Solar Flare Effects on the Thermosphere and Ionosphere

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Introduction

- Solar flares are sudden increased brightness from the Sun's active regions;
- Solar flares cause rapid increase (within minutes) of solar irradiance, especially in soft X-ray (0.1 – 10 nm) and EUV (10 – 121.6 nm).
- Their radiation only take eight minutes to arrive at Earth;
- The largest flare on record is an X28 flare that occurred on November 4th, 2003 (GOES);
- Ionosphere: Sudden Ionospheric Disturbances (SID)
  - affect HF radio communication, GPS navigation systems
- Thermosphere: rapid increase of neutral density
  - affect on satellite drag

Outline

Use model simulations and observations to understand solar flare effects in the thermosphere and ionosphere (TI) system:

- Solar flare responses in the TI system
  - Magnitudes and temporal scales
  - Altitude dependency
  - Solar zenith angle dependency
  - Effects on electrodynamics
- How flare characteristics affect the responses
  - Flare location effect
  - Flare total variability energy
- Flare response and TAD (Traveling Atmospheric Disturbance) occurrence during the active period of September 2017

Model and Data

Models

- NCAR TIME-GCM
  - Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model
  - ~ 30 – 600 km
  - 2.5^{o} x 2.5^{o}, ¼ scale height
- FISM
  - Flare Irradiance Spectral Model
  - GOES X-ray, TIME/SEE, SORCE, UARS/SOLSTICE
  - 0.1 – 190nm, 1nm spectral resolution
  - Daily (1-day temporal resolution): 1947 – present
  - Flare (1 minute temporal resolution): 1982 - present

Data

- Swarm neutral density data
- GPS TEC (Total Electron Content) data
- ISR (incoherent Scatter Radar) electron density data

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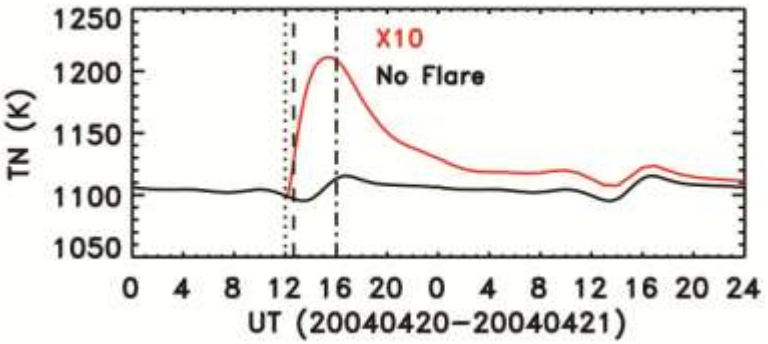
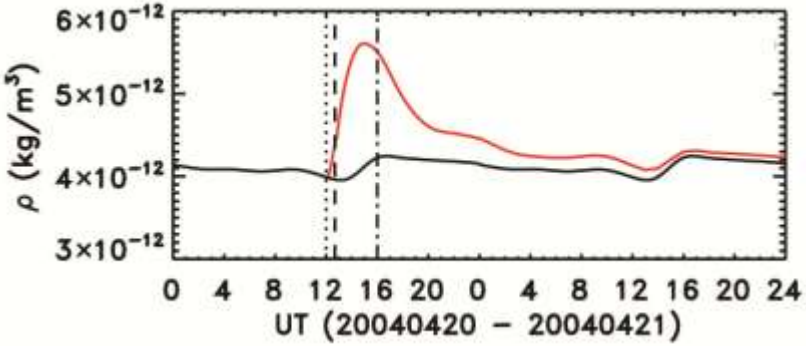
Time Series of Flare Responses to an X10 Flare

