Science and Technology Challenges in Near-Earth Space Weather

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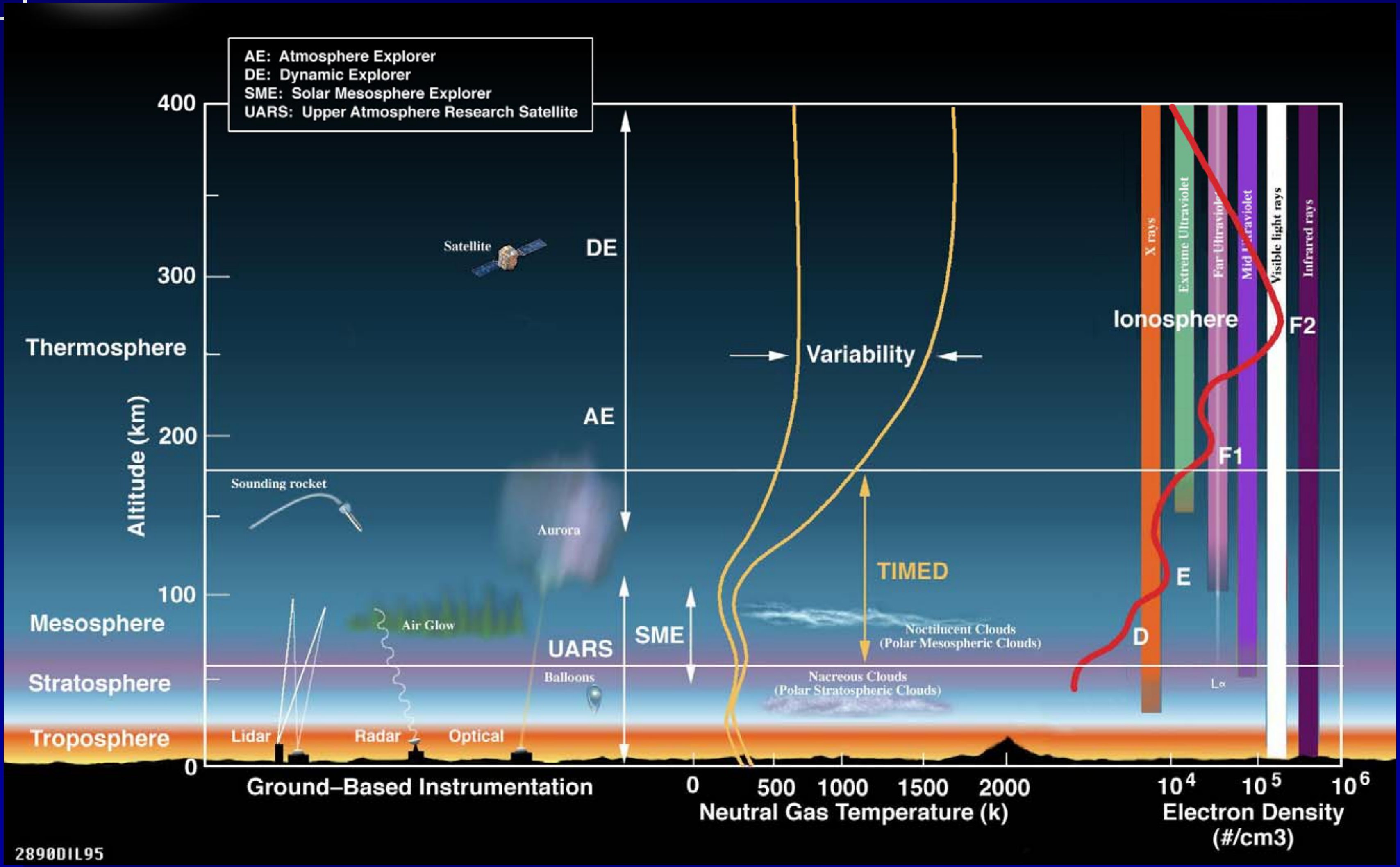
Overview and Challenges

- *Space weather, particularly that of the near-Earth environment, is undergoing a renaissance*
  - *Will the US be part of it?*
- We are seeing the advent, use and widespread development of:
  - Assimilative models
  - Small satellite payloads (cubesats and larger)
  - Re-purposing data streams from other assets
  - IT developments that have freed the evolution of models and first-principles codes
  - Knowledge management tools enabling collaboration – VxOs and VOs
- Fiscal reality means that
  - Concurrency has been lost in the NASA Solar Terrestrial Probe and Living With a Star lines
    - NASA has focused large satellite missions on the connection from the Sun to the Earth
  - NPOESS has limited space weather capability
  - DMSP Block 5D3 has 3(2) more launches then…?
  - AFWA space weather personnel mix does not have many "expert users" on staff

