Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) Project

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Joint Interagency Weather Research Meeting
NOAA, Boulder, Colorado
March 24, 2010

Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS)

Earth System Models

Radiation Dose Rates:

AIR (parametric)

HZETRN (physics-based)

Near-Earth Space Environment

•Badhwar/O'Neill GCR Model

•Empirical Cutoff Rigidity

(IGRF+T05)

•Physics-based Cutoff Rigidity

(LFM/CMIT+SEP-trajectory)

Earth Observations

Near-Earth Space Environment

NASA/ACE

NASA/HEAO-3

NOAA/GOES

Assimilated Atmospheric

Atmospheric Depth (NCEP/GFS)

Ground-Based

Neutron Count Monitors

Predictions/Forecasts

Ionizing Radiation Nowcast

3-D Effective Dose

3-D Differential Flux

NAIRAS Distributed Network System

High-Performance Computer Systems

Server Interface

Operational and Archival Databases

Differential Particle Flux

HZE Particles (A=5-56)

Light-Ions (A=1-4)

Neutrons

Pions and Muons

Electromagnetic Cascasde Particles

Observations, Parameters & Products

Decision Support Systems, Assessments, Management Actions

NAIRAS decision support tool for NOAA/SWPC space weather forecasts, warnings, and advisories

NAIRAS available at NOAA/ADD experimental aviation-related weather forecasts, observations, and analysis

Specific analyses to support the decision making

Predict real-time radiation exposure at commercial airline altitudes (includes background GCR and SEP events)

Provide accumulated radiation exposures for representative set of domestic, international, and polar routes

Specific Decisions / Actions

Limit aircrew flight hours to within recommended annual and career limits

Alter route and/or altitude during SEP events

Value & Benefits to Society

Improvements in the decision-making, decisions, and actions

First-ever, data-driven, real-time prediction of biologically harmful radiation exposure levels at commercial airline altitudes

Quantitative and qualitative benefits from the improved decisions

Comprehensive database of radiation dose rates to formulate recommended annual and career limits to ionizing radiation exposure

Comprehensive database of radiation dose rates for airlines to assess cost/risk of polar routes

Real-time prediction of radiation exposure levels to enable optimal balance between airline cost and air traveler health risk during solar storm (SEP) events

Improve understanding of biological effects of atmospheric ionizing radiation on aircrew and passengers through collaboration of epidemiological studies by NIOSH

Nowcast of Atmospheric Ionizing Radiation for Aviation Safety Prototype Development

- Nowcast Domain
  - 2.5 x 2.5 degree horizontal grid
  - Altitude Range: 0-100 km, 1 km resolution
  - 1 hour time cadence
- Experimental Data Products for Community Evaluation
  - 4-D Effective Dose (netcdf)
  - Global Effective Dose Graphics
  - Routine Flight Planning tools
  - Browsers and Google Earth
- Initial Data Availability
  - NOAA Aviation Digital Data Service (ADDS) experimental data products web interface
- Transition-to-Operations
  - Discussions with NOAA SWPC
  - Interest from Air Force Weather Agency (AFWA)

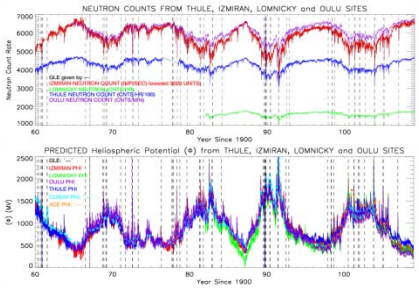
Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) Model

Real-time Neutron Monitor Data (e.g., IZMIRAN and LOMNICKY)

↓

Fit to Climax HP

↓



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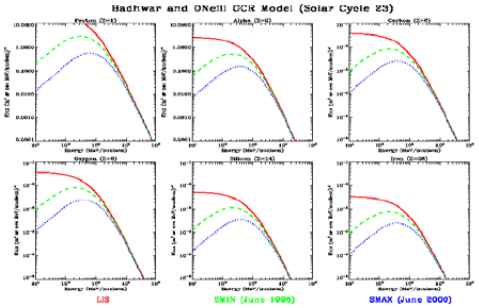
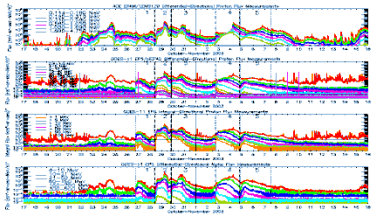
Badhwar+O'Neill GCR Model



