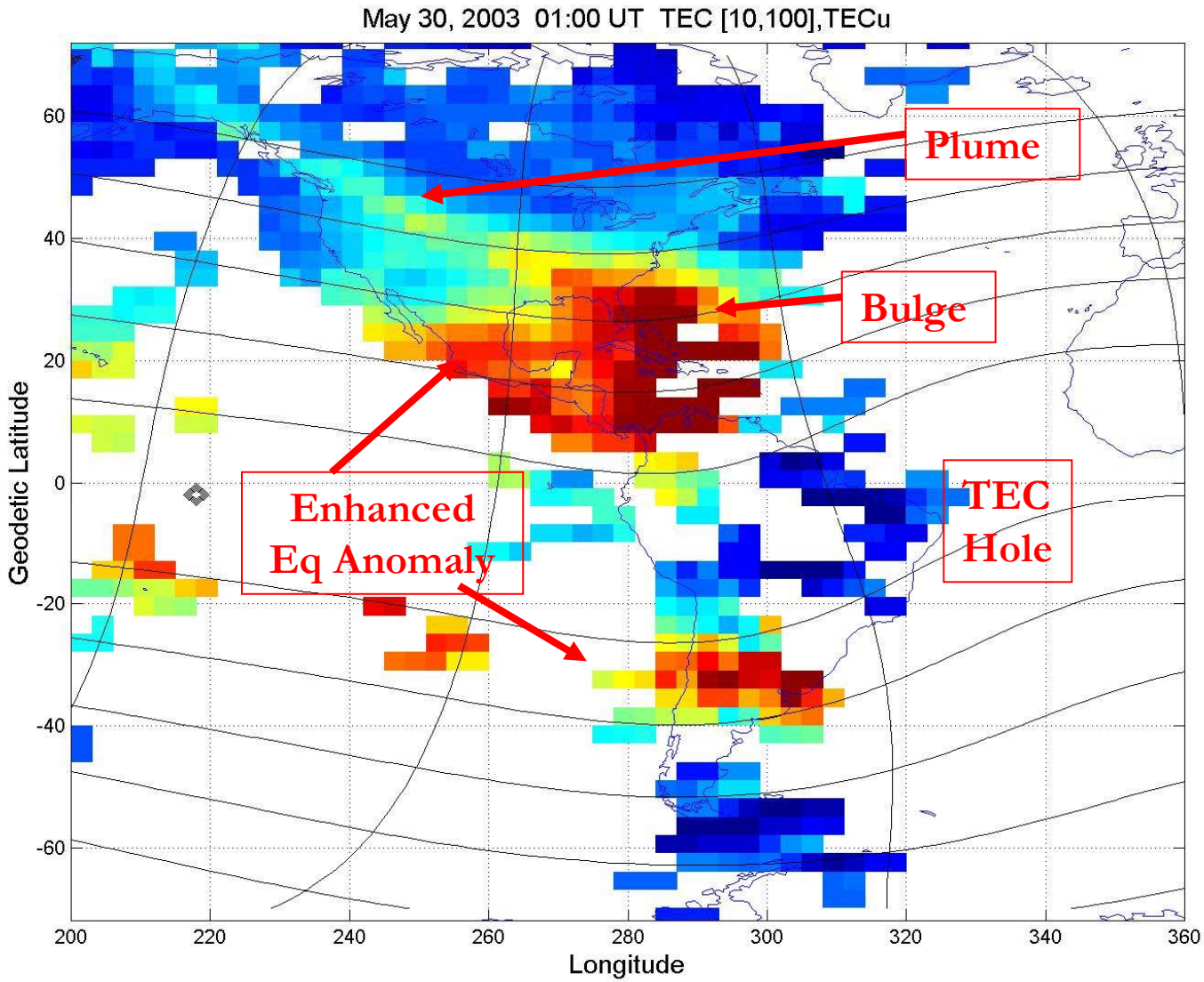

Day324
PM
MIT Haystack Observatory
GPS TEC Map from 20-Nov-2003 19:00:00 to 20-Nov-2003 19:20:00
Log10(TEC)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
Deg from solar noon

# TEC Disturbances on 15 July 2000




GPS TEC
21:00 UT
Key West
Downwelling
Guiana
Uplift
TEC units
0
50
100
150
200
10
15
20
25
30
UT hours July 15/16, 2000

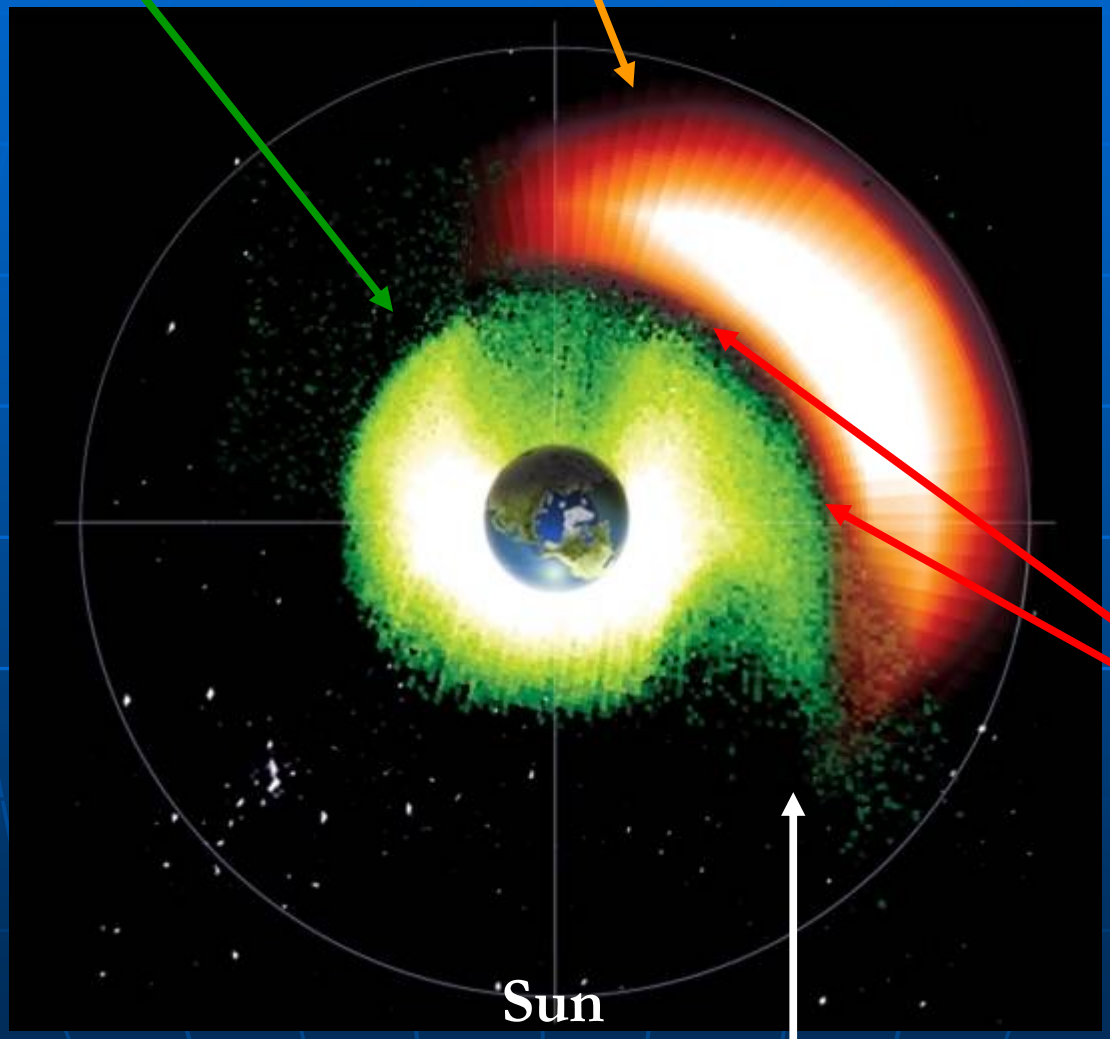
# Inner Magnetosphere – Low Latitude View



