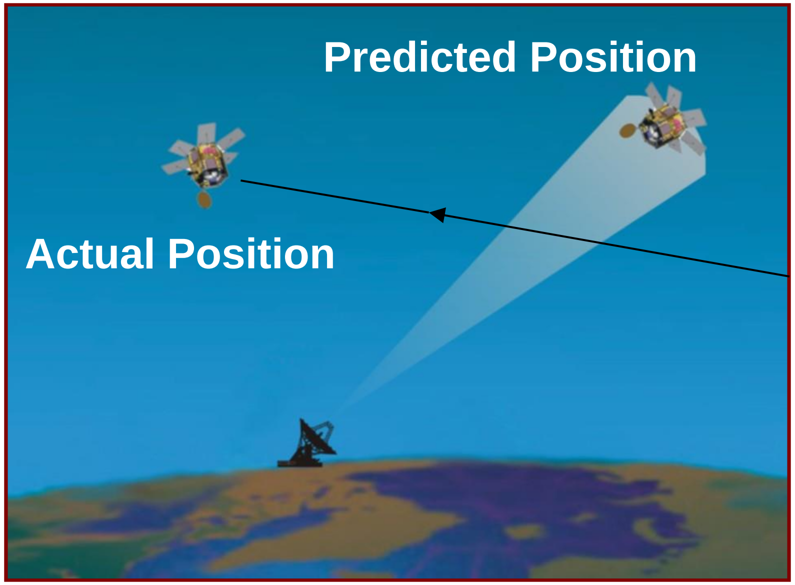
Neutral Atmosphere Density Interdisciplinary Research (NADIR)

A Multidisciplinary University Research Initiative (MURI)
Sponsored by the Air Force Office of Scientific Research

The **objective** of NADIR is to significantly advance understanding of drag forces on satellites, including density, winds, and factors affecting the drag coefficient.

We seek a level of understanding that will enable specification and prediction at the "next level" of performance.

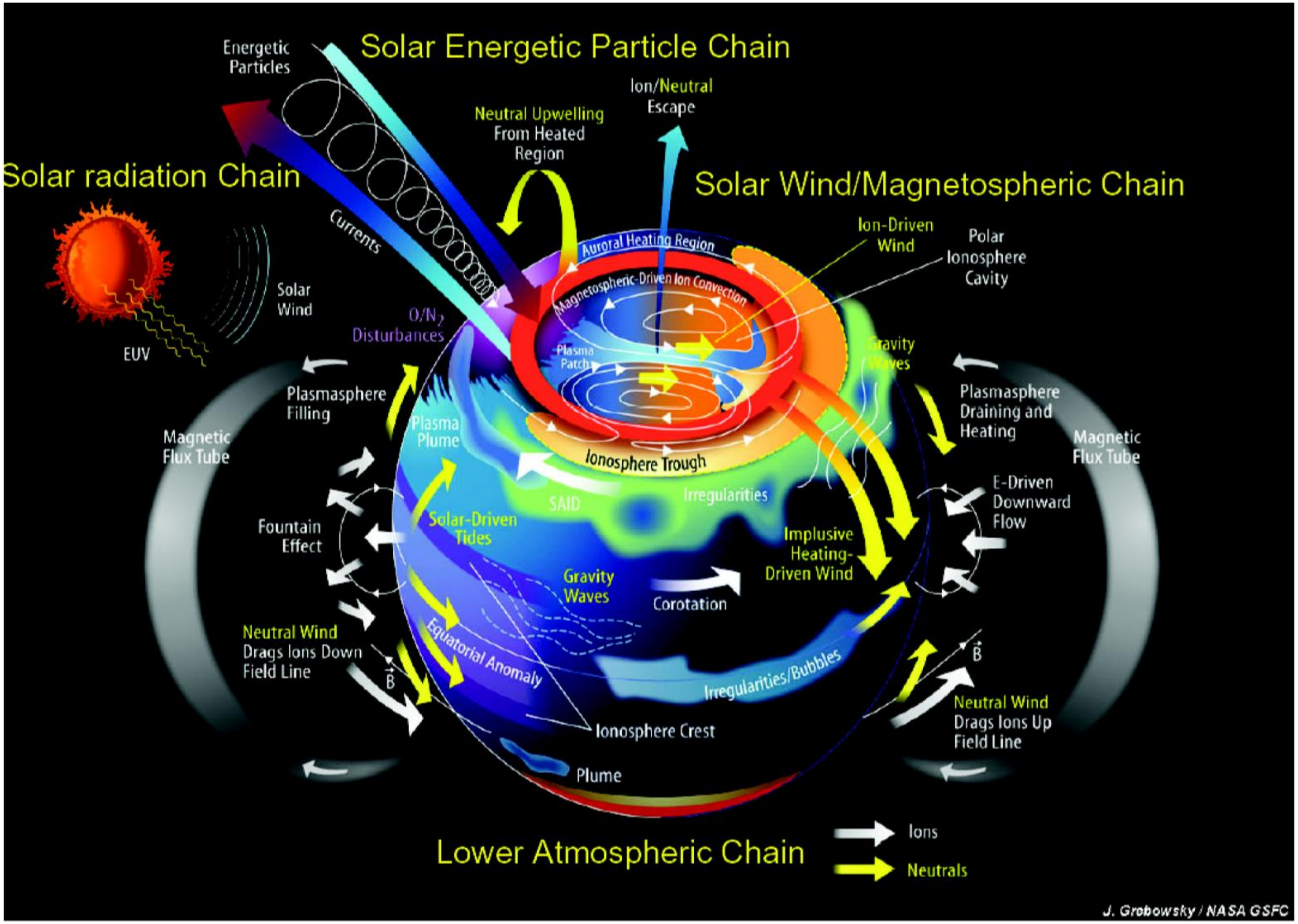


Co-Principal Investigators:
Jeff Forbes and Tim Fuller-Rowell
University of Colorado at Boulder

