Thermospheric Neutral Density Damping Response to Sheath-Enhanced Geospace storms (System Science !)

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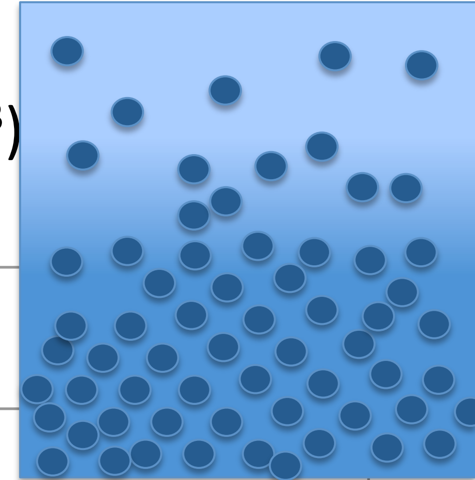
Motivation: *Why do some geomagnetic storms with strong solar wind and magnetosphere-ionosphere coupling produce lower than expected thermospheric density upheaval?*

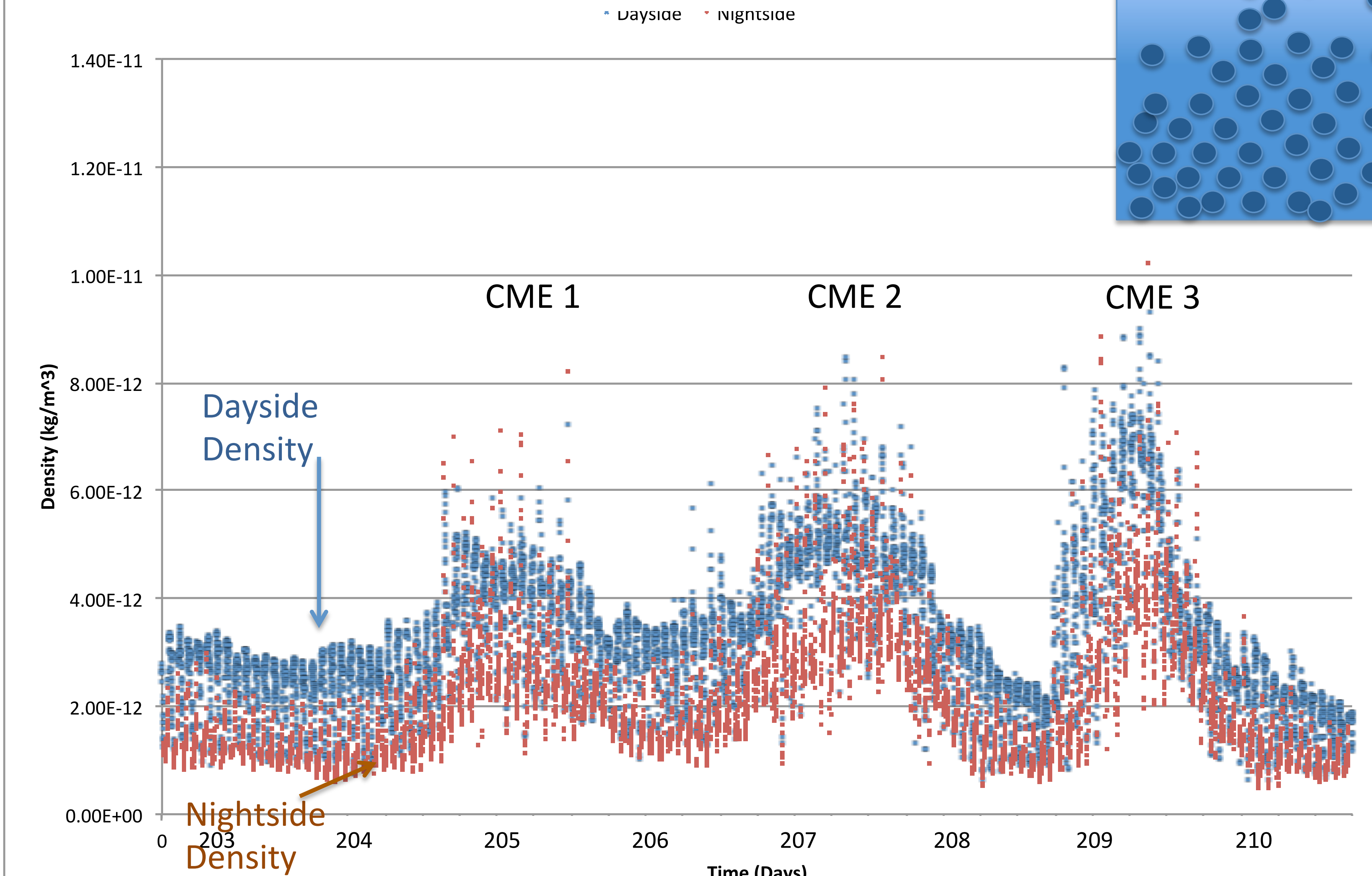
* Supported by NSF, AFRL University Small Grant, and AFOSR grant to University of Colorado

Outline

- Background -- Neutral Density
- Unexpected Response in Some Storms
- A Tale of System Science
  - M-I-T Linkages --Known, Suspected and Unknown
- Sheath-Enhanced Storms/Solar Cycle
- Conclusions

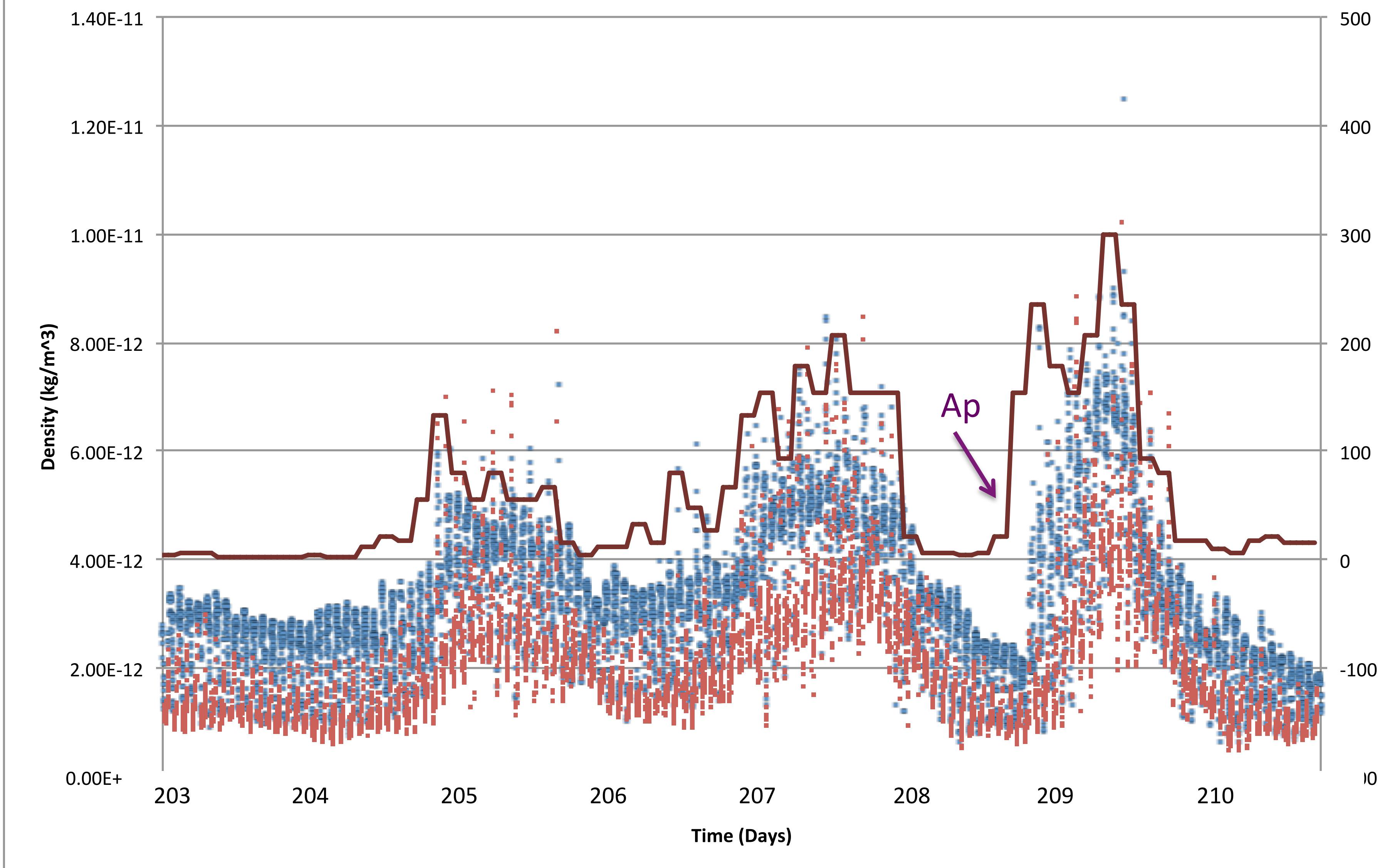
CHAMP Density Extrapolated to 400 km (kg/m^3)