# Storm-time Electric Fields

- **Cross-tail electric fields energize and inject particles into the inner magnetosphere forming the disturbance Ring Current**
- **Strong penetration eastward electric field uplifts equatorial ionosphere**
  - **Equatorial anomaly enhanced**
- **Radial/Poleward Polarization Jet Electric Fields form (Sub Auroral Polarization Stream). As the Polarization Stream overlaps the outer plasmasphere**
  - **Storm-Enhanced Density (SED)**
  - **Detached plasmas/plasma tails**

# Plasmasphere / Ring Current Interactions




April 17, 2002
NASA IMAGE

SAPS Channel

Plasmasphere Erosion Plume

(Merged image courtesy J. Goldstein)

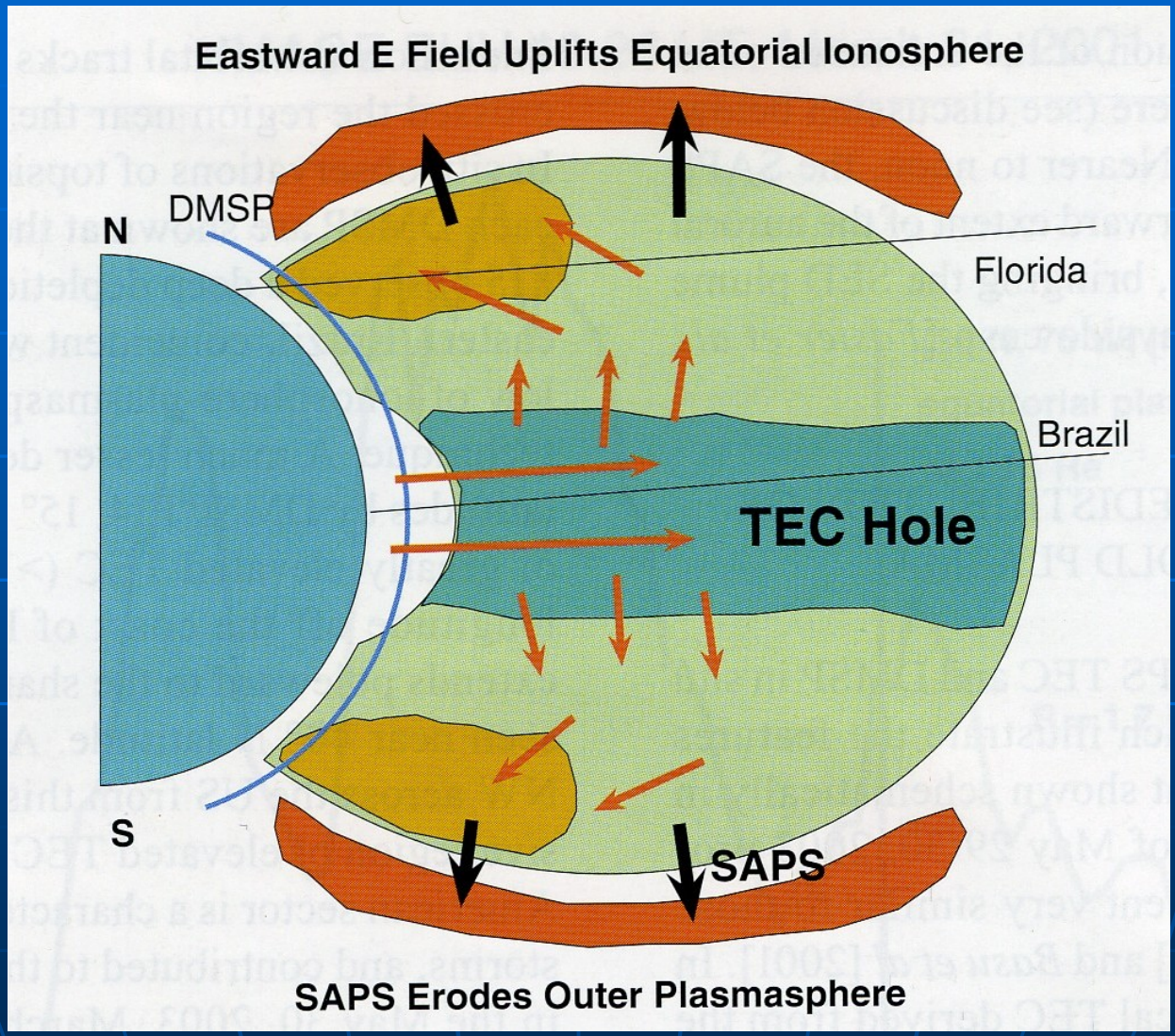
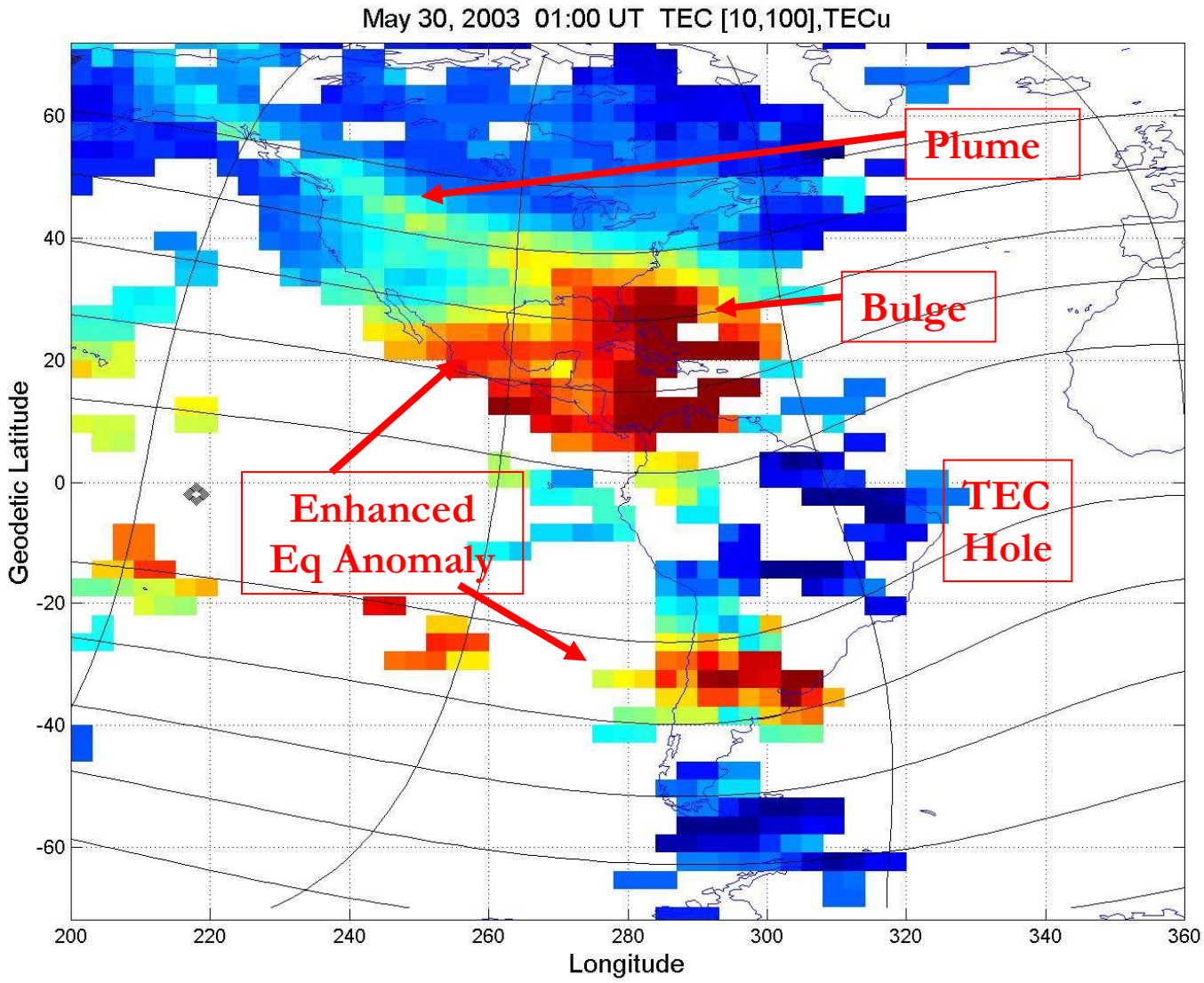
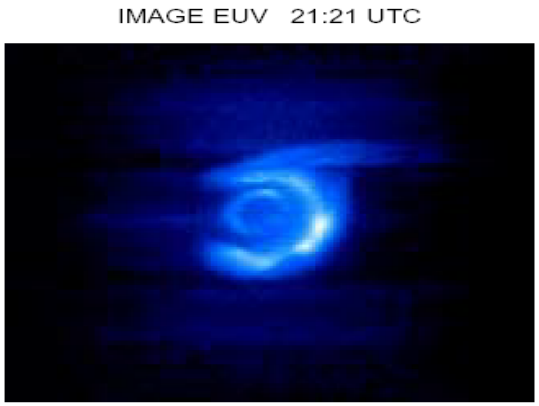