400km, noon, 2.5°S

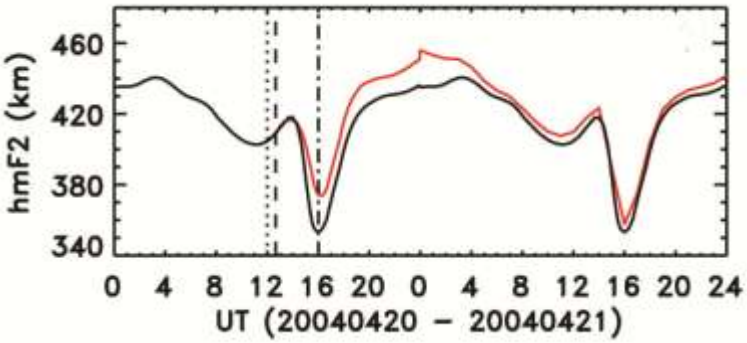


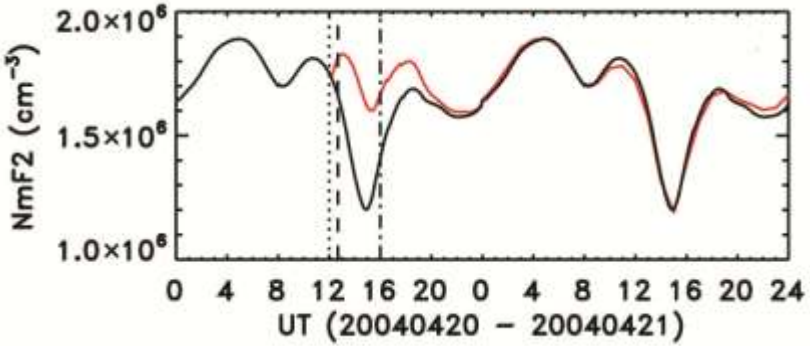
400km



Maximum Change of Temperature: ~ 100K

Maximum Change of Density: ~ 30%





Maximum Change of hmF2: ~20km

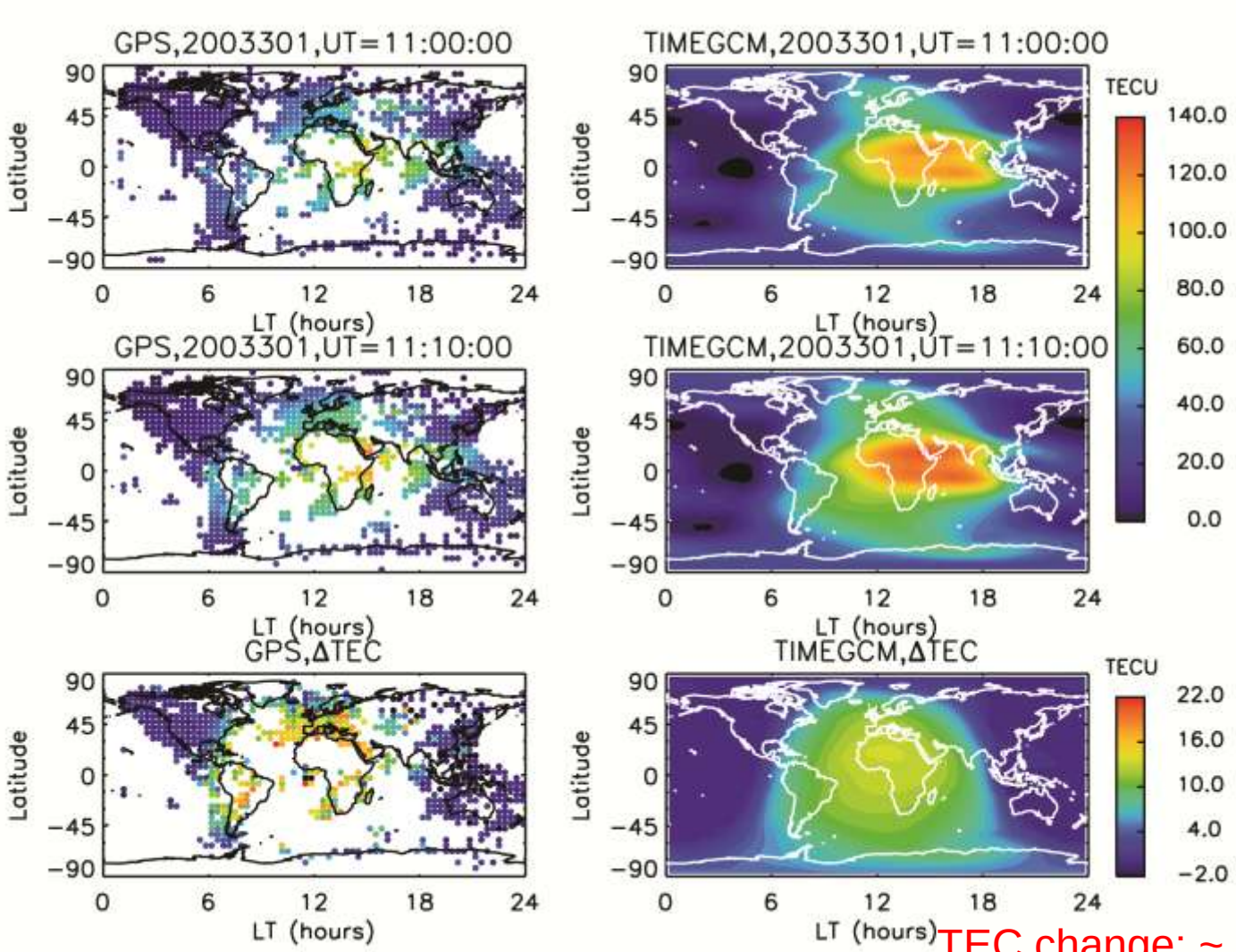
Maximum Change of NmF2: ~30%

Flare times: 12:00UT, 12:40UT, 16:00UT

Maximum changes occurred ~ 2 hrs after the flare peak

Flare effects lasted for more than a day after the flare decayed.

TEC Response to an X17 Flare Occurred on October 28, 2003



TEC change: ~ 20-30%

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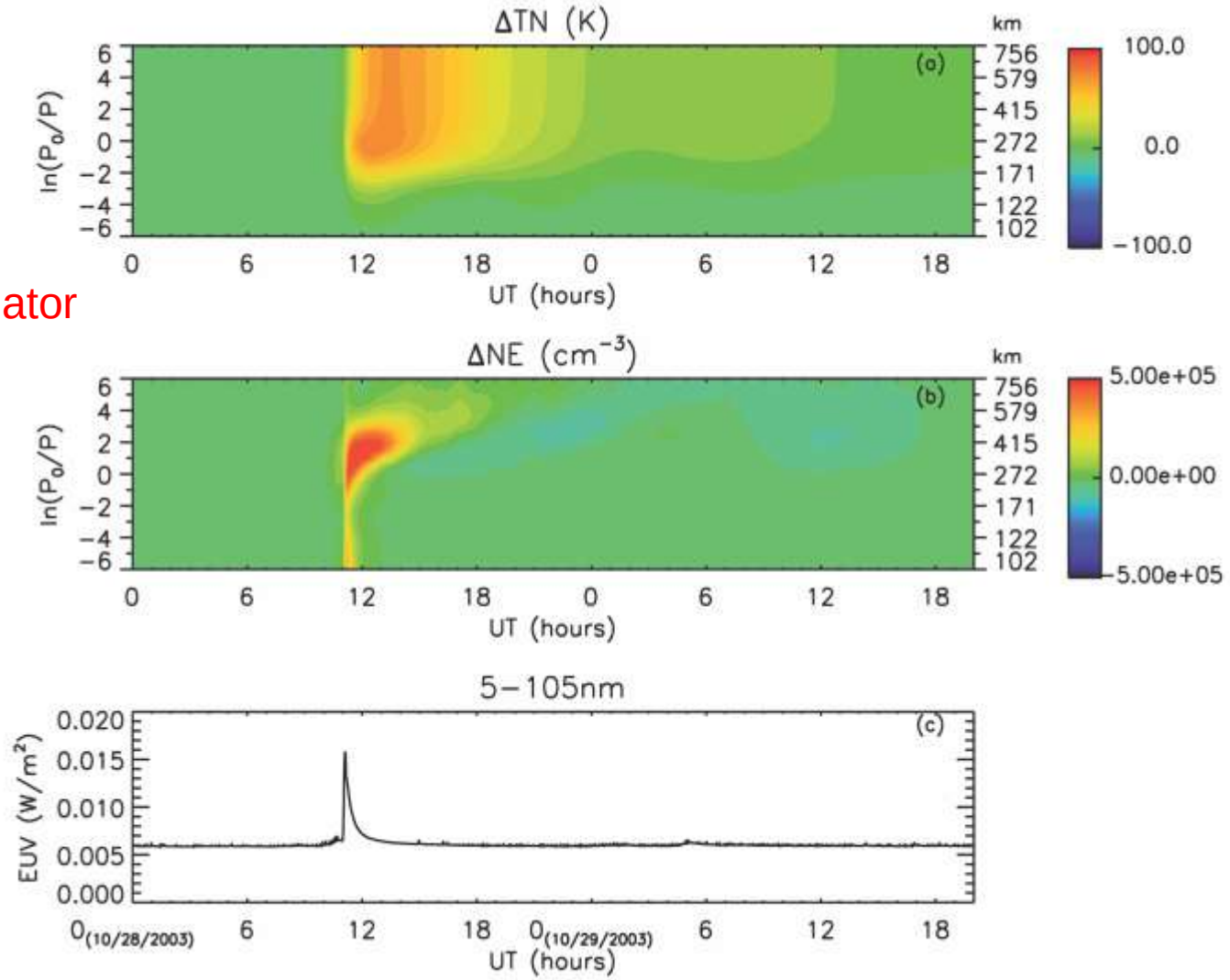
Altitude Dependency of Flare Responses to an X17 Flare Occurred on October 28, 2003

Local Noon,
Magnetic Equator



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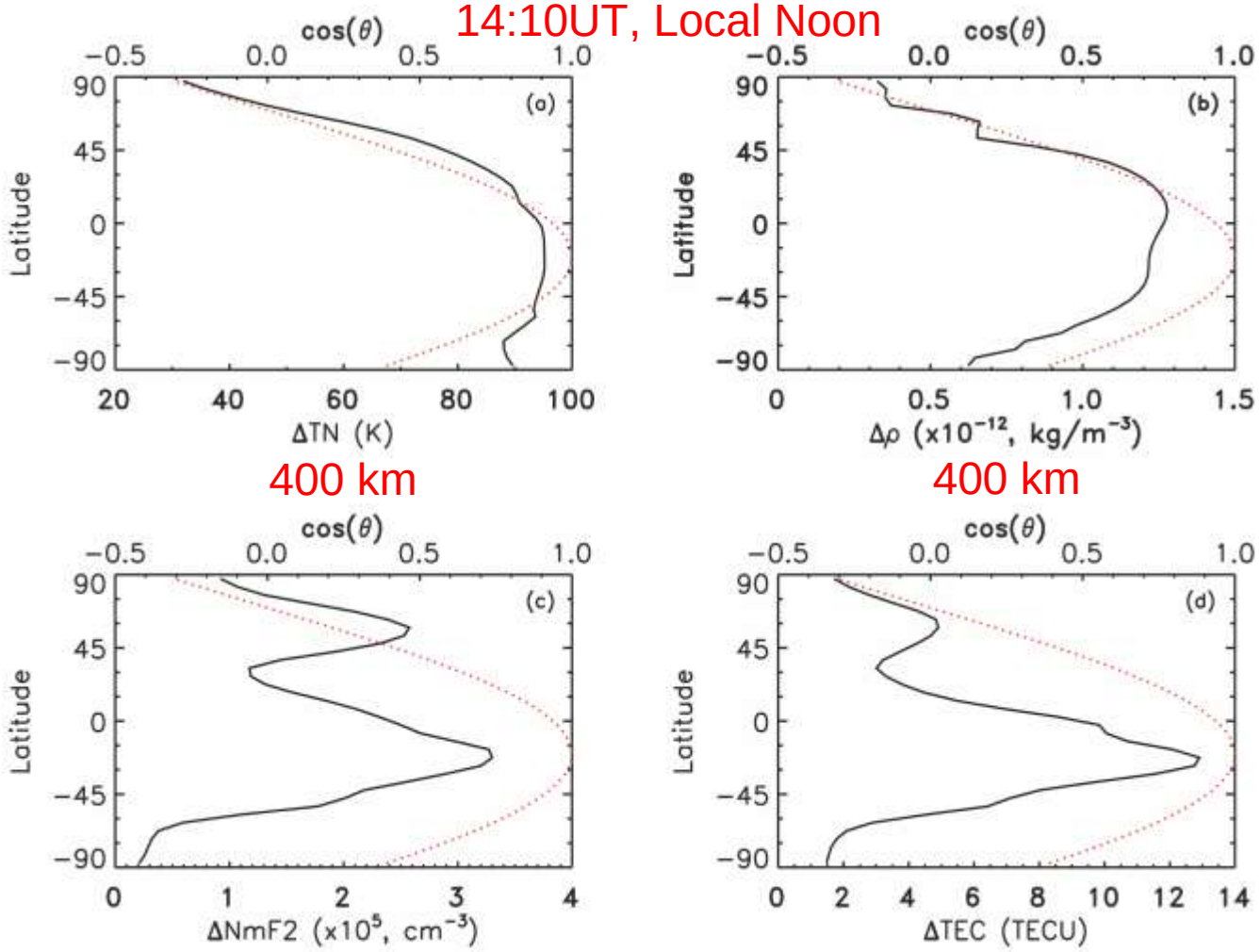
Solar Zenith Angle Dependency of Flare Responses to the X10 Flare on January 20, 2004

