Accomplishments of the Past Decade & Science Imperatives for Atmosphere-Ionosphere-Magnetosphere Interactions (AIMI) Research

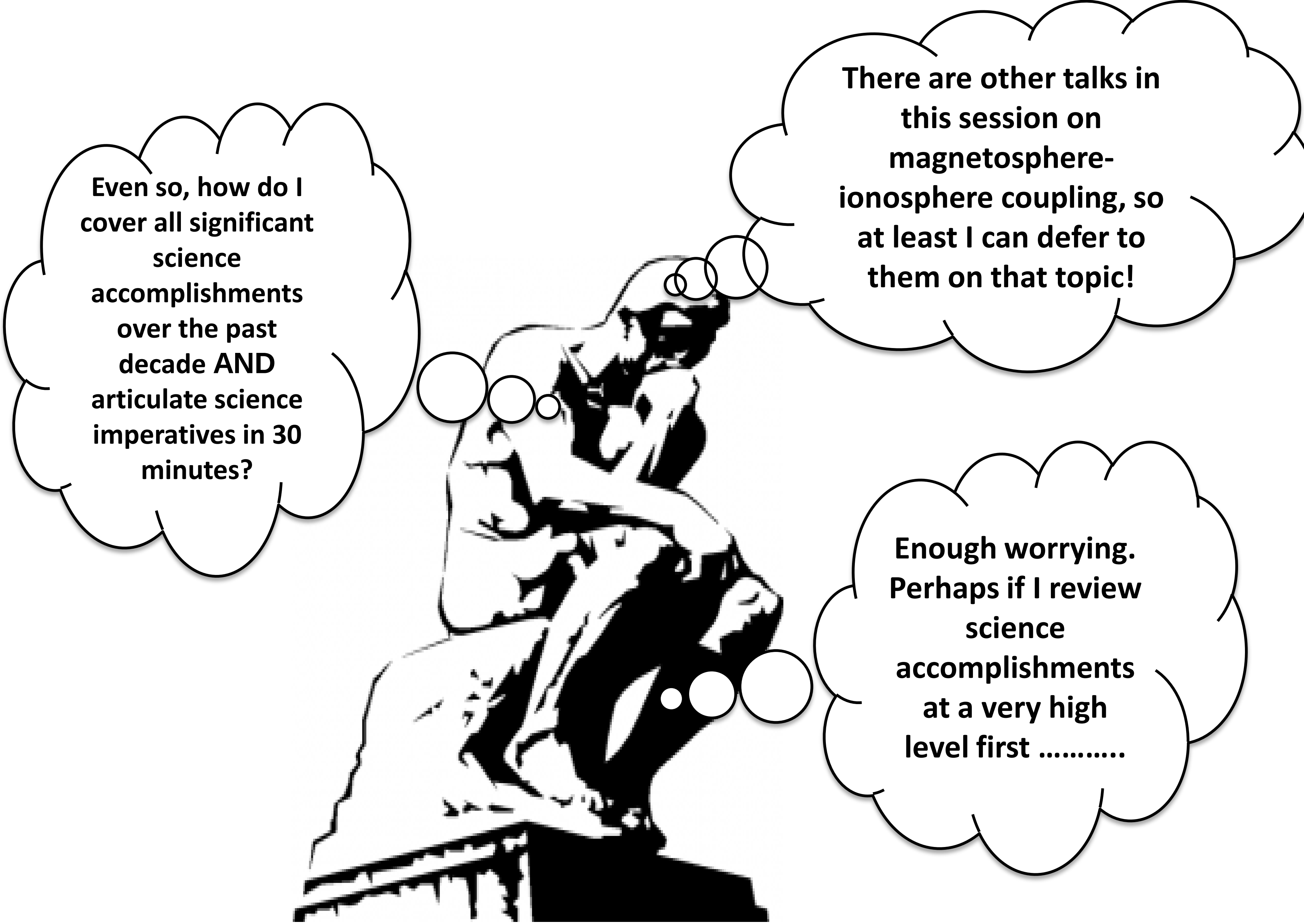
Jeffrey Forbes (University of Colorado)
chair of AIMI

CEDAR-GEM Workshop
Santa Fe, NM, 27 June 2011

What do they mean by
“science imperatives”
and why did they ask me
to give this talk?

Maybe because I am
the AIMI Panel Chair for
the Solar and Space
Physics Decadal Survey?

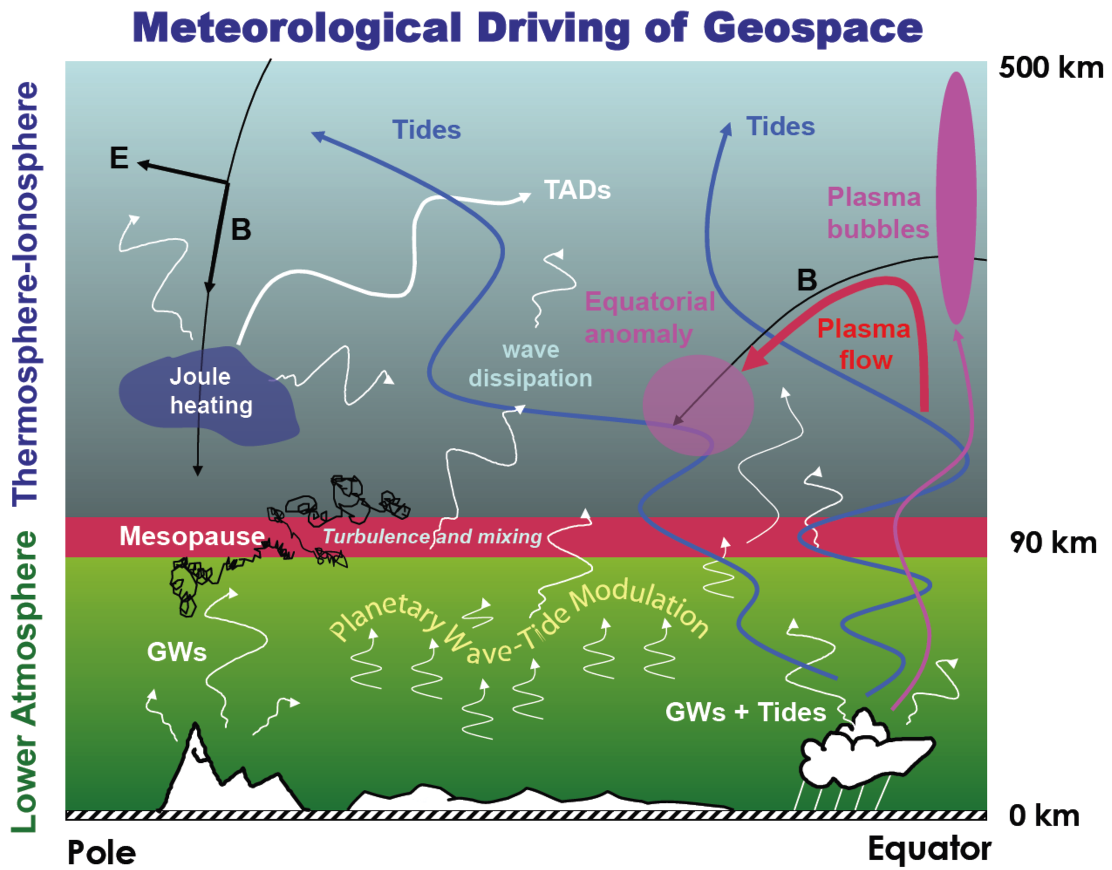
But, they must know
that I am not allowed
to discuss any of the
AIMI Panel’s
deliberations, although
145 public AIMI white
papers were submitted.