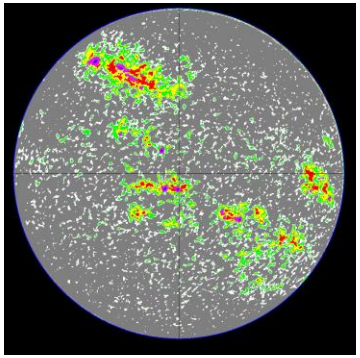
Aug 2007 - Aug 2012 $7.2 M

http://ccar.colorado.edu/muri/

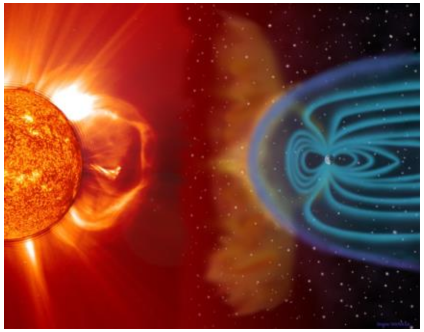
Central theme of NADIR: Understand the partitioning of density variability between 3 main sources: (1) solar EUV radiation; (2) geomagnetic disturbances; (3) waves and disturbances originating in the atmosphere below 100 km.



Terrestrial Processes and Sources Impacting Neutral Density



Focus Areas



I. Scales of Density Variability, Winds, and Drag Prediction
II. Internal Processes and Thermosphere-Ionosphere Coupling
III. Energy Partitioning at High Latitudes and Density Implications
IV. Wave Forcing from the Lower Atmosphere
V. Forecasting Geomagnetic Activity
VI. Forecasting Solar EUV/UV Radiation
VII. Driver-Response Relationships
VIII. Satellite Drag in the Transition (Reentry) Region

NADIR Participants

Co-Investigators

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- Scott Palo, CU
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- Arthur Richmond, NCAR
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Summary of NADIR Accomplishments and Research Highlights

New understanding was developed of

(1) the impact of Helium on the mass density response to geomagnetic activity;

(2) relationships between neutral and ionized structures in the equatorial region;

(3) density response to co-rotating interaction regions in the solar wind;

(4) nitric oxide cooling on the density response & recovery to magnetic storms;

(5) the relation between interplanetary magnetic field and neutral density variability;

(6) cusp density enhancements due to joule heating and particle precipitation;

Deeper Understanding of Energy Partitioning at High latitudes, and Implications for Neutral Density Response

Frontal reconnection, $B_z < 0$
side-lobe reconnection,
$B_z > 0$, B_y large

solar wind-magnetosphere interaction determines the nature of electric fields, currents, particles presented to the ionosphere-thermosphere system at high latitudes

particles

Poynting flux

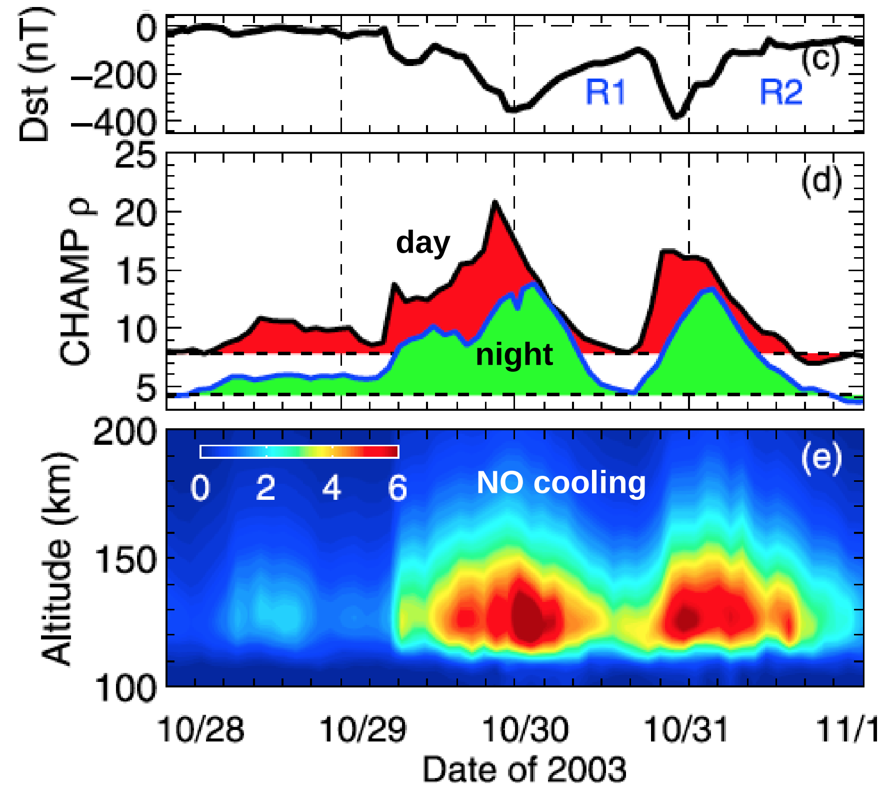
excitation of N_2^*, N^* and production of NO

IR 63μ radiative cooling by NO

height distributions of conductivity and Joule heating in the thermosphere (depends on seasonal, level of solar activity)

direct heating of the upper thermosphere

determine the intensity, response time and recovery time of density response



Summary of NADIR Accomplishments and Research Highlights

New understanding was developed of

(1) the impact of Helium on the mass density response to geomagnetic activity;

(2) relationships between neutral and ionized structures in the equatorial region;

(3) seasonal and solar cycle mass density behavior during CIR storms;

(4) nitric oxide cooling on the density response to strong magnetic storms;

(5) the relation between interplanetary magnetic field and neutral density variability;

(6) cusp density enhancements due to joule heating and particle precipitation;