14:10UT, Local Noon



400 km

400 km

12:00UT, 12:40UT, 16:00UT

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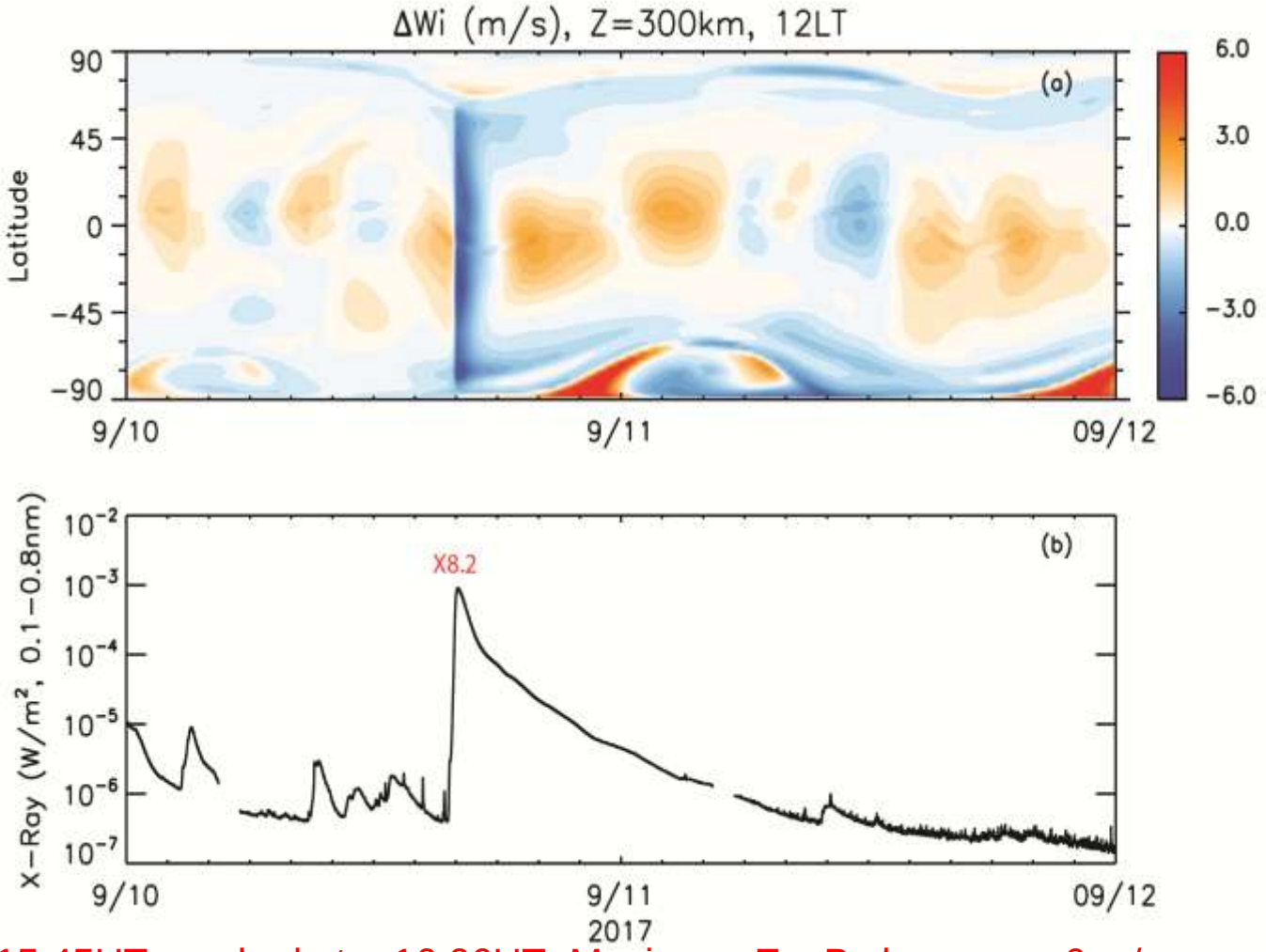
Vertical E x B drift Response to an X8.2 Flare Occurred on September 10, 2017



Started ~ 15:45UT, peaked at ~ 16:06UT; Maximum E x B change: ~ -6 m/s, or ~ -20%

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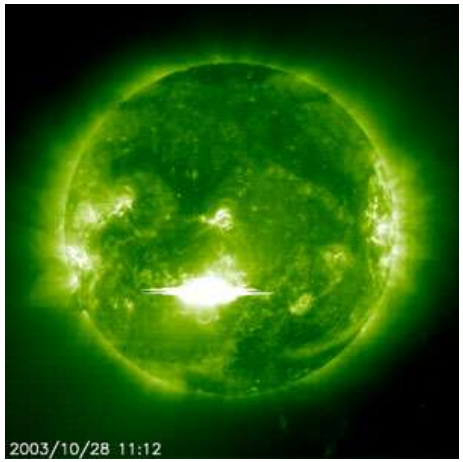
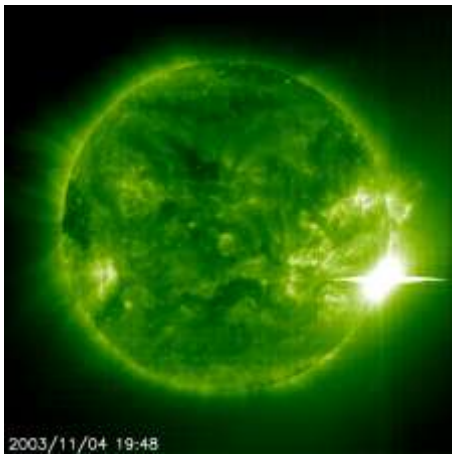
Disk Versus Limb Effect

