ITM Science

Overarching Theme – Study the coupling between Geospace Regions.

Fundamental question of how does the upper atmosphere behave as a system. In particular, a) how does the Earth's ionosphere/thermosphere respond as a non-linear system to variable and wide-ranging energy and momentum sources and b) understanding of neutral and plasma spatial and temporal scales and their interaction.

Requirement for multipoint observations - Our field is at a point where progress will be made only if all the state variables can be measured simultaneously - need simultaneous 3D spatial distributions of state variables to understand dynamic system behaviour. Critical need for global measurements in order to place the in-situ observations in context – for example, FUV imaging and constellations.

Specific Science Themes

Direct Solar Irradiance

Solar EUV creates the ionosphere, heats the upper atmosphere, and has major effects on the chemistry and aeronomy of the Earth's upper atmosphere. Despite its fundamental role in defining the ITM system, the solar EUV irradiance spectrum and its variability are inadequately known. Consequently, so are their effects on the upper atmosphere.

1. What is the response of the ionosphere and upper atmosphere to direct solar EUV/UV and particle input

Fields and Particles with the Magnetosphere

The ionosphere and magnetosphere are a coupled system exchanging energy momentum and mass. At high latitudes, the magnetospheric energy input into the ionosphere is about 2/3rd Poynting flux and 1/3rd particle precipitation. These energy inputs change the thermospheric winds and chemistry, produce electron density changes with societal impact, and create conductivity changes. The conductivity changes react back on the magnetosphere by completing field-aligned currents. The field-aligned currents also drive microphysical processes that eject the ionosphere into the magnetosphere, thereby forming a mass source at mid-latitudes producing positive ionospheric storms. Within the equatorial ionosphere penetrating electric fields suppress spread –F at pre-midnight local times and trigger spread-F at post midnight local times.

2. Response of mid-latitude area to geomagnetic storms
3. Determine the solar and geospace causes of small scale ionospheric density irregularities in the 100 to 1000 km altitude range
4. Coupling to the stratosphere: transport from lower thermosphere/mesosphere to the lower atmosphere – nitric oxide in the polar night – solar cycle variability – evidence from measurements

5. Understanding of Joule heating and auroral input to ionosphere
6. How is the IT system dynamically coupled to the magnetosphere

Transfer of energy and momentum from the lower atmosphere

The Earth's upper atmosphere receives energy and momentum from below in the form of gravity waves, thunderstorms, electric fields, and other tropospheric and stratospheric sources. The degree to which such processes influence the upper atmosphere is very poorly known due to the very sparse database.

7. Role of gravity (produced by orographic and convective sources, and wind shears), tidal and planetary waves – this is critical for understanding ionospheric/atmospheric dynamics and chemistry.
8. What is the importance of upward coupling from the lower atmosphere – such as weather systems, clouds, sprites and lightning

Processes within the Ionosphere-Thermosphere System

From the energy and momentum sources transferred through the upper and lower boundary, internal processes redistribute these inputs to establish the large temperature, composition and dynamic structure of the upper atmosphere and thermosphere.

9. Occurrence of the counter electrojet phenomena; why and how does it form – neutral wind measurements
10. Importance of daytime, large-scale phenomena (Appleton anomaly) on the nighttime irregularity (Spread-F) occurrences – ion composition and neutral measurements necessary.
11. Study midnight temperature max – generation mechanisms (lower and upper atmosphere coupling) – what is the latitudinal extent of influence on other atmospheric parameters, longitudinal dependence
12. Role of meteoric neutrals and ions in the E-region structures (e.g. sporadic E layers, descending layers, F-region metallic ion patches) – what is their importance in ITM (also important for other planets with magnetic fields)
13. What triggers planetary scale ionospheric upwellings at low latitudes that subsequently generate irregularities with scale sizes from 1000 km to less than a meter?
14. Understand the global-scale variations and structure of the electric field

Global Change

Considering that anthropological influences in the atmosphere are increasing, it is important to establish the present day structure and determine possible future trends

15. Noctilucent clouds – coupling from below in terms of methane and water transport – also solar cycle variability
16. Water cycle variations

17. Solar variability (e.g. UV/EUV energy deposition)
18. Effects of particle precipitation on the ozone layer
19. Current day structure and possible long term trends

Science Understanding Space Weather

Characterization and understanding of the ionospheric and thermospheric disturbances that impact society and technology advances science in a way that directly benefits society

20. Communication
21. Navigation
22. Atmospheric Drag
23. Ground Induced Currents
24. Spacecraft charging
25. Radiation impacts on Human in Space