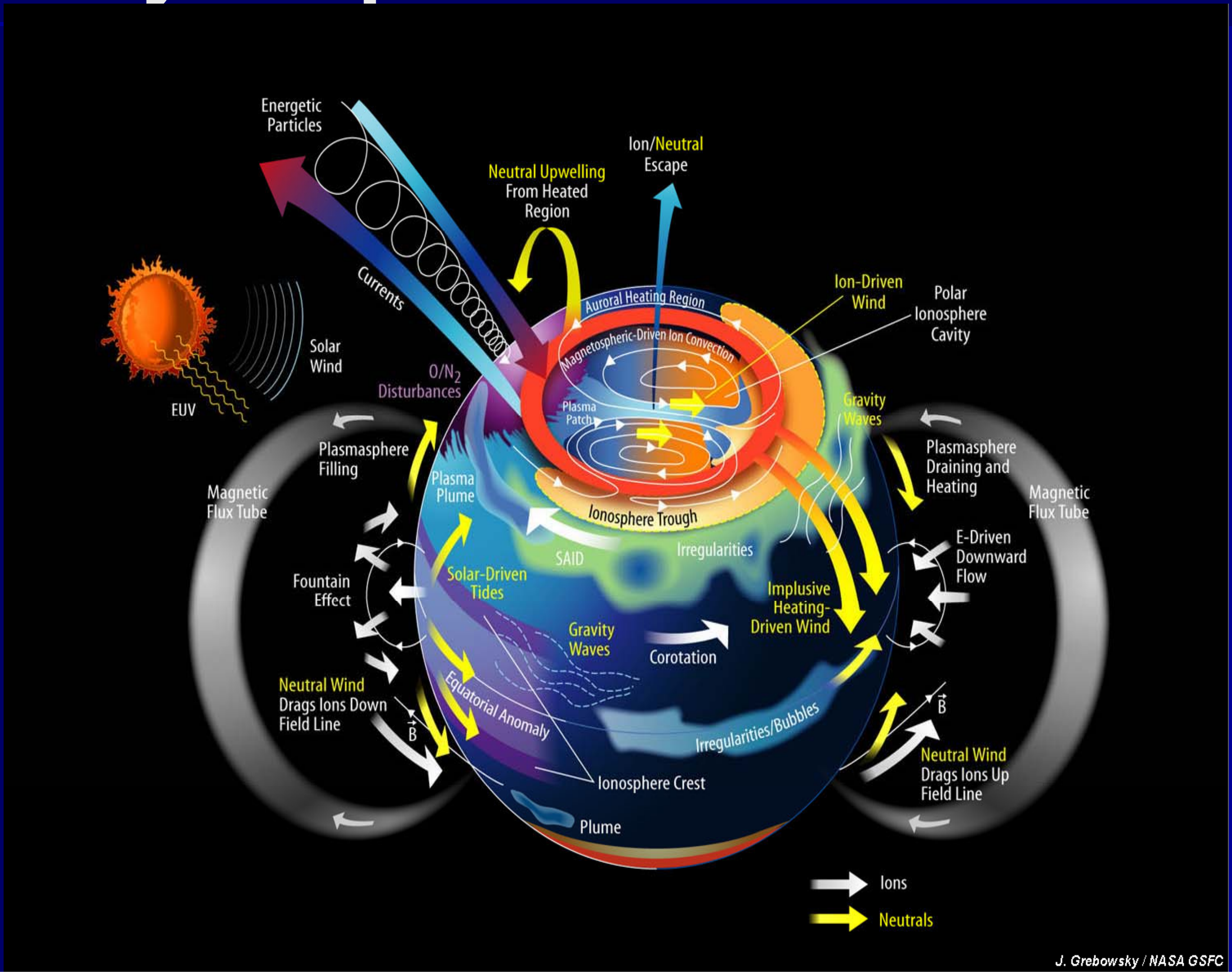
A commitment to partnerships

- There are many great things that we are doing
- We have the potential for participating in the global space weather arena in a way that enhances our national technical capabilities and builds a stronger and safer world for us:
  - emerging research and development shows promise in the near term and
  - there are many technology/capability areas that are in the pipeline with a high payoff potential
- We need to have a broad awareness of needs and capabilities and the will to build the bridges

Discovery, Reconnaissance, Exploration, and Operational Utilization

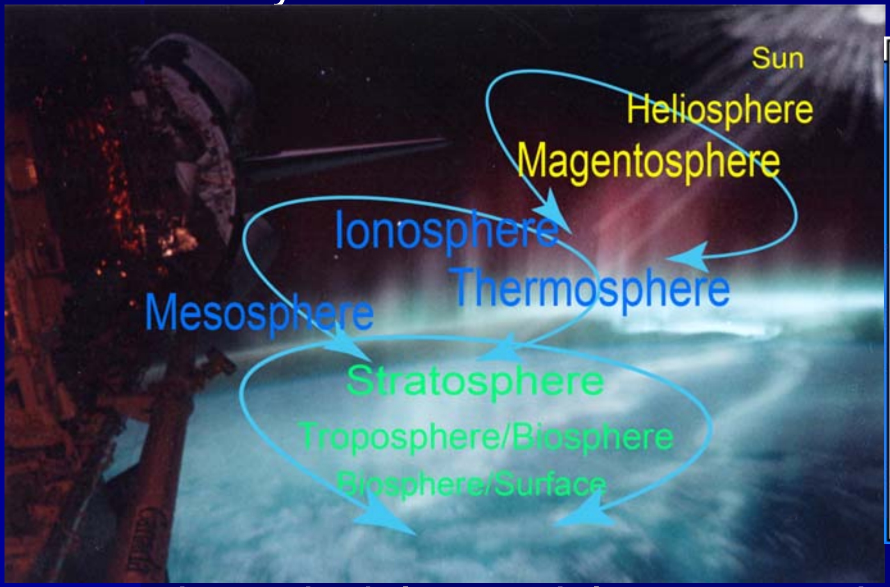


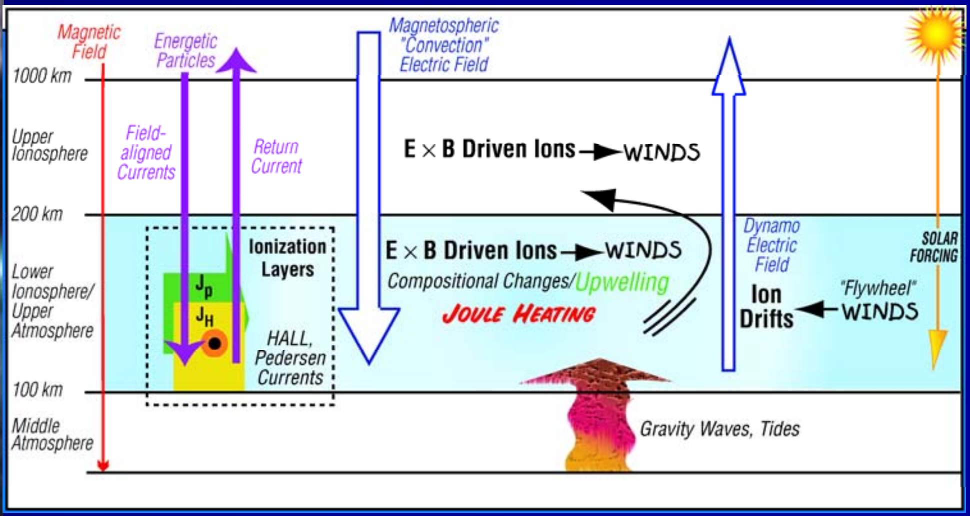
Decades of Observations from the ground and space has enabled us to identify the phenomena



Characterization, reproducibility, understanding, and a predictive capability

- The fact that we have climatologies, "understand the physics", have years of data and can match the limited observations we have – after the fact- obscures the fact that we lack a deep understanding of the magnitude of many of the key parameters that define the boundary conditions of near-Earth space weather. This limits our understanding and our predictive capability.
- How far are we away from a predictive capability for key parameters such as electron density and scintillation?