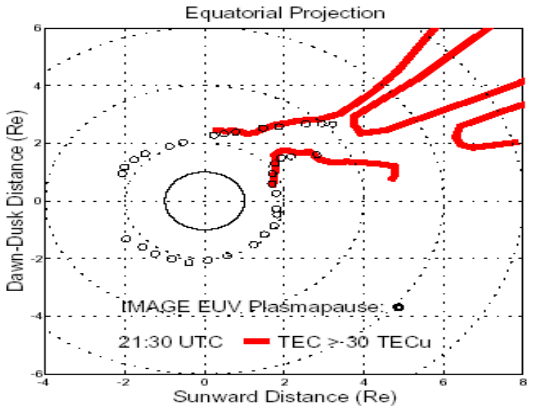

Figure courtesy of J. Foster

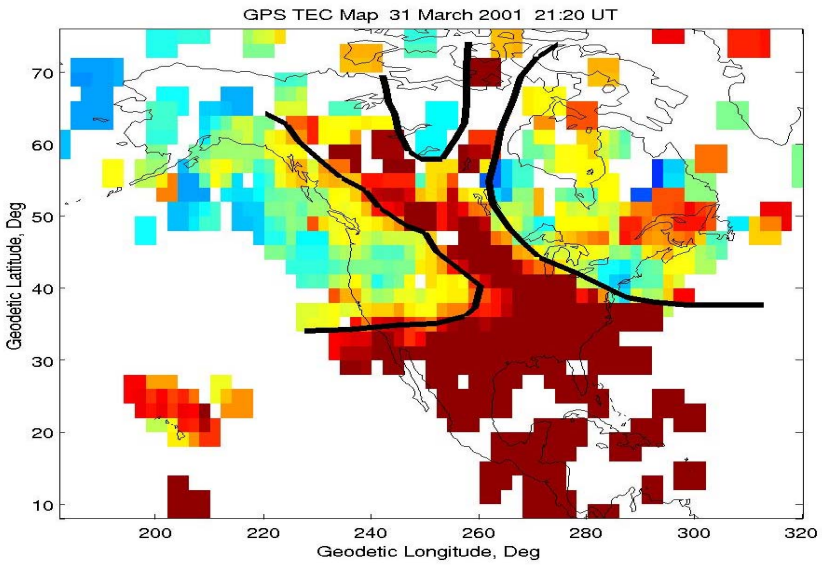
# Inner Magnetosphere – Low Latitude View



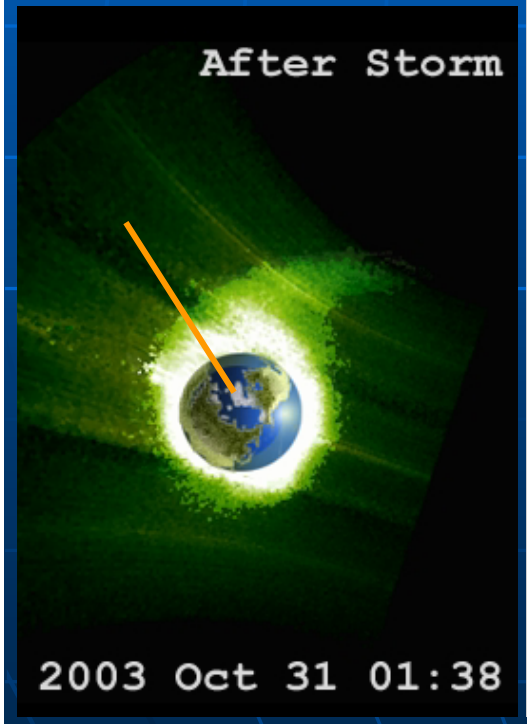
# Plasmaspheric Tails and Storm Enhanced Density