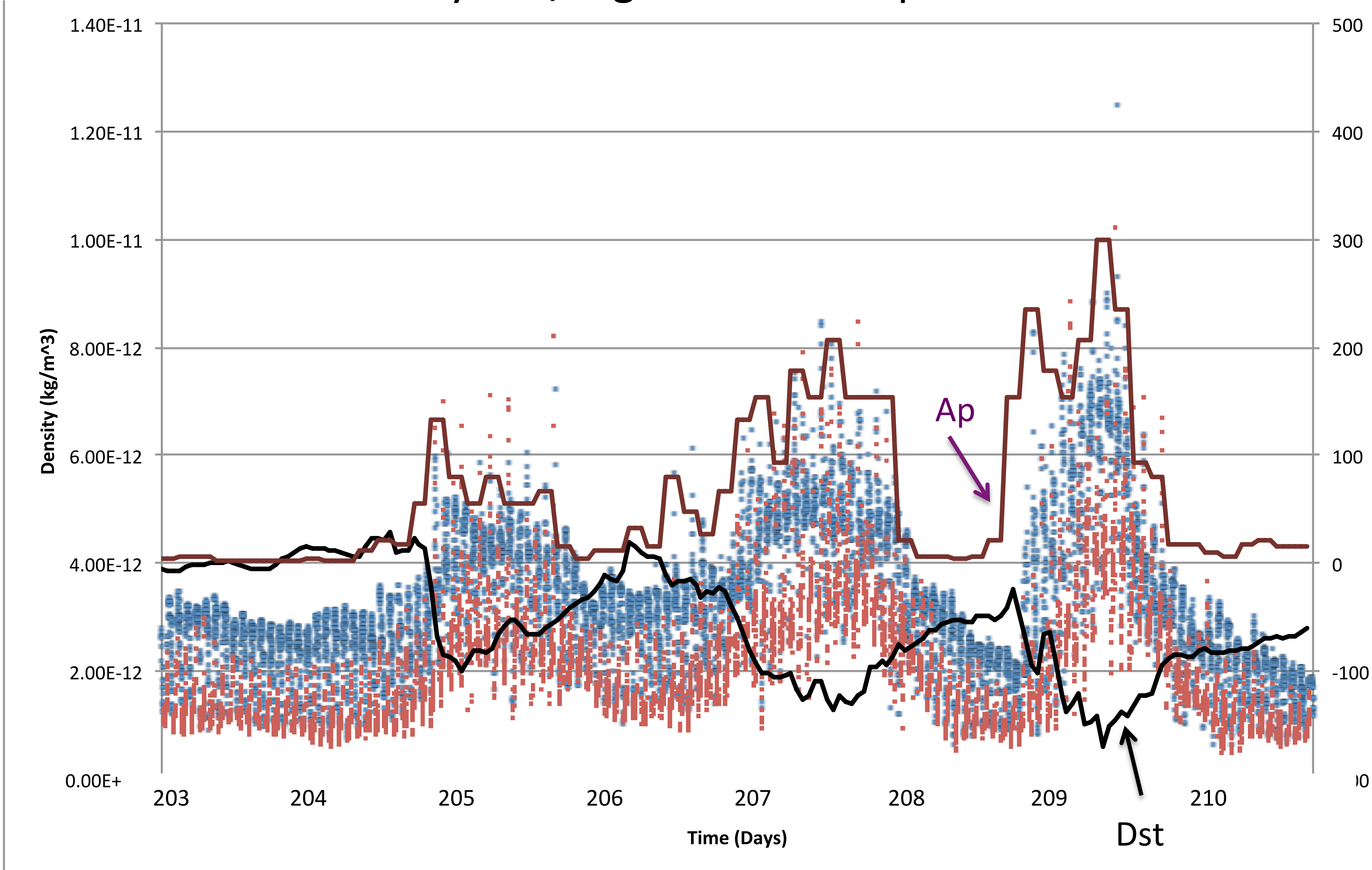


Energy deposition causes atmospheric expansion;
Heated molecules and atoms, fighting for more room, diffuse upward

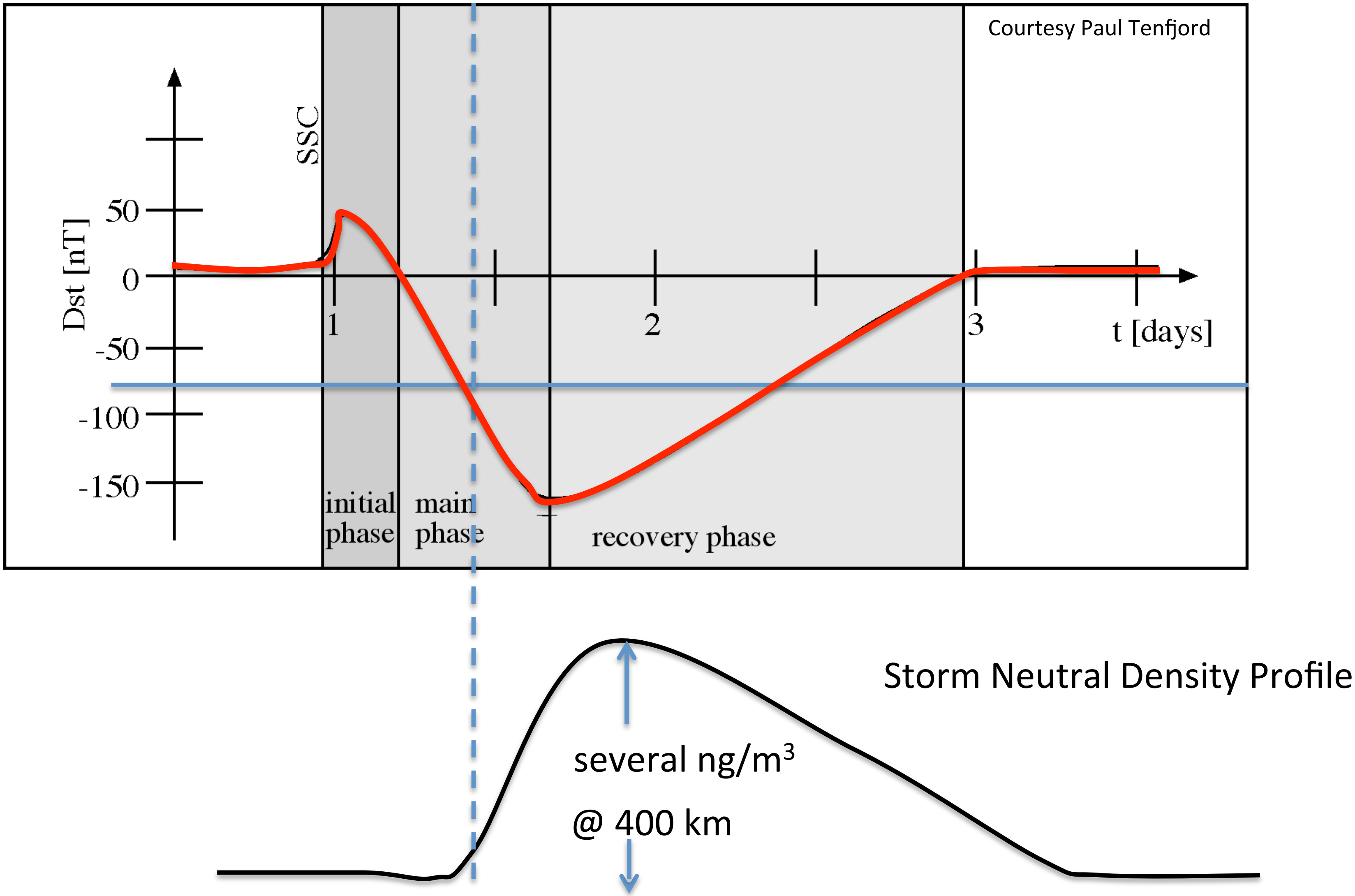
CHAMP Density Extrapolated to 400 km (kg/m^3)
Dayside/Nightside with Ap