X17, 2003/10/28 11:12

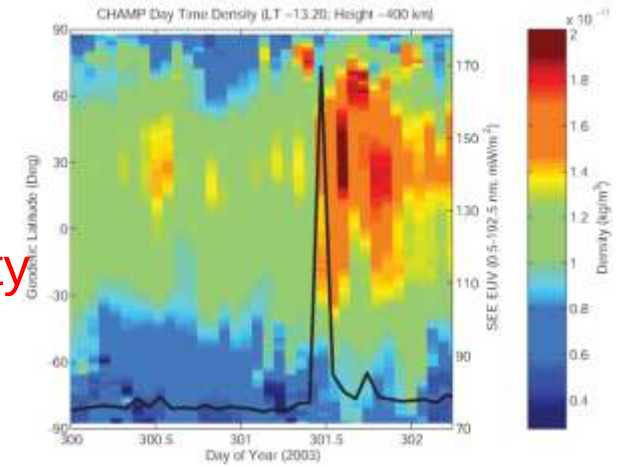
X28, 2003/11/04 19:48

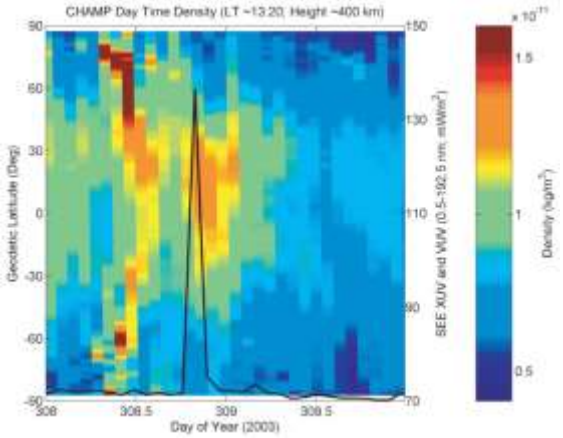
SOHO EIT





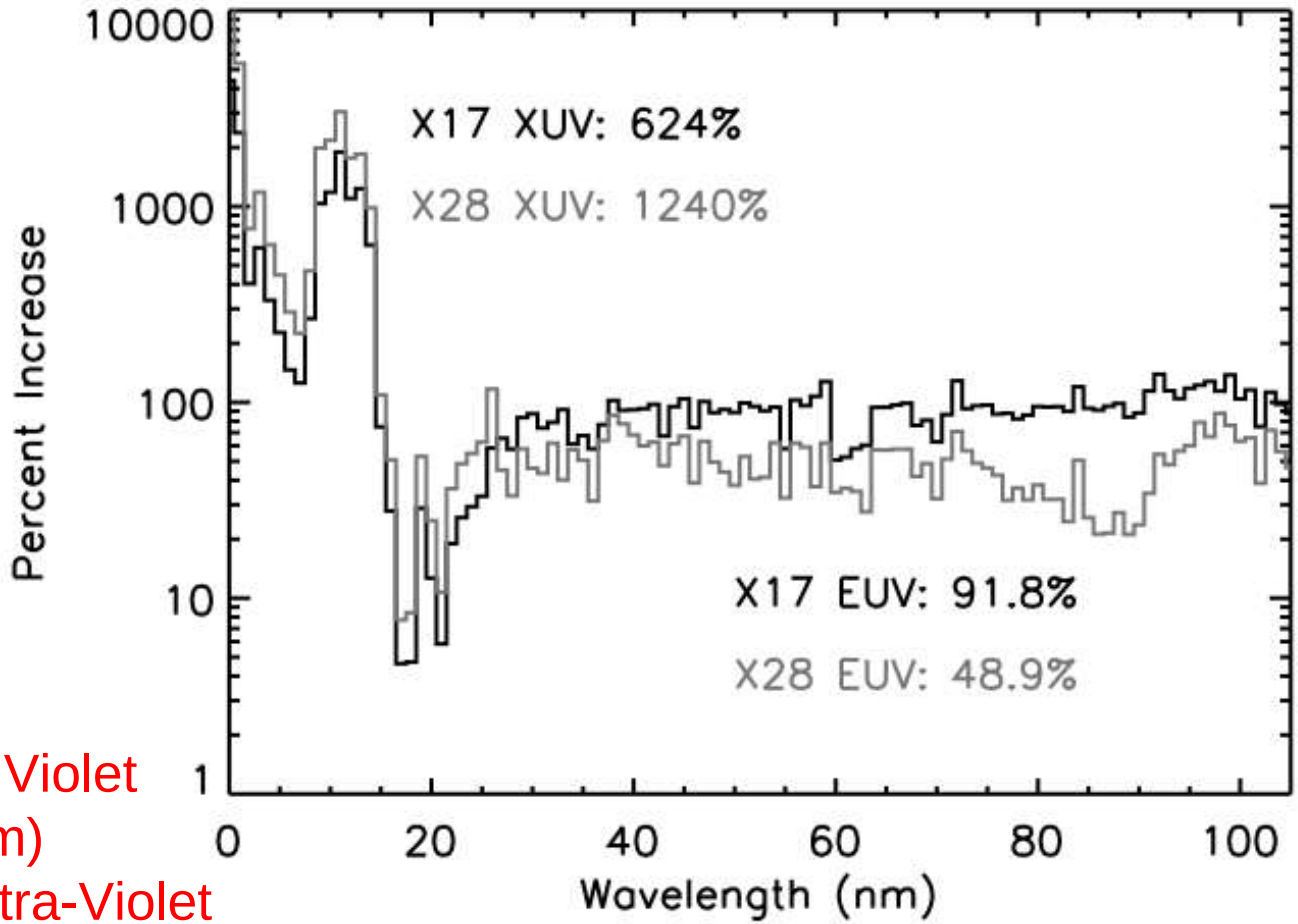
CHAMP
Neutral Density





Disk Versus Limb Effect

TIMED Solar EUV Experiment

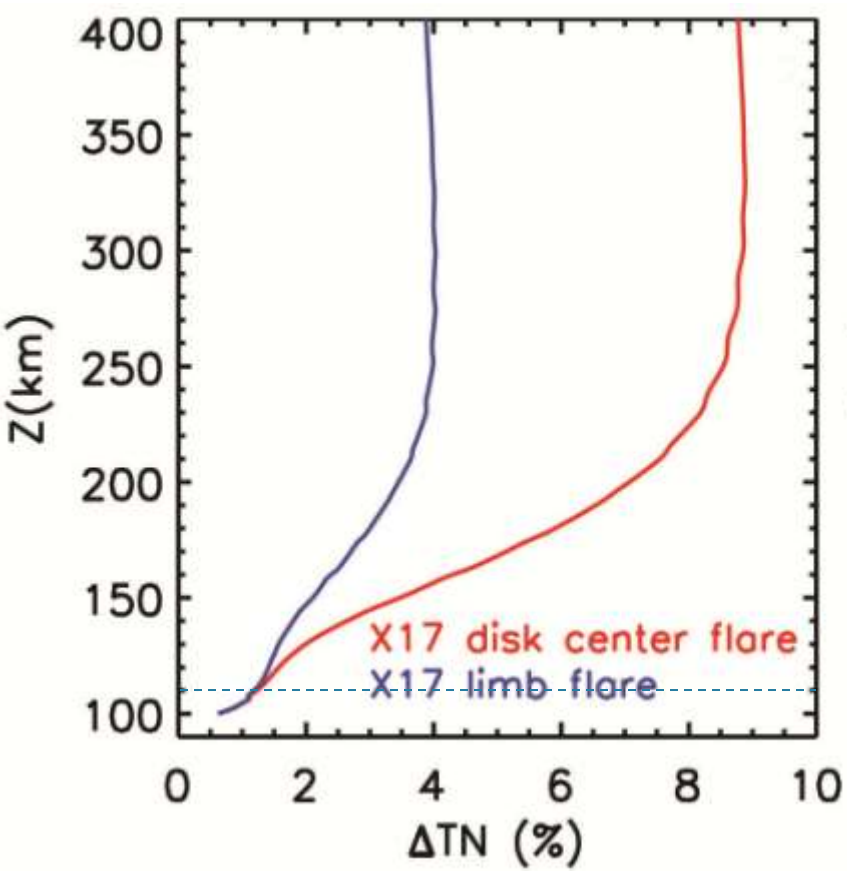


Chamberlin et al., 2008

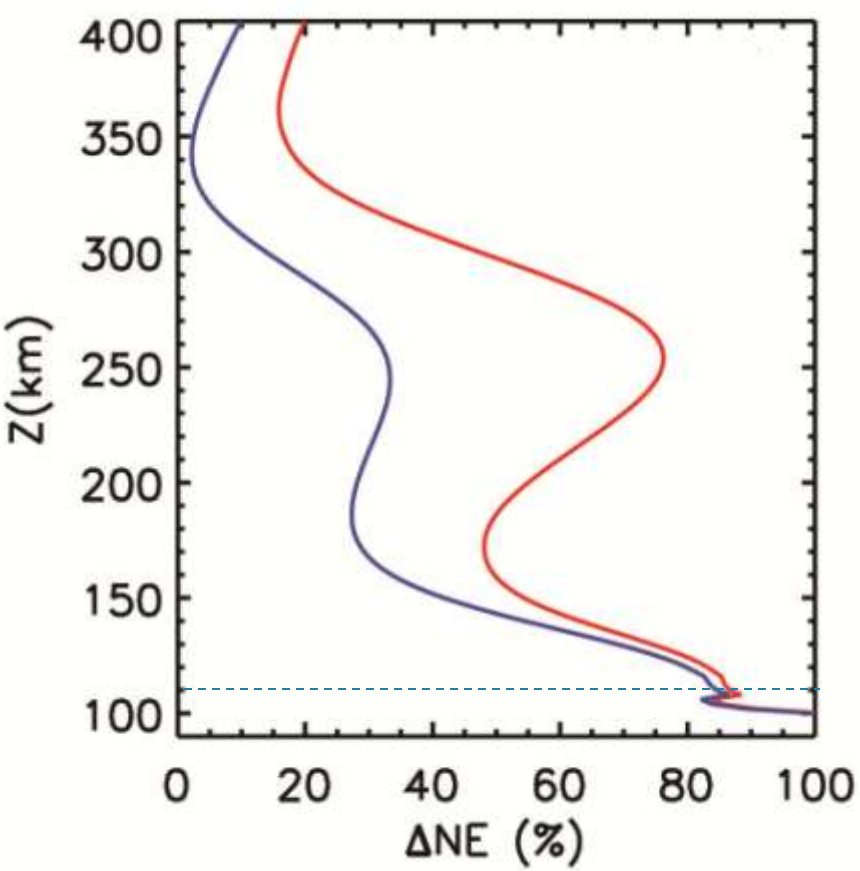
XUV: X-ray Ultra Violet
(0.1 – 27 nm)