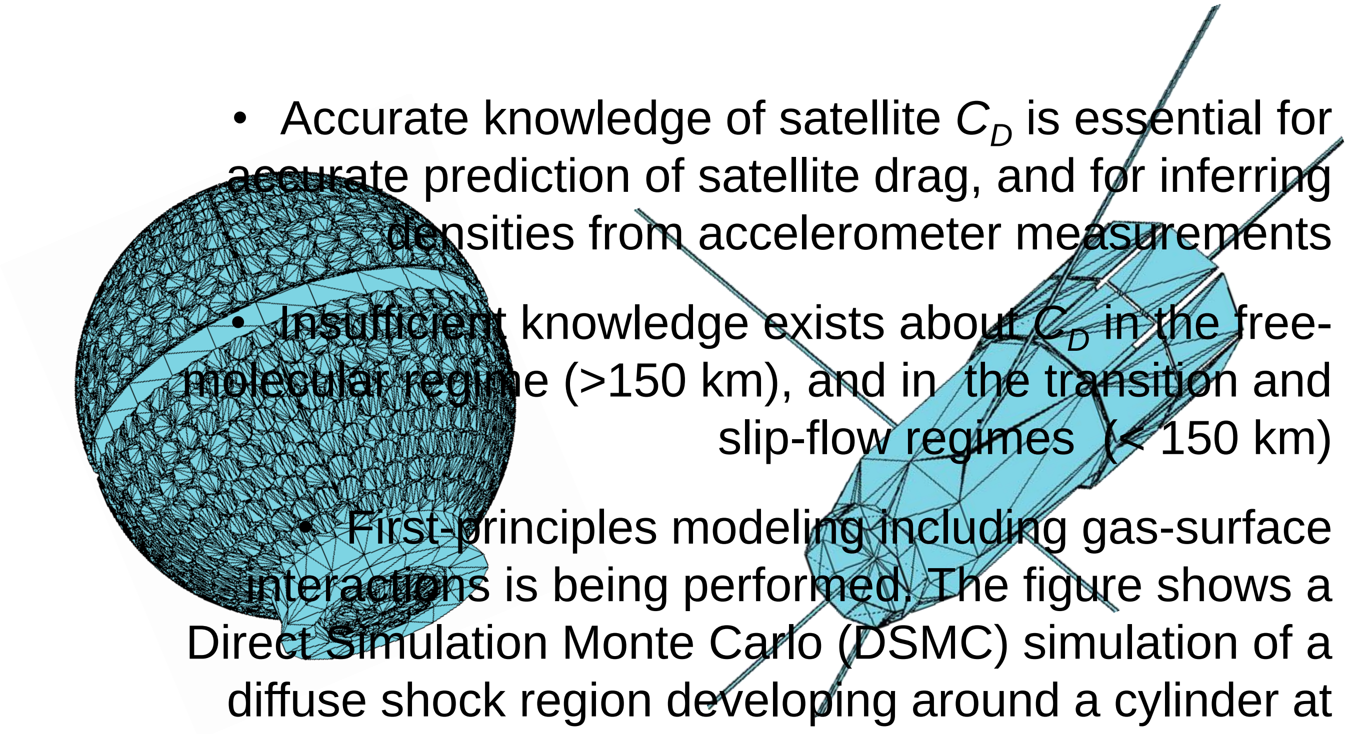
(7) the relation between high-latitude wind circulation and neutral density structures;

(8) anomalously-low densities during solar minimum;

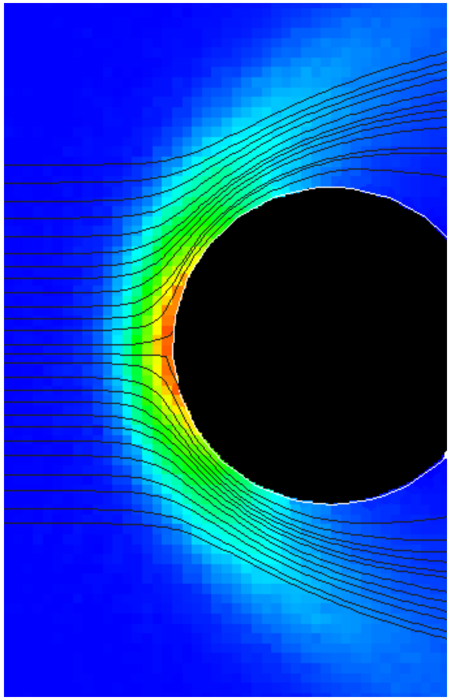
(9) drag coefficient-atmosphere interactions;

(10) rigid body dynamics of objects in transition flow and reentry;

First-Principles Modeling of Satellite Drag Coefficients



- Accurate knowledge of satellite C_D is essential for accurate prediction of satellite drag, and for inferring densities from accelerometer measurements
- Insufficient knowledge exists about C_D in the free-molecular regime (>150 km), and in the transition and slip-flow regimes (< 150 km)
- First-principles modeling including gas-surface interactions is being performed. The figure shows a Direct Simulation Monte Carlo (DSMC) simulation of a diffuse shock region developing around a cylinder at around 110 km altitude.



A DSMC simulation for force-coefficient computation

Objective: To significantly advance understanding of satellite drag in the transition and near-continuum regimes using state-of-the art numerical modeling, and to provide C_D predictions under a broadened range of conditions

