Overview of NASA MSFC and UAH
Space Weather Modeling and Data Efforts

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Outline

- Overview of capabilities
- Research / model development
- Applied space weather support
- Testing capabilities
Overview

- Support all phases of the mission cycle for space weather and space environments.
  - Research
  - Testing
  - Model development
  - Design
    - Environment definition
    - Radiation, charging analyses
  - Launch availability - LCC
  - Anomaly investigation
  - Operations
Particle Acceleration and Transport in the Heliosphere (PATH) Model

- A dynamical time-dependent model of particle acceleration at a propagating, evolving interplanetary shock developed to understand solar energetic particle (SEP) events in the near-Earth environment – from 0.1 AU to several AU

- Instantaneous particle spectra at the shock front are obtained by solving the transport equation using the total diffusion coefficient $\kappa_{ij}$, which is a function of the parallel and perpendicular diffusion coefficients.

$$\frac{\partial f}{\partial t} + v_{w,i} \frac{\partial f}{\partial x_i} - \frac{\partial}{\partial x_i} \kappa_{ij} \frac{\partial f}{\partial x_j} + v_{D,i} \frac{\partial f}{\partial x_i} - \frac{1}{3} \frac{\partial v_{w,i}}{\partial x_i} \frac{\partial f}{\partial \ln p} = Q$$

- Numerical shock is generated to represent a CME driven shock.
- Nest shells evolve (expand adiabatically and experience convection)
- At each point in time, $t_k$, model can determine:
  - Particle injection energy (via diffusive shock acceleration mechanism) and injection rate,
  - $E_{\text{max}}$, diffusion coefficient, wave intensity velocity, density, temperature, shock compression ratio, etc.
  - Energetic particle spectra at all spatial and temporal locations,
  - Dynamical distribution of particles that escape upstream and downstream from the evolving shock complex

Gary Zank, UAH / CSPAR
Space Science Department
A time-dependent model of shock wave propagation (1- and 2-D), local particle injection, Fermi acceleration at the shock, and non-diffusive transport in the IP medium does remarkably well in describing observed SEP events: This includes spectra, intensity profiles, anisotropies.

Can model heavy ion acceleration and transport in gradual events, even understanding differences in Fe/O ratios, for example.

We have begun to model mixed events to explore the consequences of a pre-accelerated particle population (from flares, for example) and have also related this to the timing of flare – CME events.

Incorporates:
- incorporates both solar flare and shock-accelerated solar wind suprathermal particles.
- Arbitrary theta Bn and r (shock strength),
- particle transport as they escape from the shock,
- protons and heavy ions
MAG4 (Magnetogram Forecast)

- MAG4 is a R20 project developing space weather forecast tool for NASA/SRAG, with access to NOAA, Air Force, and CCMC.
- It downloads HMI LOS or vector magnetograms, as well as recent flare history.
- It measures a free-energy proxy.
- The free-energy cannot be measured accurately with present instrumentation.
- The model uses empirically derived forecast curve to predict event rates.
- It presents the predicted event rates graphically, and in output files.
- Graphical on next slide

- Predicted X&M-class flare rate versus actual smoothed rate.

David Falconer, UAH/CSPAR
Comparison of Safe and Not Safe Days

June 26, 2013
C1, C1.5 flares

March 7, 2012
X5.4, X1.3, C1.6
CME 2684, 1825 km/sec,
Solar Energetic Proton Event reaches 6530 particle flux unit >10MeV

David Falconer, UAH/CSPAR
Marshall/EV44 Applied Space Weather Support

- Environment Definition for Spacecraft Design
- Modeling and Analysis
- Applied Space Weather Support
  - Anomaly investigations
  - Operational Support
- Routinely use observations for: polar, radiation belts, GEO, LEO, and interplanetary environments
Applied Space Weather Support - ISS

- International Space Station (ISS) Floating Potential Measurement Unit (FPMU)
  - Instrument suite for monitoring ISS charging, plasma environments
  - Monitor visiting vehicle and payload charging
  - Characterize US high voltage (160V) solar array interactions with LEO plasma environment
  - Anomaly investigation

- Try to collect ISS charging data during geomagnetic storm periods in order to have information for the extreme environments

Requires a strategy to improve odds of operating FPMU during geomagnetic storm periods.

L. Neergaard Parker / SWW 2016

FPMU designed and built by Space Dynamics Laboratory (Logan, UT) on contract to NASA JSC

26 March 2008: FPMU captures auroral charging data during operations in support of STS-123 ISS and ATV docking
Applied Space Weather Support – Chandra

- Mitigation strategy for ACIS degradation issue
  - Schedule observations in low proton flux environments

- Chandra Radiation Model
  - Uses data from Geotail (EPIC/ICS instrument) and Polar (CEPPAD/IPS) spacecraft to populate the model.

<table>
<thead>
<tr>
<th>Geotail</th>
<th>Polar</th>
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<tbody>
<tr>
<td>P3/H⁺ 77.3 - 107.4</td>
<td>6/H+ 87.7 102.0</td>
</tr>
<tr>
<td>P4/H⁺ 107.4 - 154.3</td>
<td>7/H+ 118.0 138.0</td>
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<tr>
<td>P5/H⁺ 154.3 - 227.5</td>
<td>8/H+ 161.0 188.0</td>
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<td>9/H+ 221.0 259.0</td>
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- ACE/EPAM real time monitoring
  - The ACE/EPAM RTSW records are the only real-time data for detecting ~100-200 keV proton events in interplanetary space that impact the ACIS instrument.
DMSP and RBSP surface charging

- MSFC developed software tools for working with DMSP SSJ and SSIES sensor data (F6 – F18)
- Developing automated charging event identification algorithms, useful for “charging indices”
- Characterize extreme charging to support spacecraft design, polar orbit operations

Developing a statistical database to understand the location, duration, magnitude, etc. of surface charging events.
Real Time Space Environmental Effects Tools

- Developing prototype engineering tools for evaluating effects of space environments on satellite systems
  - Geostationary orbit single event upset tool (real time version of CREME96)
  - Geostationary orbit internal charging tool

Electric fields resulting from internal (deep dielectric) charging as function of depth in dielectric material and electrical conductivity. Fields are updated at 5 minute intervals using NOAA GOES >0.8 MeV, >2.0 MeV electron data.
Space Environment Effects Testing and Calibration

Space environmental effects testing for broad spectrum of environments and effects:

- Energetic electron, ion radiation
- Ultraviolet (UV) radiation
- High intensity solar simulator
- Spacecraft charging (surface, internal)
- Atomic oxygen
- Thermo-optical properties
- Solar array interaction with space plasma, radiation environments
- Hypervelocity (meteor/orbital debris) impacts
- Thermo/vacuum/vibration
- Contamination/outgassing

Low Energy Electron and Ion facility (LEEIF)

- Charged particle instrument calibration for particle energy, mass, flux, and angular acceptance
- Supports iterative design, build, and testing of space plasma instruments for variety of environments
- Electron/ion/UV sources, ISO 7 tent, ISO 5 bench, vacuum chamber, and data acquisition and analysis
Summary

- MSFC and UAH are active in the modeling and development of space weather tools for R2O.

- Data from all regions of geo to interplanetary space are used for
  - Research and model development
  - Environment definition for design
  - Phenomena characterization
  - Anomaly investigation
  - Operations
  - Modeling/analysis

- Broad spectrum for space environments testing
Questions?