The Magnetosphere and Space Weather

H. J. Singer
NOAA SEC

Note: several figures need to be viewed as a powerpoint presentation since the hard copy will not show everything that appears in the dynamic presentation or will show overlays of text and figures that don't appear in the presentation.

Viewing html version go to full screen presentation to see movies on slides 12, 15, 28, 29, 35.

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The Magnetosphere and Space Weather

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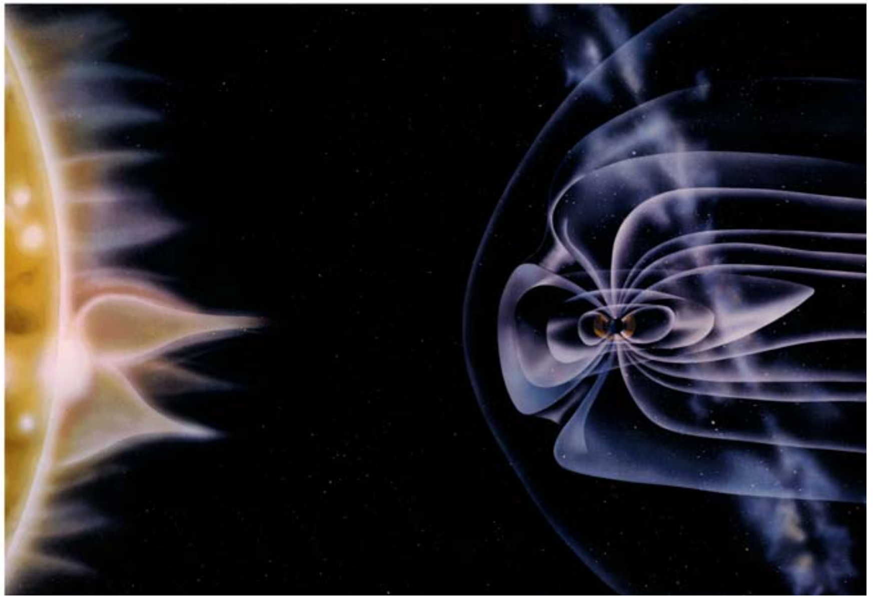
COMBINES: Understanding the fundamental physical processes governing the regime from the solar surface, through the interplanetary medium, into the magnetospheric-ionospheric regions, and ending in Earth's upper atmosphere.

WITH: Applying our understanding to the development of space weather applications.

2000 CEDAR Workshop
June 30, 2000
Boulder, CO



Outline

- **History**
- **Overview of the Coupled Solar-Terrestrial System**
- **Space Weather, Space Weather Forecasting, and Space Science**
- **Future: Research, Observations, Modeling, and Forecasting**

Acknowledgements: Arge, Evans, Fuller-Rowell, Garcia, Heckman, Hirman, Joselyn, Kunches, Li, Onsager, Pizzo, Smithtro, Turner, Viereck

Geomagnetic Storm Effects on Telegraph Operations-September 3, 1859

***Boston (to Portland operator*).--"Please cut off your battery entirely from the line for fifteen minutes."**

***Portland*.--"Will do so. It is now disconnected."**

***Boston.*--"Mine is also disconnected and we are working with the auroral current. How do you receive my writing?"**

***Portland*.--"Better than with our batteries on. Current comes and goes gradually."**

***Boston.*--"My current is very strong at times, and we can work better without batteries, as the aurora seems to neutralize and augment our batteries alternately, making the current too strong at times for our relay magnets. Suppose we work without batteries while we are affected by this trouble?"**

***Portland*.--"Very well. Shall I go ahead with business?"**

Boston.--"Yes. Go ahead."

(Annual of Scientific Discovery, ed. by D.A. Wells, Boston, Gould and Lincoln, p414, 1860; Singer, H.J., Magnetospheric Pulsations, Model and Observations of Standing Alfven Wave Resonances, Thesis, UCLA, 1980.)

1958 Geomagnetic Storm

- **On February 9, 1958 an explosive brightening was observed on the solar disk at the Sacramento Peak Observatory**
- **A notice was radioed to the IGY Data Center on Solar Activity at the Univ. Colorado's HAO in Boulder**
- **28 hours later one of the greatest magnetic storms on record began**
- **It was the 13th most disturbed day from 1932 to the present: Feb 11: Ap = 199 and Dst reached –426 nT**
  (March 1989 was the second largest storm with Ap = 246)
- **Effects: Toronto area plunged into temporay darkness**
  Western Union experienced serious interruptions on its nine North Atlantic telegraph cables
  Overseas airlines communications problems

Brooks, J., The Subtle Storm, *New Yorker Magazine*, 39-77, Feb. 7, 1959.

1958 Geomagnetic Storm

Commentary and Vision

- **British astronomer H. W. Newton stated, “it is as if the earth had been hit by a <u>celestial shock-wave</u>.”**

- **“By sunrise Feb 12th..the <u>cosmic cloud</u>, it seemed, was passed off into space.”**

- **The forecasters at the Central Radio Propagation Laboratory are among the most valorous of prophets, since they are called upon to make their predictions with <u>very little in the way of scientific knowledge</u> to guide them.”**

- **“In future years, it may be that <u>the Weather Bureau or some Space Age equivalent</u> will warn us of approaching magnetic storms, just as we are now warned of approaching hurricanes,…”**

- **“…nobody knows what kinds of <u>apparatus still undreamed of</u> may come along to be thrown out of whack by their [storms] caprices.”**

Brooks, J., The Subtle Storm, *New Yorker Magazine*, 39-77, Feb. 7, 1959.

Summary of Space Weather Effects Today

Satellites

Navigation

Astronauts in Space

Communication

Electric Power

Solar Origins of Space Weather Disturbances

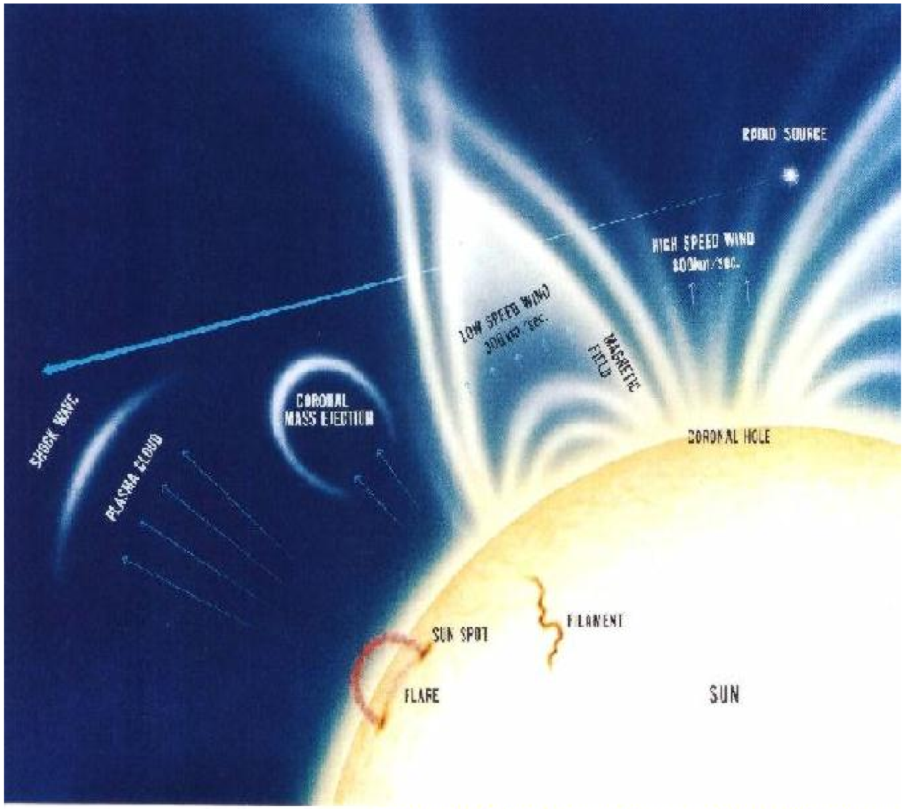


Figure courtesy of the Solar-Terrestrial Environment Laboratory, Nagoya University