CHAMP Density Extrapolated to 400 km (kg/m^3)
Dayside/Nightside with Ap and Dst

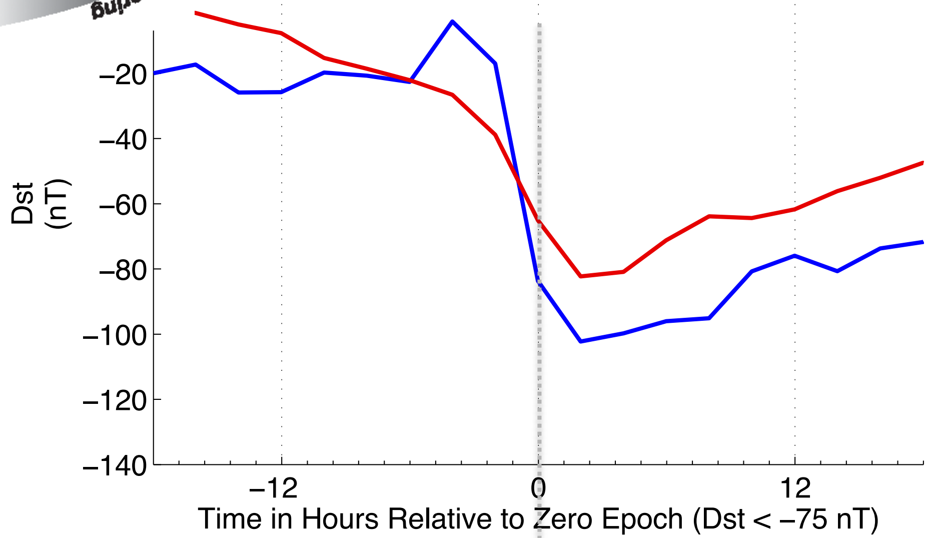


Dst and Neutral Density Perturbation



Bowman et al., 2008, Burke et al. 2009

Superposed Epoch Analysis (SEA) COMPARISON



11 Problem (blue) and 12 Control (red) Storms

Zero epoch hour Dst < -75 nT

Median values, 2 hr average bins 2004-05

__ Control Storms __Problem Storms

Problem-storm Dst has compression effect and larger negative perturbation*

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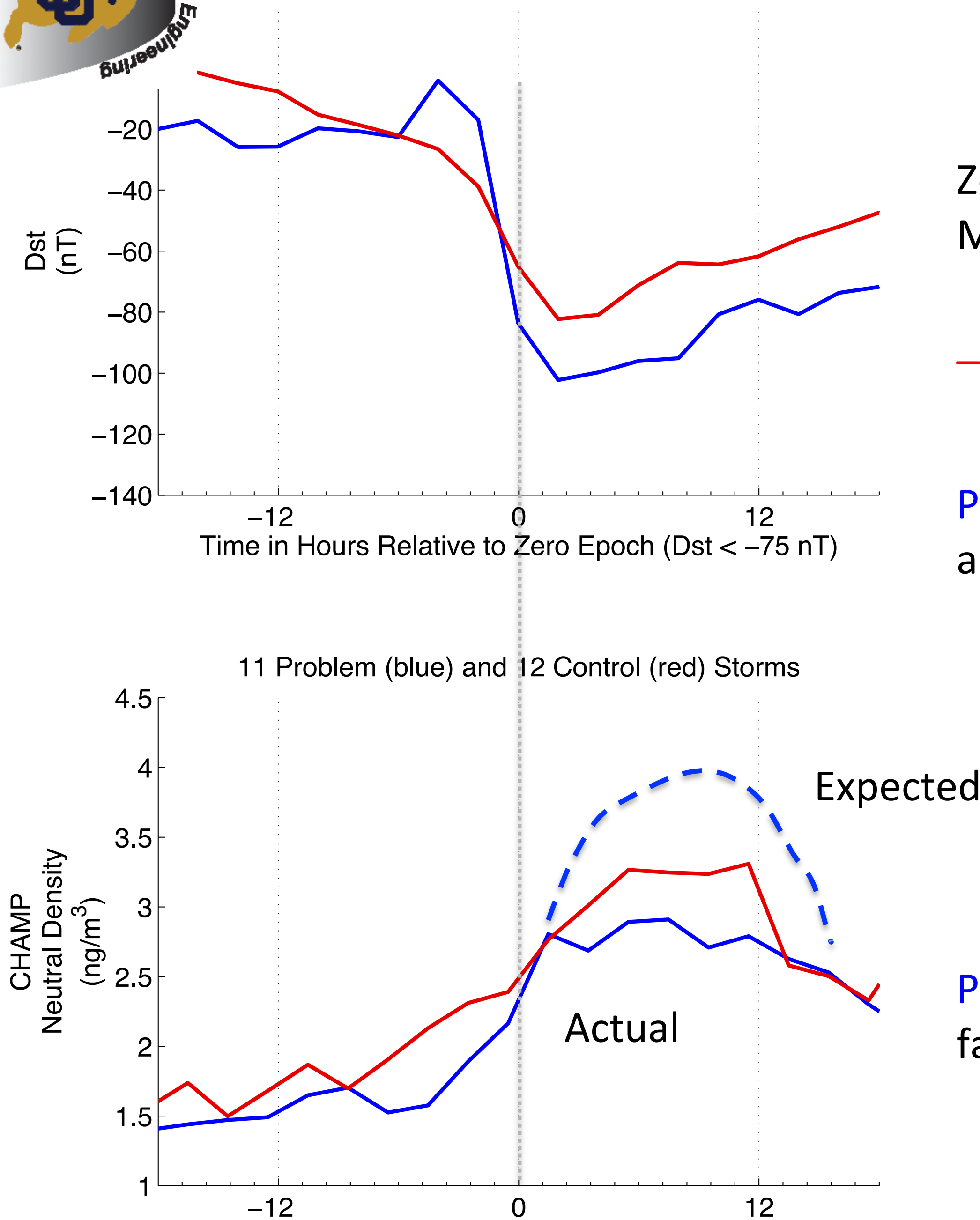

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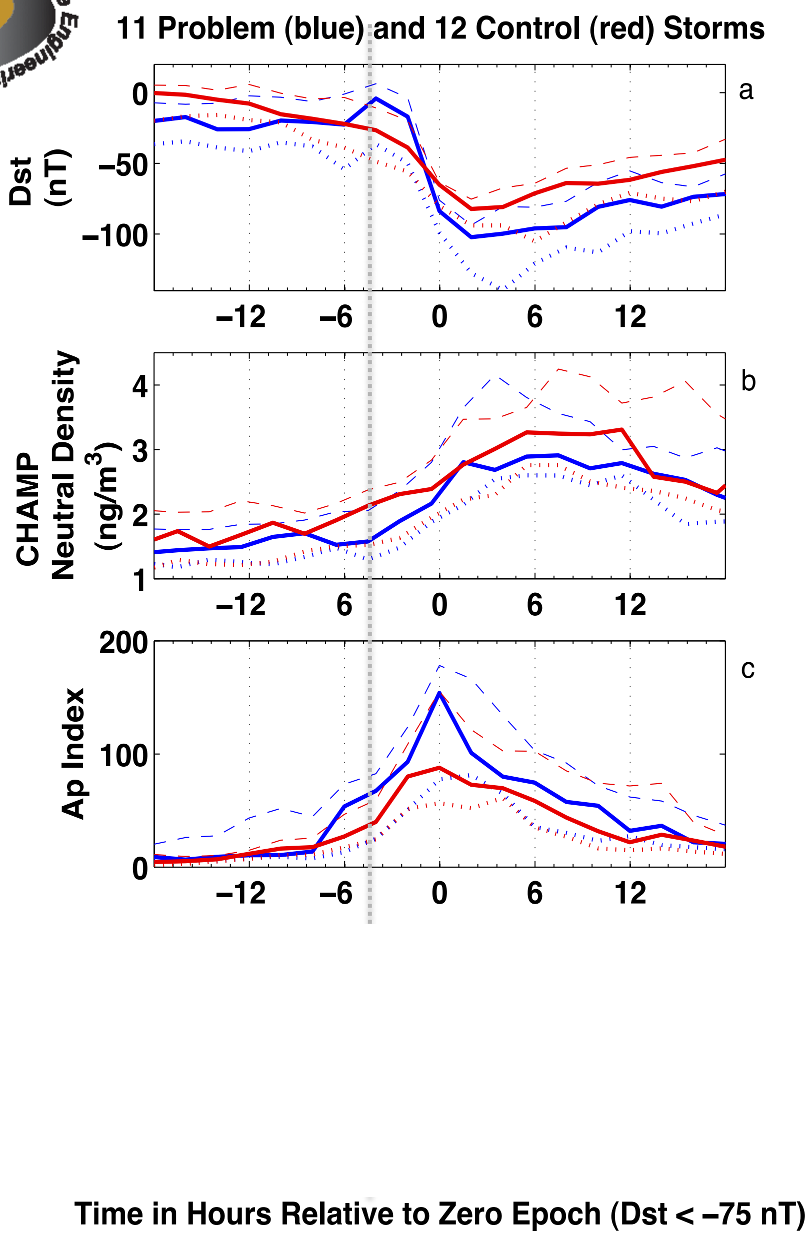
Problem-storm Dst has compression effect and larger negative perturbation*