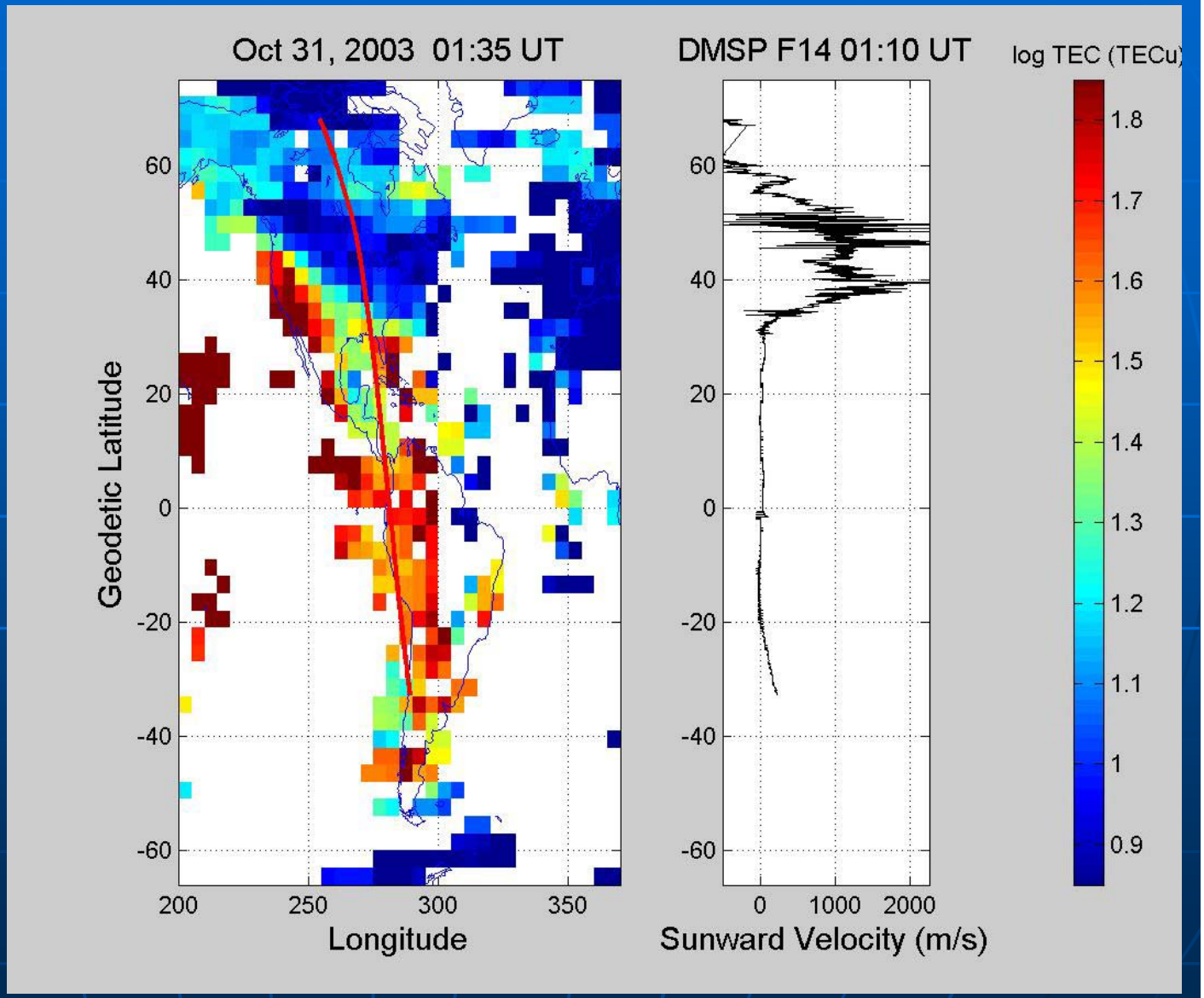


# GPS TEC / IMAGE EUV/ DMSP

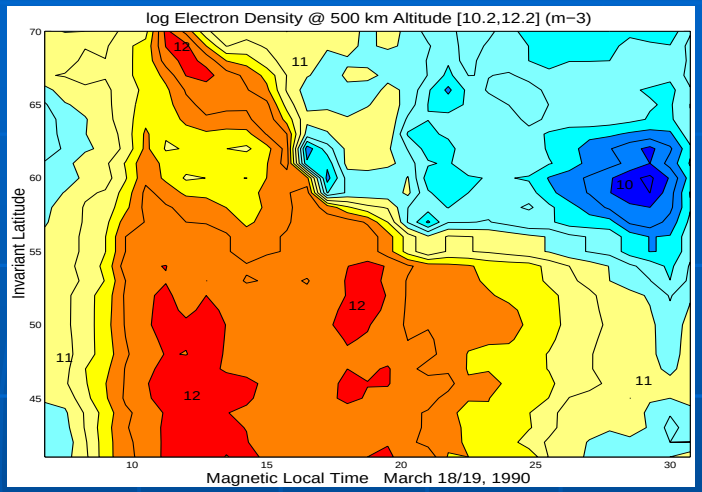


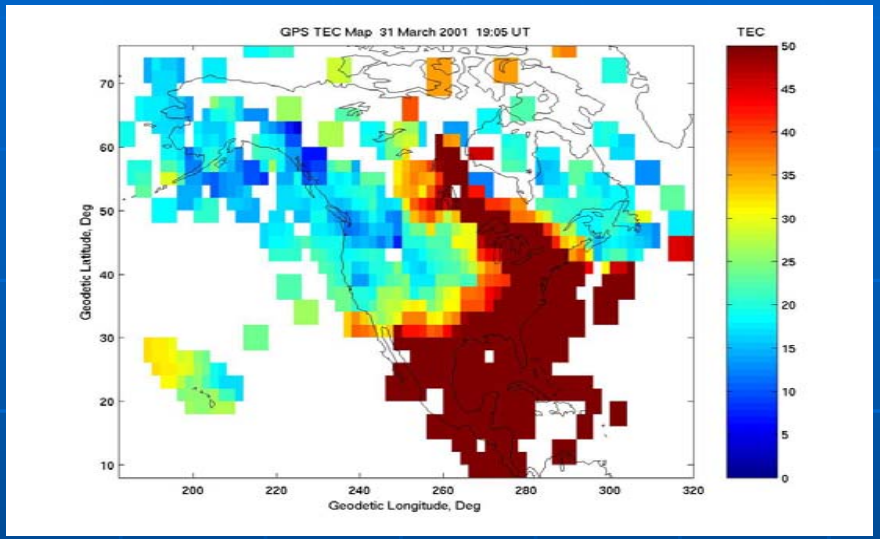

(EUV courtesy J. Goldstein)