Summary of NADIR Accomplishments and Research Highlights - continued

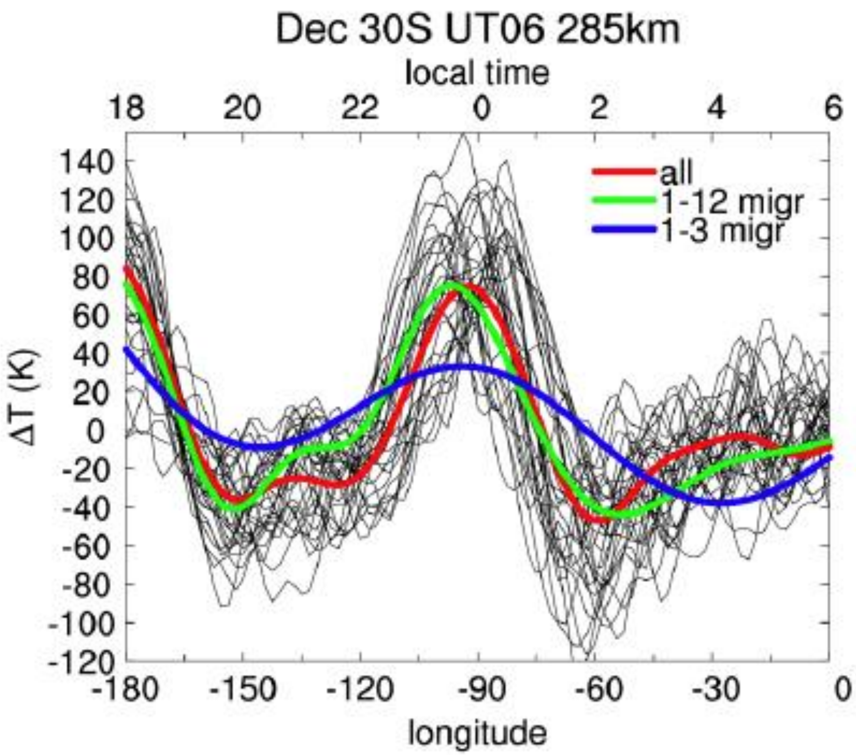
New understanding was developed of

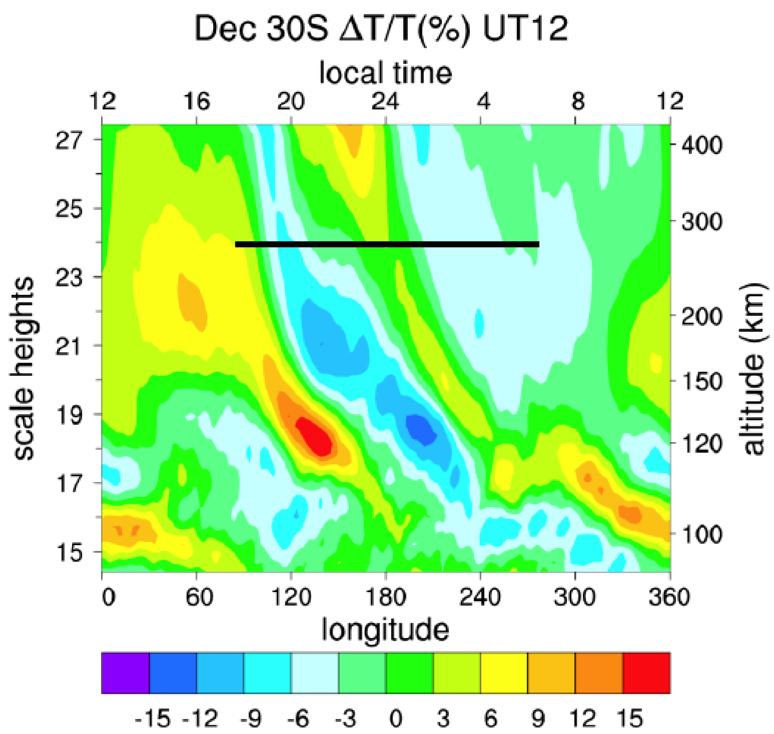
(11) how lower-atmosphere meteorology drives thermosphere density variability;

(12) how longitude-varying tidal density perturbations influence reentry and impact predictions;

Whole Atmosphere Model (WAM) Reveals New Insights Into Thermosphere Variability Driven by the Lower Atmosphere

Midnight Temperature Anomaly (MTM)

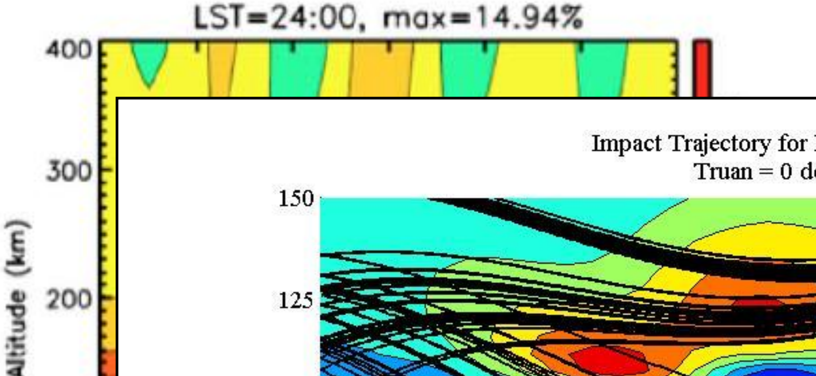


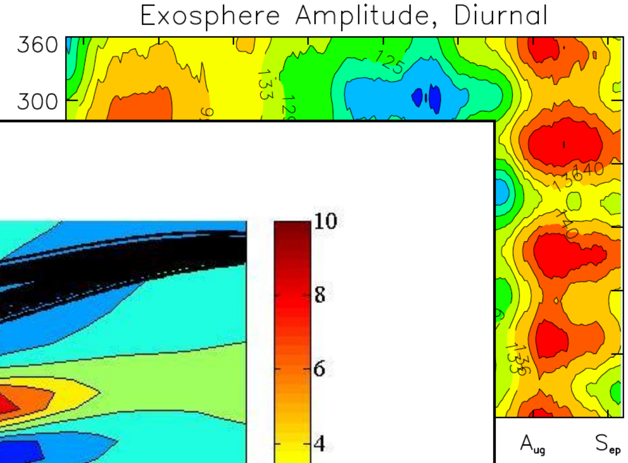


This is the first model simulation to capture the seasonal - latitudinal variability and amplitude of the MTM, and to account for its lower-atmosphere origin

Longitudinal Variability at Orbital and Reentry Altitudes Attributed to Tropospheric Wave Sources

Tidal theory, wind and temperature observations used to model density variability