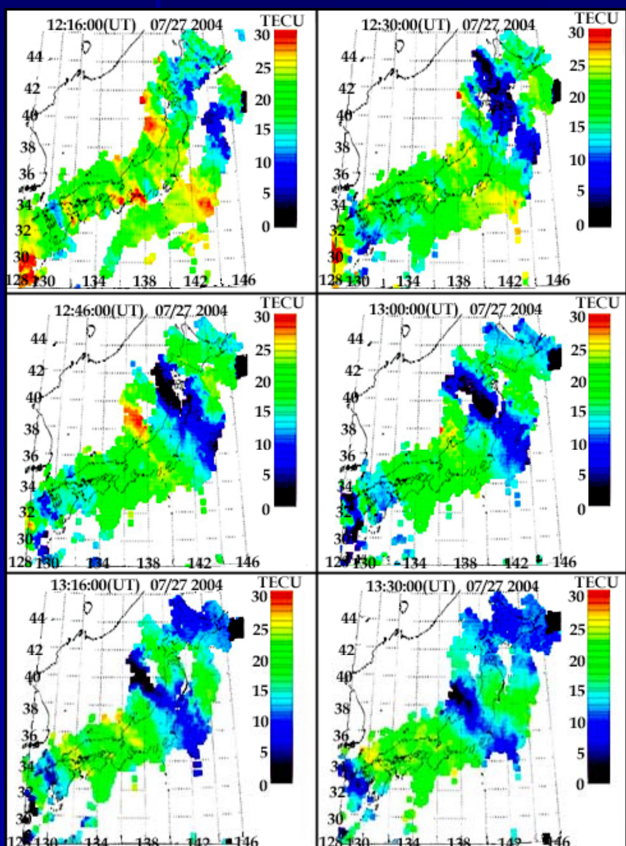


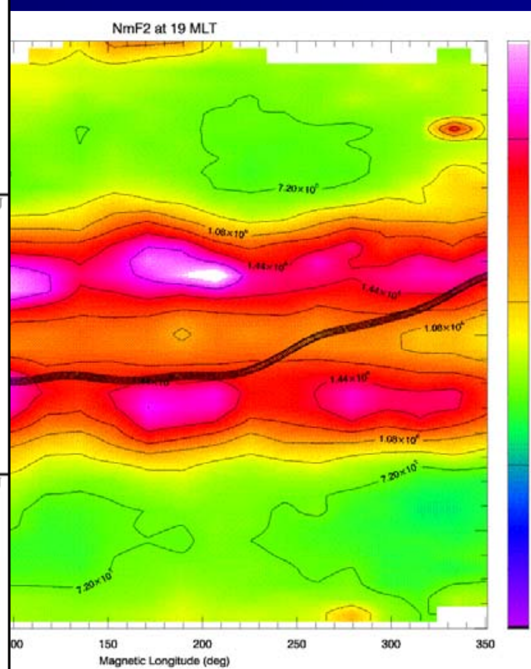


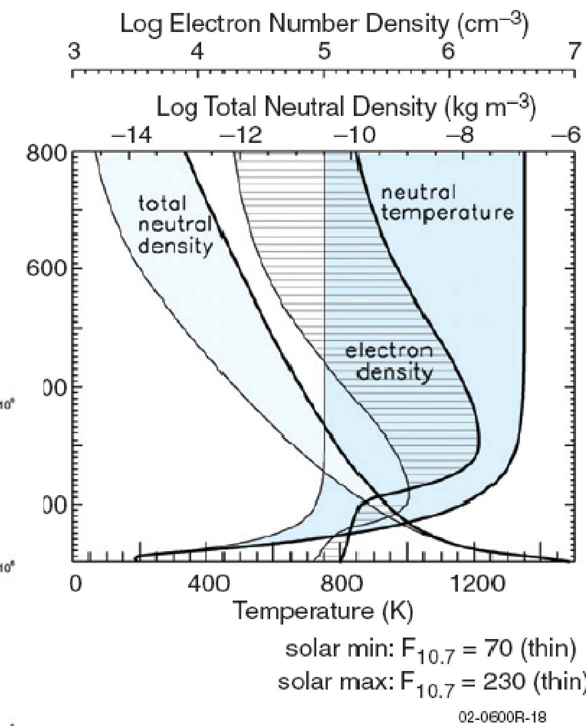
First-principles models parameterize these forcings – assimilative models have them buried within

The variation seen in most of the upper atmosphere parameters is about the magnitude of the quantity itself

- Response to external and internal drivers is observed but not yet fully understood.