EUV: Extreme Ultra-Violet
(27 – 120 nm)

Disk Versus Limb Effect



> 2 times



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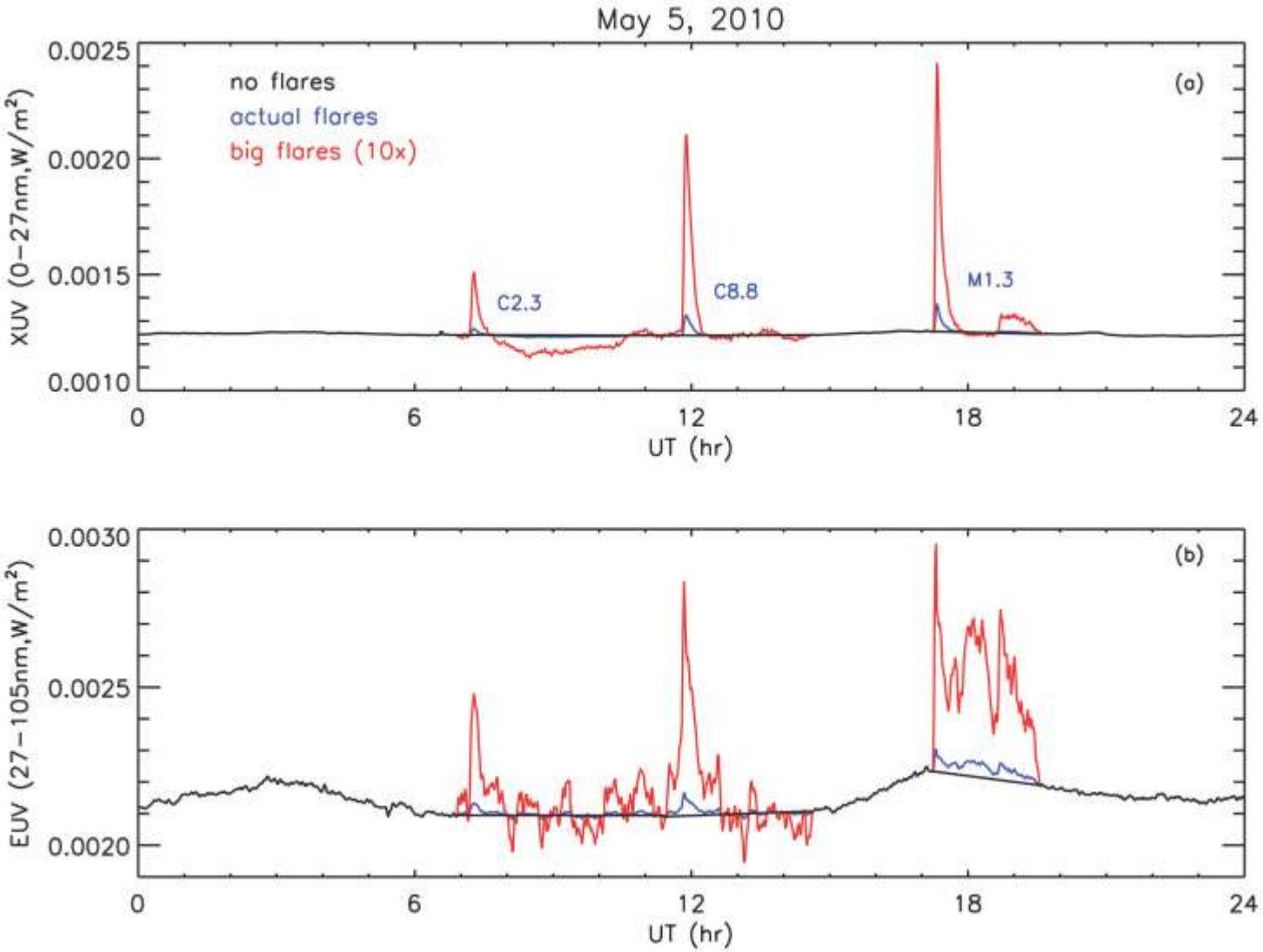
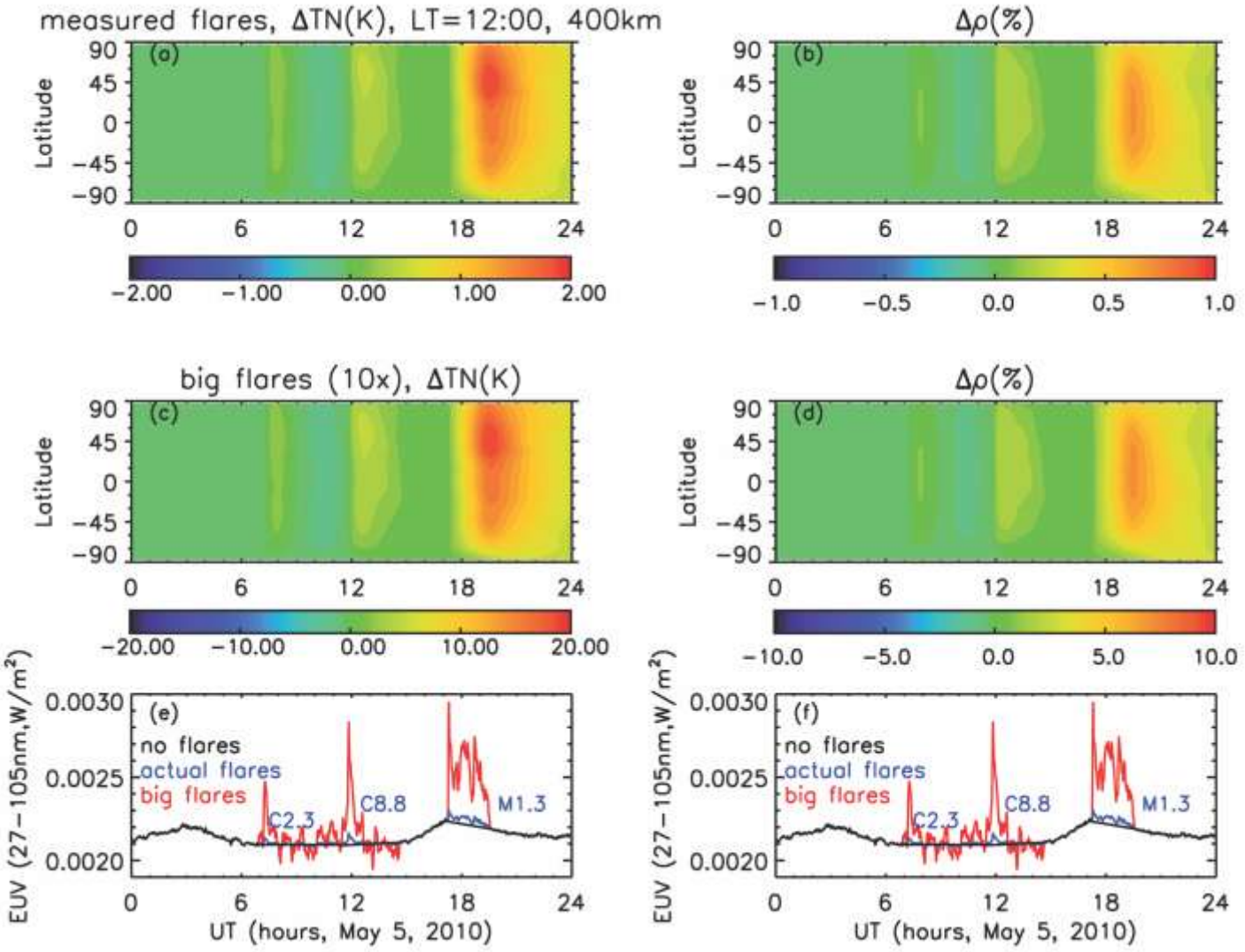
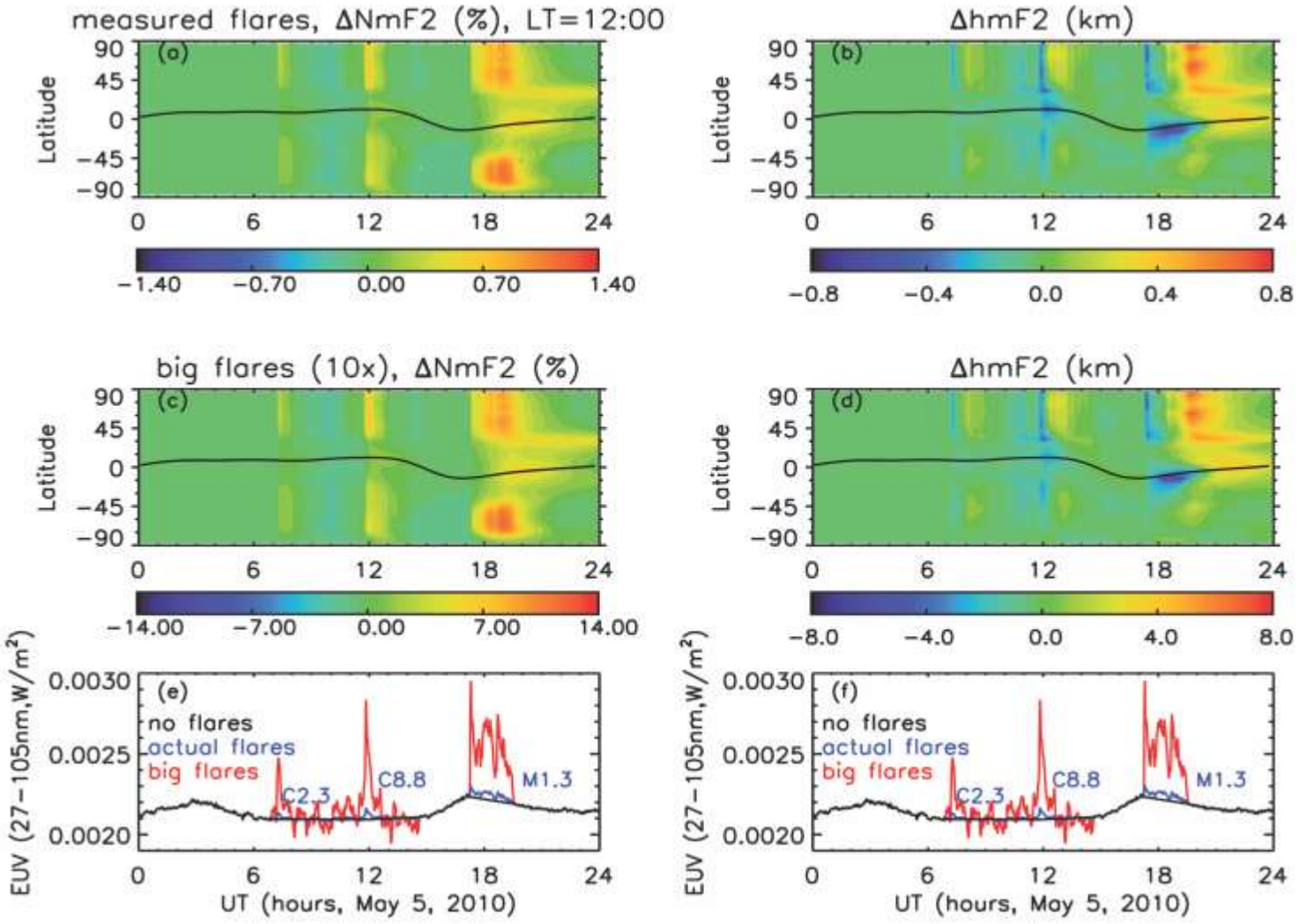
Dependency on Flare Total Variability Energy