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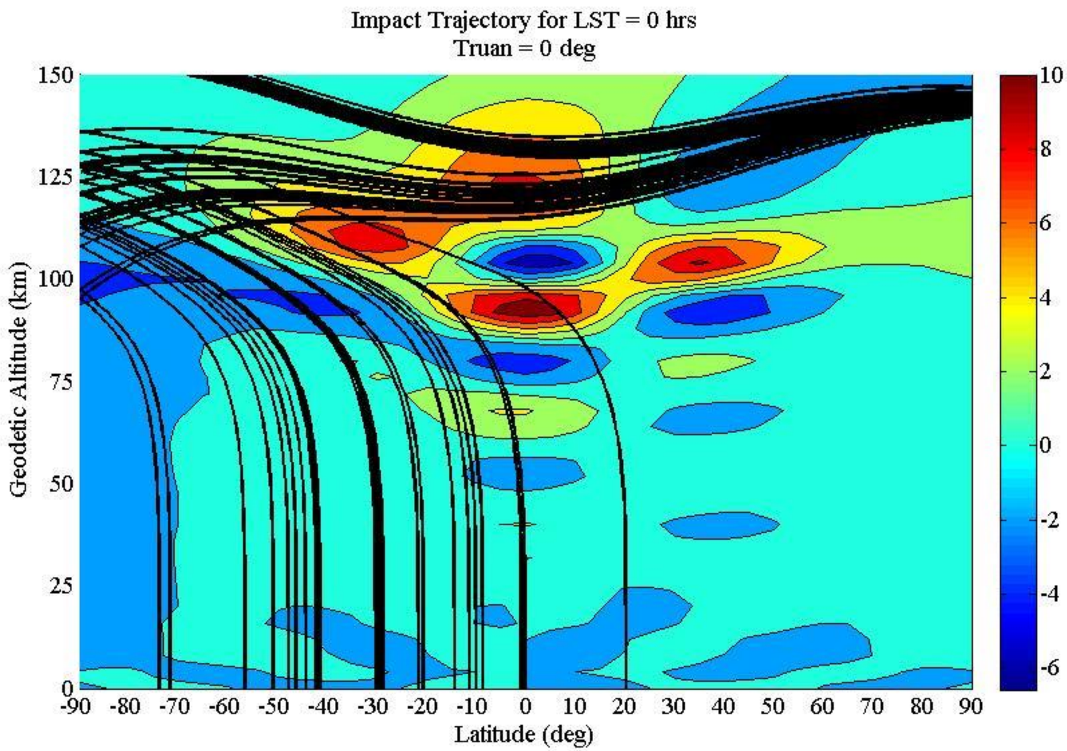


Impact trajectory dependence on longitude of reentry, with local time kept constant. Existing empirical models do not account for these effects.

Summary of NADIR Accomplishments and Research Highlights - continued

New understanding was developed of

(11) how lower-atmosphere meteorology drives thermosphere density variability;

(12) how longitude-varying tidal density perturbations influence reentry and impact predictions;

(13) how images of the near- and far-side of the Sun can be used to develop EUV forecasts; and

(14) how solar flare and magnetic free energy observations can be used to forecast coronal mass ejections (CMEs).

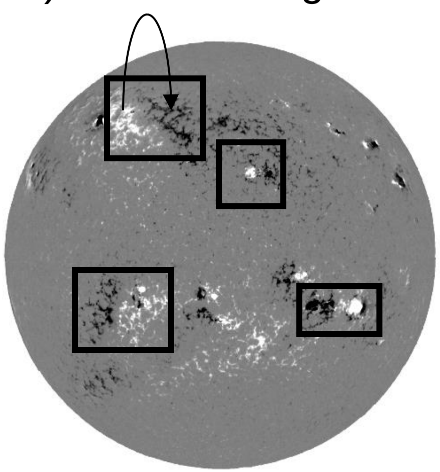
Forecasting Solar Events Using Solar Magnetograms

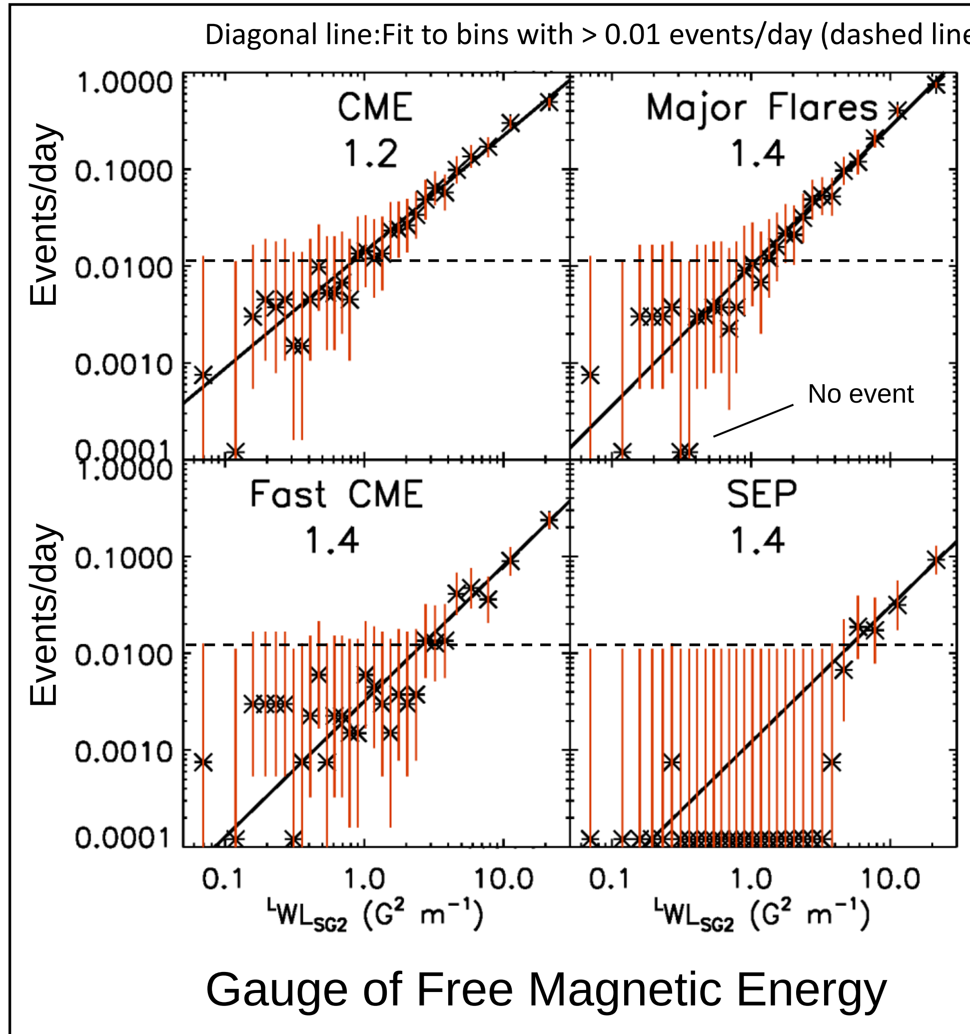
Phase I: Utilize "free magnetic energy" (~twist x size) of active regions on the Sun as a predictor of CMEs, Flares and SEP events.