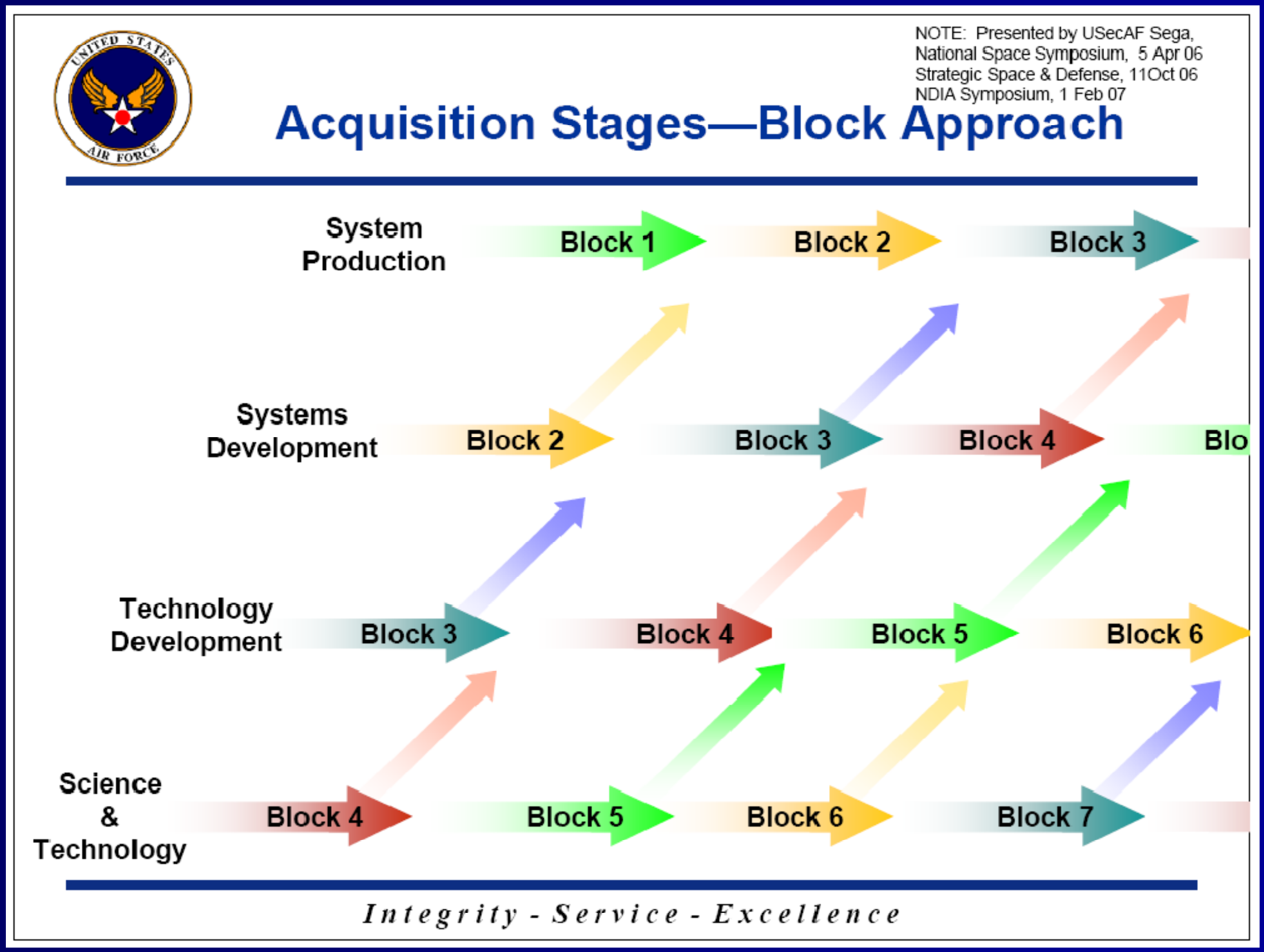


ıre **18.** Temperatures and densities calculated g the MSIS and IRI empirical neutral and sphere models, respectively. Variability in far and ıme UV solar irradiance from low to high activity s heats the upper atmosphere and increases otal neutral and electron densities, leading to variations of more than an order of magnitude. (Lean, 1997)

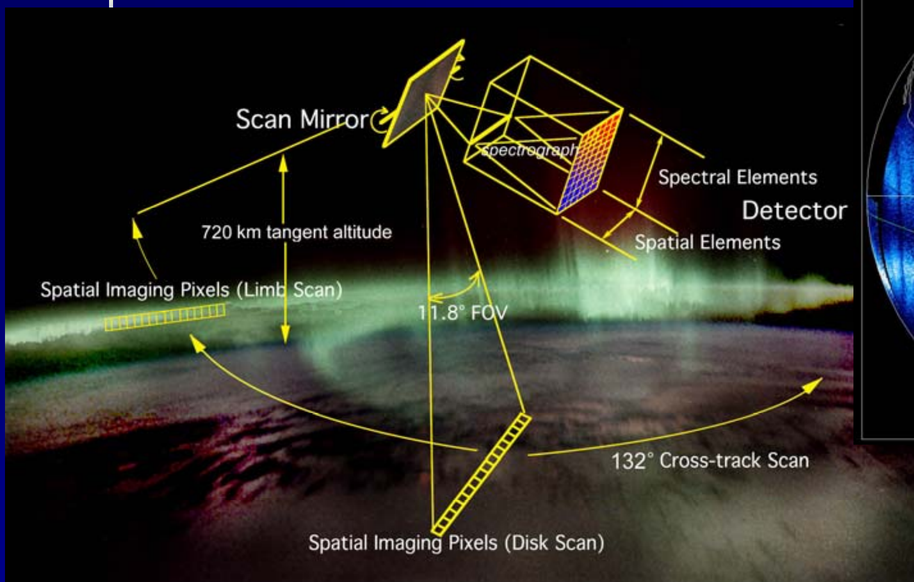
DoD Space weather needs are largely near-Earth

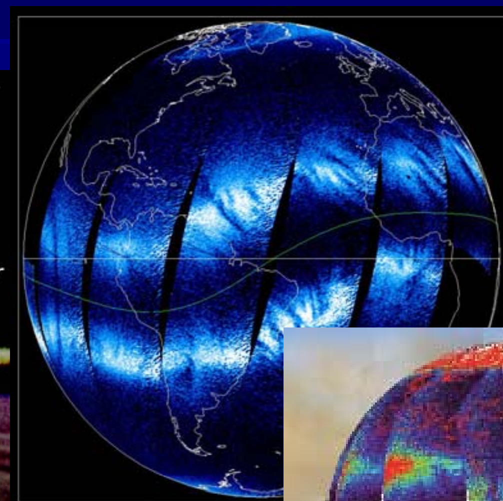
- Comms on the move, radars, attack assessment, missile intercept, precision engagement, intel, spacecraft anomaly assessment
  – All rely on knowledge of the ionospheric electron density profile and scintillations as well as an accurate predictive capability.
  – Other key components are auroral properties including high latitude inputs, and the response : winds, electric fields, and density changes.
  – See DMSP RFI for follow-on sensor needs
- Much of the important behavior is sub-gridscale for global assimilative and first principles models.

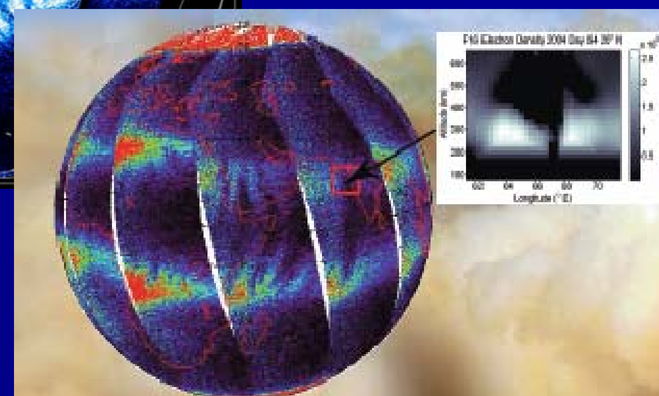
Are we making the connection between S&T (basic research) and system production?