Dependency on Flare Total Variability Energy -- Thermosphere



Dependency on Flare Total Variability Energy -- Ionosphere



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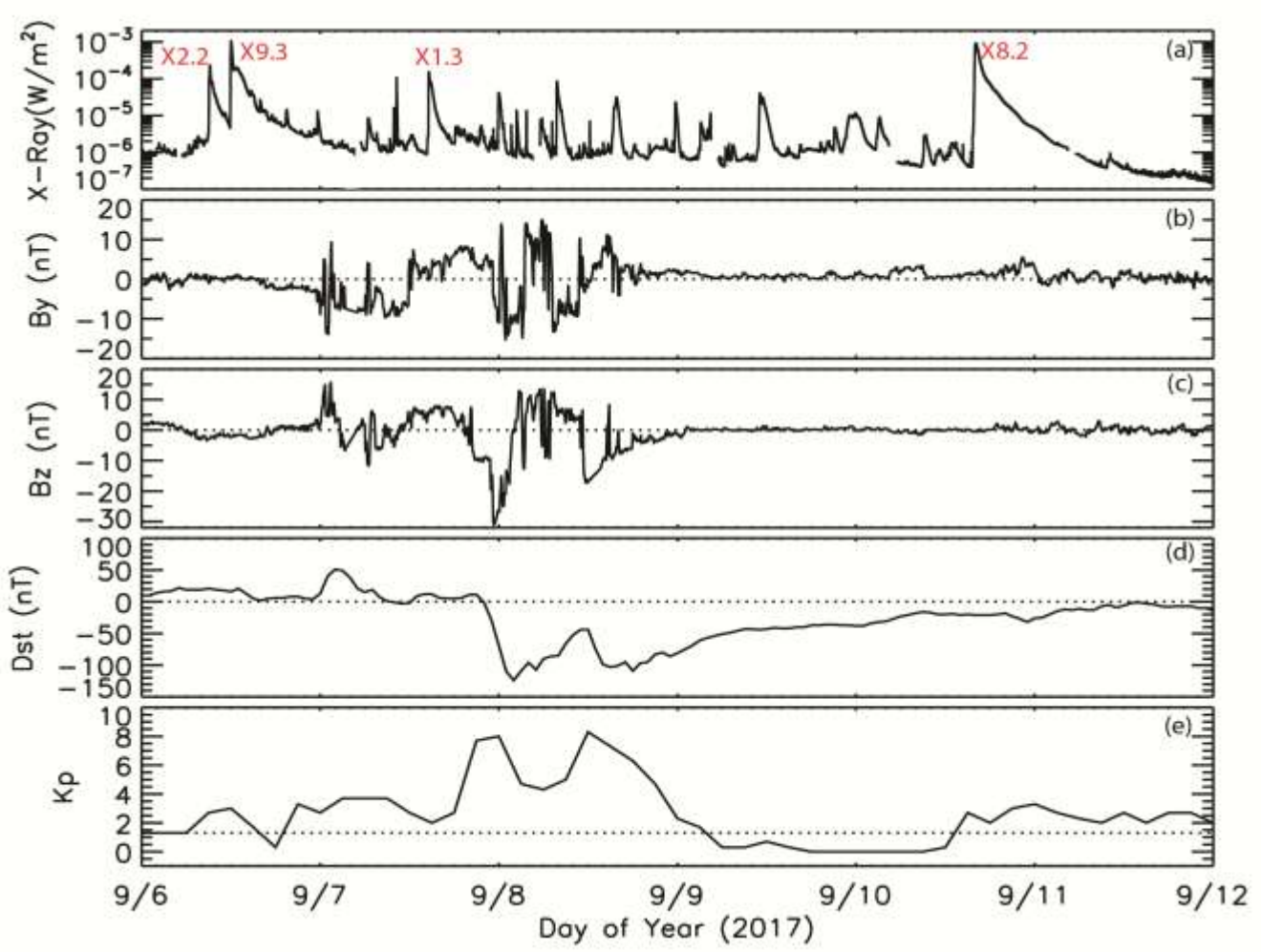
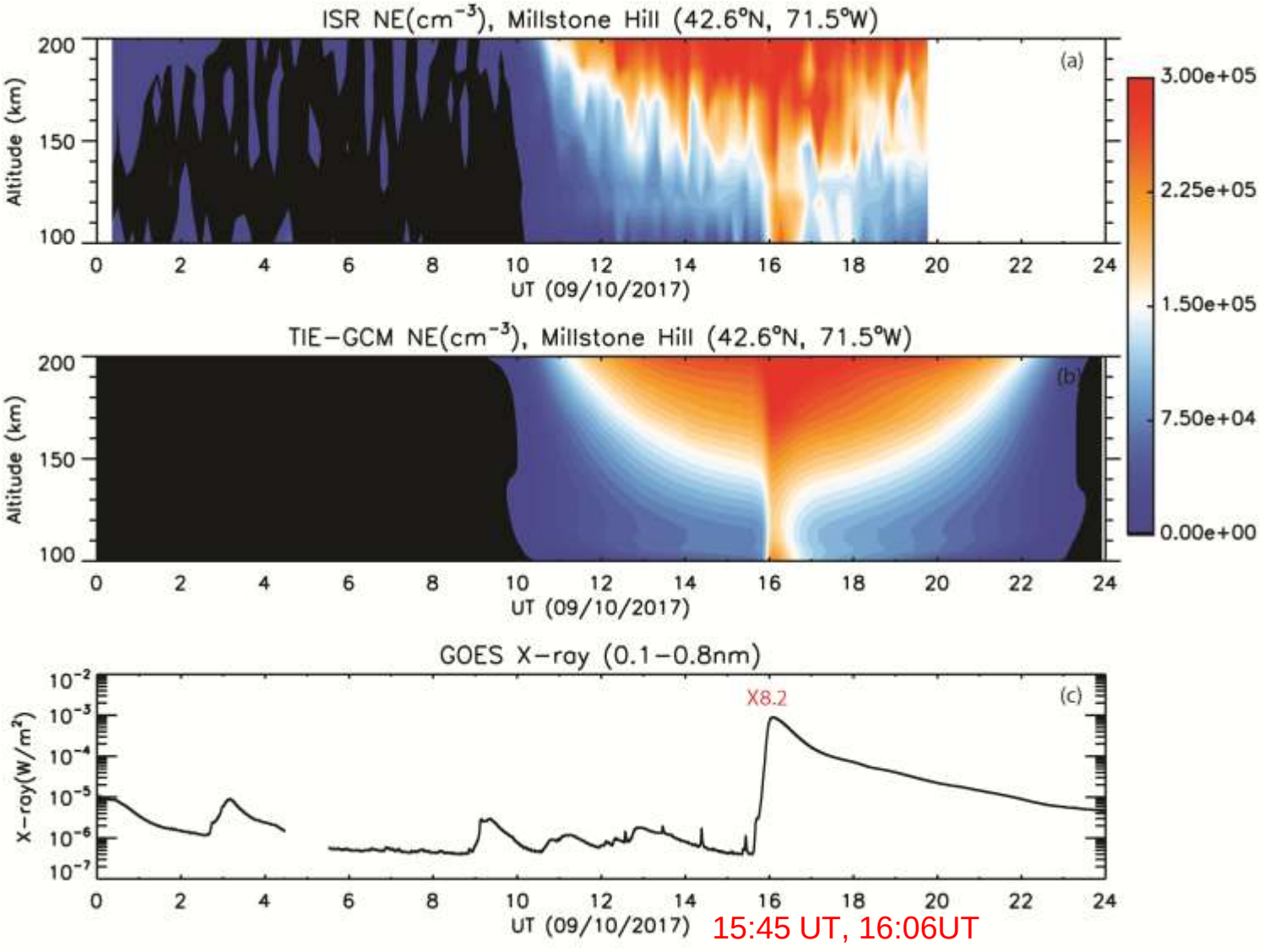
The Active Period of September 6th – 11th, 2017