Solar Wind

Coronal Holes

Flares

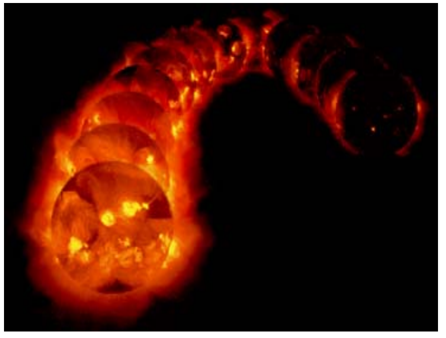
Coronal Mass Ejections

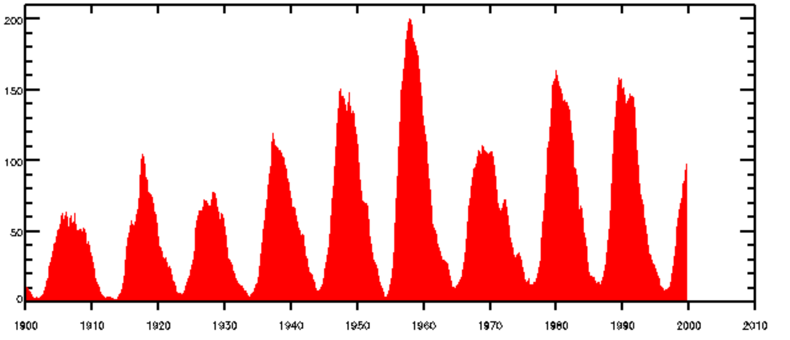
Solar Proton Events

EUV Radiation

http://www.stelab.nagoya-u.ac.jp/omosaic/crle.html

Solar Cycle





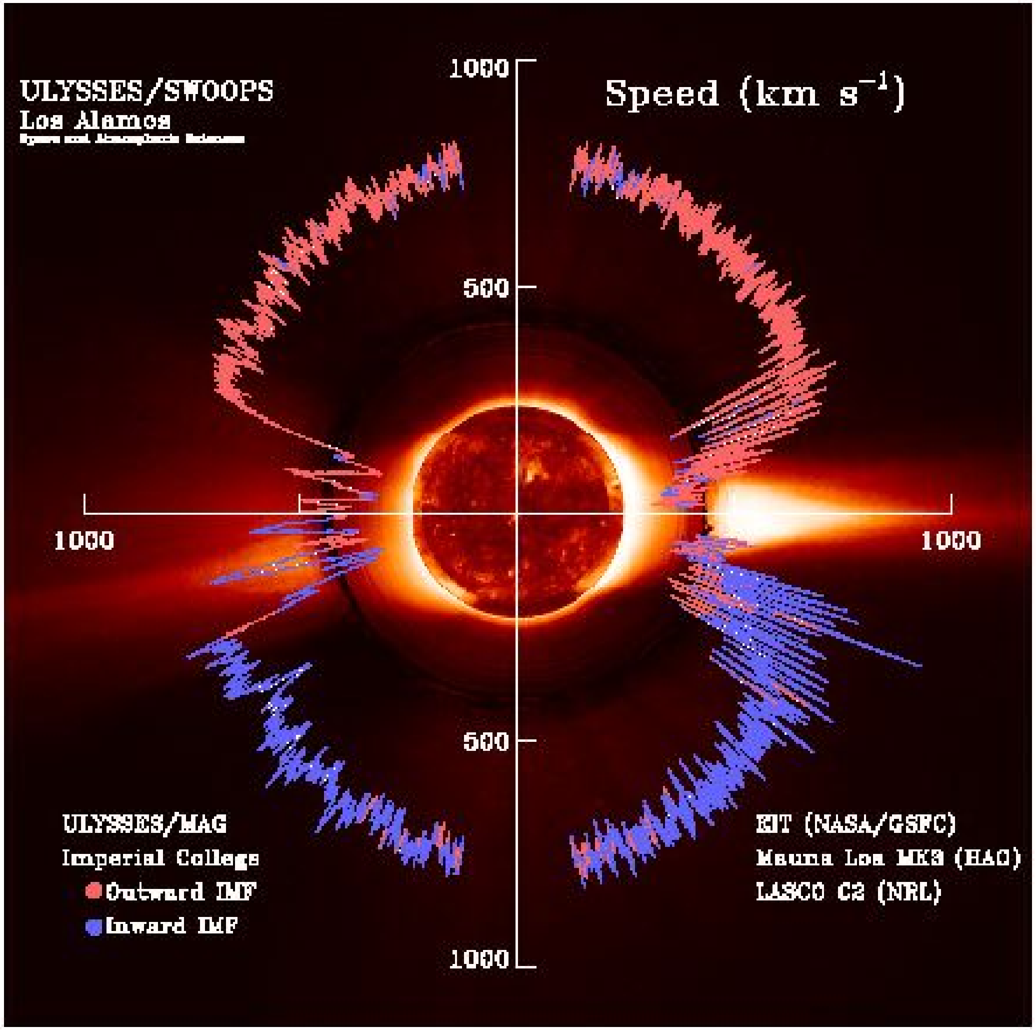
Discovery of the Sunspot Cycle

Excerpts from *Solar Observations During 1843* by Heinrich Schwabe, (Astronomische Nachrichten, vol. 20., no. 495, 1843)

The weather throughout this year was so extremely favorable that I have been able to observe the Sun clearly on 312 days... From my earlier observations, which I have reported every year in this journal, it appears that there is a certain periodicity in the appearance of sunspots and this theory seems more and more probable from the results of this year. …

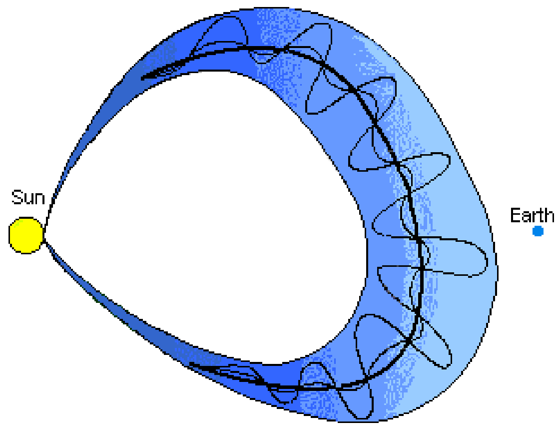
http://www.space.lockheed.com/SXT/html2/The_Changing_Sun.html
http://www.oma.be/KSB-ORB/SIDC/
http://www-spof.gsfc.nasa.gov/Education/Intro.html

Solar Wind Speed and Variability

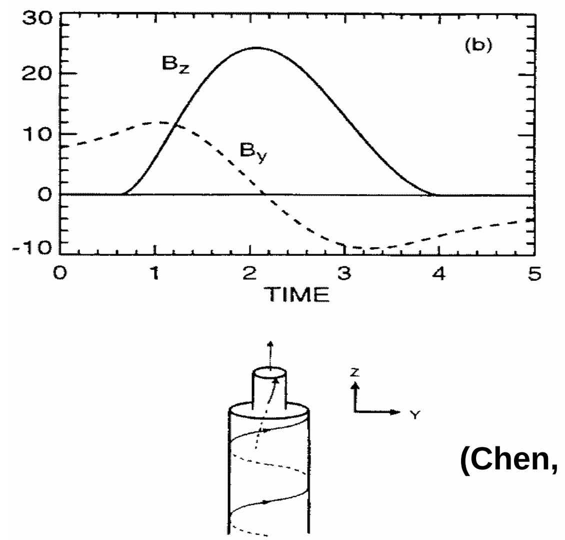


McComas, D.J., et al., Geophys. Res. Lett., 25, 1-4, 1998

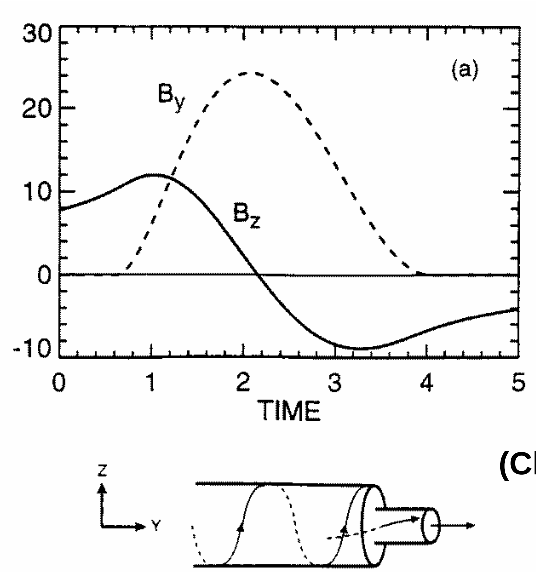
MAGNETIC CLOUD



http://lepmfi.gsfc.nasa.gov/mfi/mag_cloud_pub1.html



(Chen, NRL)

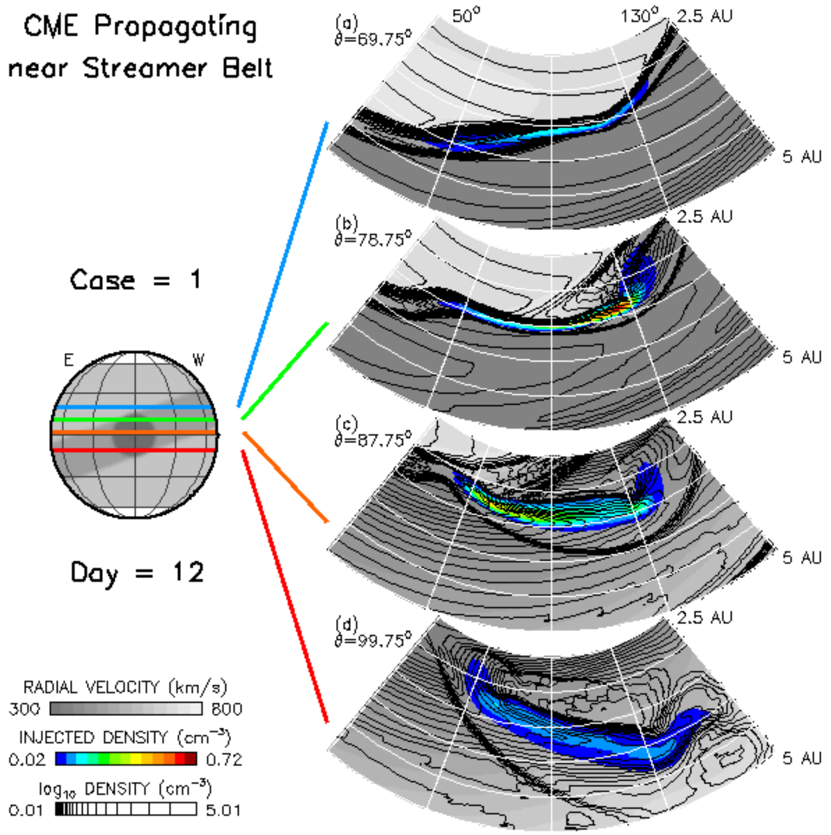


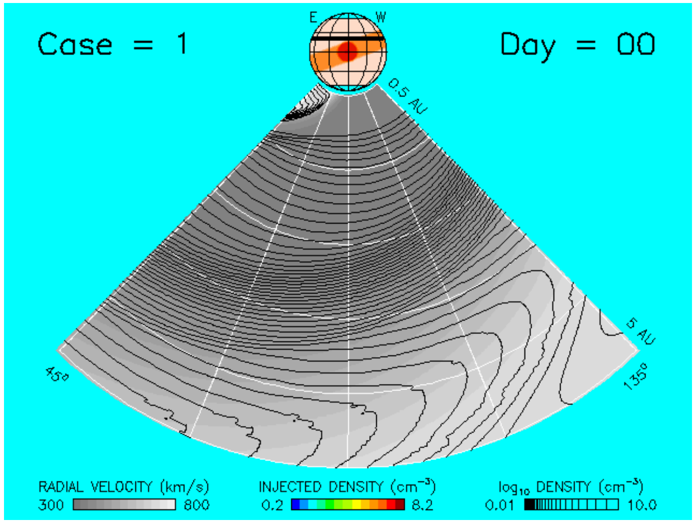
(Chen, NRL)

A magnetic cloud is a transient ejection in the solar wind defined by relatively strong magnetic fields, a large and smooth rotation of the magnetic field direction over approximately 0.25AU at 1AU, and a low proton temperature [Burlaga et al., 1981].