Example: Transition from basic research to operations







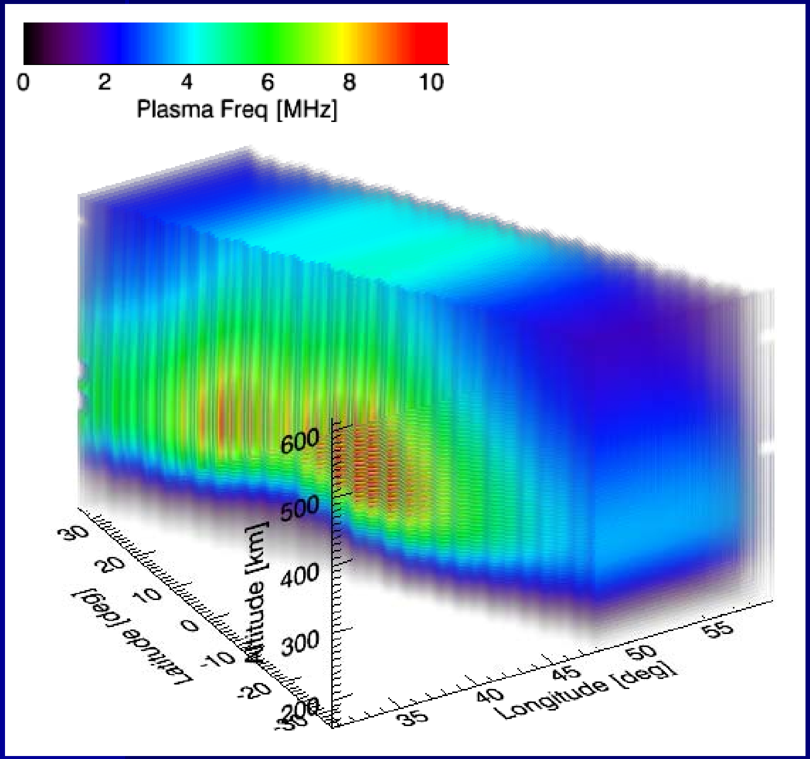
- Basic and applied research efforts have produced the capability to routinely make hyperspectral far ultraviolet images of the Earth's upper atmosphere.
- The ionosphere, ionospheric bubbles and regions of scintillation can be imaged.
- The shape of the bubbles is tied to their drift rate – enabling our first prediction capability

LEO UV Sensor Data Compared to a Standard Ionosphere Model

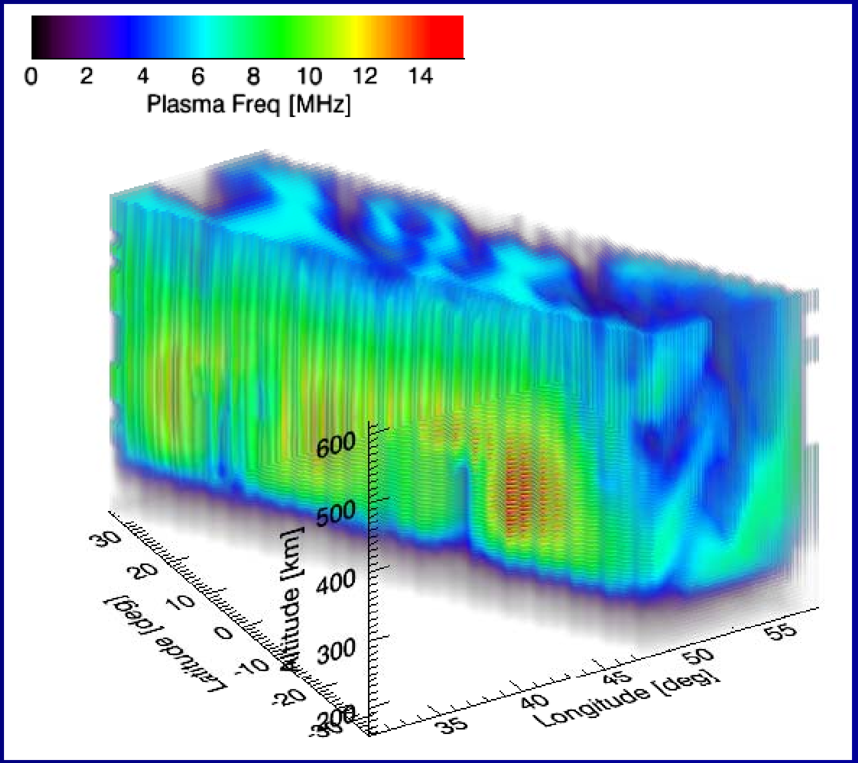
IRI-2001 model (left) predicts smooth variation in electron density.

Sensor data (right) show the location of ionospheric irregularities affecting HF propagation.