Only active regions that have a large free energy are likely to produce major events in the next 24 hours.

Based on ~40,000 magnetograms from 1,300 Active regions (AR), 1996-2004, and NOAA's flare, CME and Solar Energetic Particle (SEP) event catalog.

SOHO Michelson Doppler Imager (MDI)

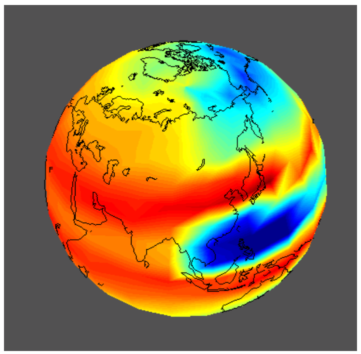




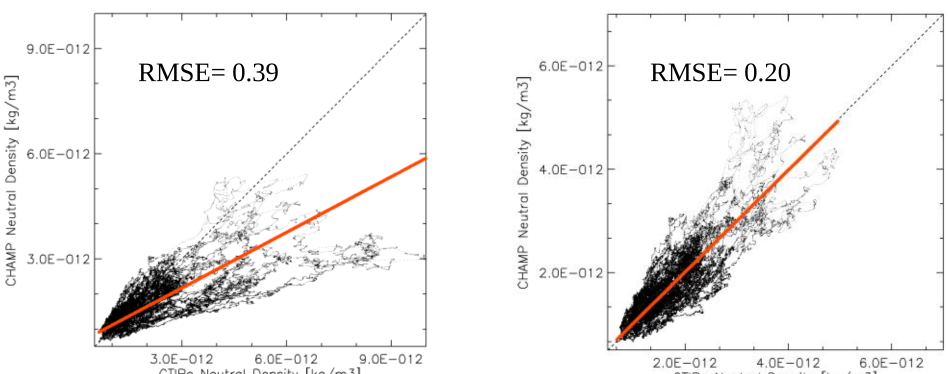
Phase II: Find secondary measures that influence an AR's probability of producing an event, e.g., **size, flare history, magnetic isolation** (fewer flares for > 10 active regions on disk).

A Transition-ready Physics-Based Thermosphere-Ionosphere Model

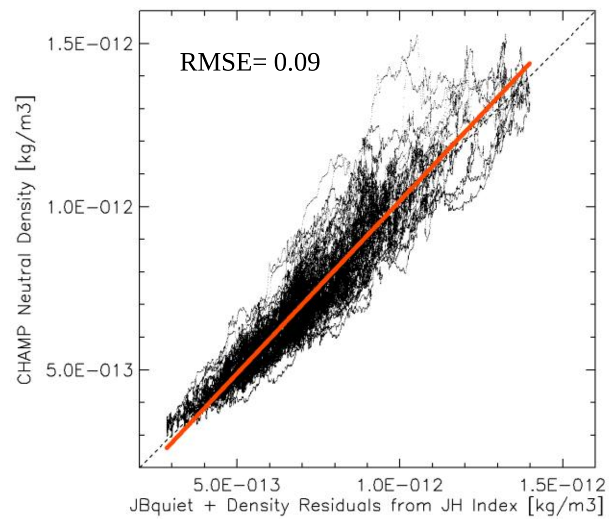
Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model (CTIPe)



Over the course of the NADIR MURI the accuracy of neutral densities in the CTIPe physics-based model has improved and can now match and sometimes exceed those of empirical models for satellite drag.

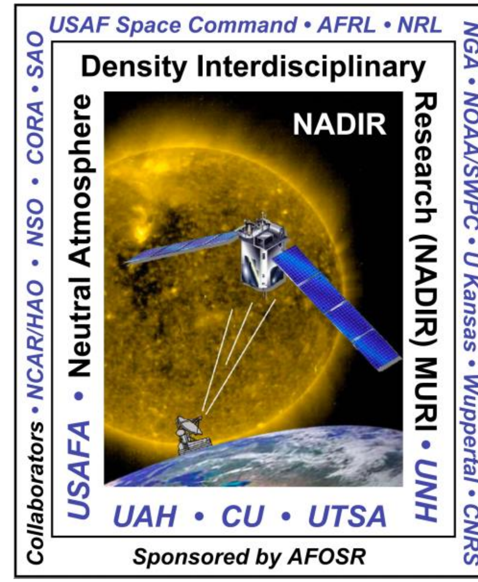


Inclusion of TIMED/SABER-based NO cooling algorithm significantly improved accuracy of CTIPe model compared with CHAMP data in 2005



CTIPe has also been used to create a Joule Heating Index (JHI) that captures measured density variability very well. The above figure illustrates its use in the Jacchia-Bowman (JB) model to further improve CHAMP density predictions [Fedrizzi et al., 2012].

CONCLUSIONS



• As a result of NADIR we better understand the physical processes that drive satellite drag variability and that underlie a predictive capability.

• Our work included solar predictions, evolution of disturbances from the Sun to L1, into the magnetosphere, throughout the ionosphere-thermosphere system, and encompassed numerical simulation and data analyses.

FUTURE CHALLENGES

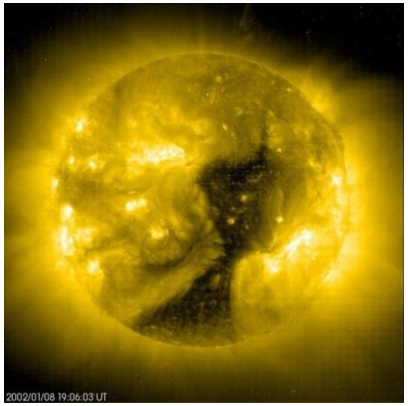
• The outcomes of NADIR need to be transitioned to practical use. This is being facilitated through SBIRs, and by scientists at AFRL.