# A Decade Of Storm Enhanced Density

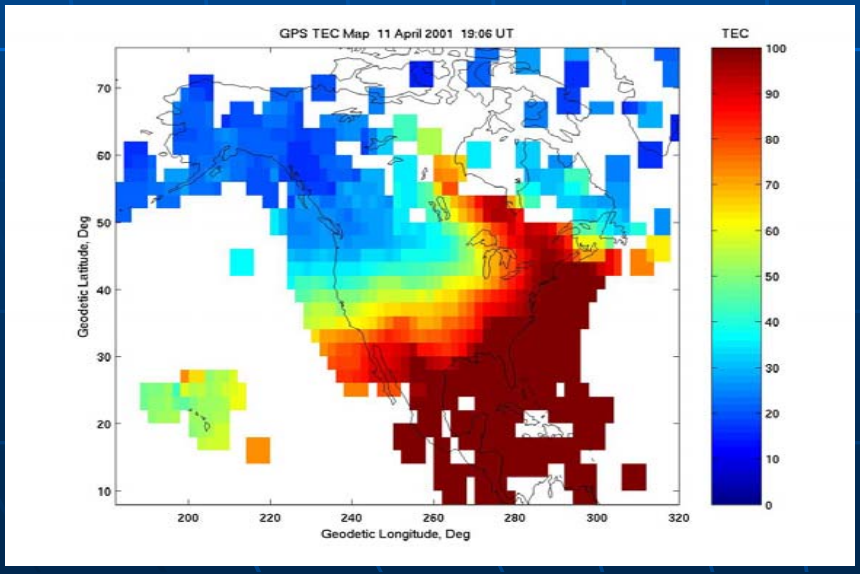
## Day 77, 1990



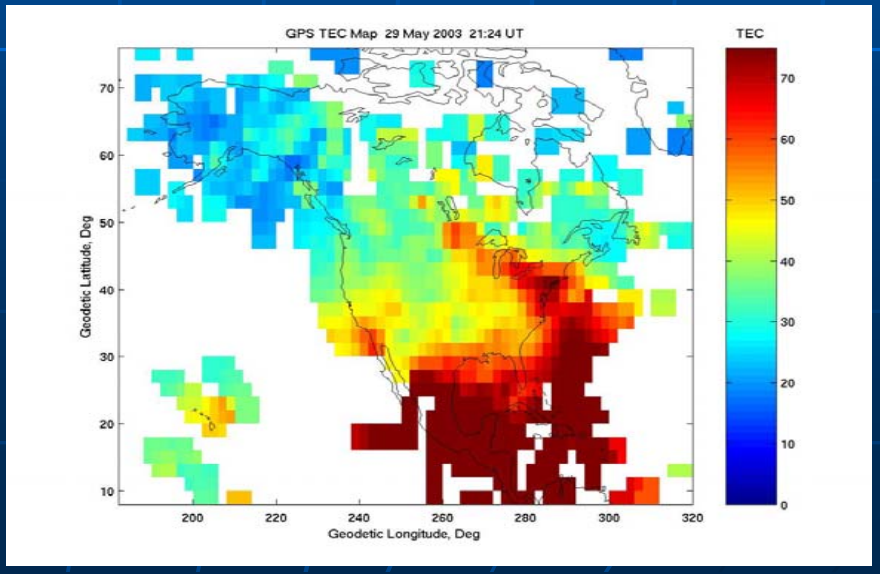

## Day 90, 2001




## Day 101, 2001

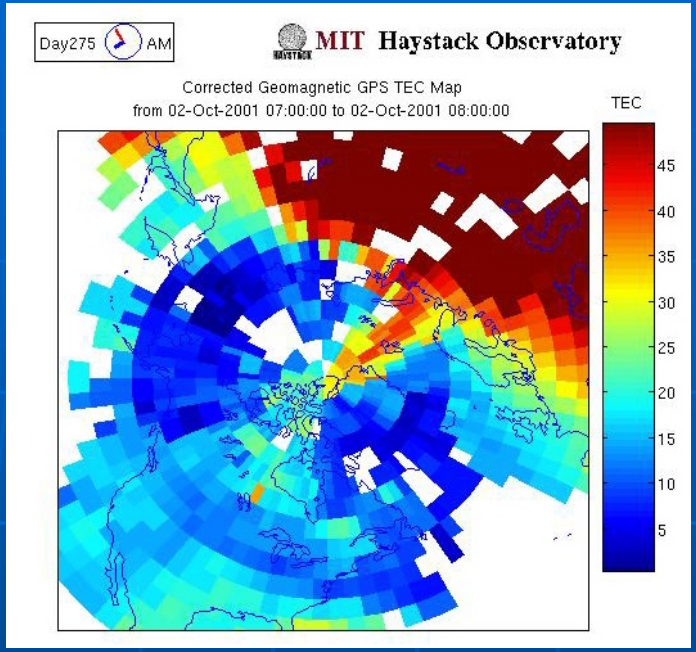


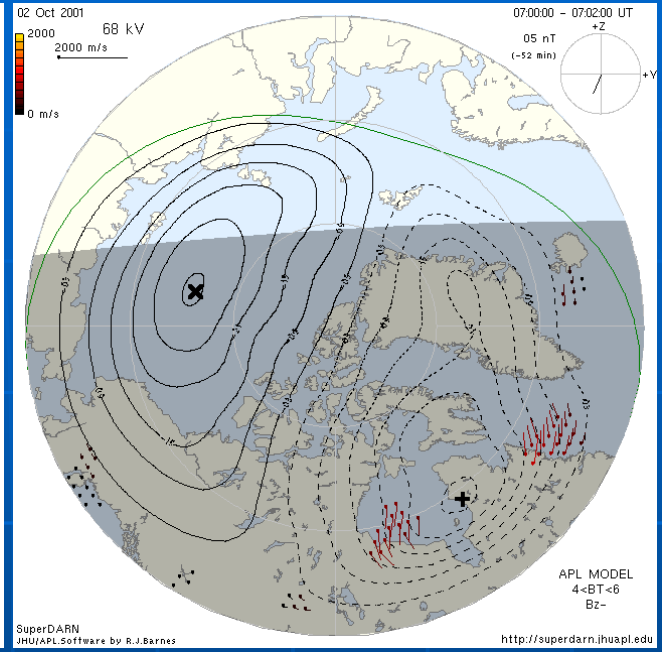

## Day 149, 2003



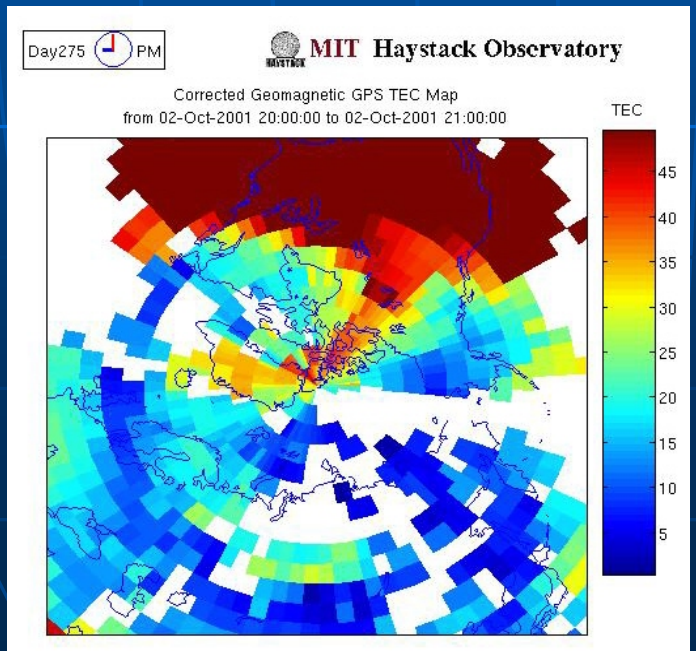
# Northern Europe and American Sector SED Plumes