Even so, how do I cover all significant science accomplishments over the past decade AND articulate science imperatives in 30 minutes?
There are other talks in this session on magnetosphere-ionosphere coupling, so at least I can defer to them on that topic!
Enough worrying. Perhaps if I review science accomplishments at a very high level first ……….

AIMI Accomplishments During the Past Decade:

Meteorological Driving of Geospace

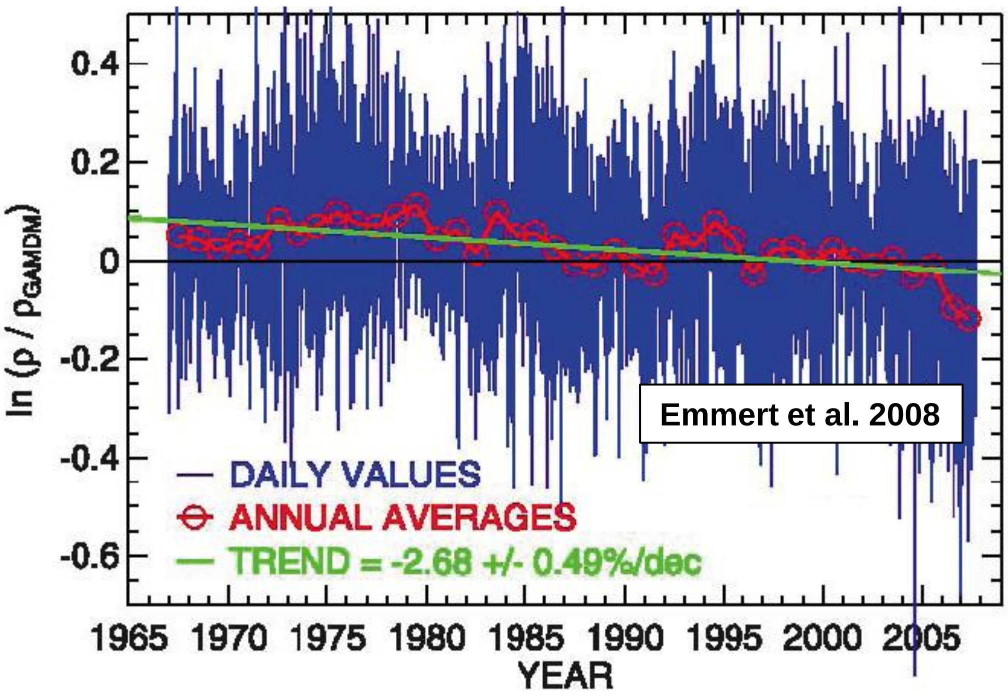
- Atmospheric tides and other waves generated by tropical convection are driving significant ionosphere and thermosphere variability.
- Gravity waves generated in the troposphere penetrate well into the IT system and are dissipated there.
- Polar stratospheric warmings produce global effects in the IT system.



AIMI Accomplishments During the Past Decade:

Planetary Change is Occurring

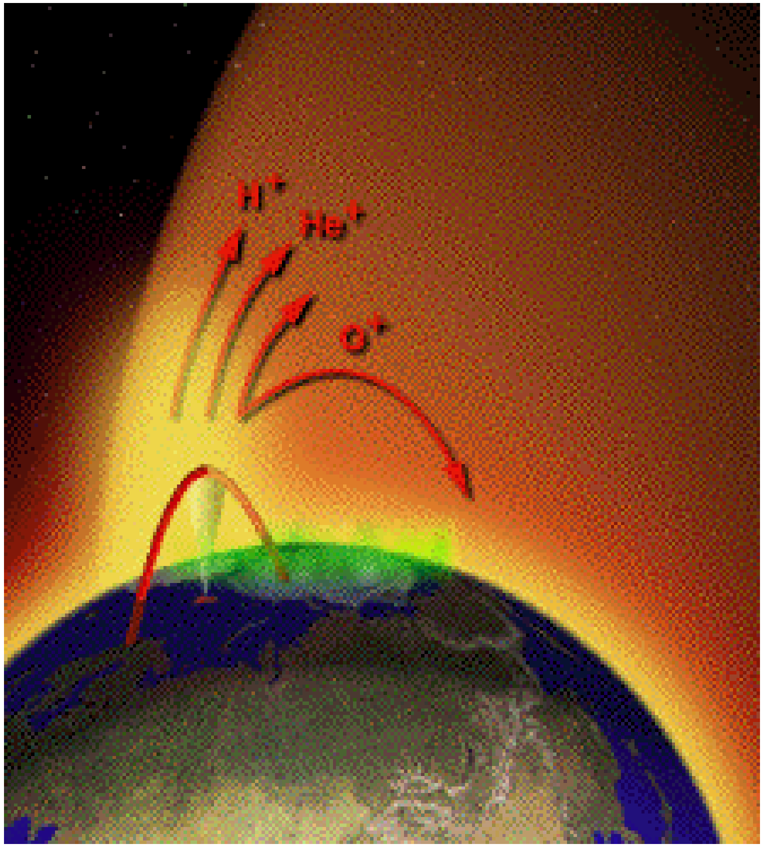
- Observational evidence exists that that thermosphere is contracting, probably an anthropogenic effect due to rising CO_2.
- Evidence exists for long-term ionospheric effects due to secular changes in the geomagnetic field