NOAA/GOES +NASA/ACE Data



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Spectral Fitting

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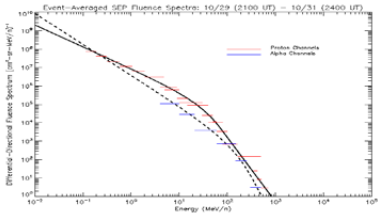

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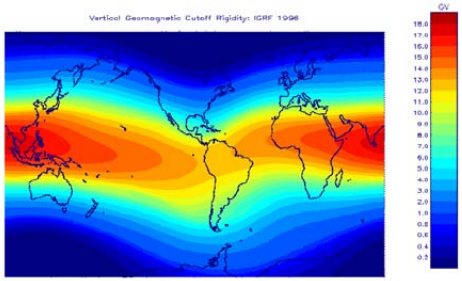
Cutoff Rigidity (IGRF)



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Magnetospheric Magnetic Field (e.g., T05) Effects on Cutoff Rigidity

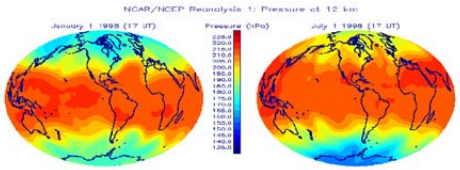
← **NASA/ACE Solar Wind and IMF Data**

HZETRN + Dosimetry

↑

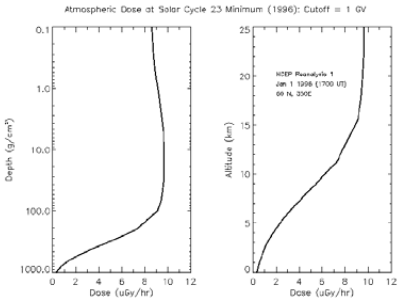
Atmospheric Density

↑



NCEP/GFS

→



Atmospheric Dose and Dose Equivalent

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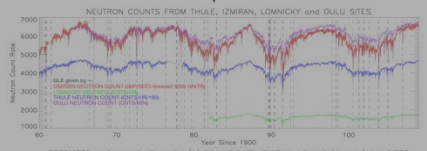

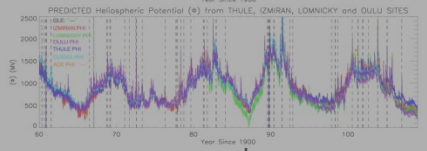

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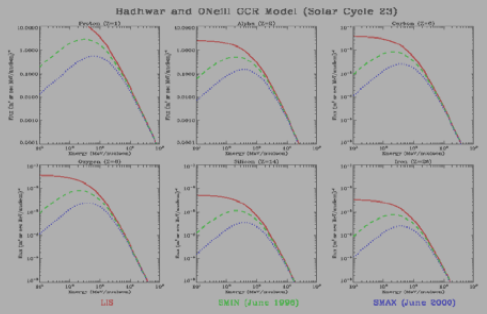

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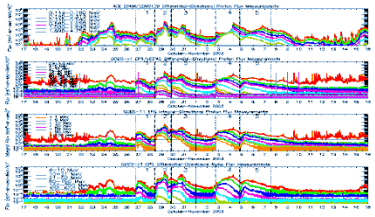

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Spectral Fitting

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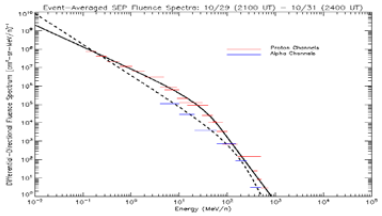

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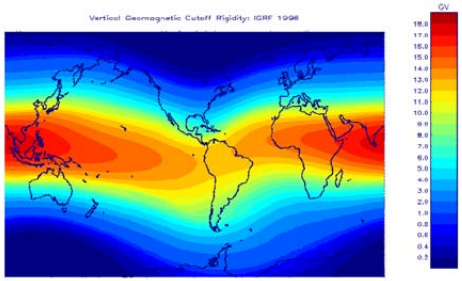

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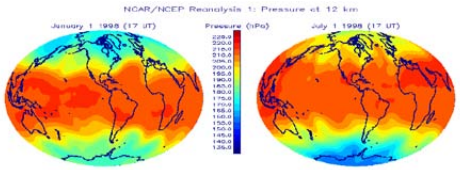