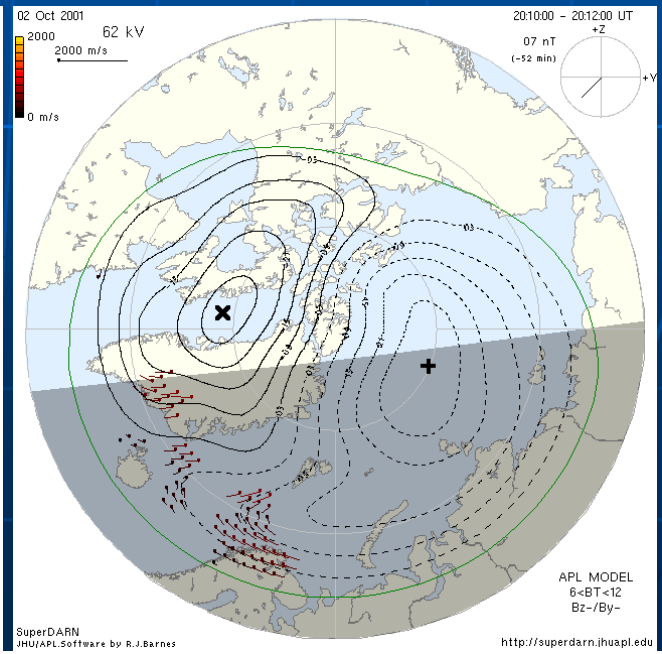
Northern Europe



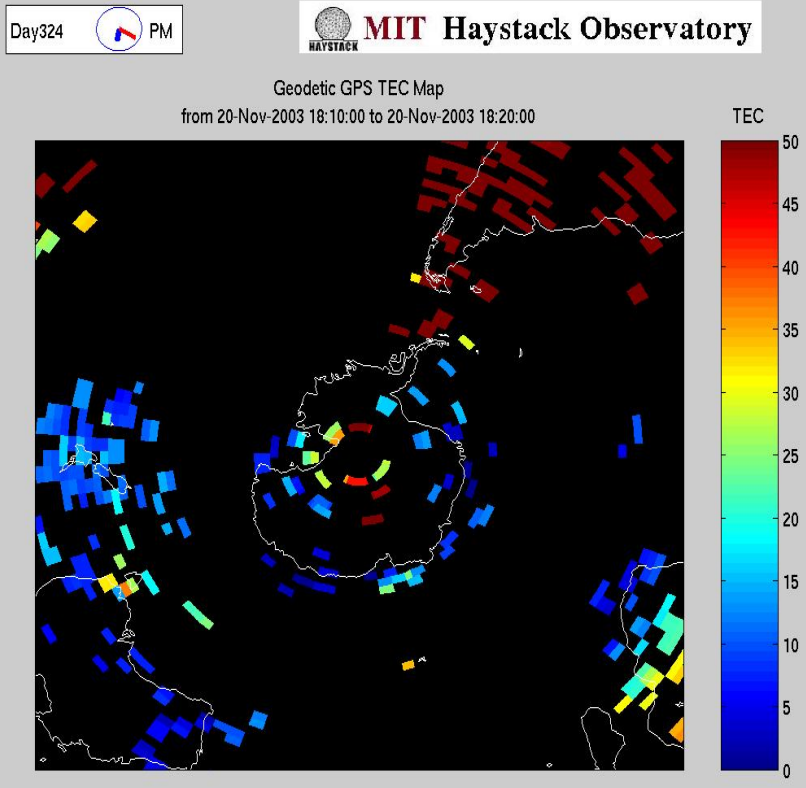



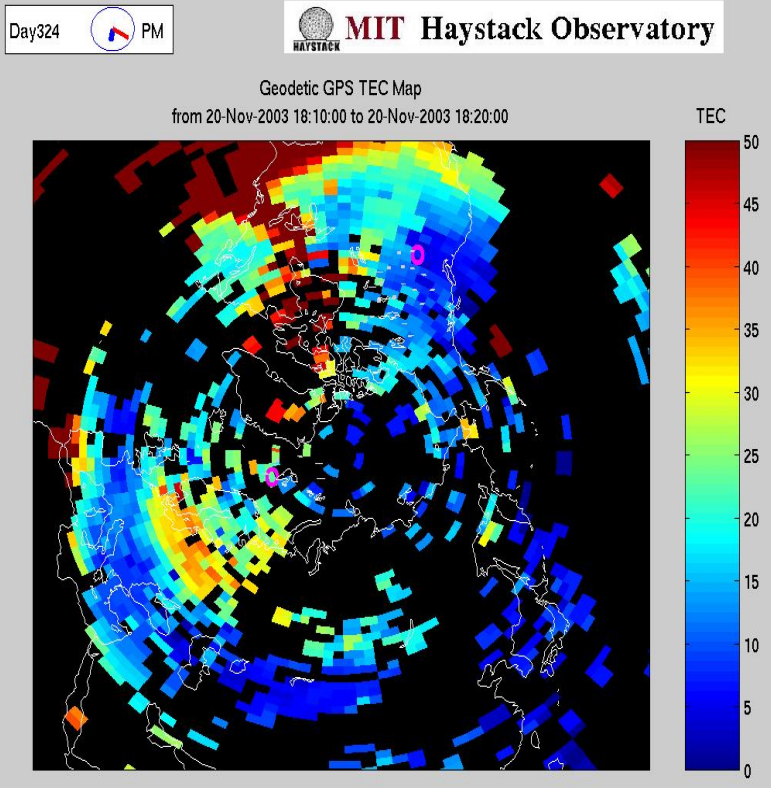

American Sector



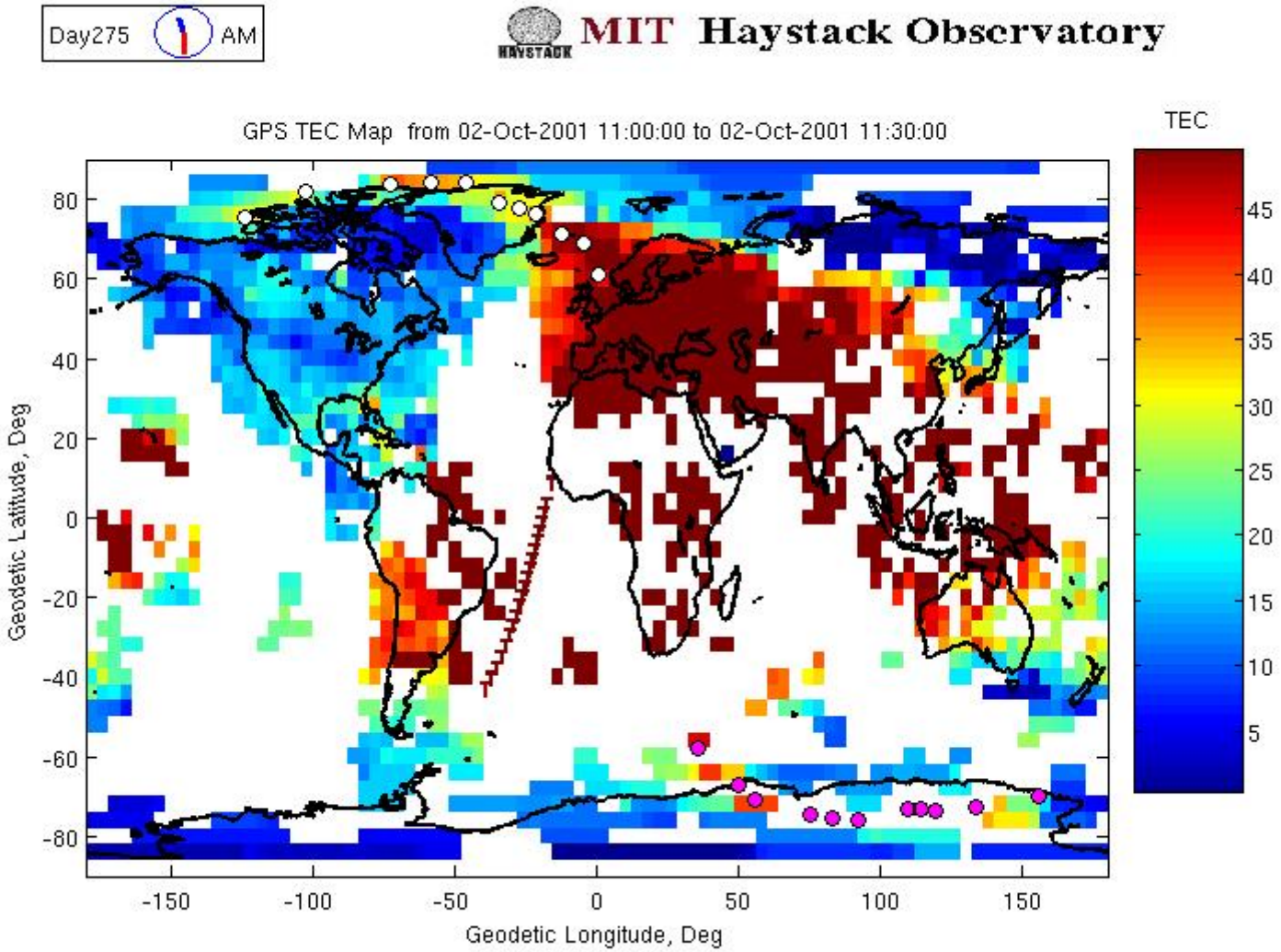