AIMI Accomplishments During the Past Decade:

Ion Outflow Recognized as Important to Solar Wind-Magnetosphere-Ionosphere Coupling

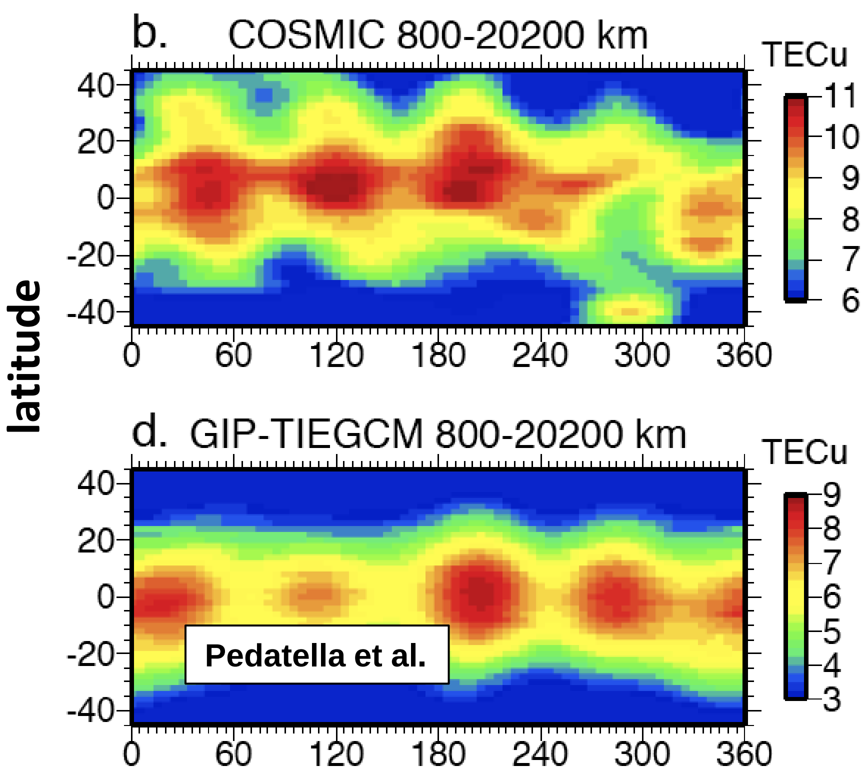
- Significant O^+ is supplied to the magnetosphere by the ionosphere.
- The presence of enhanced O^+ affects such processes as reconnection and could precondition the magnetosphere's response to subsequent solar wind forcing.
- The global effect of outflowing O^+ may be to moderate forcing of the ionosphere.

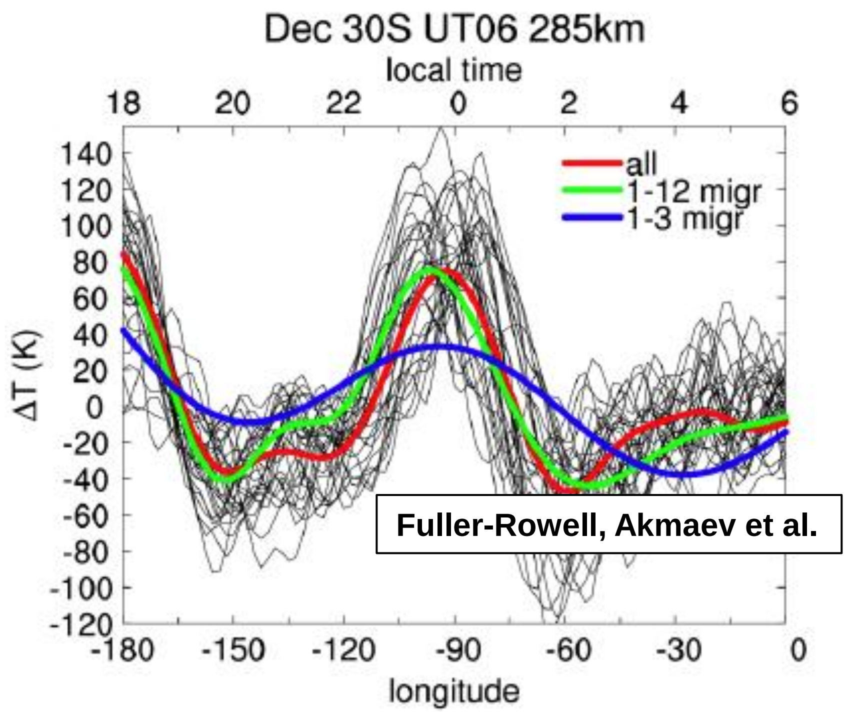


AIMI Accomplishments During the Past Decade:

Advanced Simulation Models Developed

Comprehensive Multi-Physics Global Models Extend to the Ground and Include Plasmasphere- and Magnetosphere-Ionosphere Coupling



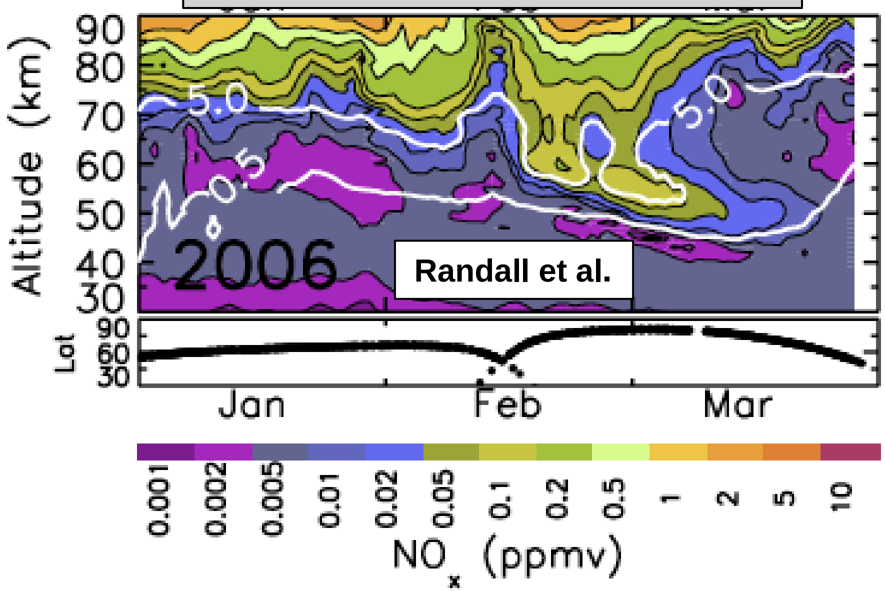


Whole Atmosphere Model (WAM)