IRI-2001 model



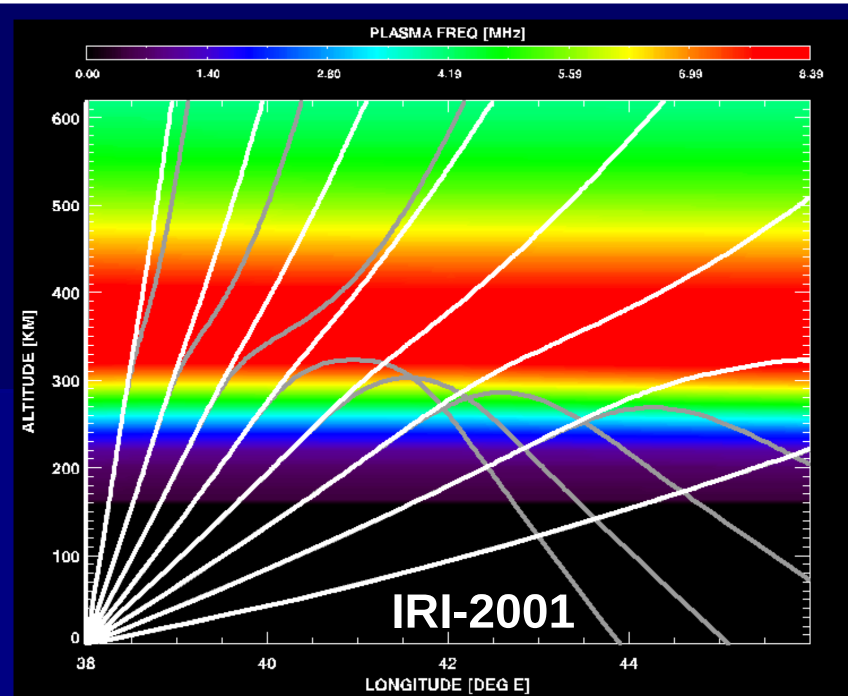
One image – as a data cube

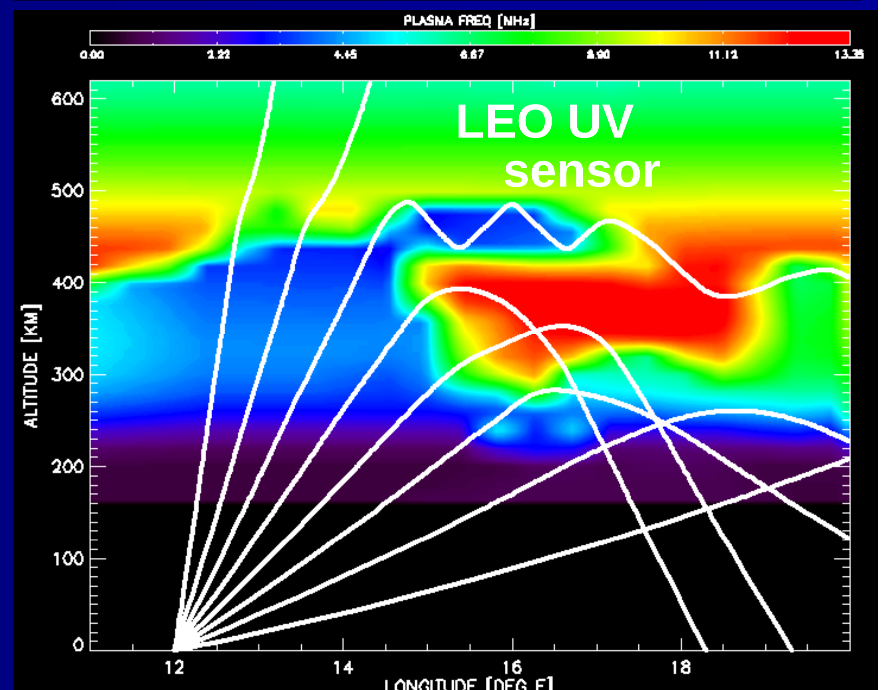


2004 Day 94 (April 3)

Effects on HF Signal Paths

- LEO UV sensor reconstructions show higher density than climatological model, resulting in shorter ground range (by as much as *few hundred km*) and fewer penetrating rays.
- Anomalous refraction due to bubbles/irregularities is observed in the real ionosphere.
- Calculated quantities:
  - Signal absorption along path
  - Time delay
  - Maximum Usable Frequency

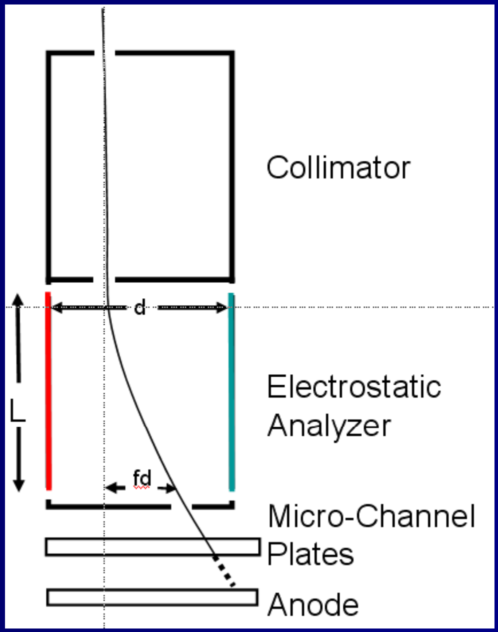


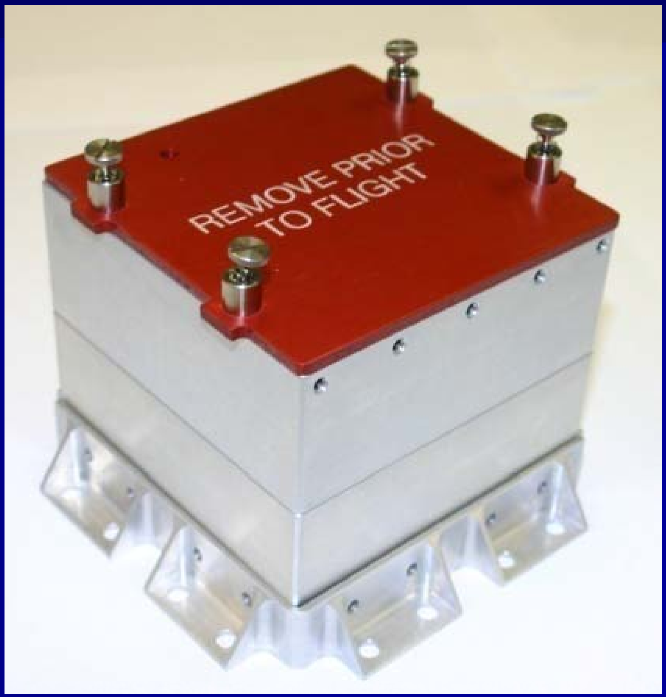


MEMS technology sensors may hold the key for new insights into the space environment

HOW IT WORKS

- Select ion rays with small divergence in a collimator
- Particle trajectories of a given energy are deflected by the potential difference across the parallel-plate electrodes according to the speed and direction with which they enter the analyzer
- Smaller $d(1-f)$ means smaller aperture and better energy resolution
- Larger Plate factors (L/d) means capability to detect higher energy particles