Problem-storm neutral density has delayed, fast rise and then a sudden plateau



SEA COMPARISON

Problem-storm Dst has compression effect and larger negative perturbation*

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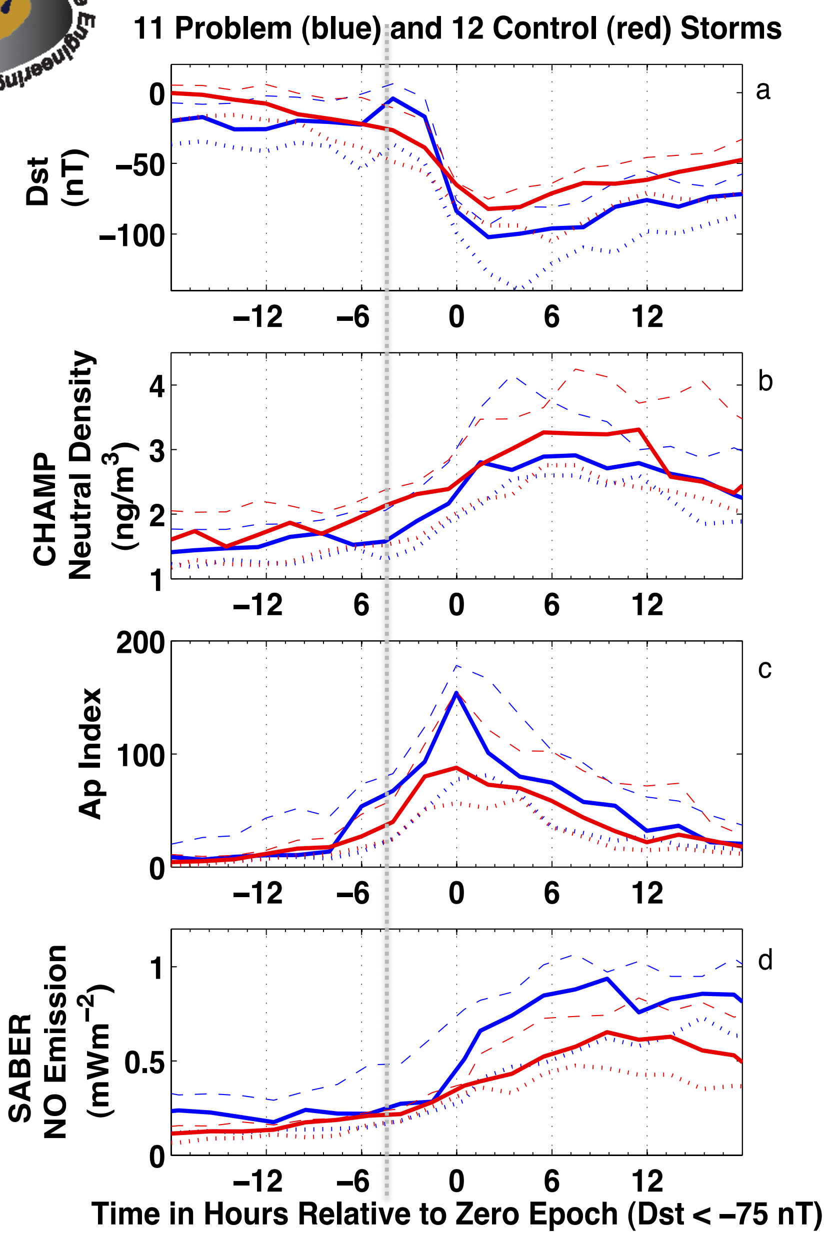
Problem-storm Ap Index is much higher

Knipp et al., Thermospheric Damping Response to Sheath -Enhanced Geospace Storms, GRL 2013



SEA COMPARISON

Problem-storm Dst has compression effect and larger negative perturbation*

Problem-storm neutral density has delayed, fast rise and then a sudden plateau

Problem-storm Ap Index is much higher

Problem storm Nitric Oxide Emission is much larger

Knipp et al., Thermospheric Damping Response to Sheath -Enhanced Geospace Storms, GRL 2013

Nitric Oxide — Why it is important?

Present in the thermosphere - maximum density near 110 km:

- Abundance — several times 10^{-4} mixing ratio at 130 km
- Highly variable — factor of ten — 27 day and 11 year variation
- Always larger in the auroral region (max at 65° geomagnetic latitude)

Nitric Oxide is the most important cooling mechanism in the lower thermosphere:

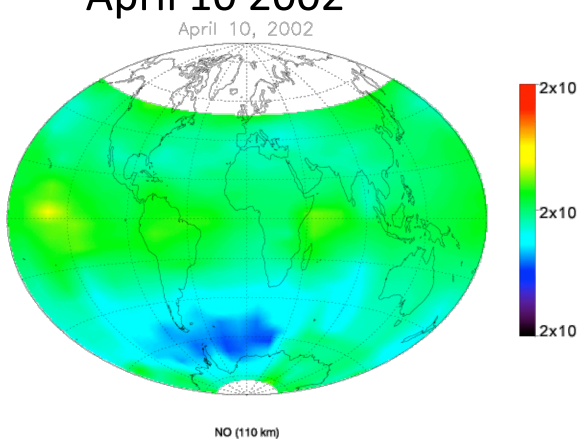
- Heteronuclear molecule has a permanent electric dipole moment
  - Infrared cooling in the 5.33 μm band—thermostat effect

Odd nitrogen controls the composition of the lower Ionosphere:

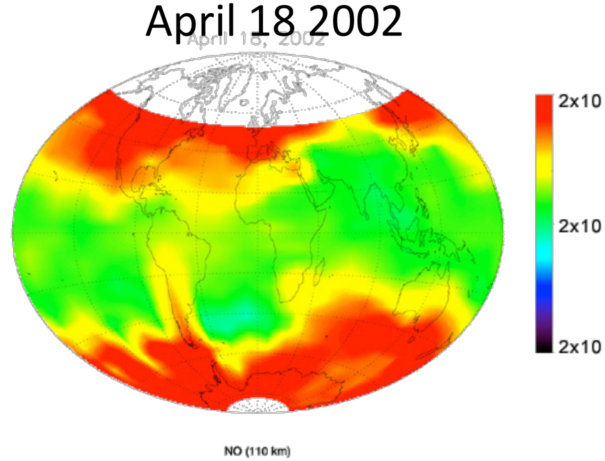
$$NO + O_2^+ \rightarrow NO^+ + O_2$$
$$N + O_2^+ \rightarrow NO^+ + O$$
$$NO^+ + e \rightarrow N + O$$

- Controls temperature in the critical 120 km region

April 10 2002

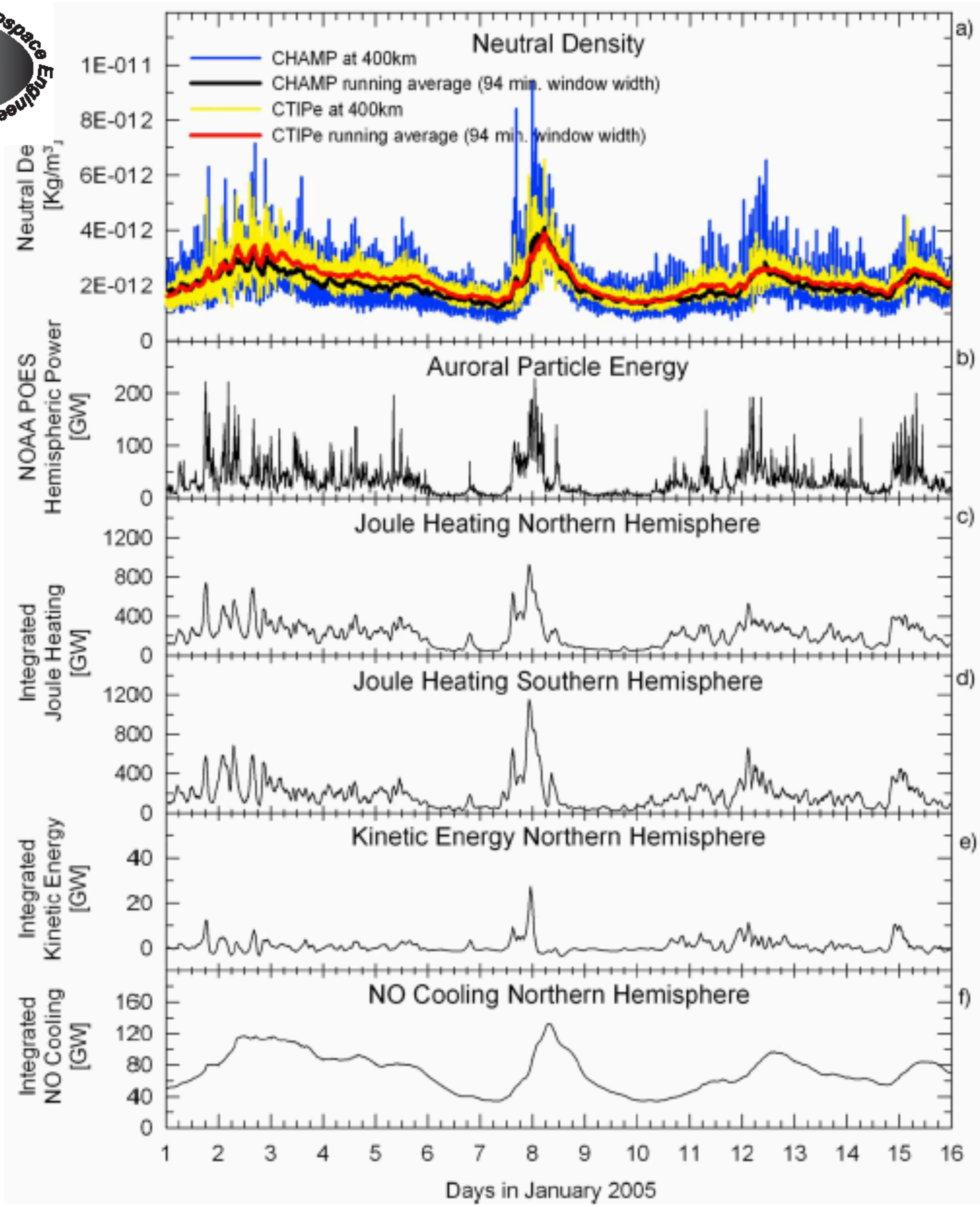


April 18 2002



Why do the problem storms produce more Nitric Oxide?