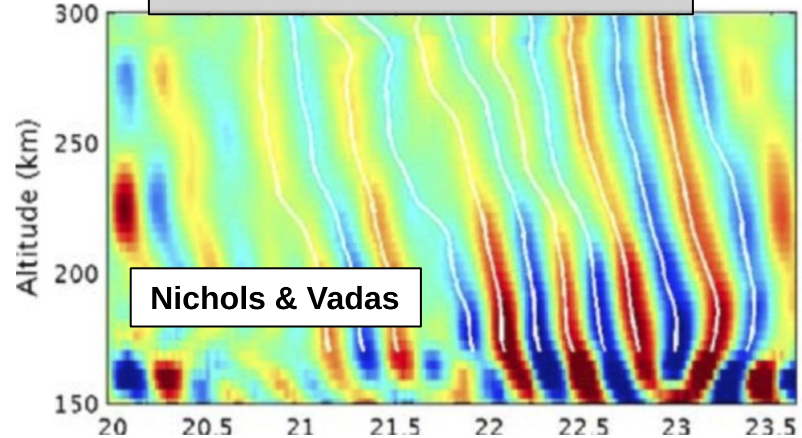
AIMI Accomplishments During the Past Decade:

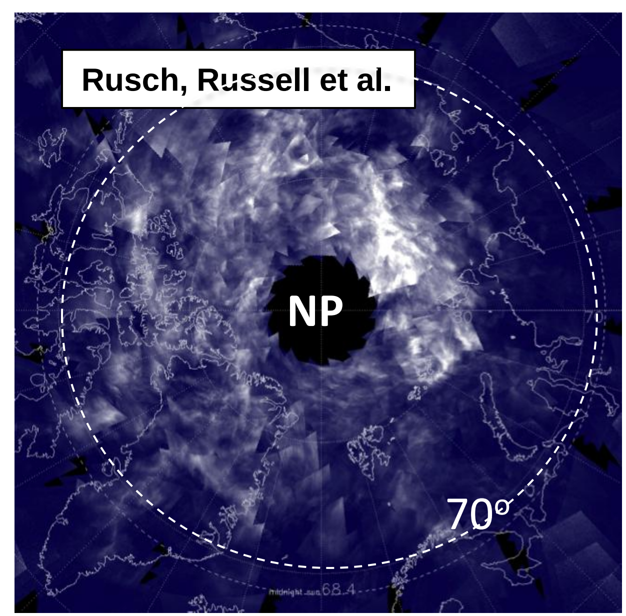
New Insights Into Vertical Coupling in the Polar Regions

NO produced by energetic particles in the thermosphere can be transported down to the stratosphere and catalytically destroy O_3.



Gravity waves propagating into the thermosphere

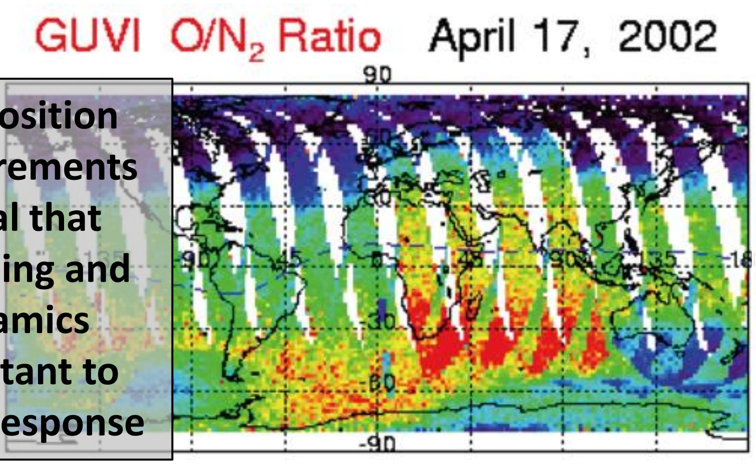




Polar Mesospheric Cloud (PMC) and complementary observations reveal insights into formation mechanisms, local and global dynamics.

AIMI Accomplishments During the Past Decade:

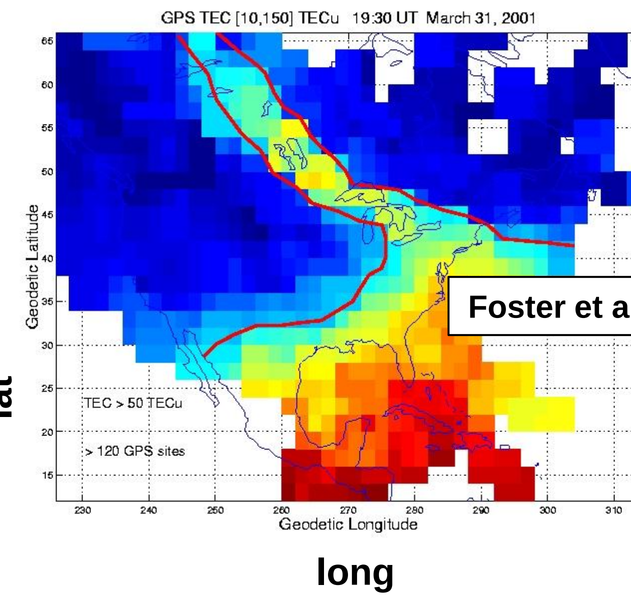
Global Response of the Ionosphere-Thermosphere to Solar Variability is Complex