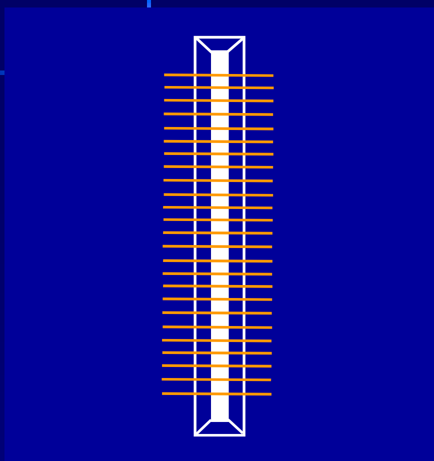




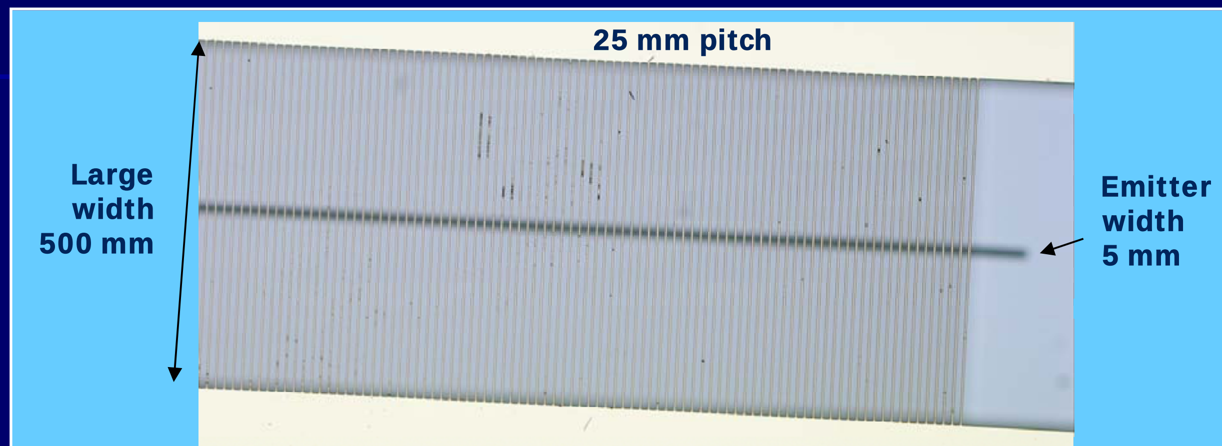
Mass: 0.5 kg
Size: 1000 cm^3
Average Power: 0.9 W
Number of sensors: 7
FOV: 15º X 15º
Energy Resolution: 5% - 10%
Ion energy detection: 0-2000eV
Plate voltage sweep: 0-50V
Plate factors: 2.5, 10, 30

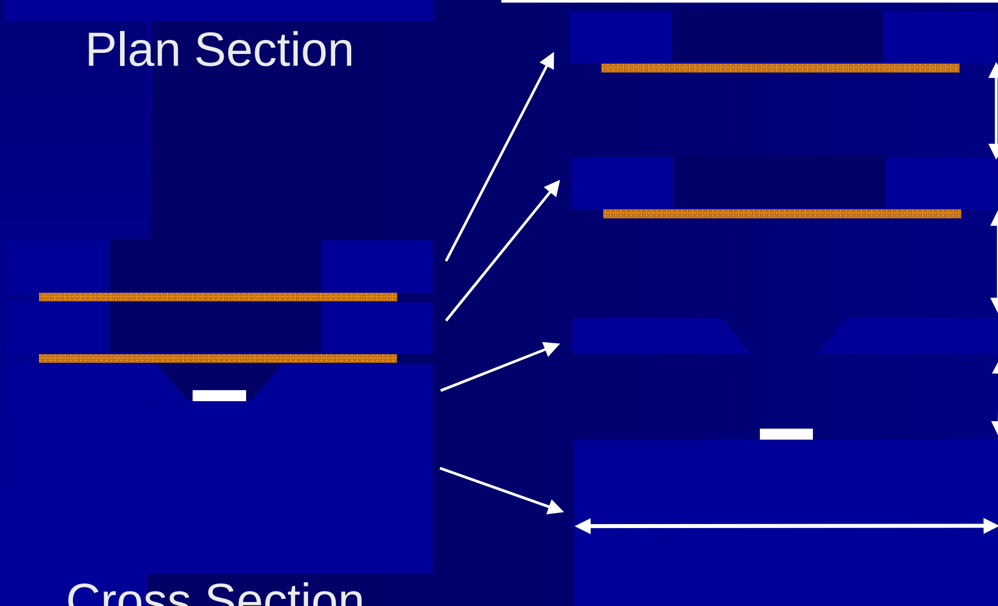
Wafer Integrated SPectrometER (WISPER)

Carbon Nanotube (CNT) Field Emitter Provides Low Power Ionization of Neutrals



Plan Section





Cross Section

A MEMS sensor development plan could be executed as a block-style plan to lead to new capabilities

- Ion density and temperature
- Electron density and temperature
- Ion drift velocity
- Neutral density and temperature
- Neutral wind velocity
- Ion and neutral composition

Plasma Spectrometer (ion density and temperature; electron density and temperature)

Plasma Spectrometer with ionizer (ion drift velocity; neutral density and temperature; neutral wind velocity)