Comparative Planetology (Planetary atmosphere missions)

Comparing and contrasting planetary atmospheres is essential to understanding how atmospheres are formed, evolve, and respond to external perturbations

26. What can we learn from other planets
27. Formation, evolution, stability and structure of atmospheres
28. External energy sources – sunlight, solar wind, role of planetary magnetic fields
29. Atmospheric motion – coupling between atmospheric regions
30. Systematic observations – short and long term variability
31. Quantification of underlying physical and chemical processes

Modeling and Data Handling

- Assimilation modeling
    - Type 1 is simply to use an assimilation technique to provide a best-fit or smooth distribution of a set of observations at a particular time to an initial climatological distribution (no specific understanding)
    - Type 2 is a physics-based assimilation technique in which the physical hypothesis (present day understanding) is used as the core of the assimilation model and its forward propagation for ITM dynamics. The observations then refine the physical representation of the ITP and also are the basis by which the assimilation goodness of fit is determined. A mismatch between physics and observations is revealed by ever decreasing goodness of fit, correlation coefficients in the covariance matrices.

- We need programmatic infrastructure for the sharing of simultaneous data from different sources (both ground and space-based)

Missions to address Science Questions

GEC (5, overarching questions)
LWS Geospace (1, 2, 3, 6, 14, 17, 18, 20, 21, 22, 23, 24, 25)
ITM Waves (4, 7)
Tropical Dynamics Coupler (4, 8, 9, 10, 11, 12, 13)
High Latitude Noctilucent Cloud Explorer (15)
Global Mesospheric Water Cycle Probe (16)
Global ITM Constellation (2, 3, 6, 11, 14, overarching questions)
Sun-Earth Energy Connector (overlap with LWS Geospace)
Remote Sensing Opportunity (airglow and aeronomy spectometer) (overarching questions, 5, 12)
Magnetosphere-Ionosphere Observatory (MIO) (overarching questions)
Auroral Multiscale (2, overarching questions)
Planetary Aeronomy (26-31)

E/PO Topics

- Formal Education
- Atmosphere
- Charged particles
- Magnetic field (use Earth and planetary fields as examples of naturally occurring magnetic fields) – show auroral pictures
- History of science
- Technology – Models
- Complex and coupled systems
- Cycles and scales
- Cool, new science and technology issues (e.g. Nano-satellites, new propulsion technologies, multi-satellite)
- “See the invisible” theme

Outreach Opportunities
- Press releases
- Informal science education (museums, web, community groups)

ITM Specific Ideas
- Meteors
- Visible airglow
- Radio (illustrates variability and impacts on radio wave propagation)
- Space Debris (gravity and drag) – Hazards aspect – re-entry of space vehicles (most of them burn up)
- Games to explore orbital dynamics – perturbed by space weather events –incase ot decrease speed to change altitude of orbit
- Space radiation – effects on astronauts

- Sprites, lightning (good imagery)
- Tracking satellites, electron gun experiments
- GPS system (how it works) – illustrating ionospheric effects – scintillations (monitor position of desk with GPS which will move by 10 meters in a given day and even more during storms)
- Sounding rockets
- Comparative planetology

Technology issues

- Break through since last roadmap – reduce mass and power by a factor of 50 – MEMS technology – help for nano-satellites
- Radiation hardness is not as important an issue for ITM
- Cost of star sensors – cost reduction associated with less stringent pointing requirements? 0.1 deg (10 m/s uncertainty in winds) to 0.01 deg (1 m/s uncertainty) requirement
- Lidars and UV spectrometers in space – low TRL item at present – need science driver to make progress
- Digital capability for sounders – example on IMAGE – high value of remote-sensing for specifying large-scale regions
- Low cost telemetry to LEO
    - Any space-based trade-offs? (e.g. using TDRSS) – Opportunity this year to influence aerospace technology at NASA – looking for specificiations and requirements for architectures
    - Getting data back is a major negative driver
    - What's barrier to using commercial civilian communication technology
        - Frequency allocation to NASA might be a problem
    - Will be developing ability to use wireless communication through satellites
        - Work is being done in this area – practically problems with security
    - Need to understand requirements for future missions as driver for development
- Heavy GPS sensors – by next solar cycle we should have one that fits into a wrist watch. Civilian code will replace encrypted military code. Get height profiles out easily. Receiver design is driven by information that is available. Over next ten years this information will change. Introduce civilian frequency and code (dual frequency TEC measurements) in place by next solar max
- High priority – deep dipping – whether from the ground upwards to the E-region or downward from satellites