Courtesy of Scott Bailey



Fedrizzi et al. Space Weather Journal (2011)

Neutral Atmosphere Energy Budget

Particles:
~50 GW

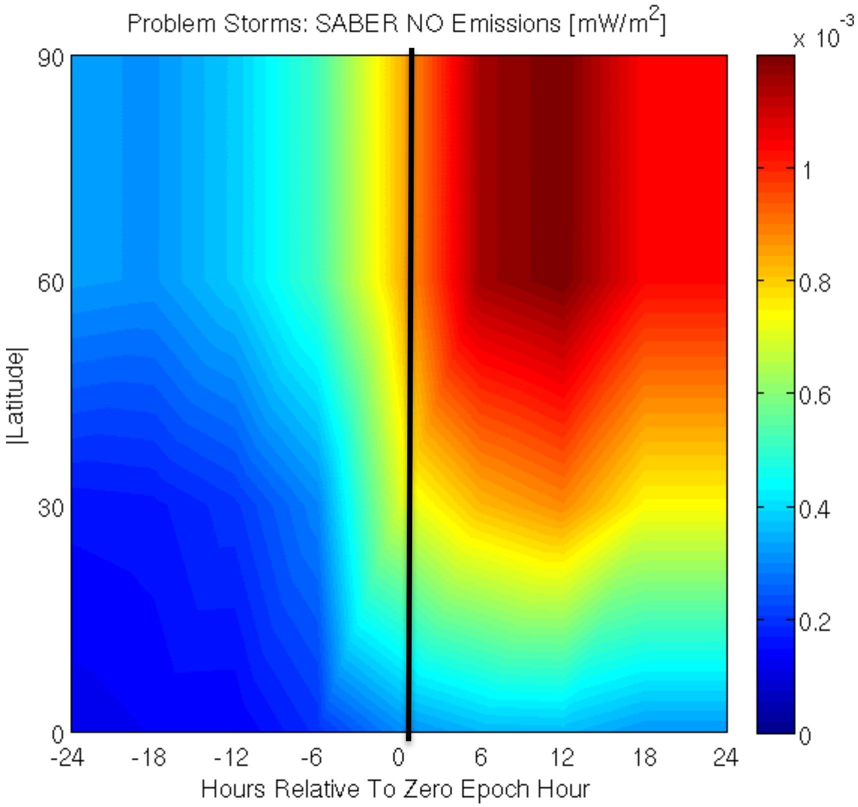
Joule Heating:
~700 GW

Kinetic Energy
~5 GW

NO Cooling
~100 GW

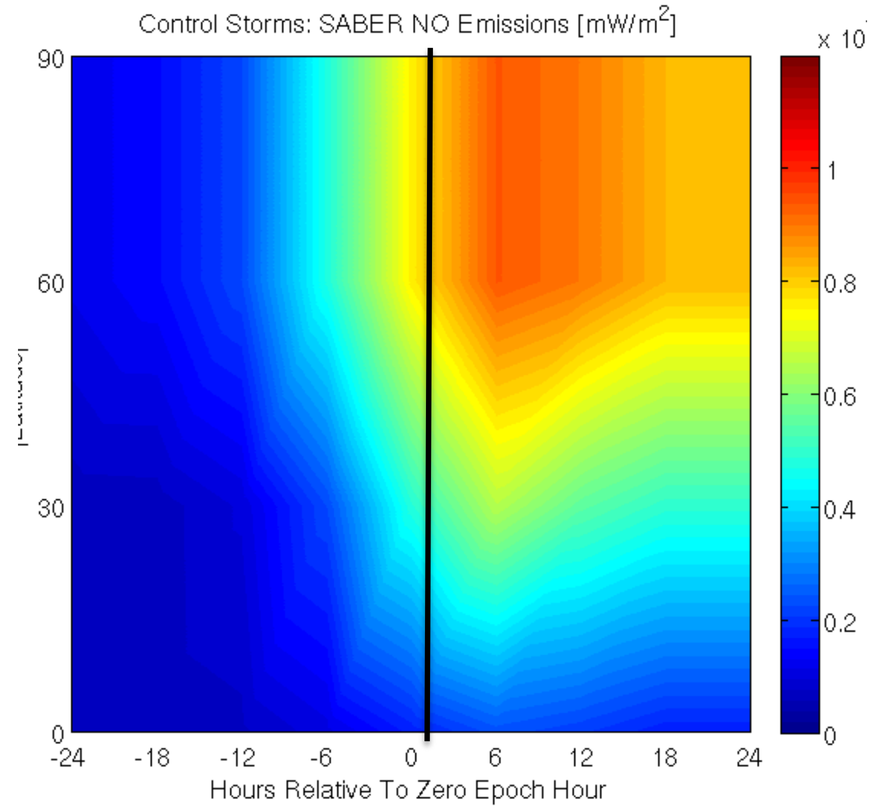
SABER NO Comparison

Problem Storm NO Flux



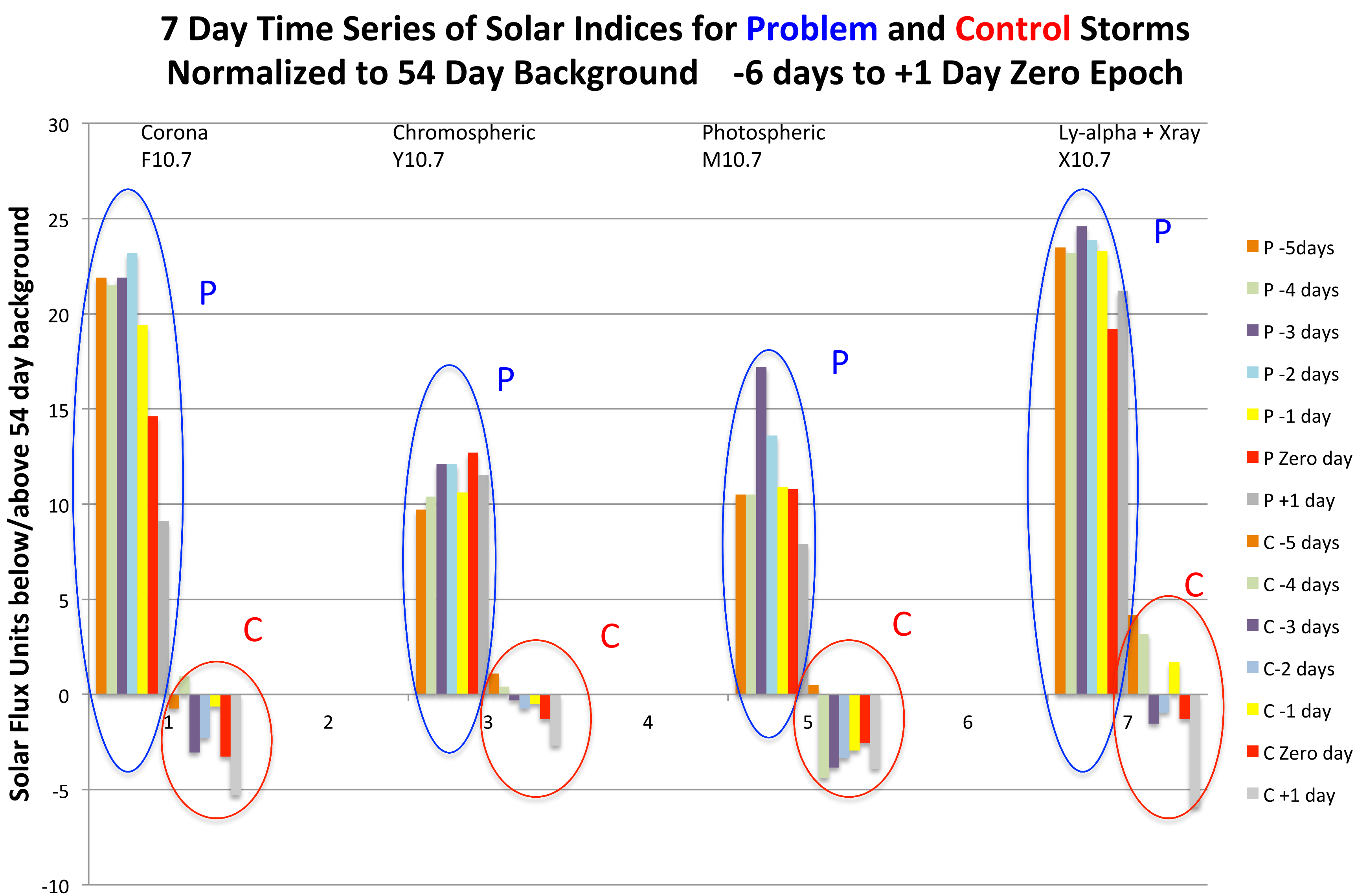
Problem storms have later IMF southward turning and more intense NO flux that extends to low latitudes