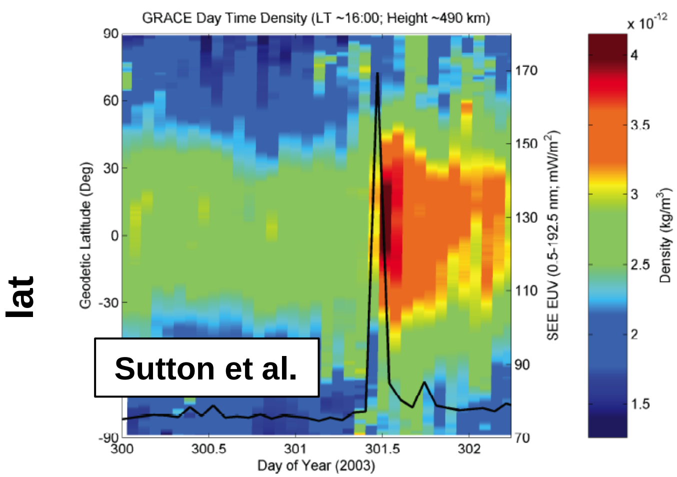


Composition measurements reveal that upwelling and dynamics important to global response

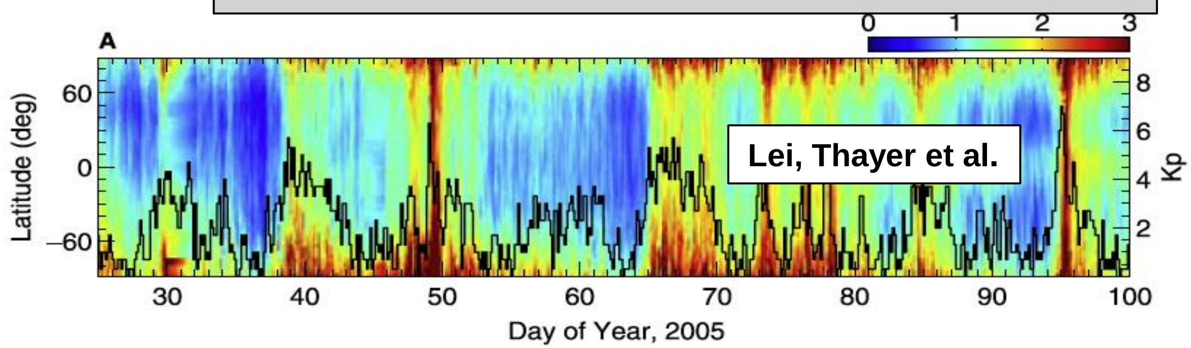
The thermosphere responds significantly to solar flares.

Storm-enhanced plasma density (SED) signatures connected to plasmasphere erosion and sub-auroral E-fields





Solar coronal holes and associated periodic high-speed streams impose these same periodicities on the IT system.

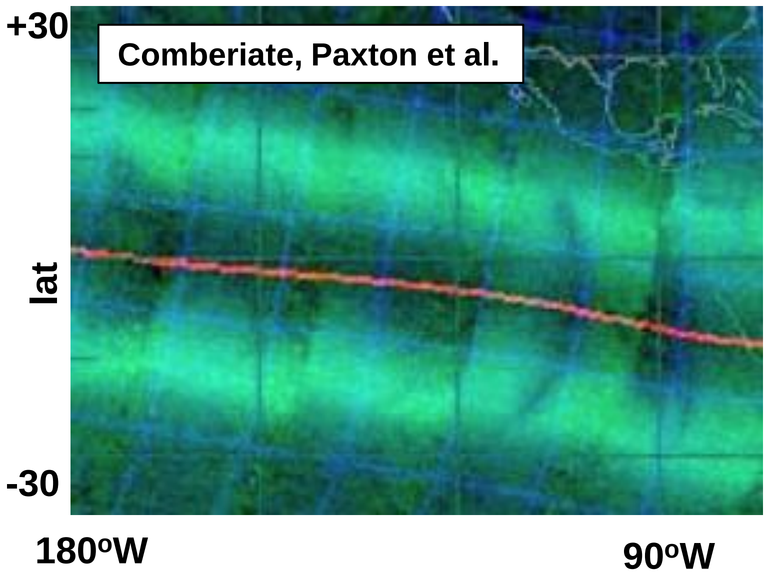


AIMI Accomplishments During the Past Decade:

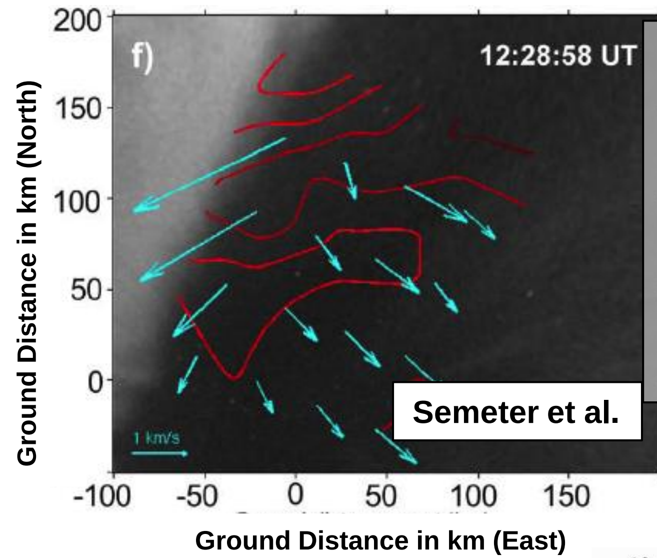
Responses Occur Over Multiple Cross-Connected Scales