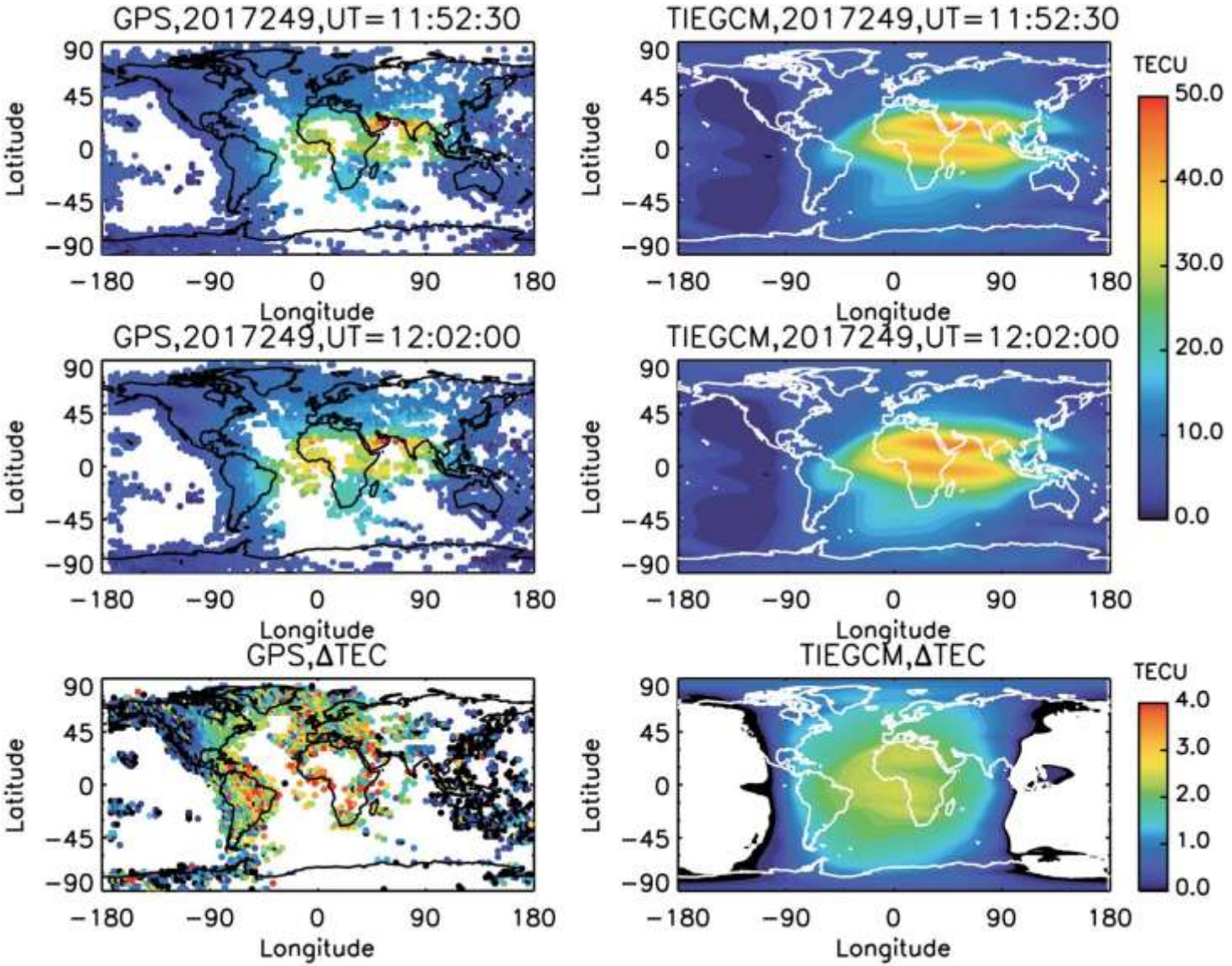
AR2673 was responsible for 27 M-class flares, 4 X-class flares, and 2 storms.
The two strongest flares of solar cycle 24: X9.3 flare on 09/06, X8.2 flare on 09/10.