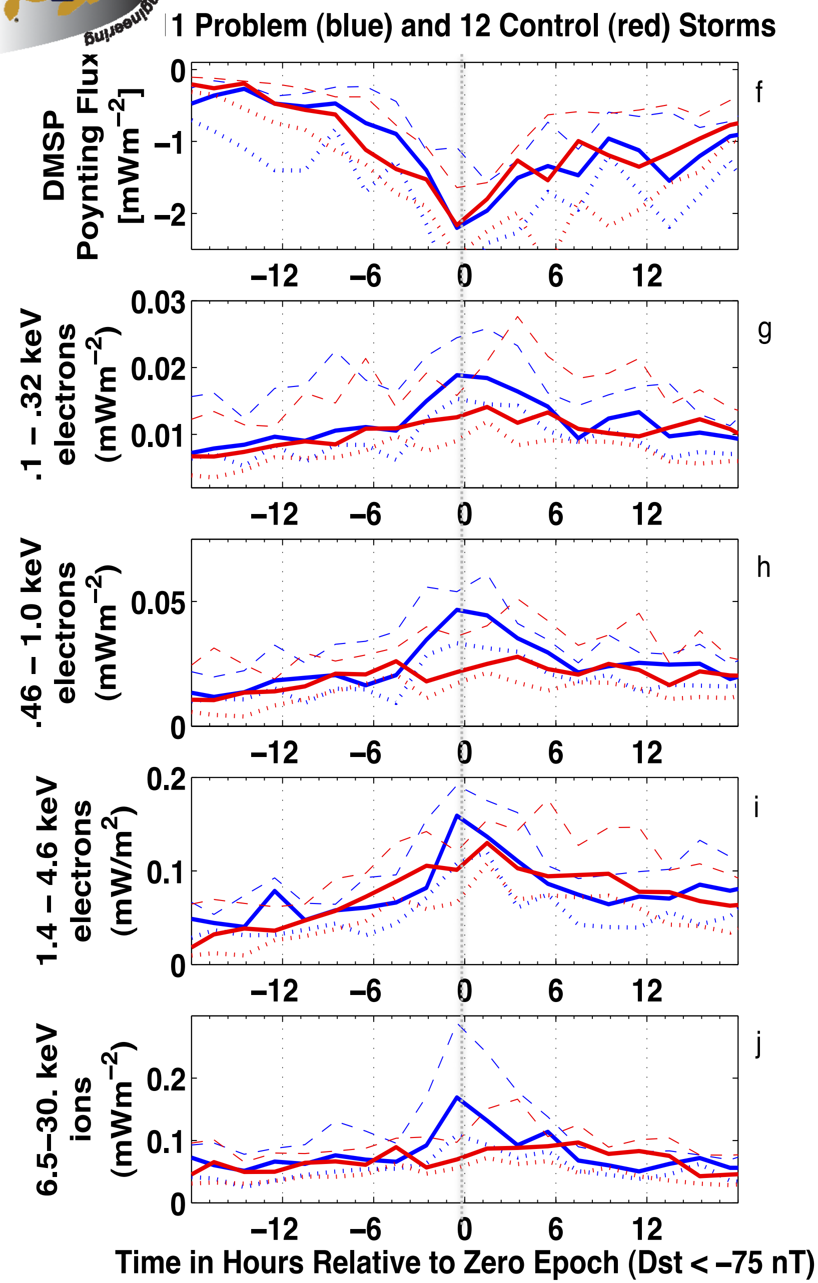
Control Storm NO Flux



Control storms have early IMF southward turning and less intense NO flux at all latitudes

Solar Background:
Problem Storms Arise from More Active Solar Disk





SEA DMSP COMPARISON

Problem storm DMSP Poynting Flux similar for problem and control storms

Problem storms have more low energy particle precipitation in pre, initial and main storm phases

Source of these particles?
- shock aurora?
- plasmasheet?
- ring current?

Lowest energy particles are important to rapid upheaval in neutral density and enhanced Joule heating

Higher energy particles create NO and damp neutral density response

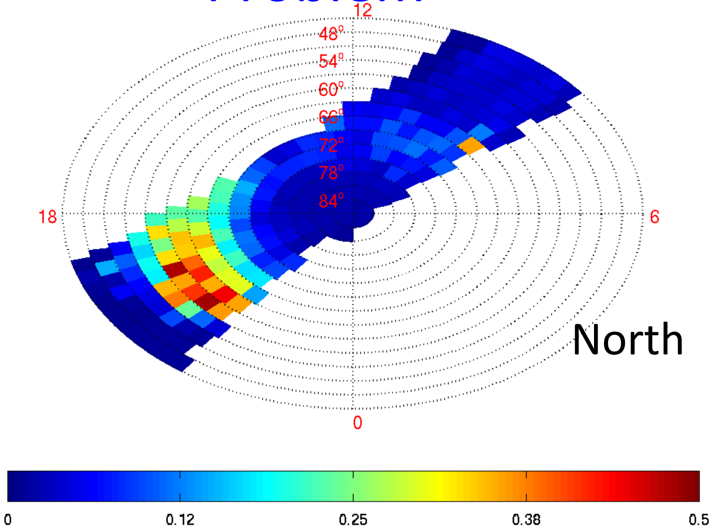
Joule heating enhances NO production

Knipp et al., GRL 2013,

Knipp et al., manuscript in preparation

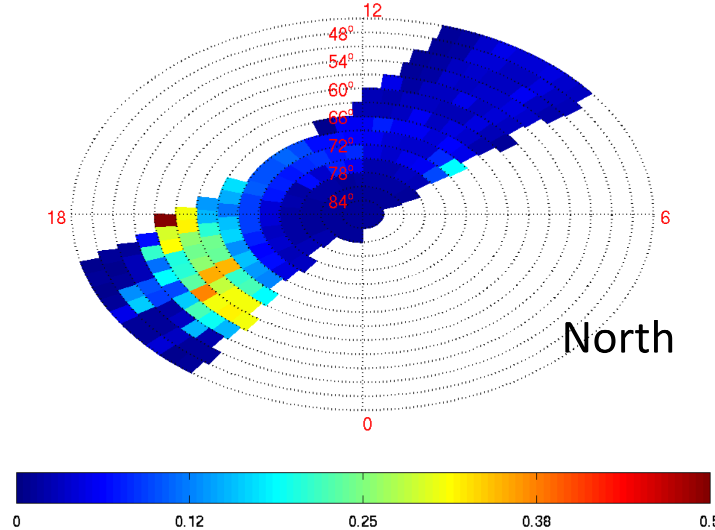
DMSP F-15 6-30 keV Precipitating Protons

Problem



0 mWm^{-2} 0.5

Control



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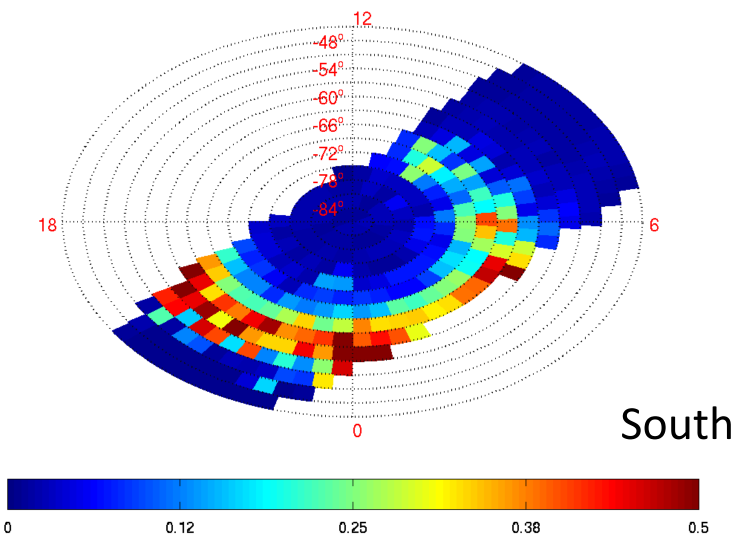

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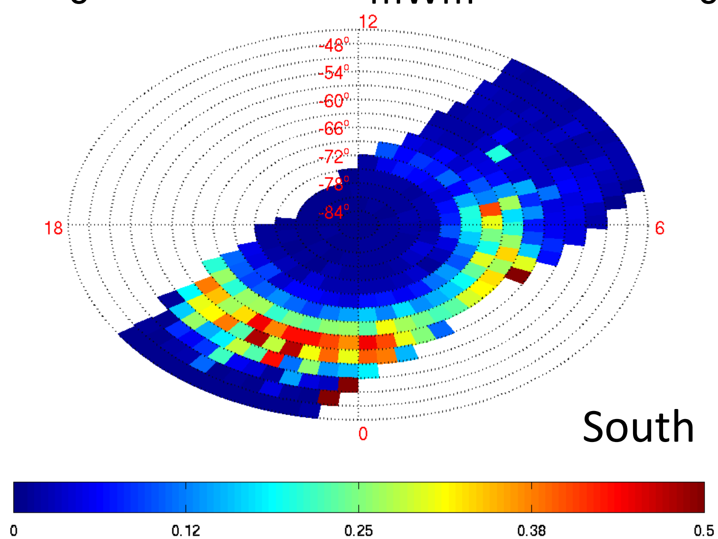