Plasma structures imaged globally

Regional & Local Structures



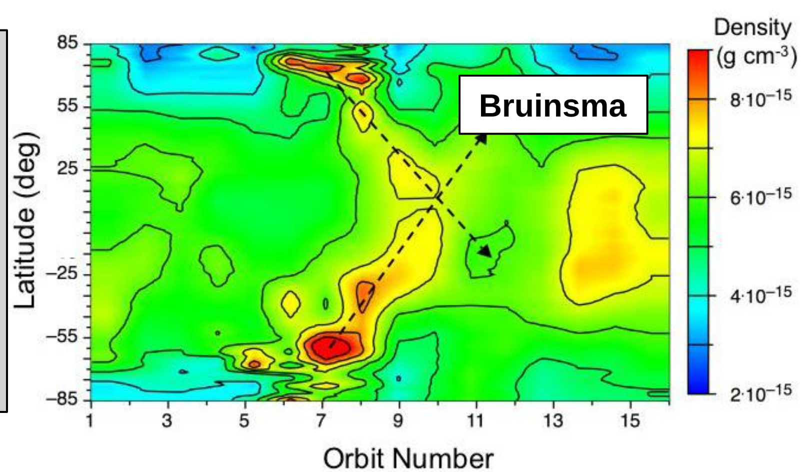
Local Structures

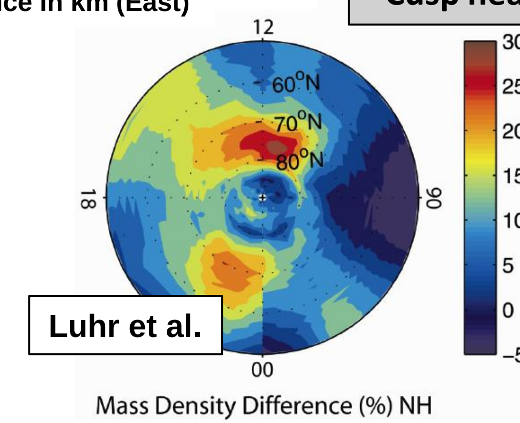


Flow fields and ion temperatures associated with a dynamic auroral boundary during the substorm recovery phase.

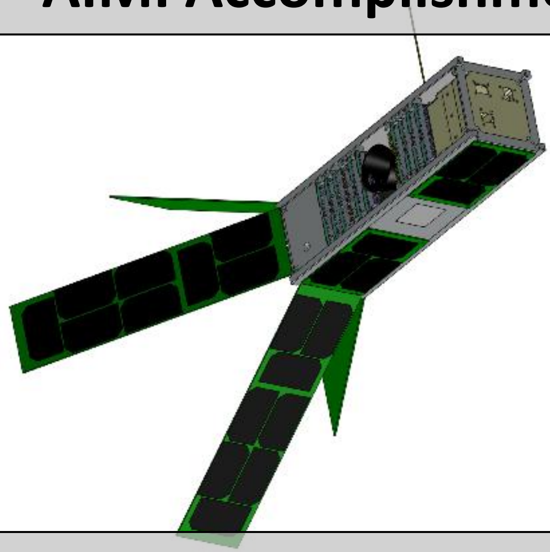
Cusp heating

Large-scale traveling atmospheric disturbances generated at high latitudes can propagate into the opposite hemisphere.

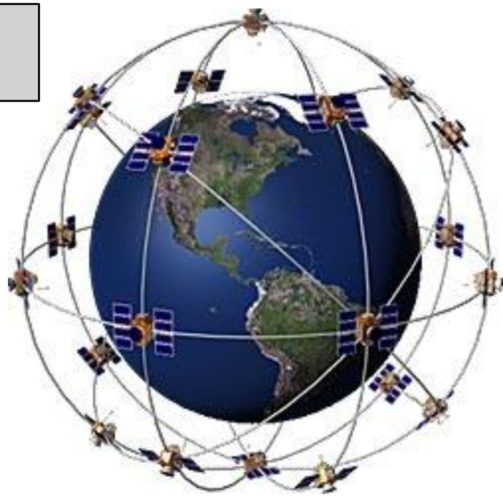




AIMI Accomplishments During the Past Decade:



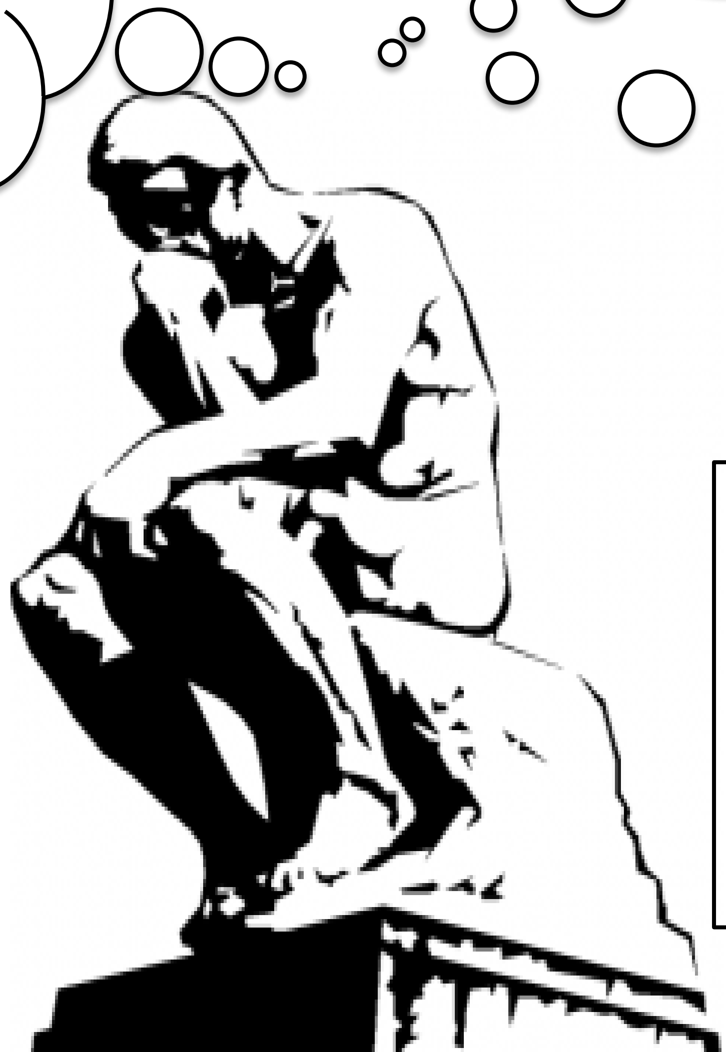
New Technologies



- Nanosatellites and miniaturized sensors represent a viable option for exploring geospace.
- Advanced Modular Incoherent Scatter Radar (AMISR) provides unprecedented high spatial and temporal sampling of the IT system at selected locations.
- Radio occultation by GPS provides a global view of ionospheric variability.

Science Imperatives for (AIMI) Research

If all of AIMI research disappeared tomorrow, who would care?



OK, now I am back to "science imperatives"

An imperative must derive from a need.

Imperative: Something that demands attention or action; an unavoidable obligation or requirement; necessity.

JMF's corollary: There will be significant consequences if the imperative is not carried out.