Background Solar Wind Controls the Propagation of Transient Solar Activity

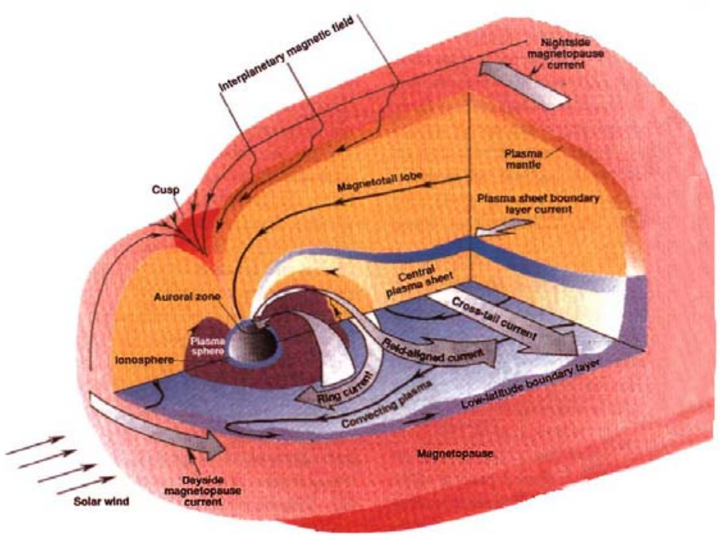
3-D HD Propagation of Coronal Mass Ejections into the Solar Wind





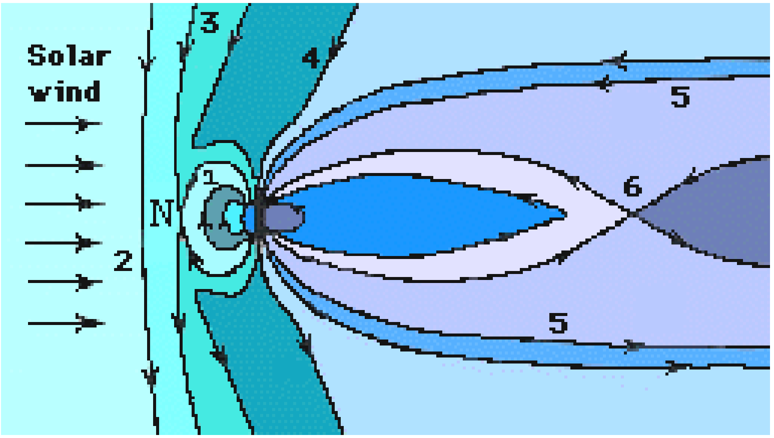
D. Odstrcil and V. Pizzo, NOAA/SEC

Solar Wind Coupling to the Magnetosphere



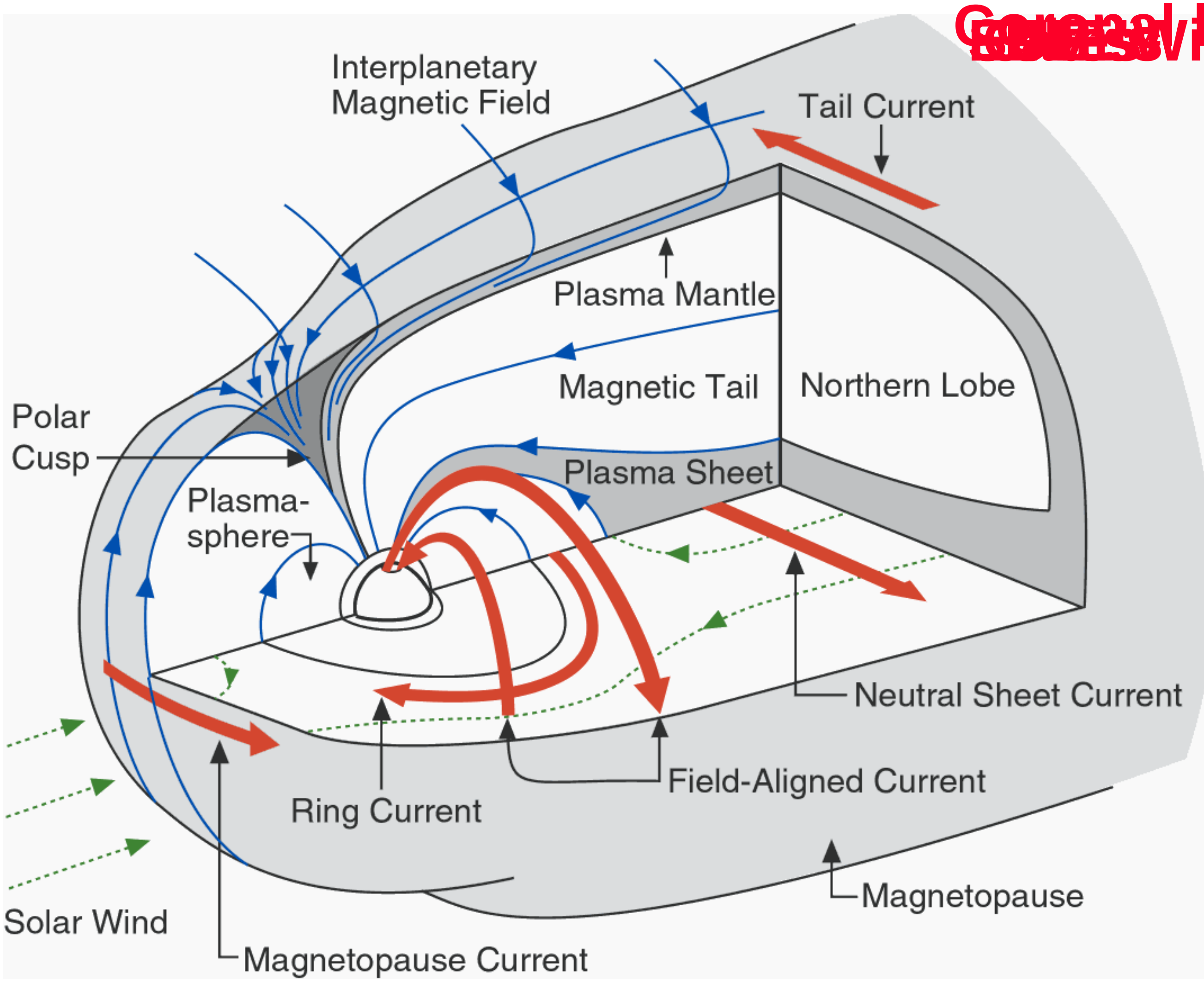
The magnetosphere responds to variations in solar wind pressure that results primarily from changes in solar wind density and velocity.

The magnetosphere responds to changes in the solar wind magnetic field orientation allowing energy transfer to the magnetosphere.



MAGNETOSPHERE

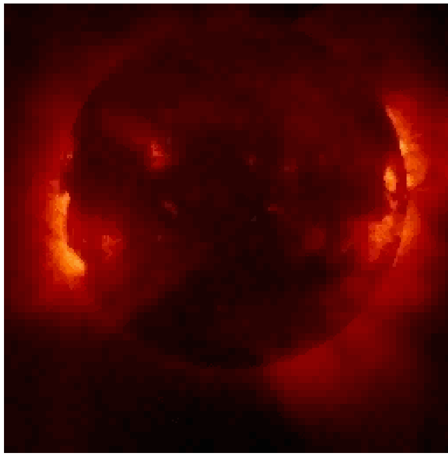
Coronal holes



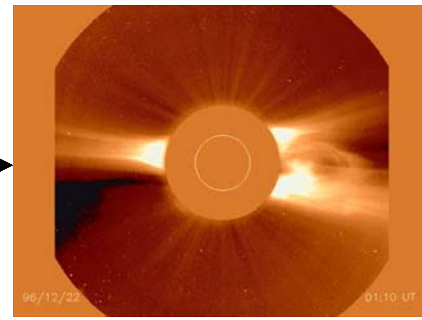
Russell, in Intro to Space Physics, 1995.