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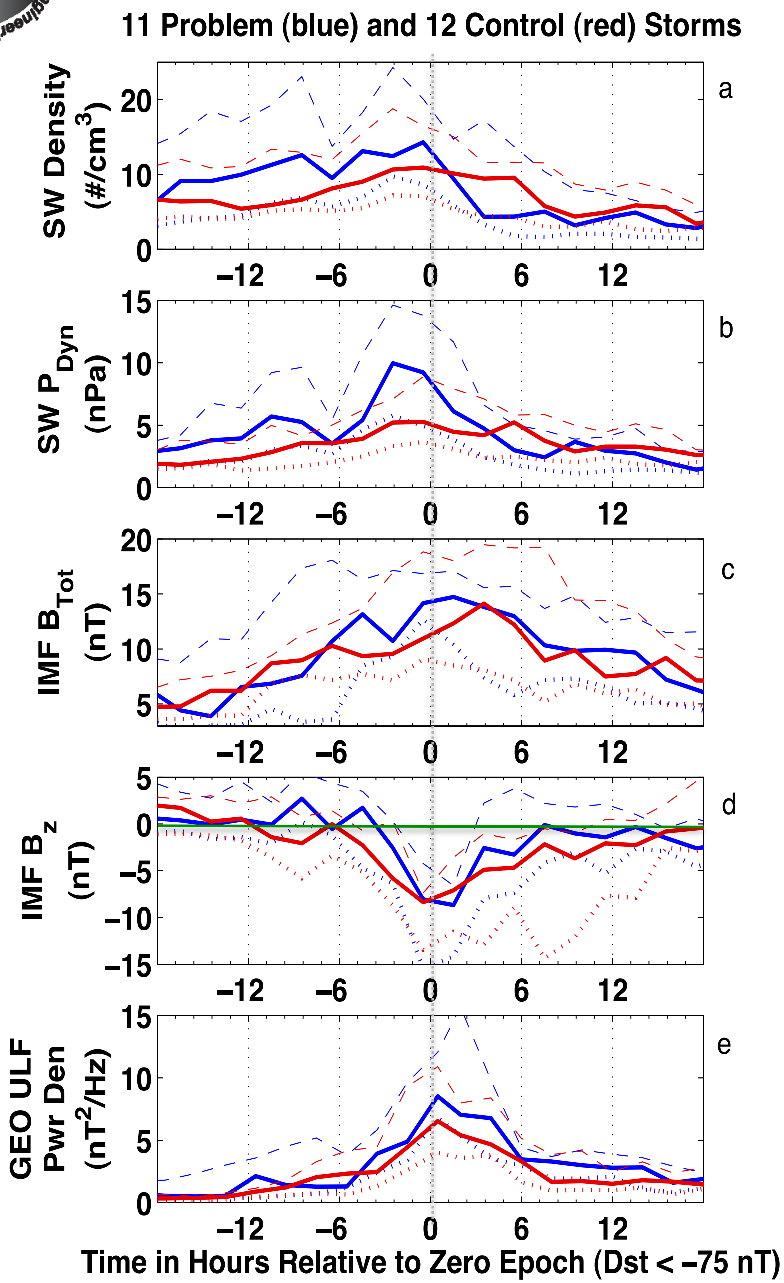


Solar Wind IMF COMPARISON

Problem-storm solar wind density has long interval of pre-storm enhancement

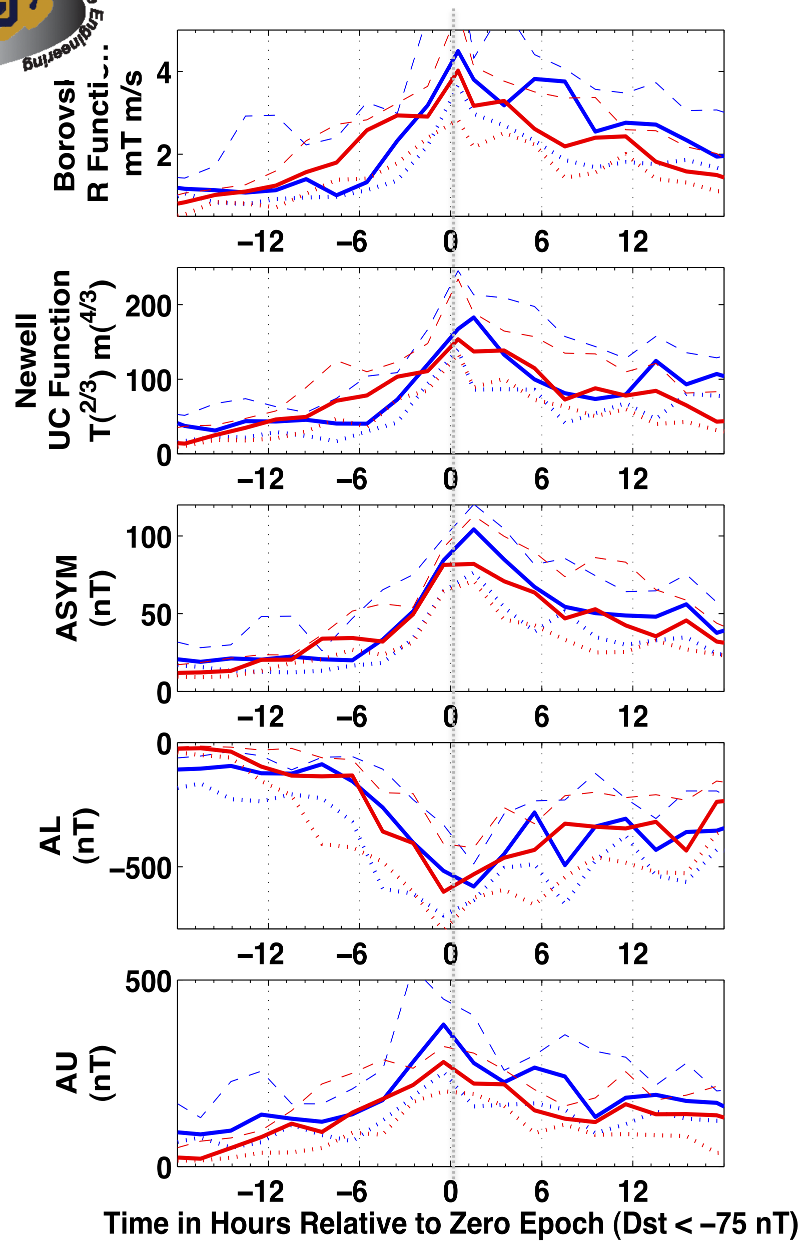
Problem-storm solar wind dynamic pressure is elevated with strong prestorm enhancement

Problem-storm IMF B_{Tot} is larger during prestorm interval

Problem-storm IMF B_Z has long positive to neutral phase relative to control storms

Problem storm ULF waves at geo are enhanced relative to the control storms

Knipp et al. GRL 2013



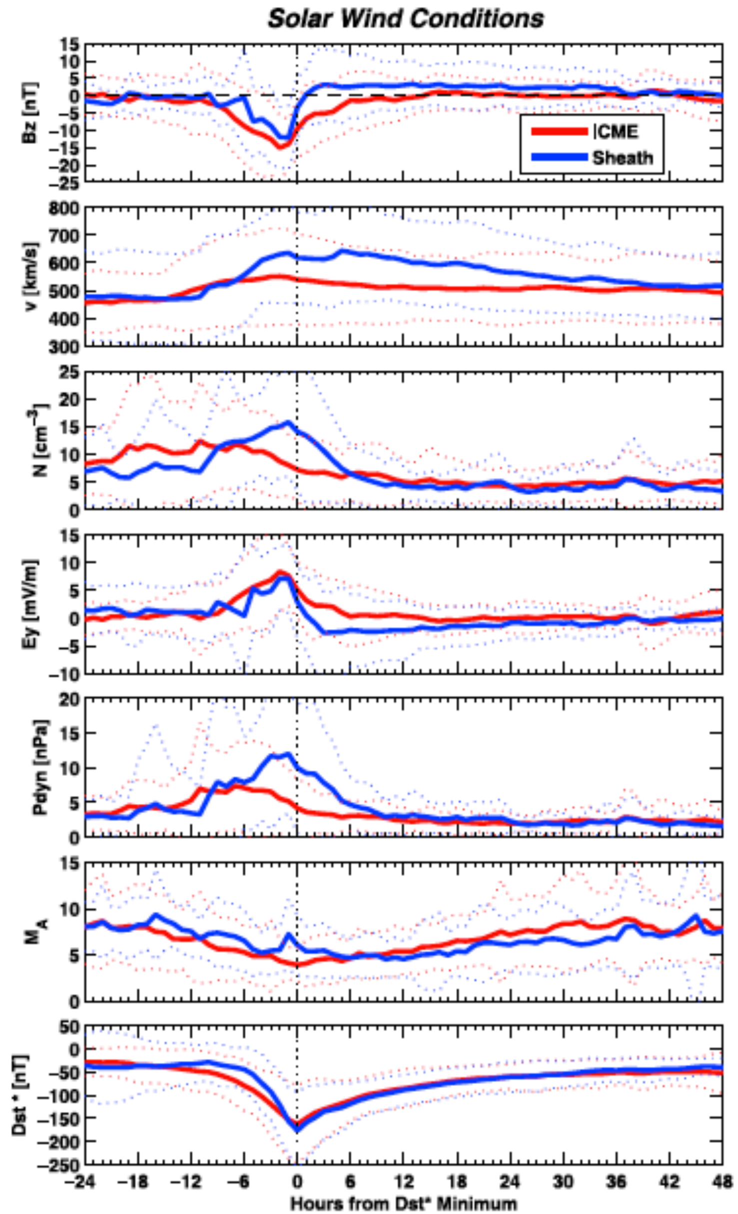
SEA COUPLING & INDEX COMPARISONS

Problem storm coupling functions and AL have delayed sharp rise with slightly higher main phase values