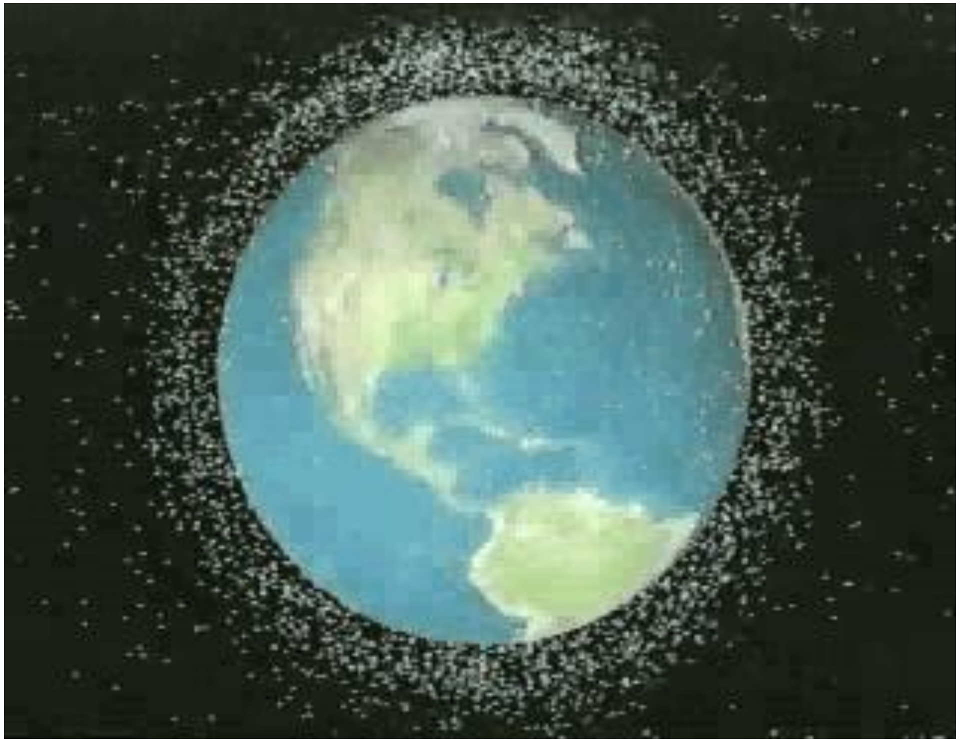
Space Weather is gaining significant traction nowadays …….

To have traction in today's society, it must be recognized as important by the public and our government

Satellite orbit prediction would serve as a focused example leading to a series of AIMI science imperatives, so ……..

A Recognized Societal Need: Satellite Orbit Prediction

What are the science imperatives that follow from the need to keep track of, and significantly improve our ability to predict the future positions of, all objects orbiting Earth?

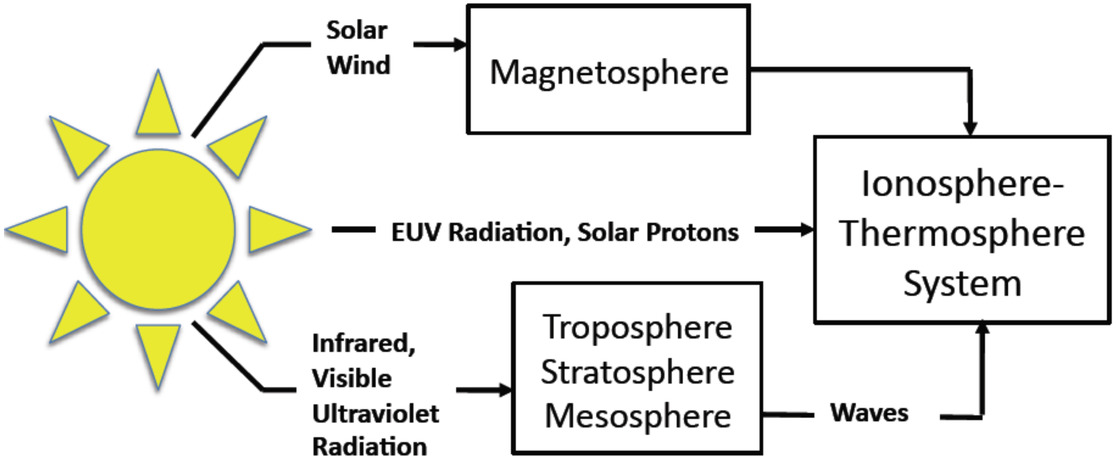


- ***Currently well over 10,000 orbiting objects are tracked every day.***
- ***Knowledge about orbiting objects and their "activities" are important to national security.***
- ***Collisions between orbiting objects have occurred, creating problematic debris clouds – a snowball effect is possible.***
- ***In the coming decade there will be "civilians" in space that we will need to worry about.***
- ***It is important to predict collisions in order to take mitigating actions.***
- ***Total mass density and winds are the most critical parameters for drag prediction.***

A Recognized Societal Need: Satellite Orbit Prediction

What are the science imperatives that follow from the need to keep track of, and significantly improve our ability to predict the future positions of, all objects orbiting Earth?

1. **Measure** the global response of the system to variable external forcing.
2. **Understand** the interrelationships and processes that determine the response, and that underlie a predictive capability.
3. **Understand** how the ionosphere-thermosphere moderates energy input into itself.
4. **Develop Models** of the response to variable external forcing based on the above.
5. **Predict** the variable energy inputs.



A Recognized Societal Need: Satellite orbit Prediction

What are the science imperatives that follow from the need to keep track of, and significantly improve our ability to predict the future positions of, all objects orbiting Earth?

1. Measure the global response of the system to variable external forcing

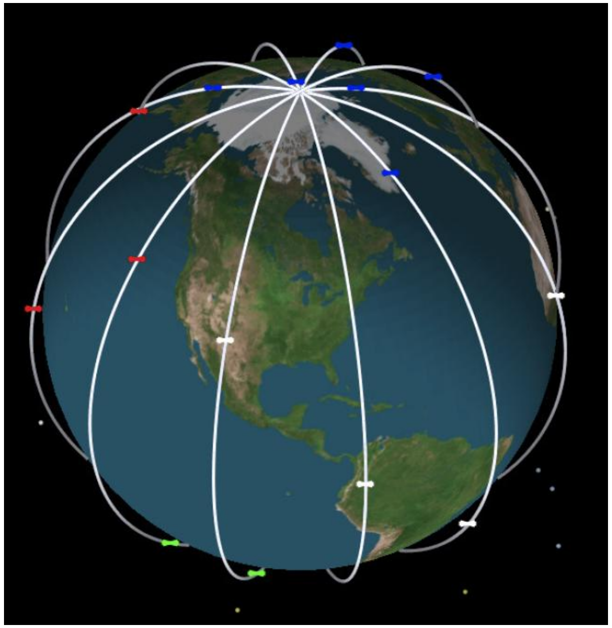
2. Understand the interrelationships and processes that determine the response, and that underlie a predictive capability.