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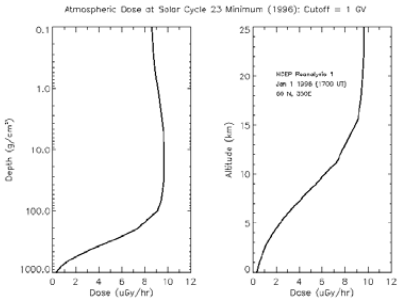
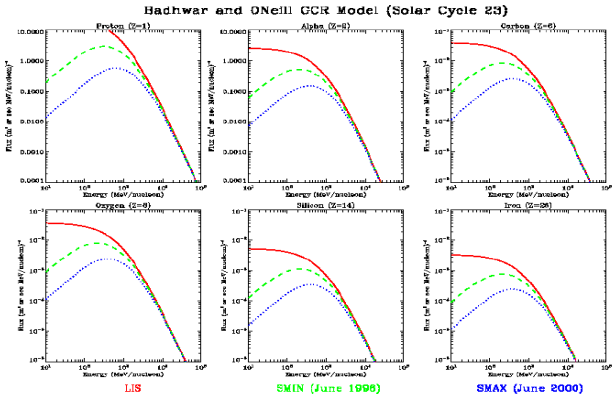
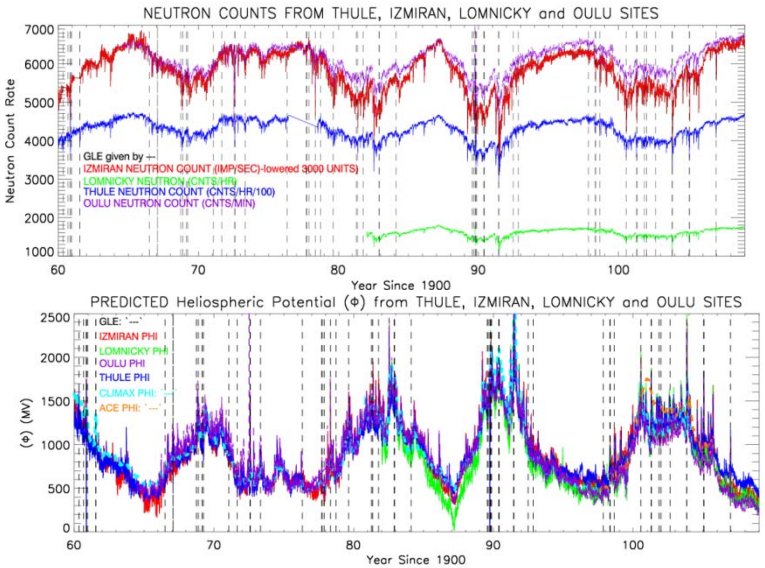


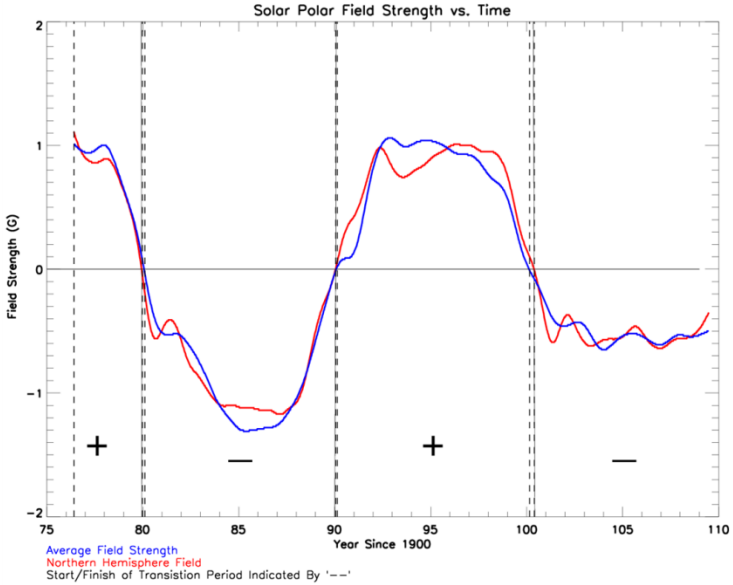
Atmospheric Dose and Dose Equivalent

GCR Fluence Spectra

- Ground-based neutron monitor count rates related to incident GCR flux
- Use high-latitude, real-time neutron monitor count rates to derive heliospheric potential (HP)
- Fit real-time neutron count rates to Badhwar & O'Neill GCR HP
    - Steady-state Fokker-Planck transport to 1 AU