Problem storms have enhanced ASYM and AU values

consistent with higher conductance created by enhanced precipitating particles on the dusk side

Knipp et al., manuscript in preparation



Sheath Driven Storm Comparison

Gou et al., JGR 2010

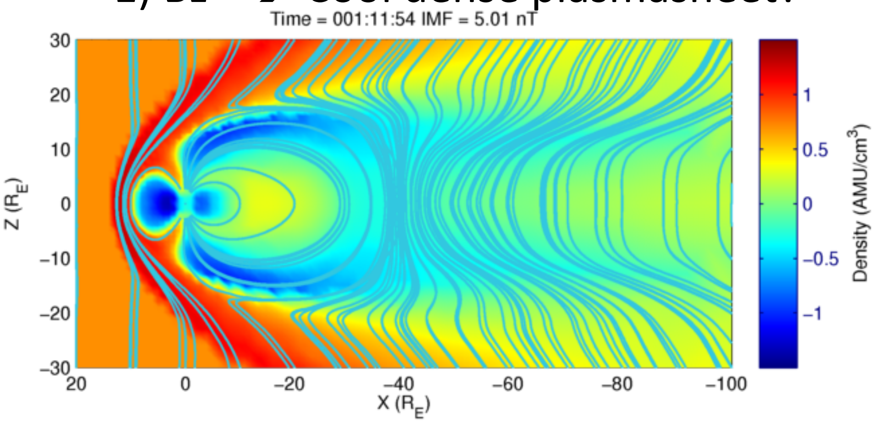
Our problem storms have most of the solar and indicial characteristics of solar wind CME sheath driven storms identified by Guo et al., 2010

Our problem storms appear to be a subset of sheath driven storms with Bz+ IMF in the sheath and leading field in the CME.

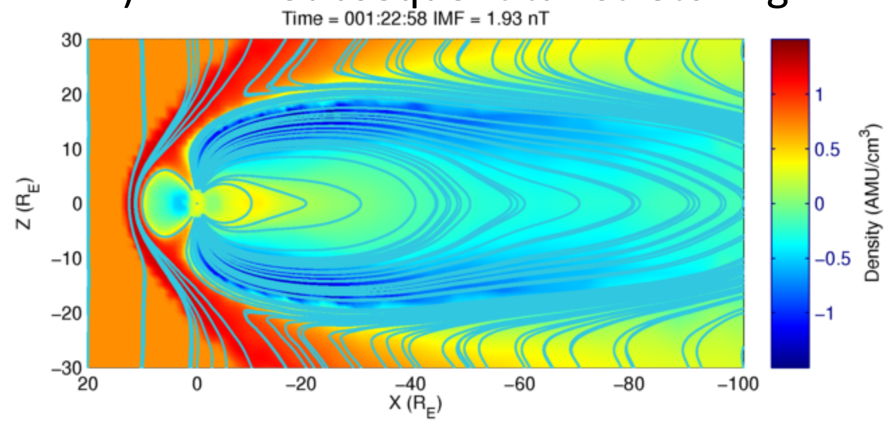
The IMF orientation provides the "calm before the storm" set up for a magnetospheric cold dense plasmasheet

Does solar wind preconditioning of the magnetosphere alter the intensity of auroral particle precipitation and thus the production of nitric oxide?

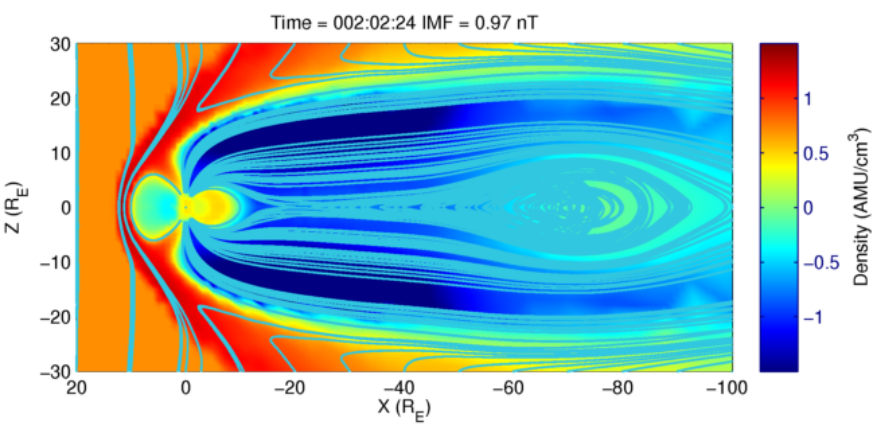
1) Bz+ ➔ Cool dense plasmasheet?



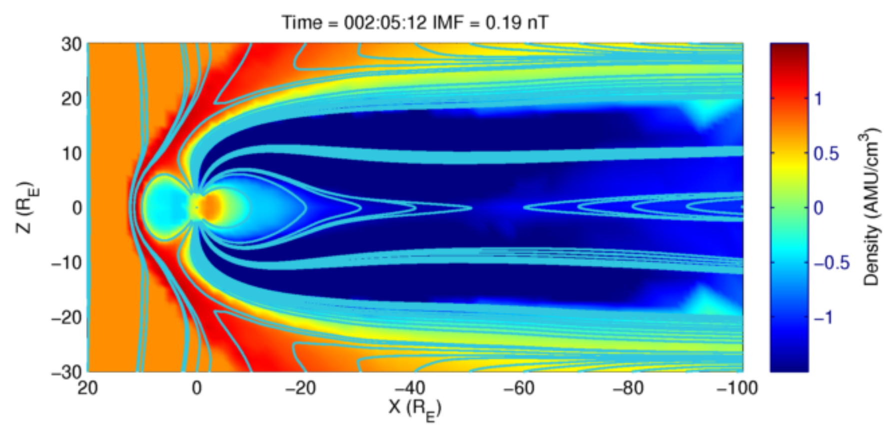
2) Bz- ➔ Subsequent tail stretching



3) Bz- ➔ More intense tail activity



4)➔ Enhanced particle precipitation



LFM output, courtesy of Binzheng Zhang

Solar Cycle Magnetic Cloud Orientation

23 to 24

Decline and min between even to odd odd to even cycles

Even to odd Solar cycle transition: CME's tend to arrive south field first

Odd to even Solar cycle transition: CME's tend to arrive north field first

Magnetic Rope Types Lying In Ecliptic Plane

Magnetic Cloud Type	SEN	SWN	NES	NWS
Leading Field	South (-Bz)	South (-Bz)	North (+Bz)	North (+Bz)
Axial Field	East (+By)	West (-By)	East (+By)	West (-By)
Trailing Field	North (+Bz)	North (+Bz)	South (-Bz)	South (-Bz)
Helicity	LH	RH	RH	LH

Figure 1. Four orientations of ecliptically oriented flux rope model and its magnetic signatures. Note N=north, S=south, E=east, W=west [after *Bothmer and Rust* [1997]].

Combined north field storm sheath and north field first CME may be a factor in "Problem" NO storms

Summary

The imprint of solar wind density and dynamic pressure perturbations reaches into the thermosphere during CME sheath-driven storms

CME Sheath-driven storms induce rapid production of thermospheric nitric oxide

- Shock aurora effects and low energy electrons
- Likely dense plasmasheet
- Magnetospheric waves and or plasmaspheric plumes
- Excess particle (electron and ion) precipitation

Infrared nitric oxide emission competes with storm-driven energy deposition

The result is thermospheric "damping," and mis-forecast of neutral density

These effects influence satellite drag and satellite operations

UNKNOWNS: role of heliospheric current sheet, effects of ionospheric upflow/ outflow, ring current effects; plasmasphere and TEC variations; F-region behavior, SAPS; thermospheric winds; mesospheric impacts….

OMNIweb, NASA Langley, Kyoto University, CEDAR data base and National Geophysical Data Center provided data for this study

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