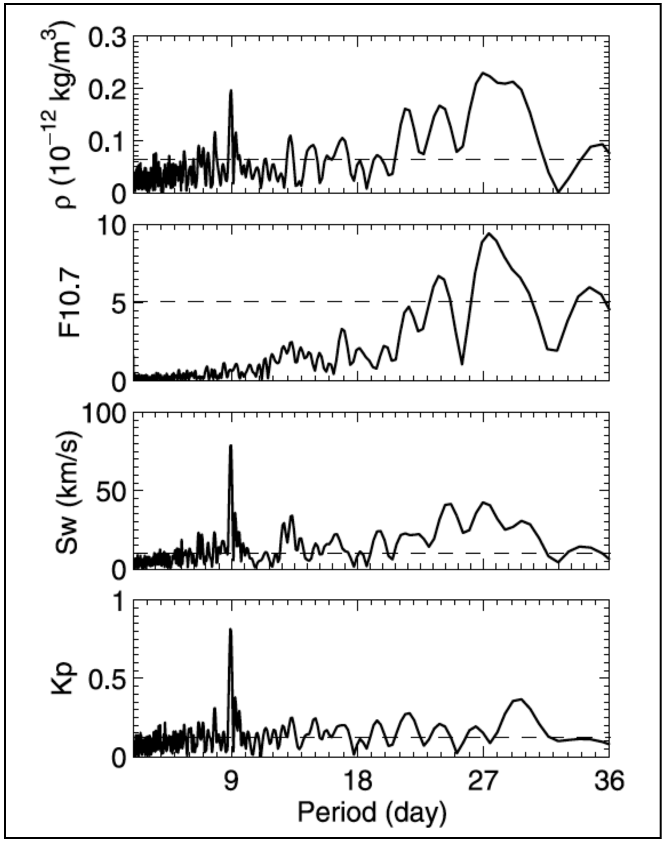
• While some important advances can be made with regard to empirical models, the key to future success will be global computationally-efficient first-principles models that assimilate real-time data, ***and*** predictions of solar and magnetospheric energy inputs.

• Global measurements of winds and composition are desperately needed.

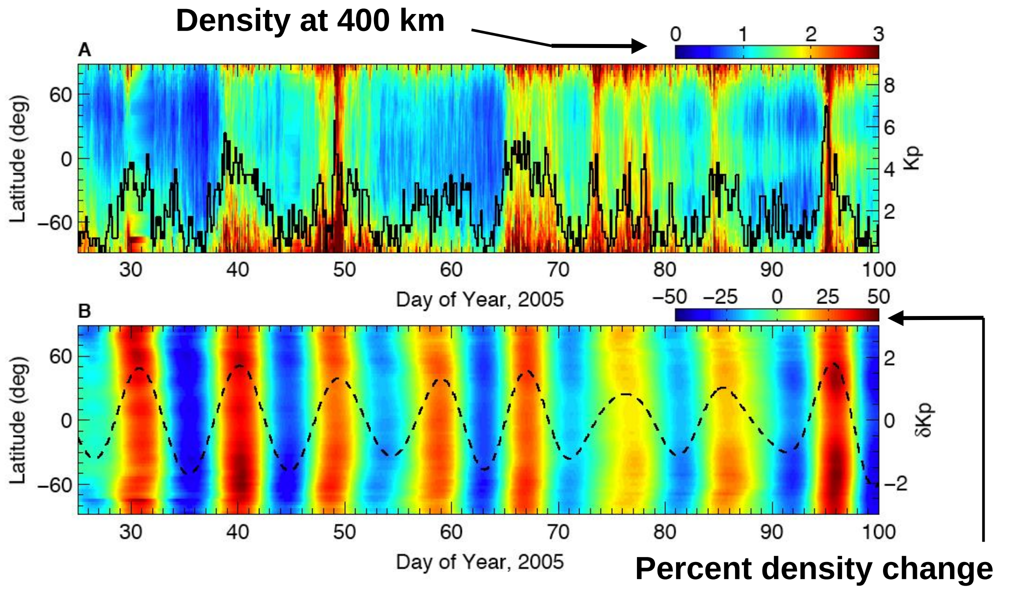
BACK-UP SLIDES

Rotating Coronal Holes and Periodic Modulation of Energy Input into the Ionosphere-Thermosphere System





Rotating coronal holes give rise to periodic fast solar wind streams and corotating interaction regions (CIRs) that modulate the energy input into the geospace system