# 20 Nov 2003 18:20 UT



# Conjugacy Examples



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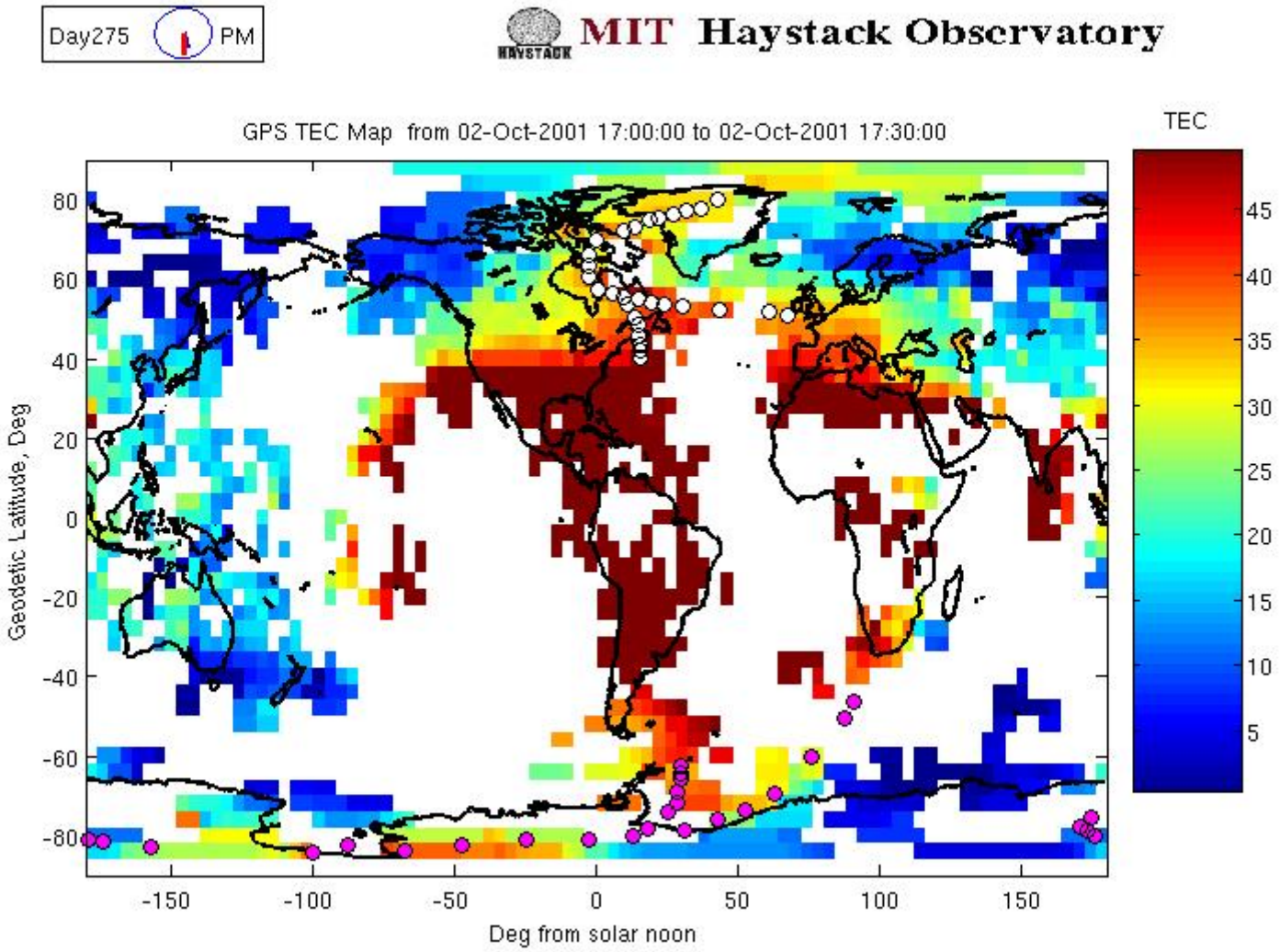
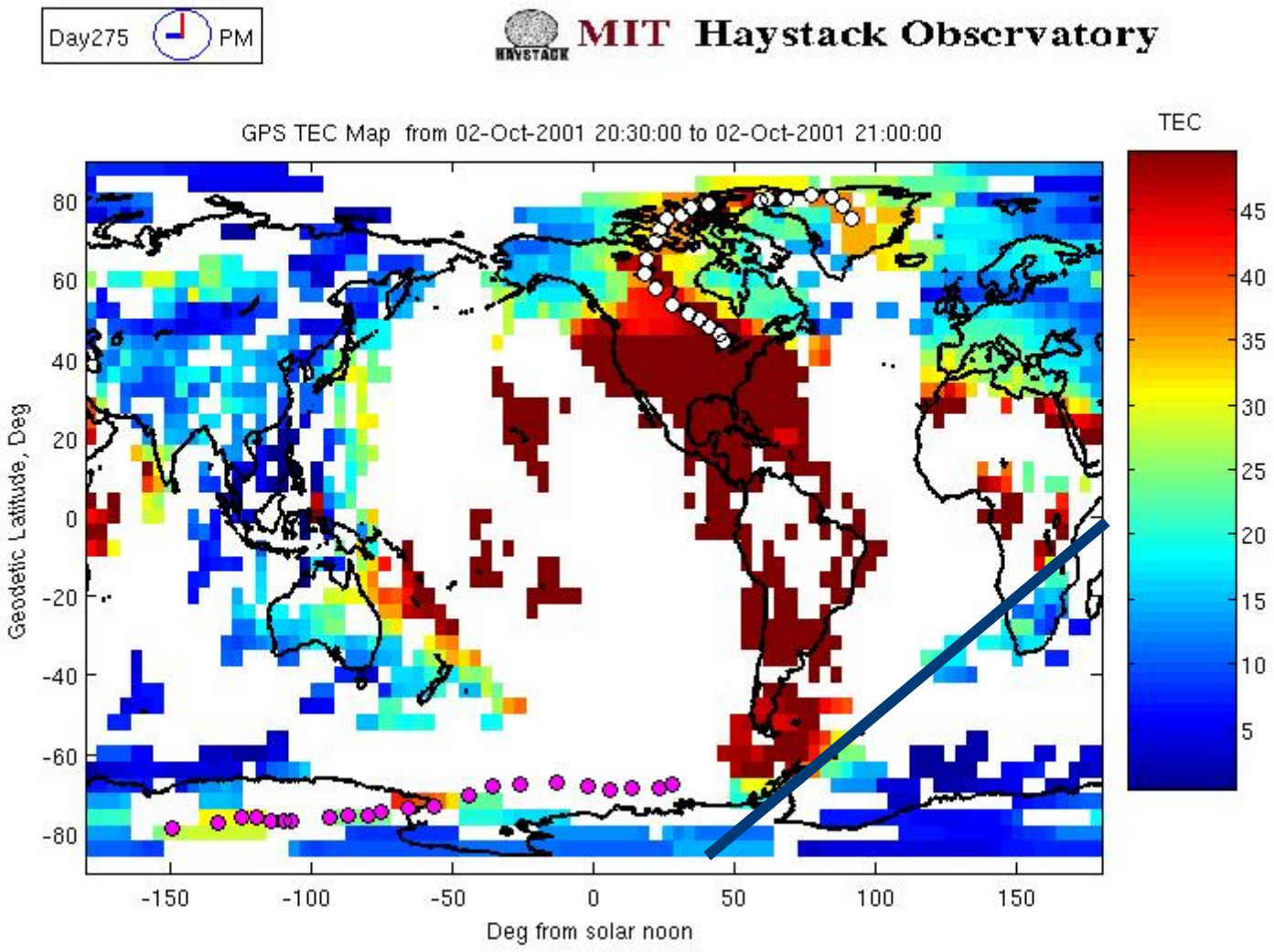