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Real-time Neutron Monitor Data (e.g., IZMIRAN and LOMNICKY)

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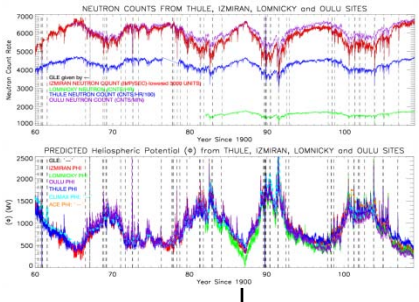

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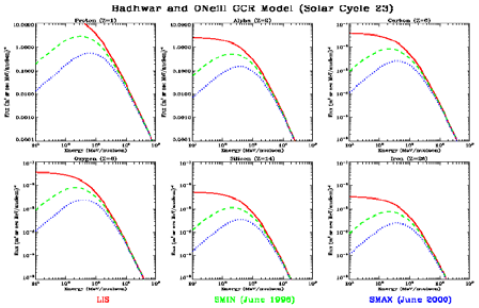
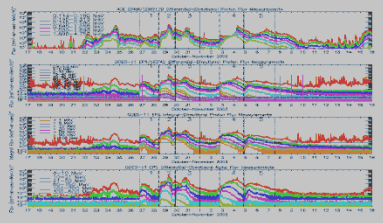


NOAA/GOES +NASA/ACE Data



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Spectral Fitting

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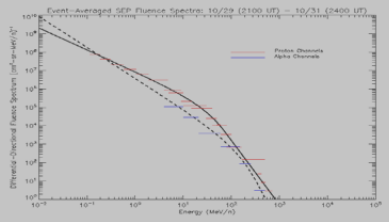

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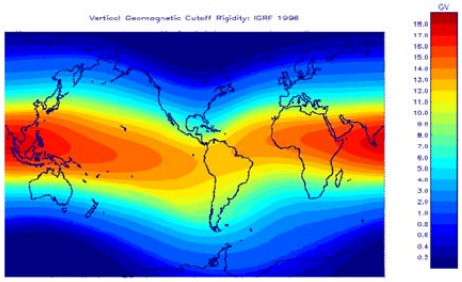

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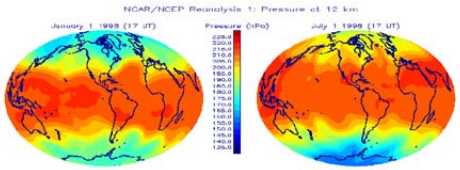
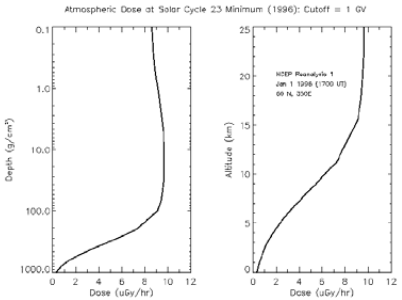