Measure neutral densities (O and N_2 better than ρ) and winds globally

3. Understand how the ionosphere-thermosphere moderates energy inputs into itself.

Measure energy inputs into the system

- ***Poynting flux (i.e., E, δB)***
- ***Large-scale waves from the lower atmosphere***
- ***Solar UV/EUV spectra***



Some limited success can be achieved by developing empirical relationships/models based on the above, but we know this approach to be inadequate – each magnetic storm is different!

2. Understand the interrelationships and processes that determine the response, and that underlie a predictive capability.

How do winds, thermal expansion and composition work together to determine the global density response?

Action: Measure the global wind and temperature fields, chemical constituents and total mass density

What determines the global distribution of chemical composition at the base of the thermosphere (100 km)?

Action: Measure the constituents and the dynamical fields responsible for their global and local transport

Action: Develop the theory underlying the generation of turbulence and the interaction between chemistry and dynamics

How does the ionospheric plasma and B-field modify global dynamics, thermal balance, and density response?

Action: Measure the global distribution, composition and motions of ions

How does Joule heating vary in space and time (determines amplitude and temporal evolution of response)?

Action: Measure the distributions of electrons, neutral densities, and energetic particle spectra.

2. Understand the interrelationships and processes that determine the response, and that underlie a predictive capability.

How do vertically-propagating waves and aurorally-produced waves modify the mean state of the thermosphere?

Action: Measure the waves and their spatial and temporal evolution

Action: Measure the mean state relative to the waves

Action: Develop theory and modeling to understand wave dissipation, wave-wave and wave-mean flow interactions

How does radiative cooling moderate the response and recovery to variable magnetospheric forcing?

Action: Measure the relevant radiative species (i.e., NO, CO_2) and their emissions along with everything else!

3. Understand how the ionosphere-thermosphere moderates energy inputs into itself.

How does the ionosphere-thermosphere basic state control dissipation and upward penetration of waves, and the response to variable magnetospheric forcing ("preconditioning")?

Action: Measure evolution of the wave spectrum and, and global density response to magnetospheric forcing, over different levels of solar activity

How does ion outflow moderate how the magnetosphere transfers its energy into the ionosphere-thermosphere system?

Action: Measure and understand the source distribution of O^+ ions (Joule and particle heating, auroral imaging)

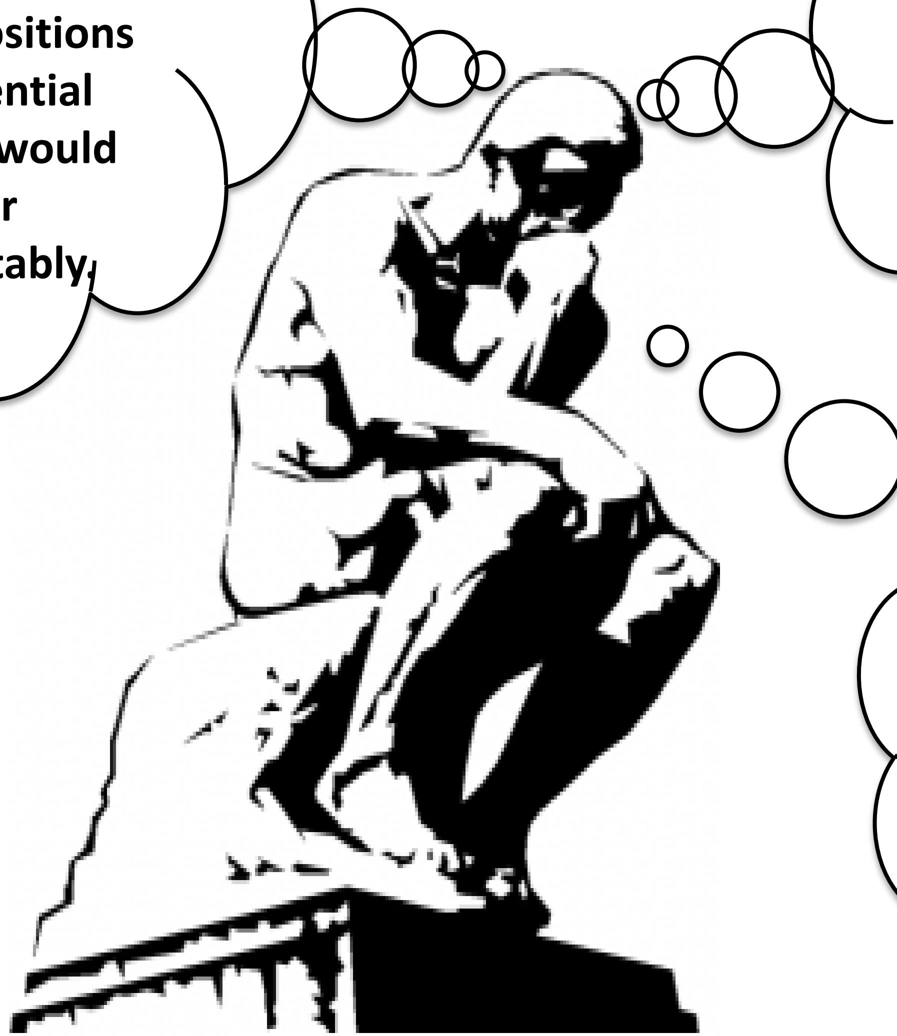
Action: Measure and understand the acceleration mechanisms (DC and wave **E**,**B**; electron and ion distribution functions)

Action: Measure the distribution functions/fluxes of O^+, He^+ and H^+

FINAL THOUGHTS

OK, if all of AIMI science disappeared, our ability to predict satellite positions and potential collisions would suffer unacceptably.

This is but a single example. We haven't considered the science imperatives connected with, e.g., communications and navigation problems, satellite anomalies, etc.



Isn't it great that so much stimulating science remains to challenge the CEDAR and GEM communities, and to inspire our students!

What are **Your** Thoughts?