NOAA Space Environment Center

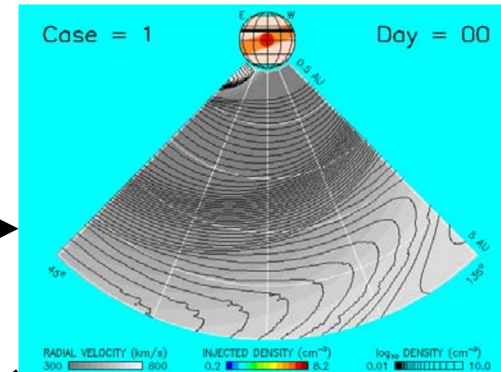
ILLUSTRATION OF ENERGY FLOW THROUGH THE DYNAMIC COUPLED SUN-EARTH SYSTEM



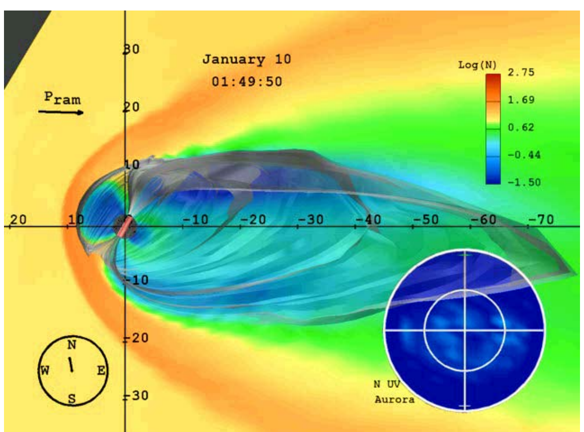
Sun



Coronal Mass Ejections

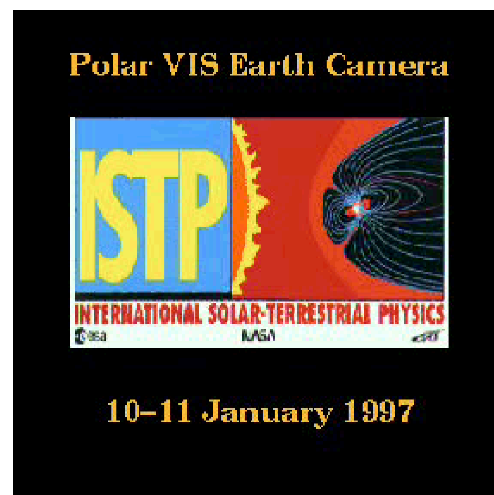


CME in the Solar Wind



Magnetosphere

SHINE
GEM
CEDAR



Ionosphere/Thermosphere

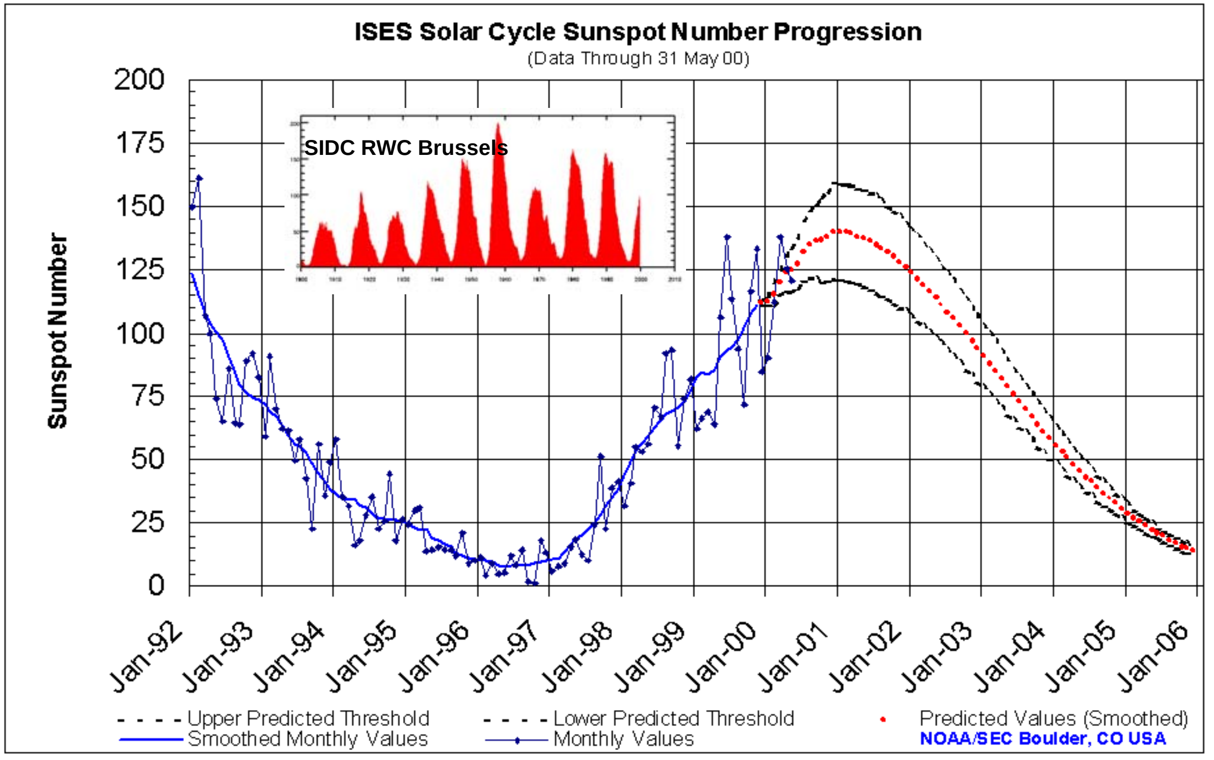
SPACE WEATHER OPERATIONS CENTER

Space Weather Parameters and Goals

Space Weather Domain	Goal Specify and Forecast:
Solar coronal mass ejections	Occurrence, magnitude, and duration
Solar activity flares	Occurrence, magnitude, and duration
Solar and galactic energetic particles	At satellite orbit
Solar wind	Solar wind density, velocity, magnetic field strength, and direction
Magnetospheric particles and fields	Global magnetic field, magnetospheric electrons and ions, and strength and location of field aligned current systems. High-latitude electric fields and electrojet current systems.
Geomagnetic disturbances	Geomagnetic indices and storm onset, intensity, and duration
Radiation belts	Trapped ions and electrons from 1 to 12 Re
Ionosphere/Thermo	Neutral and electron density, variability

Adapted from: NAS Radiation and ISS Report

Solar Cycle Forecasting



Input: Even/odd; precursor, spectral, climatology, neural net

Output: F10.7, Sunspot Number, geomagnetic disturbance occurrence

Lead time: years

User: satellite drag, ISS, Hubble; ionosphere/upper atmosphere

Solar Cycle 23 Project NOAA/NASA; Joselyn et al., 97 ISES update each month

Solar Proton Event Forecasting

Beta Test **Proton Prediction** Beta Test

M1.1 Flare -- 1999 04 08 at 1605 UT
Probability of >10 psu @ >= 10 MeV: 0%

0 - 20%	20 - 50%	50 - 100%

If the flaring regions is east of E40, the probability is not valid
If the flare is <M6 and rises to its peak value in < 0.2 hours, the probability of protons is reduced by 30%
If the flare is >M6 and rises to its peak value in < 0.2 hours, the probability of protons is reduced by 15%

X-ray Flare			Model Inputs		Predicted	Observed		
#	Flare Date	Flare Peak UT	Flare Mag	Flare Temp. (MK)	Proton Event Probability	Proton Event	Proton Arrival Date UT	Solar Reg. Longitude (deg)
1	1999 04 08	1605	**M1.2**	**14.4**	0%	No		
2	1999 04 03	2252	**M4.4**	**14.6**	25%	No		
3	1999 04 02	0803	**M2.2**	**21**	0%	No		
4	1999 03 18	0824	**M3.4**	**20.7**	0%	No		
5	1999 03 17	1441	**M1.2**	**16.8**	0%	No		

Input:

Solar X-ray intensity at two wavelengths (and flare location)

Output:

Probability of solar proton event

Lead Time: Minutes to hours

User: Humans in space
Satellite Operations

H. Garcia, SEC

Hard X-Ray Spectrometer Launched

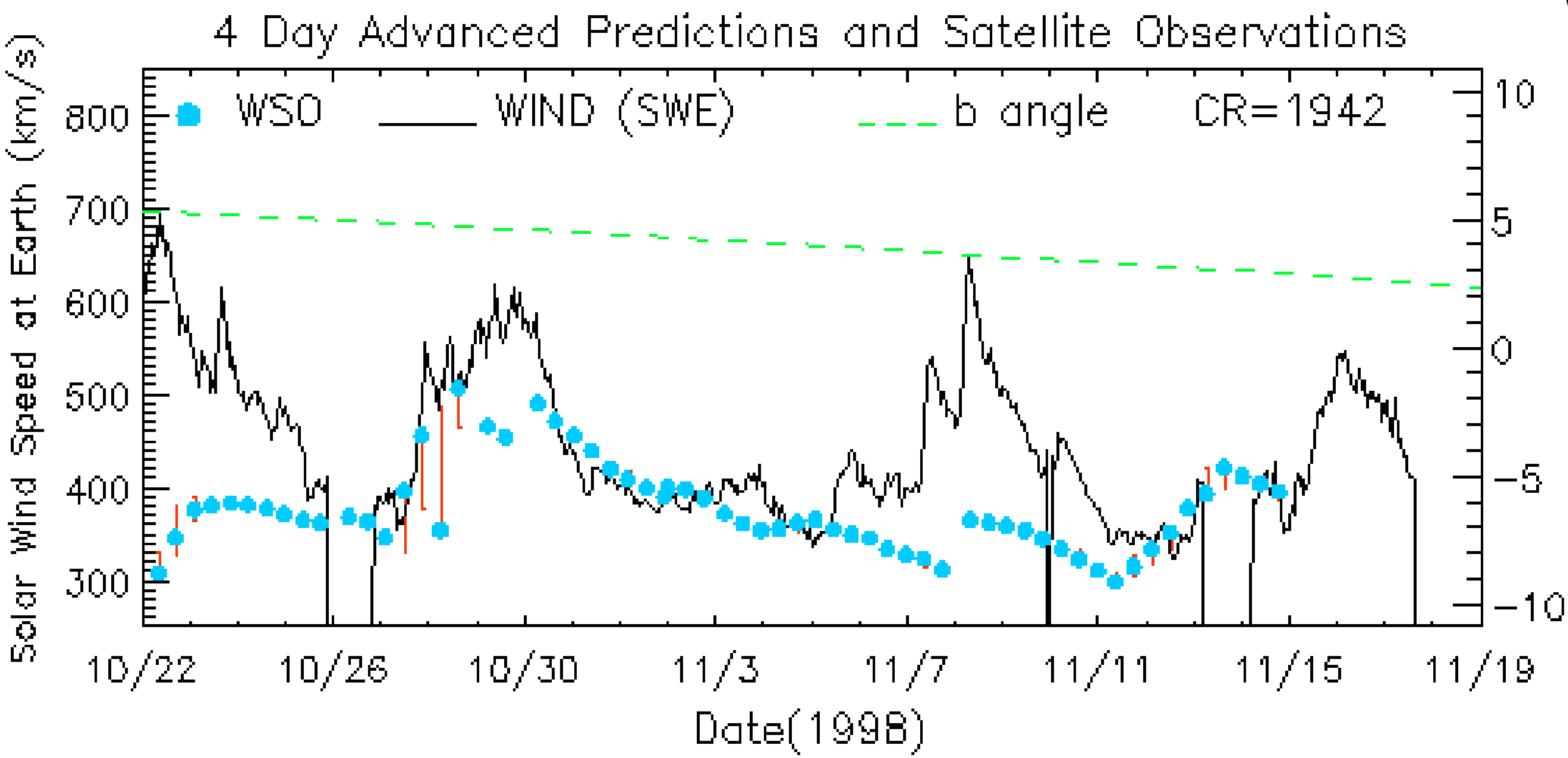
Purpose: **To predict proton storms in the vicinity of Earth that are harmful to satellites and humans in space.**

Launch: **Mar. 12, 2000 0929 GMT Orbital Sciences Taurus (T5) Satellite Multi-spectral Thermal Imager (MTI) operated by Sandia National Laboratories for DOE built by Ball Aerospace and Technologies Corp.**

Support: **NOAA International Affairs Office and** SEC, Astronomical Institute of the Czech Academy of Sciences, **Czech-U.S S & T grant, USAF European OARD, NASA Space Radiation Analysis Group, DoD Space Test Program**