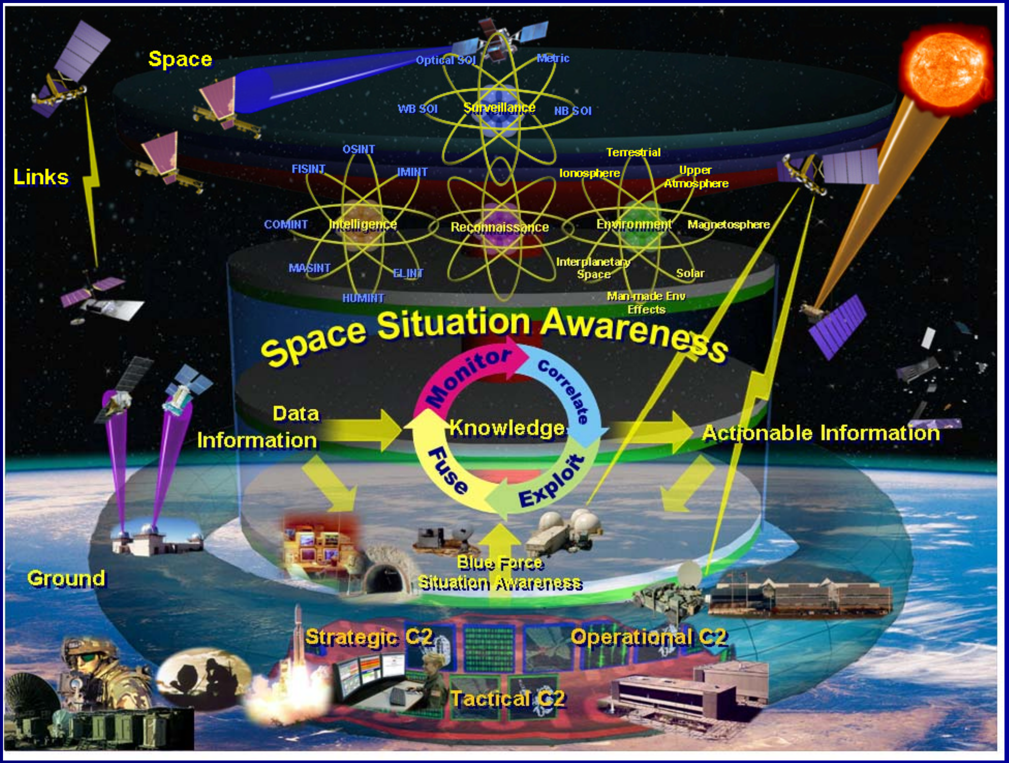
Mass spectrometer (ion and neutral composition)

Small satellite missions have major advantages

- more frequent mission opportunities and therefore faster return of science and application data
- larger variety of missions and therefore also greater diversification of potential users
- faster expansion of the technical and/or scientific knowledge base
- smaller investment enable a small sat program to be more risk tolerant
  - Everybody is willing to accept a risk until there is a failure!
- Simpler, ubiquitous sensors may be more cost effective for many applications than a few very powerful sensors
- greater involvement of local and small industry and, most importantly educational institutions.

What is the need?

- Education
- Prediction
- Mitigation
- Security
- Exploration
- Understanding
- The tools that we have at our disposal to address these issues are driven by opportunity – opportunity begets ingenuity.



A key technology need for our community is the establishment of a Virtual Organization

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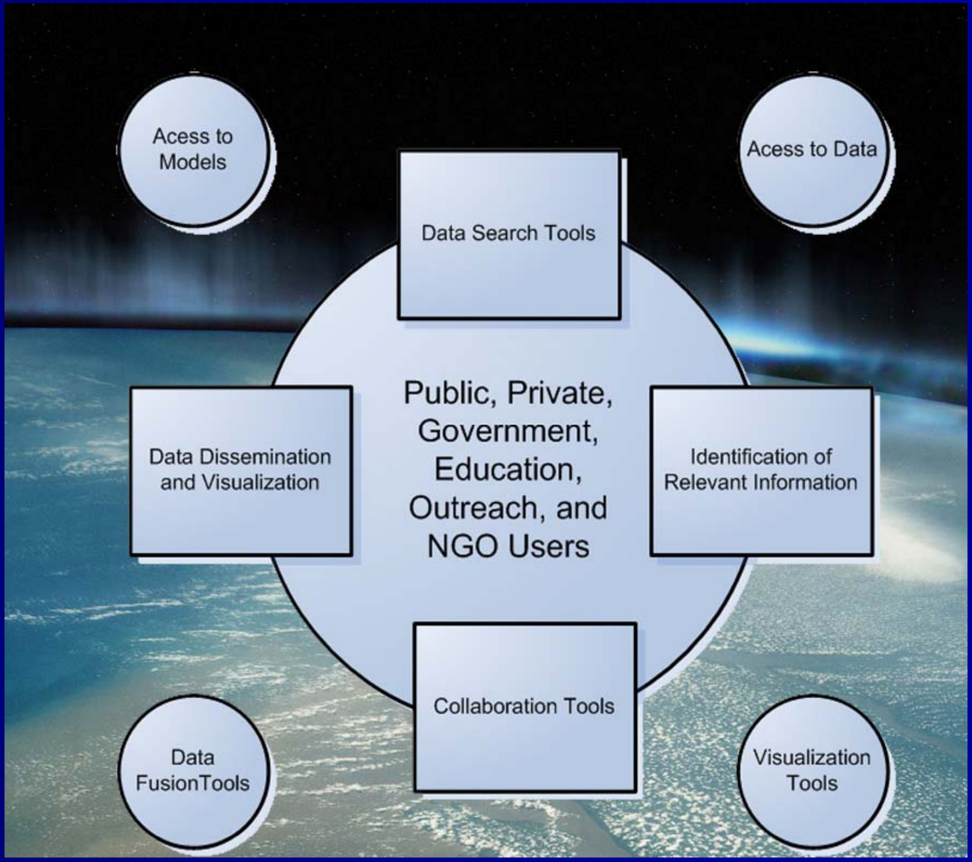

A key technology need for our community is the establishment of a Virtual Organization

"Back to Basics"

- System wide issues:
  - Starting program with unrealistically low cost estimates and budgeting
  - Failing to provide discipline in requirements definition and growth
  - Erosion in Government's ability to lead and manage
- Change needed:
  - Emphasize delivering initial capability
  - Manage program risks
  - Manage expectations
  - Stabilize budgets
  - Identify most critical technologies and align them with incremental delivery plan
  - **Maintain and grow experienced, professional space acquisition and engineering cadre**

From briefing by Mr. Gary Payton – USAF Back to Basics

A robust space weather program can take advantage of many opportunities

- Technology migration paths can be implemented at all scales:
  - Ground
  - Balloon
  - Sounding rocket (tended and untended)
  - Student explorers
  - SMEX
  - MidEx
  - Large Missions
- Current programs are hurt by the lack of opportunities
  - No path for new ideas
  - Tyranny of the TRL restricts the science that you can do
  - The grant process focuses on “rewriting the textbooks”, “discovery” and “closure”
  - The lack of opportunity leads to much higher costs and greater risk
  - Since you can’t afford to fly sensors you lose the inherent/organic capability to develop new sensors
  - No new opportunities mean you become dependent on others for your capabilities