E-Region Electron Density Response

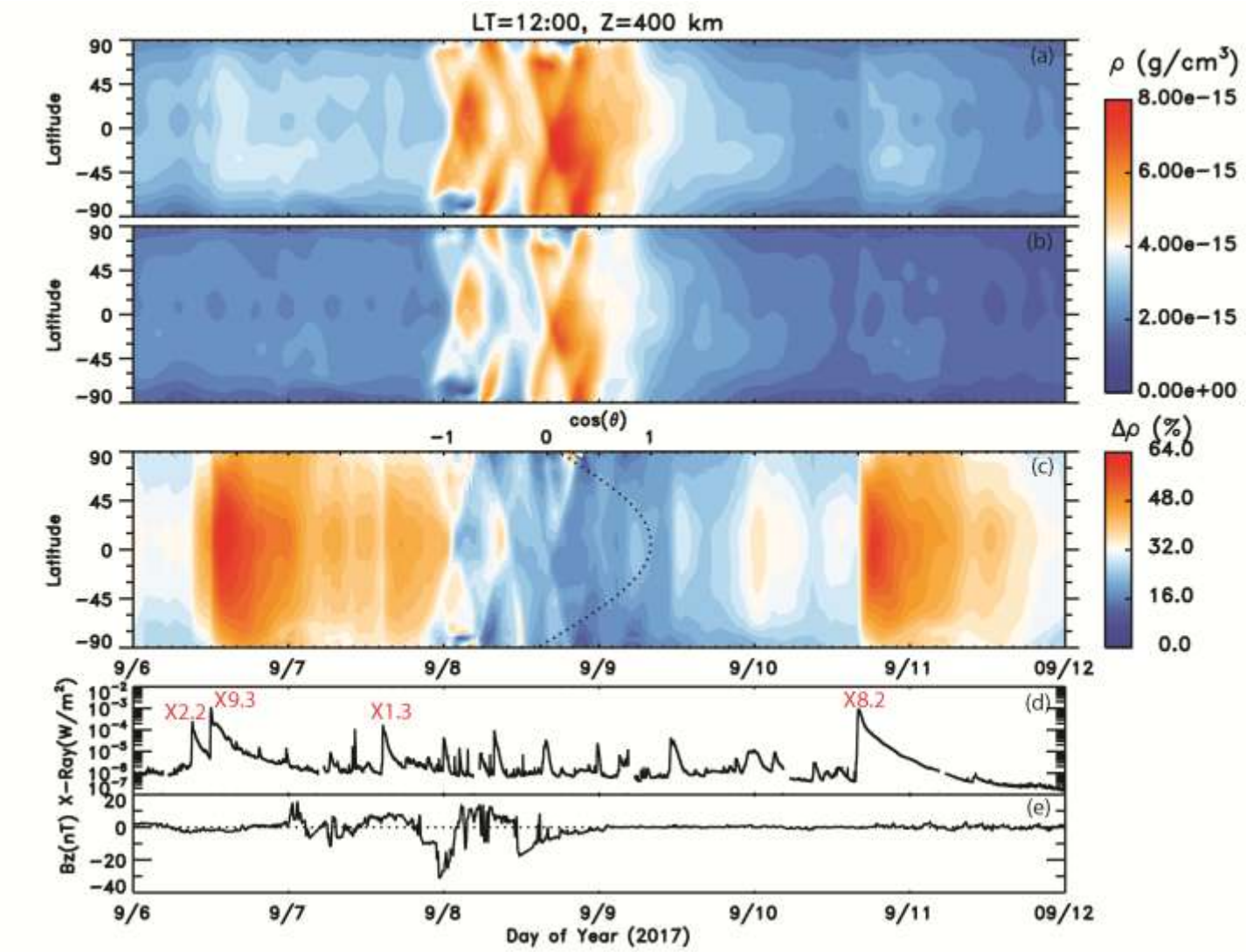


15:45 UT, 16:06UT

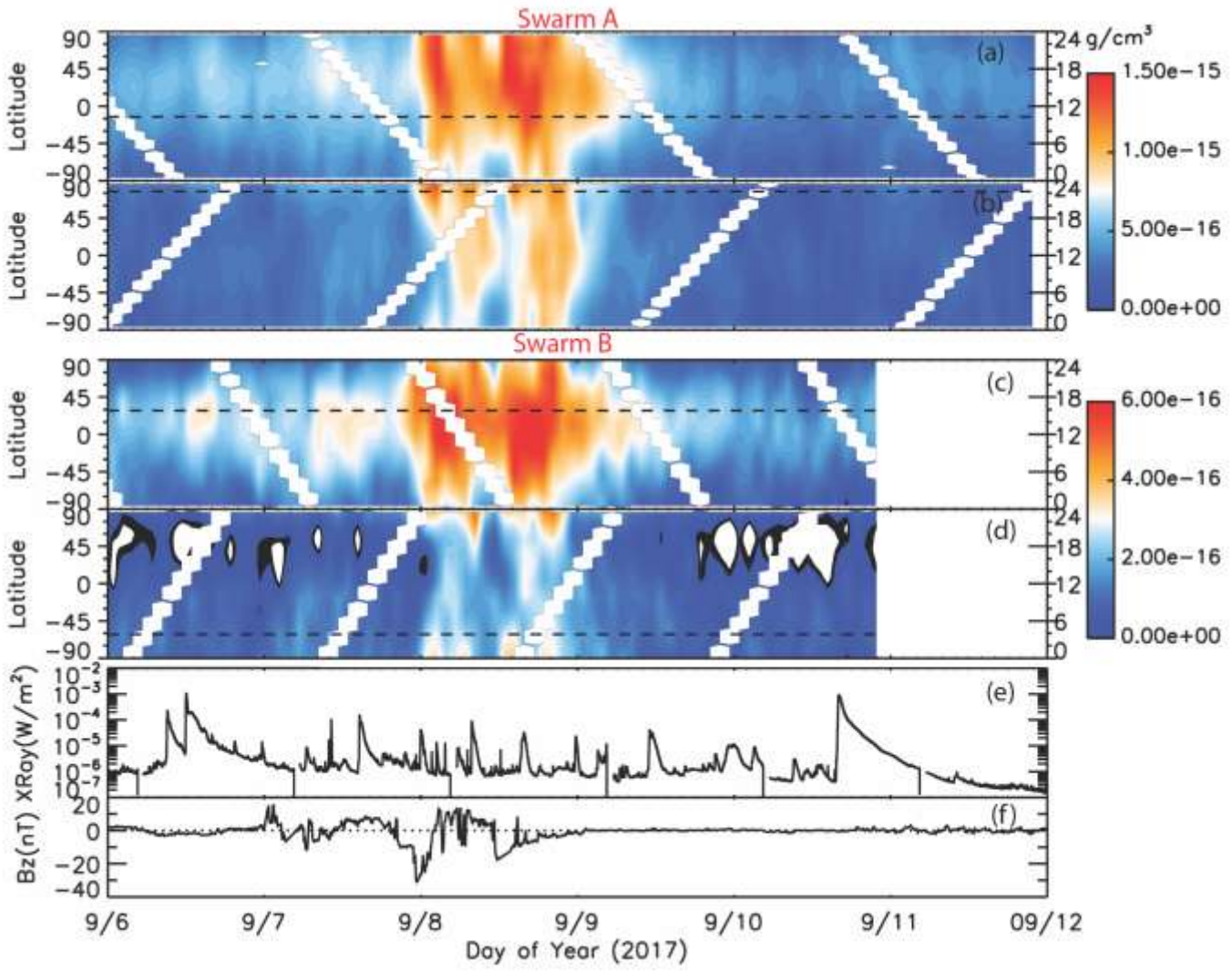
TEC Response to the X9.3 Flare



Mass Density Response
-- Simulations



Mass Density Response
-- Observations



Summary - 1

- E –region responds to flares immediately and recovers with flares;
- Neutral temperature response increases with altitude. For the X10 flare, neutral temperature and F-region ionosphere reach peak response about 2 hrs after the flare peak;
- Magnitudes of flare response depend on local time and latitude. For the X10 flare, at local noon and equatorial latitudes, flare responses are ~ 20-30% in the TI system;
- Thermosphere response largely follows solar zenith angle, ionosphere response deviates from solar zenith angle effects (composition, plasma transport);
- Flares decrease daytime eastward electric field, decrease E x B (~ 20% for the X8.2 flare), weaken the EIA;

Summary - 2

- Disk flares are more geoeffective, especially in the F-region and upper thermosphere (> a factor of 2);
- Flare responses in the TI system essentially linearly depend on flare total variability energy;
- During the space weather events of September 6th – 11th, 2017, large-scale TADs occurred when there were both flares and storms. The flares changes the magnitudes and propagation speeds of the TADs. There was no evidence that large-scale TADs occurred when there were only flares but no storms, indicating that flares alone are not sufficient to excite large-scale TADs.