Garcia and Kiplinger (SEC)

Solar Wind Speed Forecasting



Input: Potential field source surface model, Wang-Sheely expansion factors, Ground-based solar observations of photospheric magnetic field

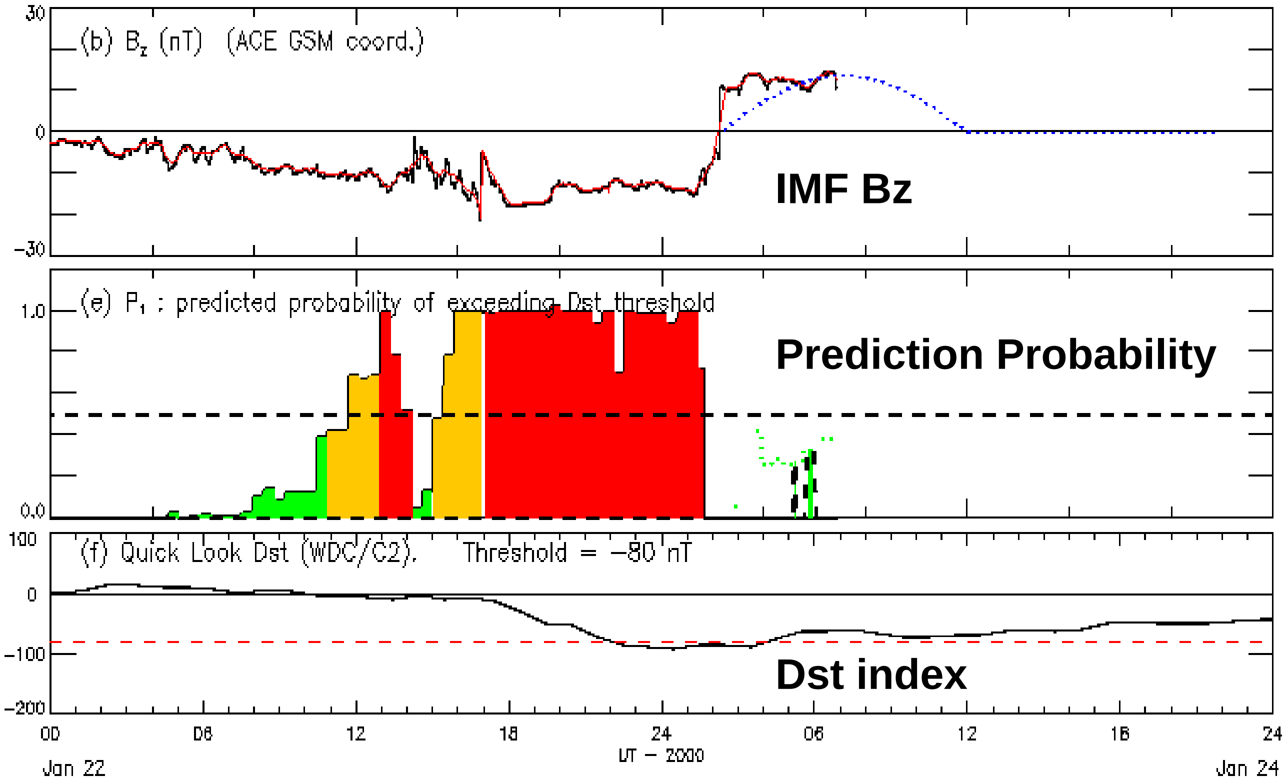
Lead time: 3 – 4 days

User: Models; Background for transients

Output: Solar wind speed at 1 AU; Sector structure

Arge and Pizzo, SEC

Forecasting Large Nonrecurrent Geomagnetic Storms



Input: L1 observed IMF

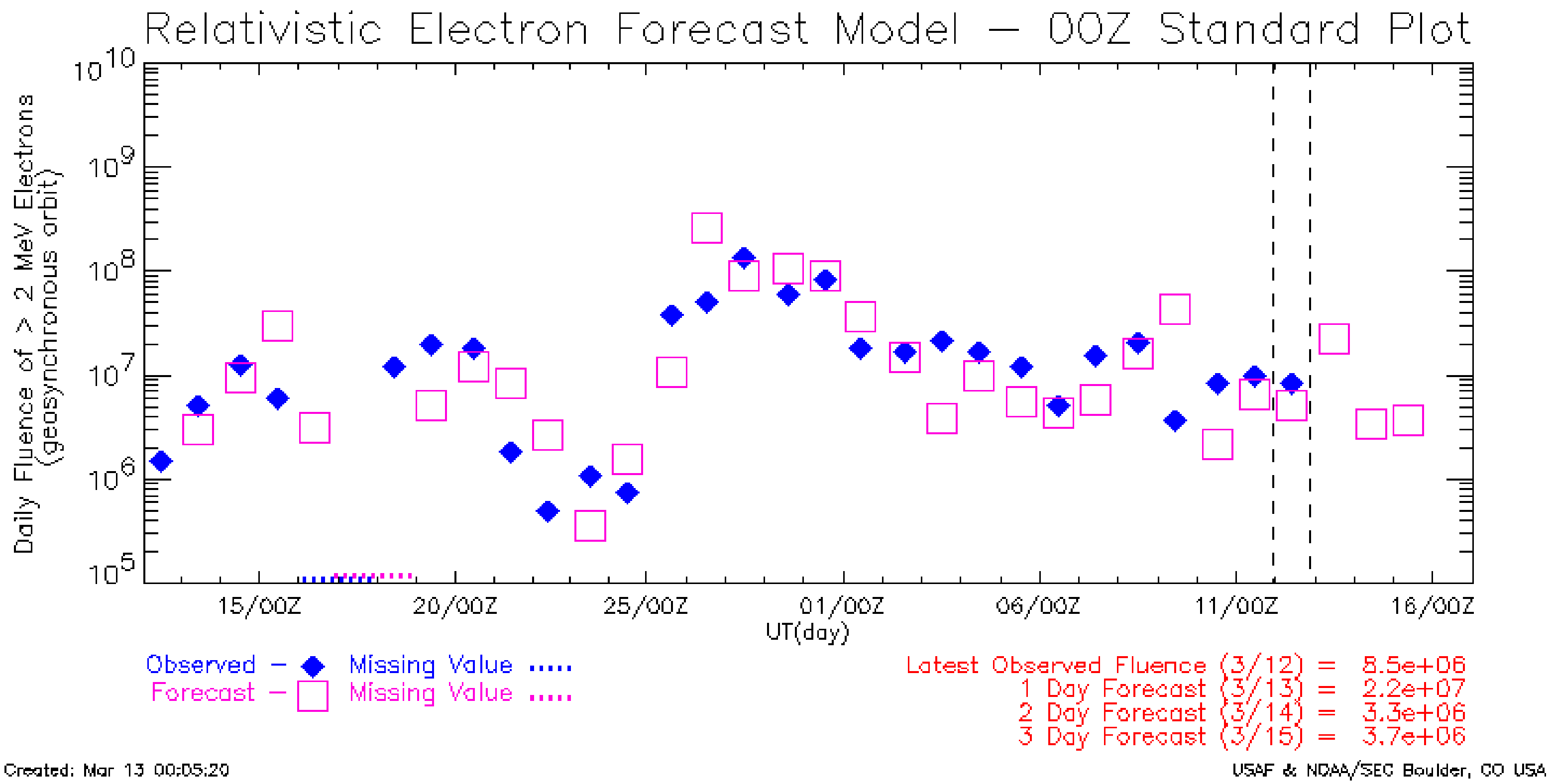
Output: hourly predictions of occurrence, duration, and strength of geomagnetic storm

Lead time: few to more than 10 hours

User: Models and those impacted by geomagnetic activity

Arge, Chen, Slinker, Pizzo

Relativistic (MeV) Electron Forecasting



Input: ACE solar wind velocity
Baker et al. model (modified)