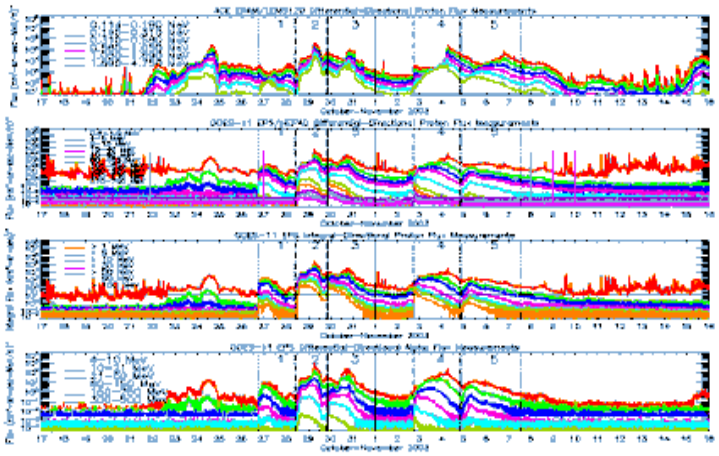
NCEP/GFS

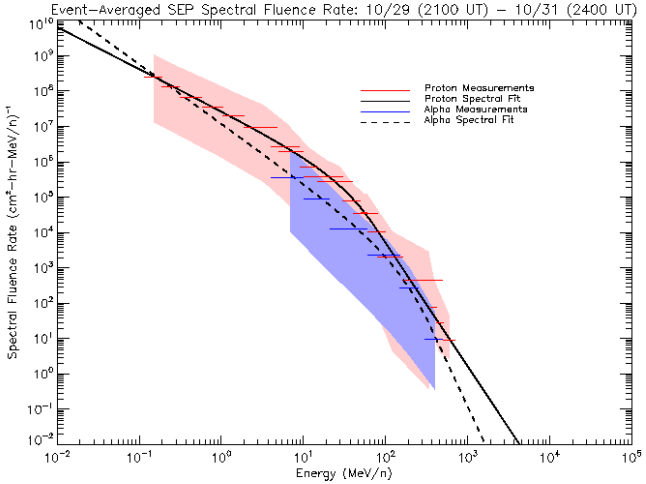


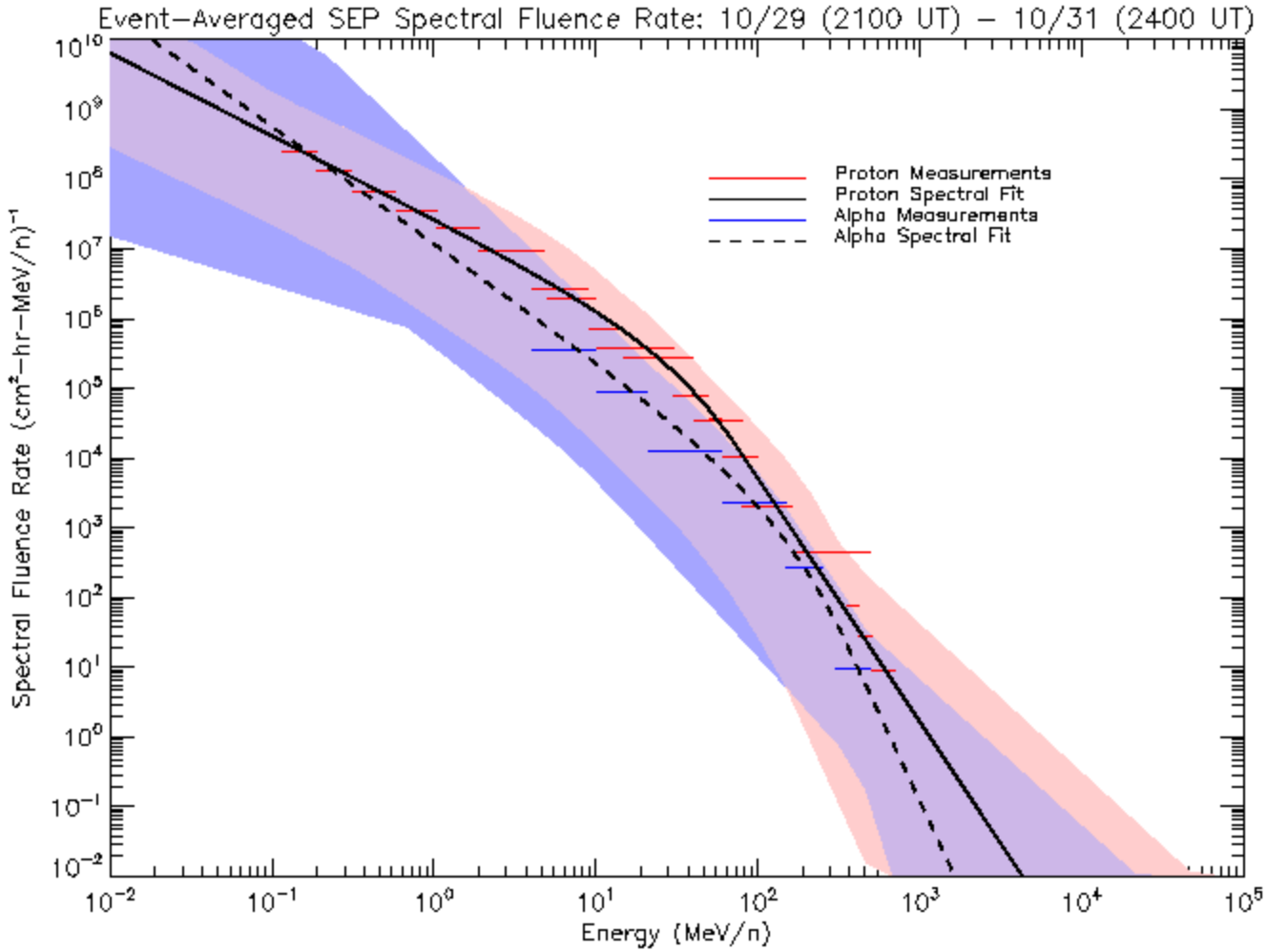
Atmospheric Dose and Dose Equivalent

SEP Fluence Spectra

- GOES and ACE observes proton/alpha fluxes and which we need do derive the fluence rates and spectral characteristics
- For the Halloween storms a single power-law did not work
  - Used a double power law spectrum as suggested by *Mewaldt, 2003*
    - Includes a corona and flare seed population
    - Require the power-law functions and first derivatives to be continuous at merge energy






Event–Averaged SEP Spectral Fluence Rate: 10/29 (2100 UT) – 10/31 (2400 UT)
Proton Measurements
Proton Spectral Fit
Alpha Measurements
Alpha Spectral Fit
Spectral Fluence Rate (cm²–hr–MeV/n)⁻¹
Energy (MeV/n)
10¹⁰
10⁹
10⁸
10⁷
10⁶
10⁵
10⁴
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻²
10⁻¹
10⁰
10¹