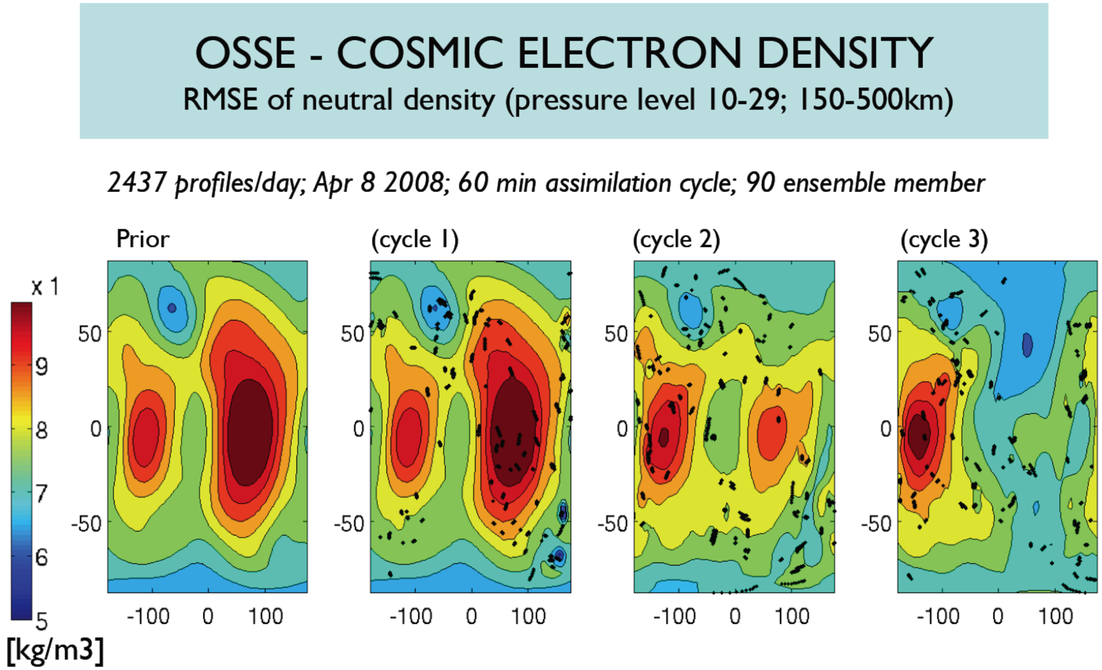


VII. Driver-Response Relationships, *Tomoko Matsuo*, *Co-I*

HIGHLIGHT: Observing System Simulation Experiments, *T. Matsuo*

Sensitivity studies are performed using "synthetic data" from TIEGCM to identify the critical parameters for data assimilation to reduce total mass density errors.

Assimilating COSMIC electron densities into TIEGCM can reduce the RMSE of neutral density globally. The RMSE reduction is mostly coming from better constrained neutral temperature by COSMIC observations.

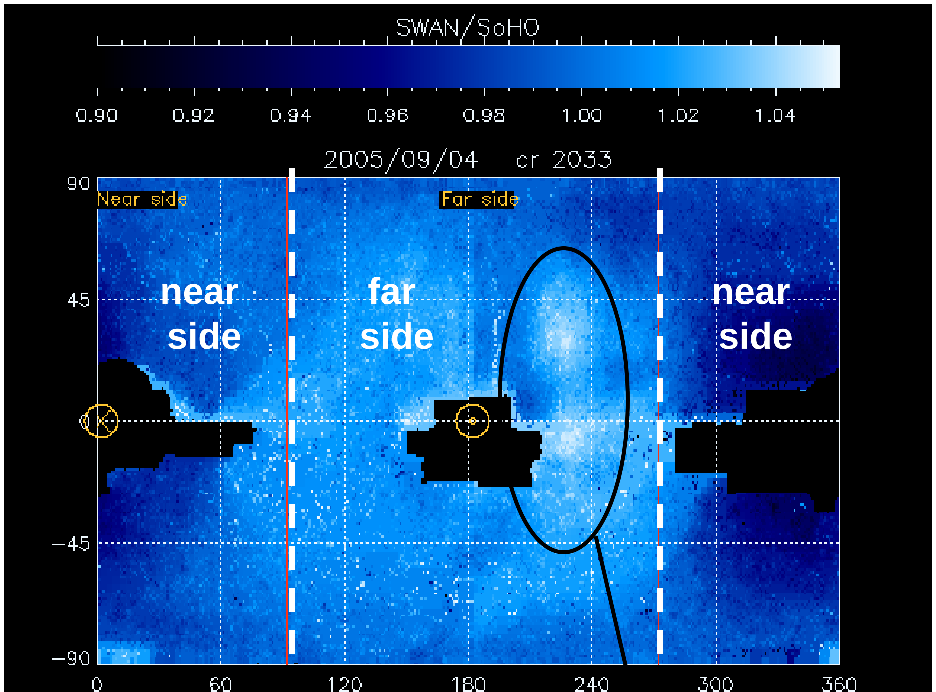


This preliminary result shows that assimilation of global observations of the electron density into a coupled thermosphere-ionosphere general circulation model is effective in constraining the global neutral density - potentially more effective than density observations along a single satellite track (e.g. CHAMP-type sampling of the neutral density).

VI. Forecasting Solar EUV/UV Radiation, *Juan Fontenla, Co-I*

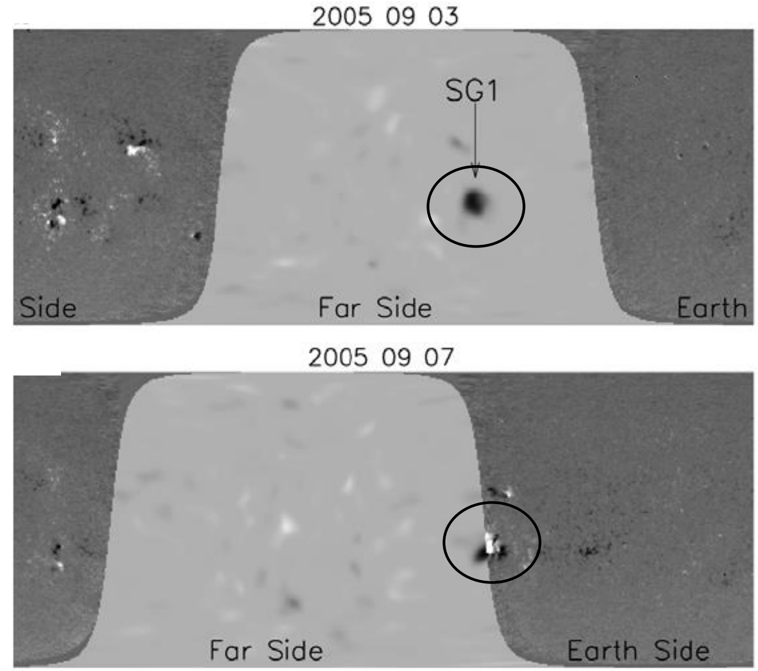
HIGHLIGHT: Far-Side Imaging

Lyman-alpha radiation far-side back-scattering
(Quemerais, Bertaux et al.)



Enhanced Lyman-alpha radiation from active regions on the far side of the Sun, resonantly back-scattered from H atoms in the inner heliosphere.

Phase-sensitive helioseismic holography
(Lindsey, Braun et al.)



Active regions on the far side of the Sun can be detected due to the difference in travel time between going into and out of an active region. This phase sensitivity is observed in waves appearing on the surface on the near side of the Sun.