Output: Predicted MeV electrons

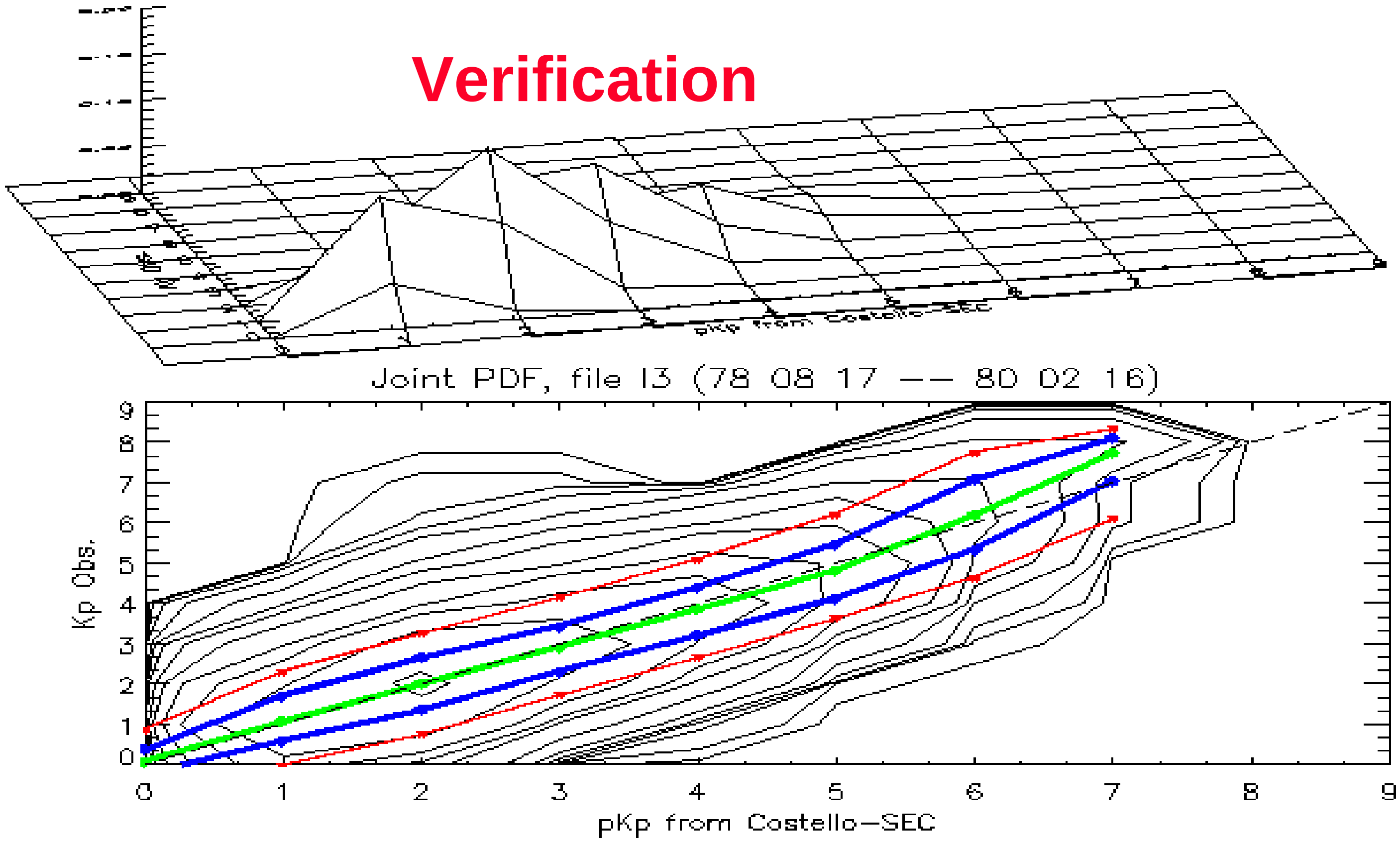
Lead time: 1-3 days

User: spacecraft operations

Smithtro (USAF/SEC), Onsager (SEC)

Geomagnetic Activity Kp Forecasting

Verification



Input: ACE solar wind velocity, B, Bz, and Costello Neural Net

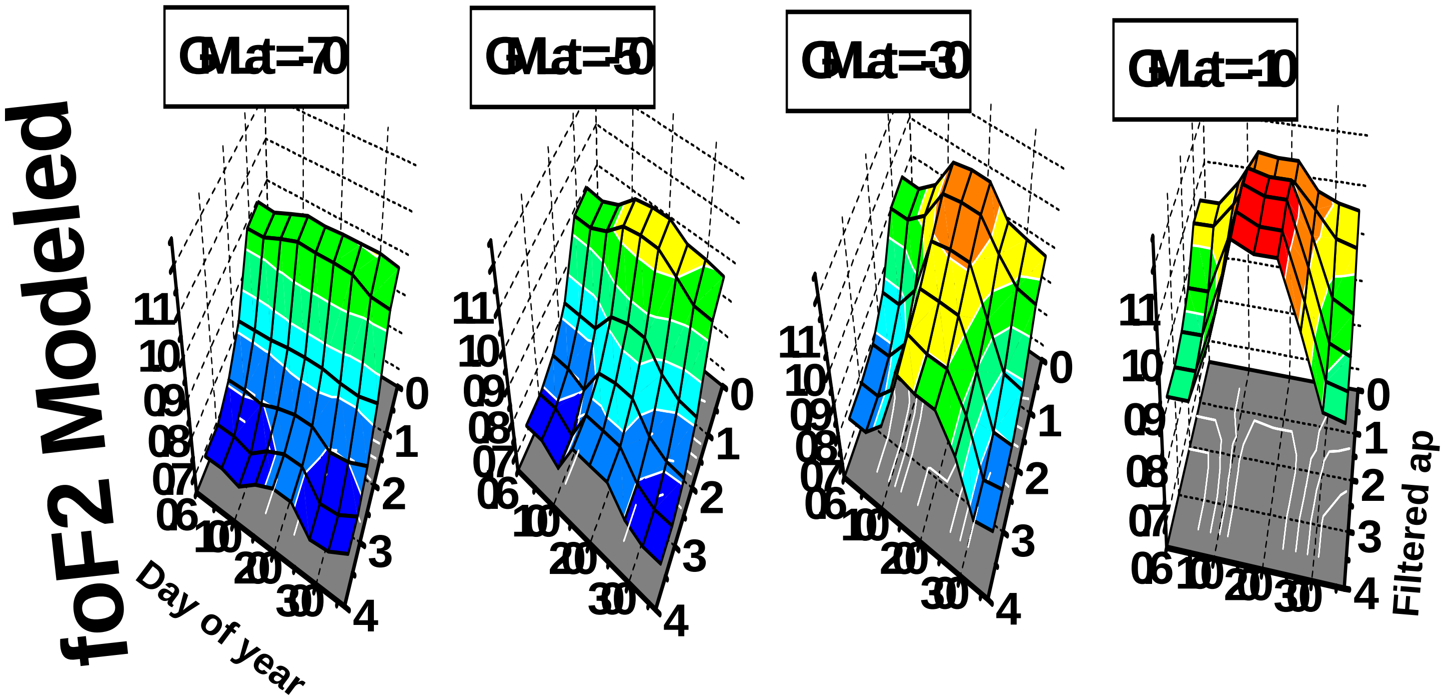
Output: Predicted Kp Index

Lead time: 1 – 2 hours

User: Models and those impacted by geomagnetic activity

Costello (Rice); Onsager, Sahm, Detman (SEC)

Empirical Ionospheric Storm-Time Correction Model



Input: 36 hour filtered ap, (based on ap, global ionospheric foF2, Many years of storm-time intervals)

Output: Ionospheric foF2 correction

Lead time: depends on ap lead time

User: HF communications correction for IRI users

Araujo-Pradere, Fuller-Rowell, Codrescu (SEC)

ACE Future Tracking Station Coverage
Noon is midpoint

(Winter/Summer Coverage)

Updated January 10, 2000

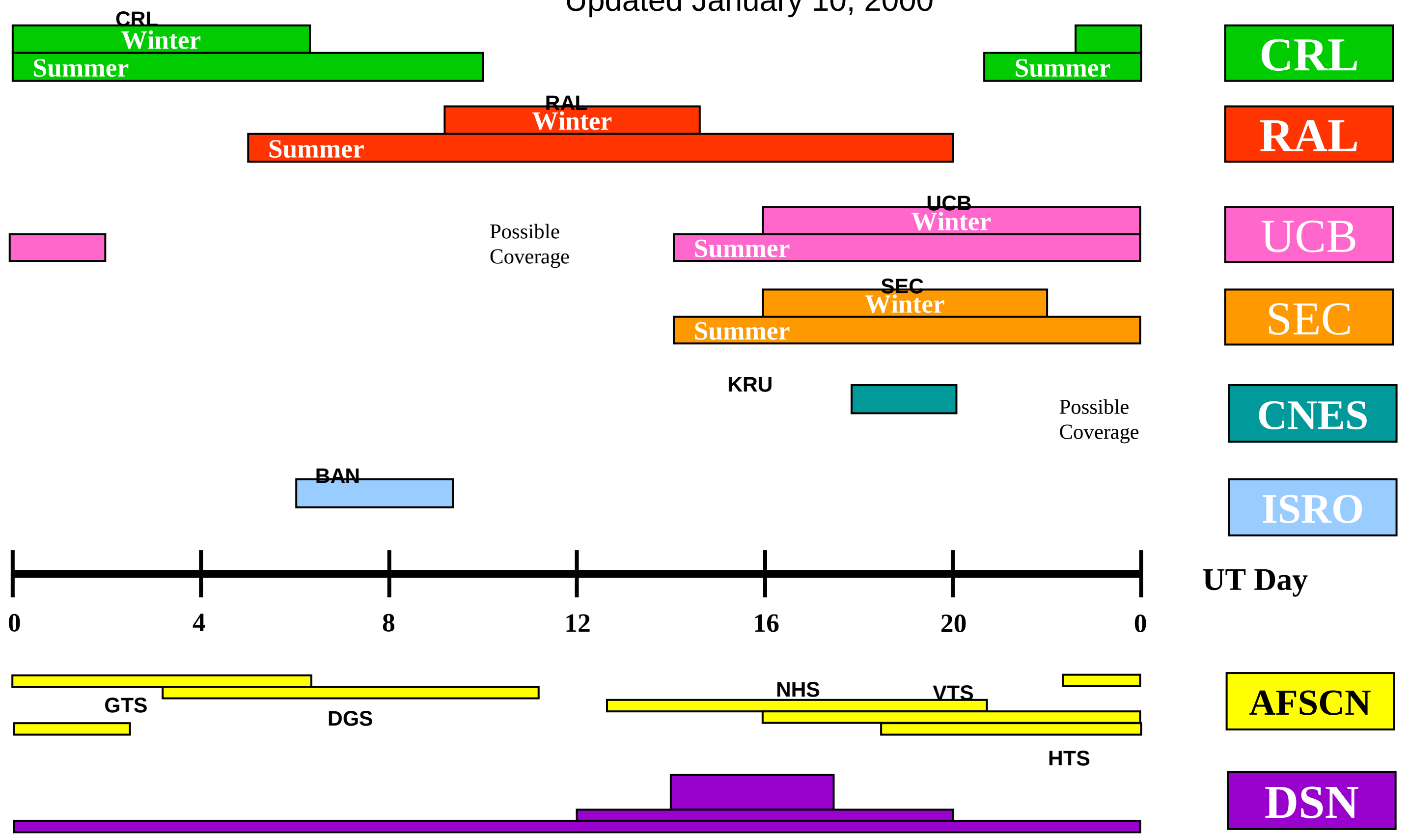


IMAGE: Imager for Magnetopause-to-Aurora Global Exploration is a NASA Explorer Satellite

Launched March 25, 2000

Real-time Data transmission

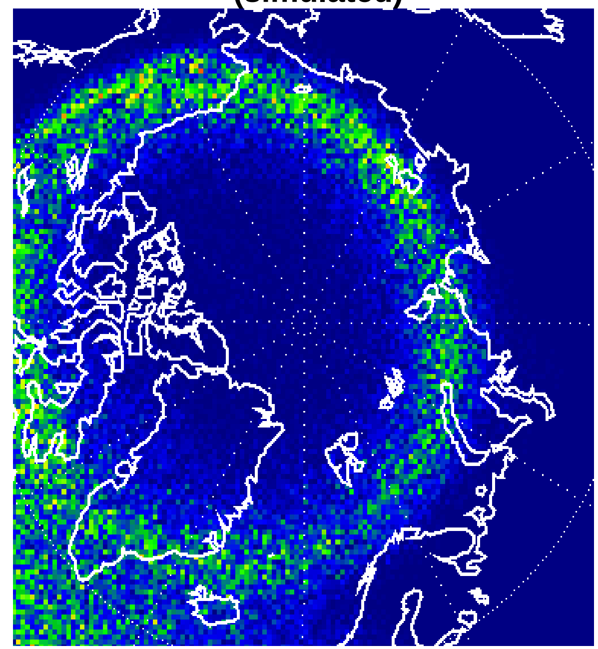
- Energetic Neutral Atom Imagers
- Far Ultraviolet Imager
- Extreme Ultraviolet Imager
- Radio Plasma Imager