# Conjugacy Examples



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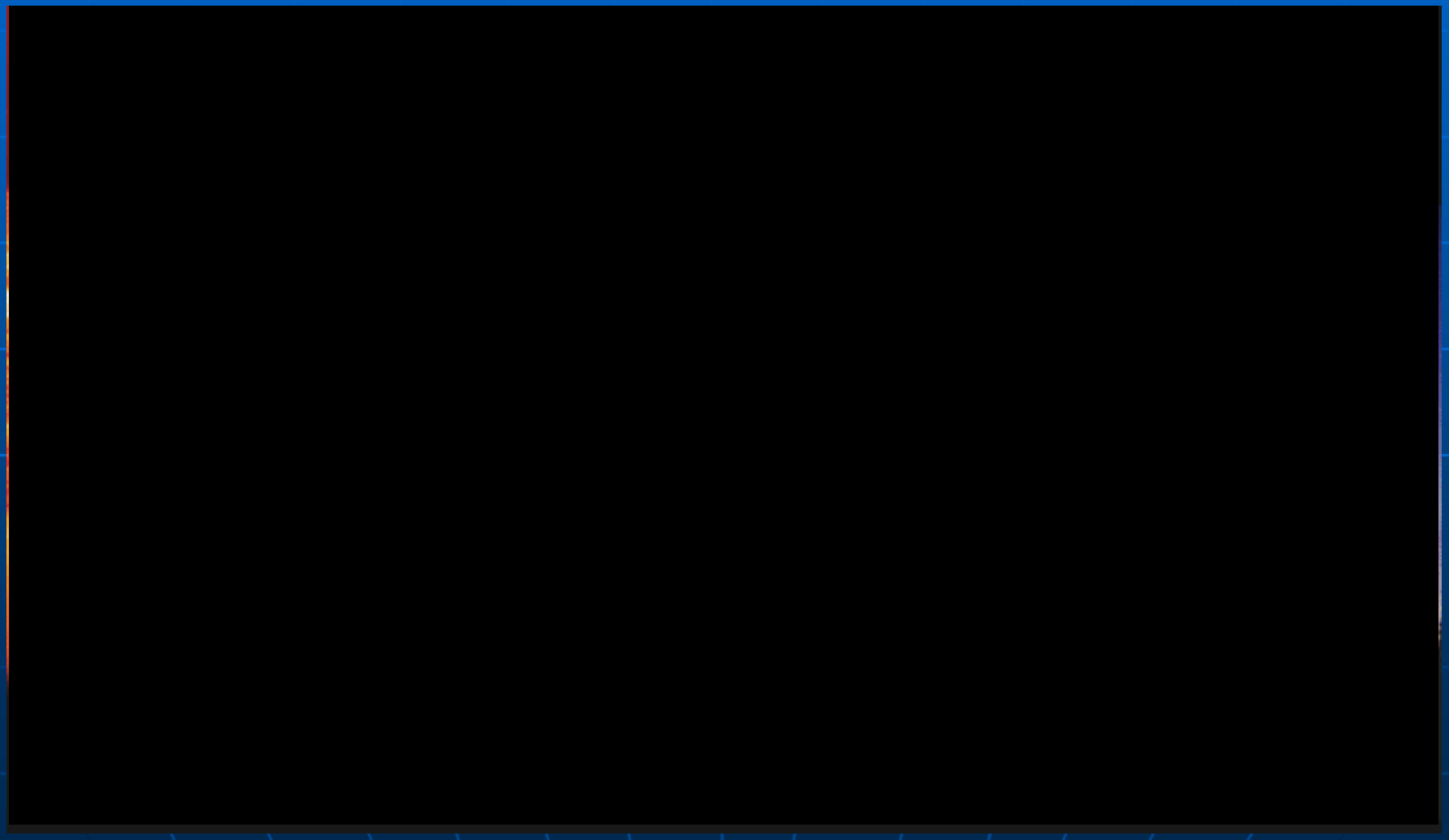

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