Potential Ground Stations:

CRL (Japan), UC Berkeley, NOAA Ak, Rutherford-Appleton, US Naval Academy

Latest FUV Image

(simulated)

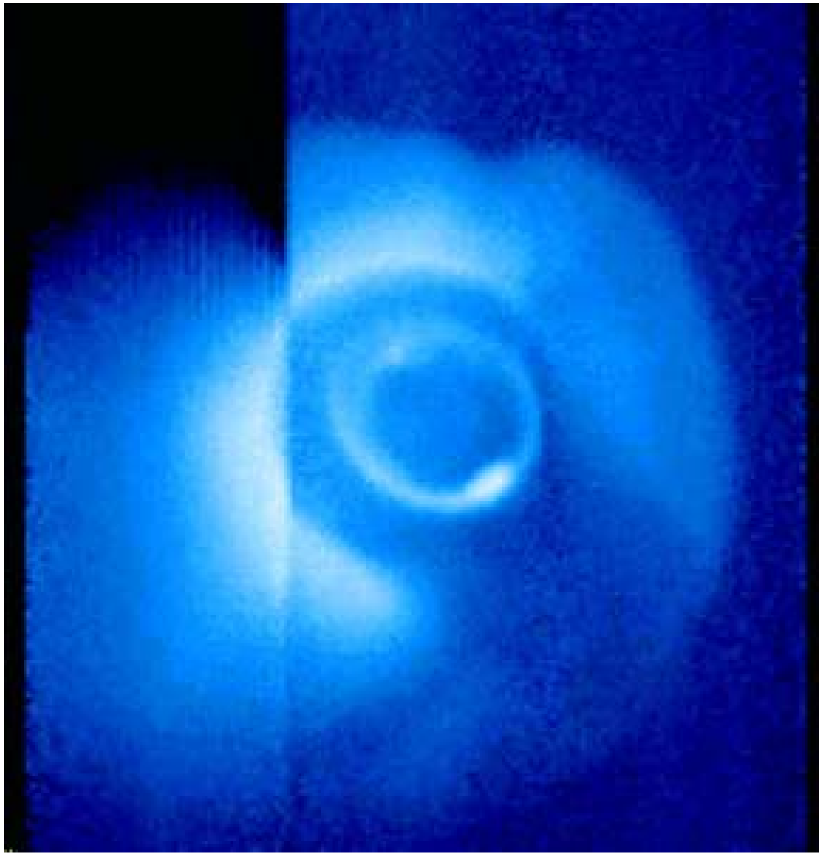


The IMAGE FUV instrument (Steven Mende PI) was built at and is managed by the Space Sciences Laboratory of the University of California at Berkeley.

Onsager, Sahm, Vickroy NOAA/SEC

IMAGE

Imager for Magnetopause-to-Aurora Global Exploration



The EUVI will detect ultraviolet photons from the Sun that are scattered by helium ions in the plasmasphere, a torus of cold dense plasma surrounding the Earth in the inner magnetosphere.

Solar X-ray Imager (SXI)

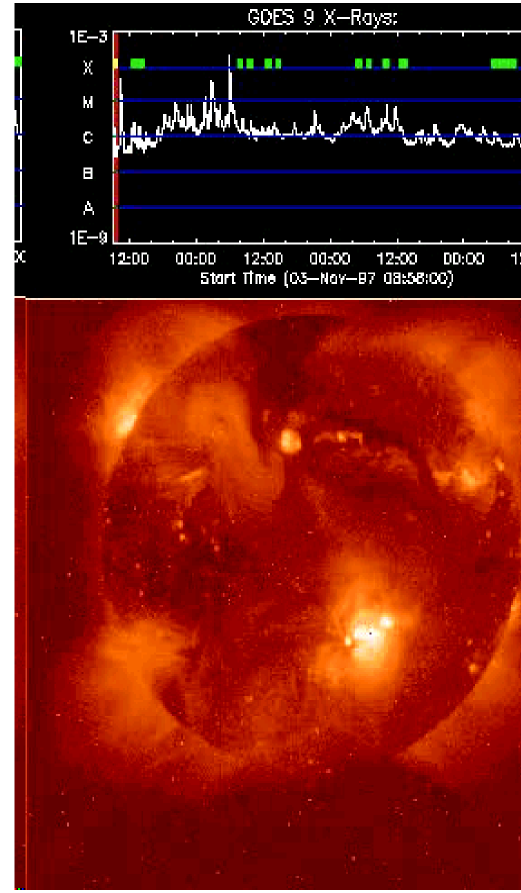
Launch on GOES M in summer 2001

One full solar image per minute.

- 5 arc sec pixels, 512 x 512 pixel array.

SXI will monitor:

- Coronal hole locations for geomagnetic storm predictions.
- Flare location for particle events.
- Monitor for changes indicating coronal mass ejections (CMEs).
- Active regions beyond east limb for activity predictions.
- Active region complexity for flare prediction.
- ***Without SXI, we get only two numbers from XRS to represent solar x-ray activity.***



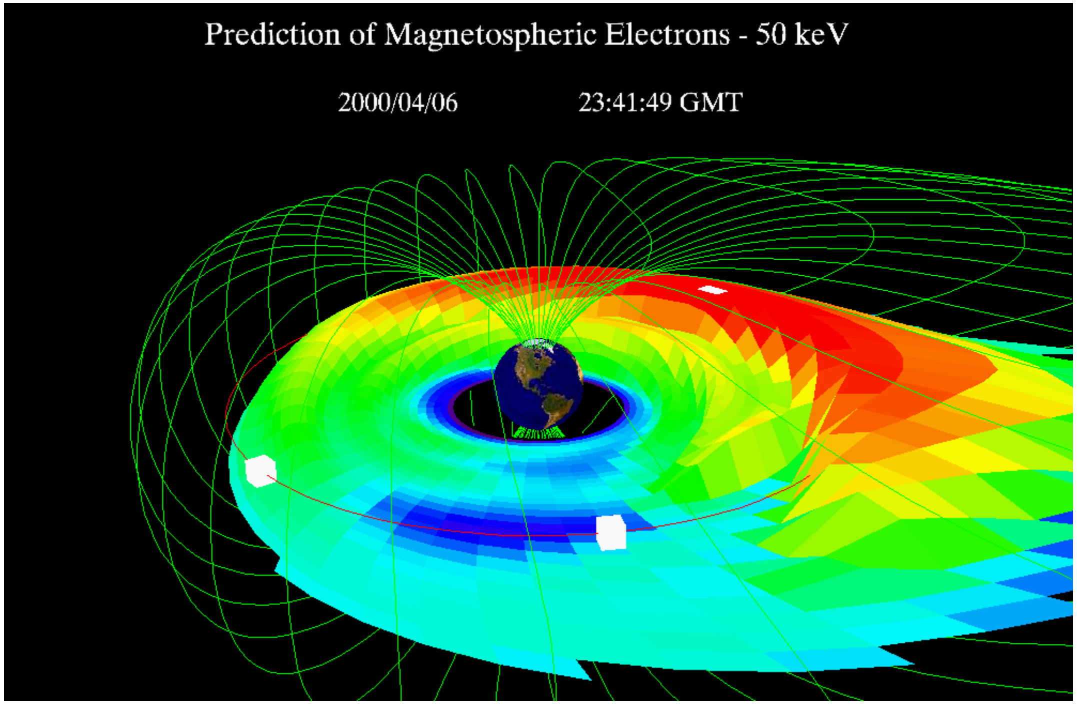
GOES 9 XRS and Yohkoh Image

Hill (SEC)

GOES NO/PQ Under Development

- **Include Improved Energetic Particle Measurements**
- **10's to 100's of keV Electrons and Protons**
- **Provides for Improved Specification, Model Validation and Data Assimilation**

Models at SEC Nowcast and Forecast Medium-Energy Electron and Proton Fluxes in the Magnetosphere

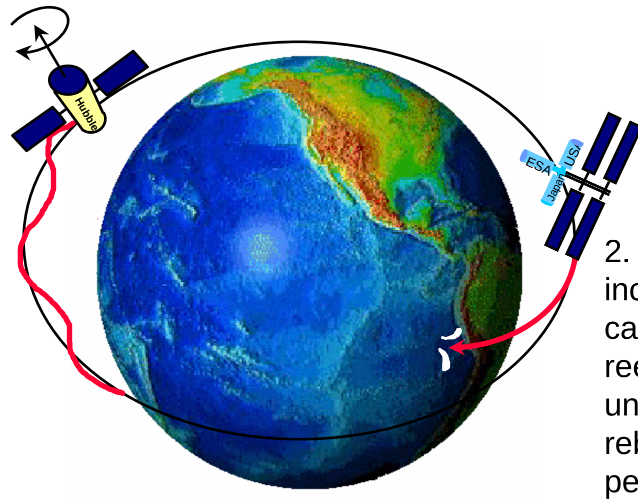


T. G. Onsager, NOAA/SEC

EUV Importance: Thermospheric Effects on Operational Systems

Example, Spacecraft such as the Hubble Space Telescope and Space Station will feel the effect of atmospheric drag in two ways:

1. If density is high, the fluctuations in atmospheric drag will cause satellite pointing errors.
This makes the Hubble Space Telescope unusable and would ruin microgravity experiments on Space Station



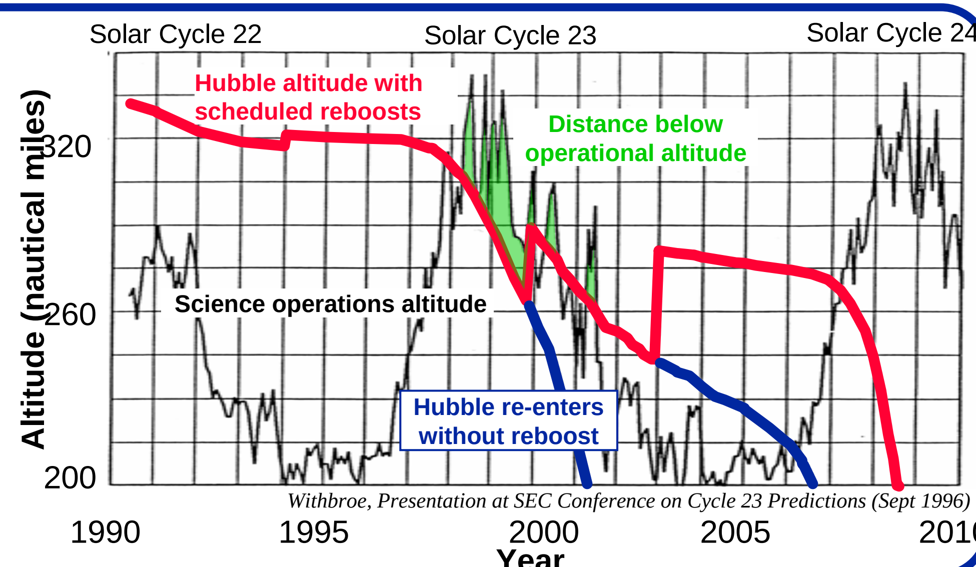
2. Long periods of increased drags could cause spacecraft to reenter prematurely unless expensive reboost operations are performed

Example: Hubble Altitude for a Large Solar Cycle 23

During the next solar max period the Hubble space telescope will...

- go below the operational altitude (green area)
- prematurely reenter (blue lines)

without additional shuttle flights to reboost it to higher orbits



EUV Measurents added to GOES NO/PQ

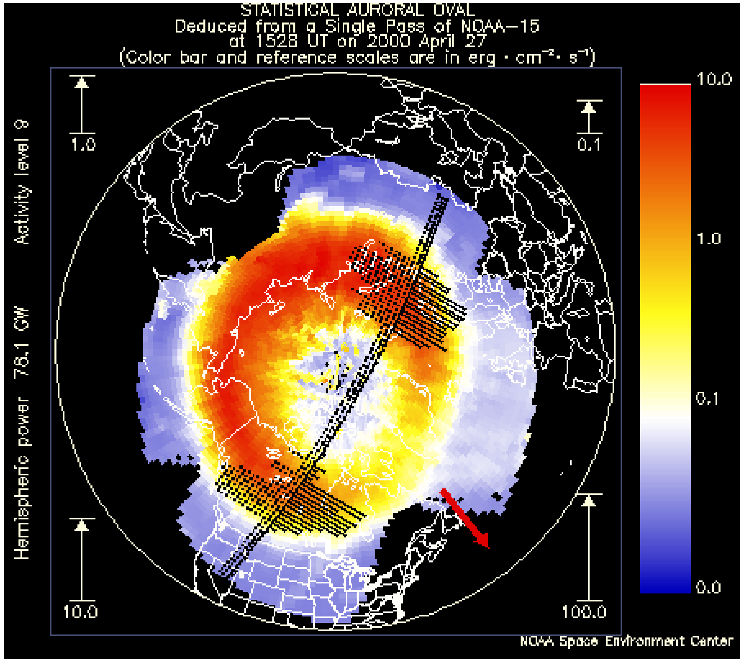
NOAA Space Environment Center

NOAA Polar Operational Environmental Satellite POES

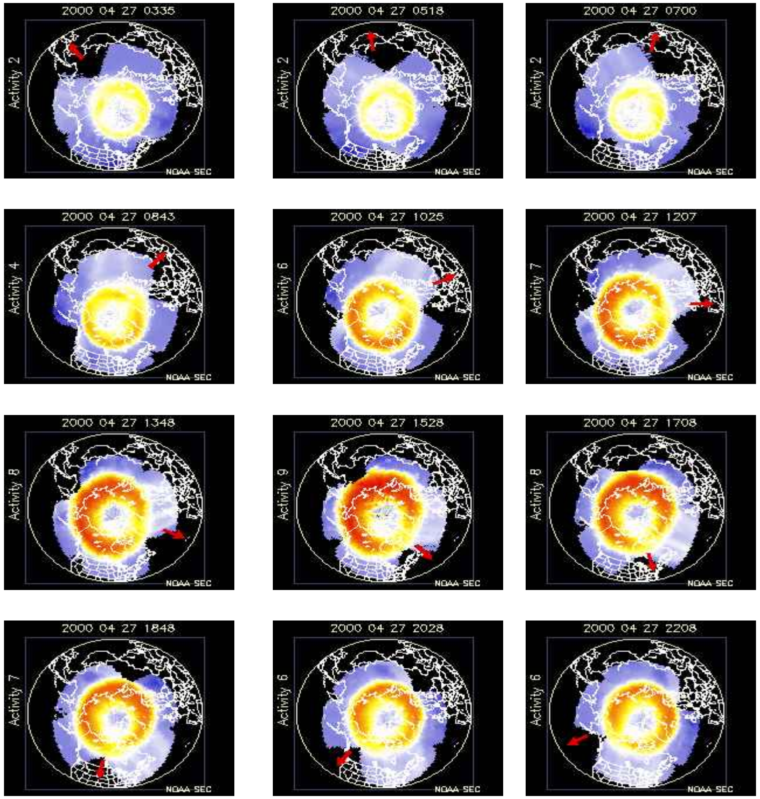
NOAA – 15 on line

SEM 2: more and wider range of energy channels

50 eV – 20 KeV



Single pass showing particle flux used to determine statistical oval.



One day of NOAA –15 power input from electron and proton precipitation.

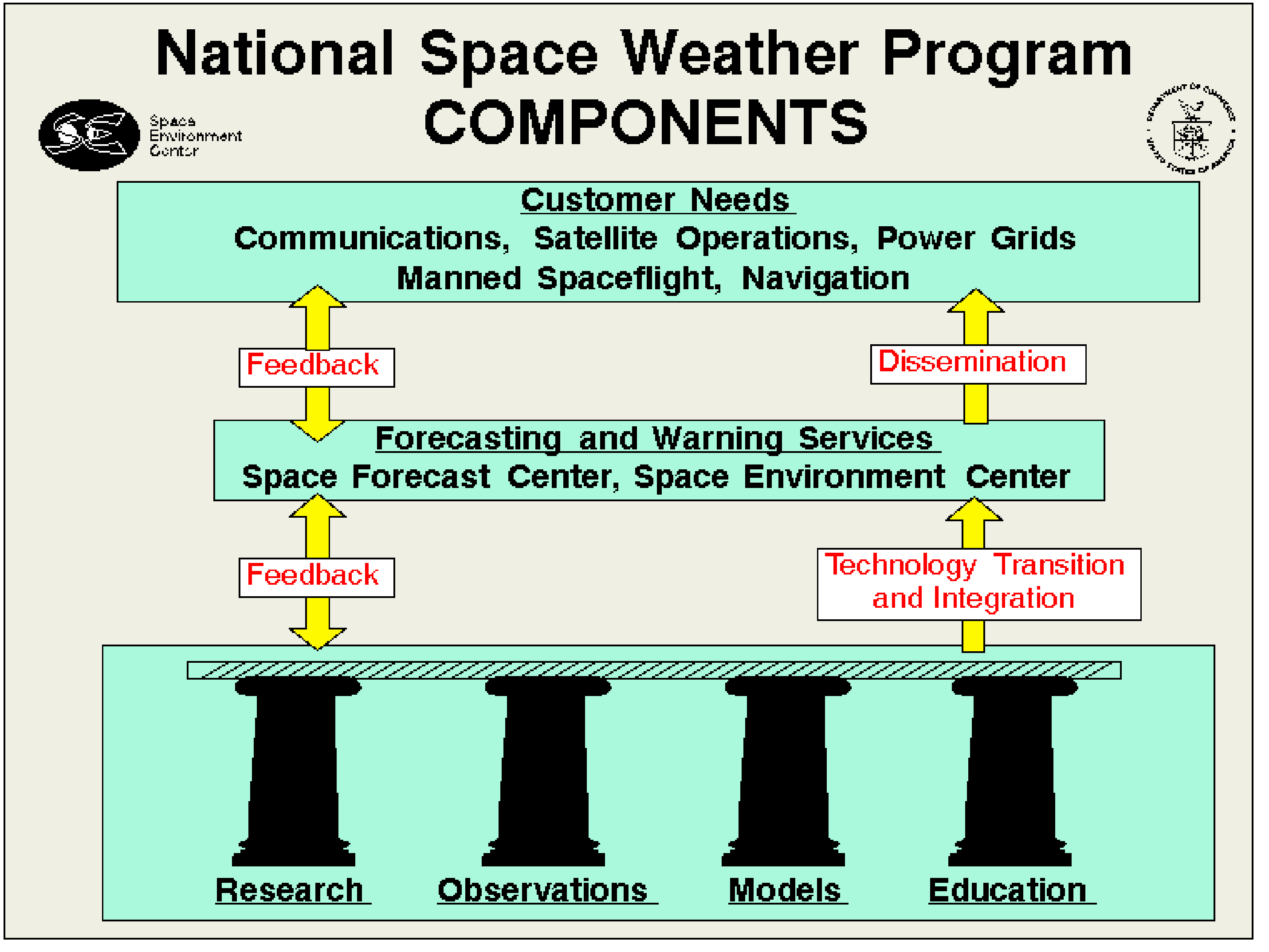
Evans and Greer (SEC)

SPACE WEATHER PROGRESS DEPENDS ON
Collaboration, Participation, and Partnership

Space Weather's strength is the diversity of its science and its programs.

- **INTERDISCIPLINARY**
  - **NSF's CEDAR, GEM, and SHINE**
  - **Space Weather Week**
- **INTERAGENCY**
  - **National Space Weather Program**
  - **NASA's Living With a Star**
  - **Community Coordinated Modeling Center**
  - **Space Weather Week**
- **INTERNATIONAL**
  - **ISES**
  - **Space Weather Week**

A Framework Space Weather



The Magnetosphere and Space Weather

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