10²
10³
10⁴
10⁵

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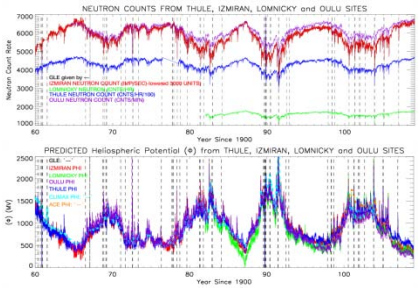

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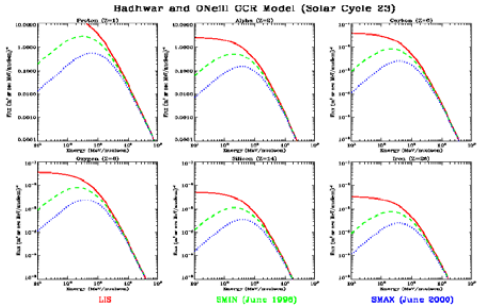
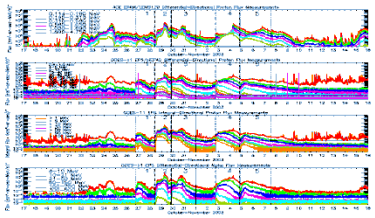


NOAA/GOES +NASA/ACE Data



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Spectral Fitting

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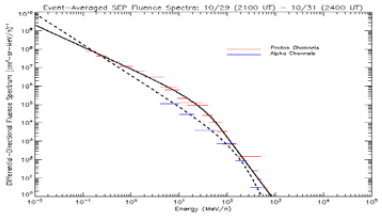

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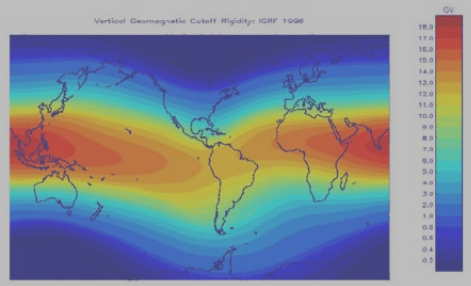
Cutoff Rigidity (IGRF)



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Magnetospheric Magnetic Field (e.g., T05) Effects on Cutoff Rigidity

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Atmospheric Density

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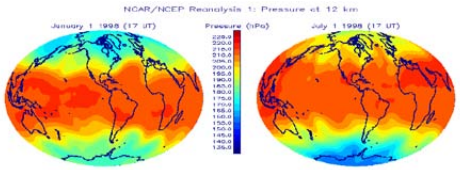
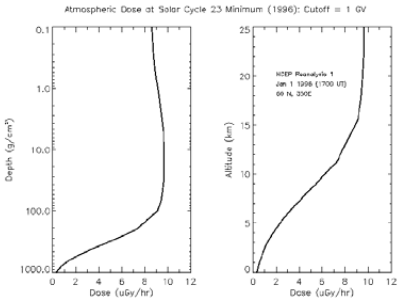
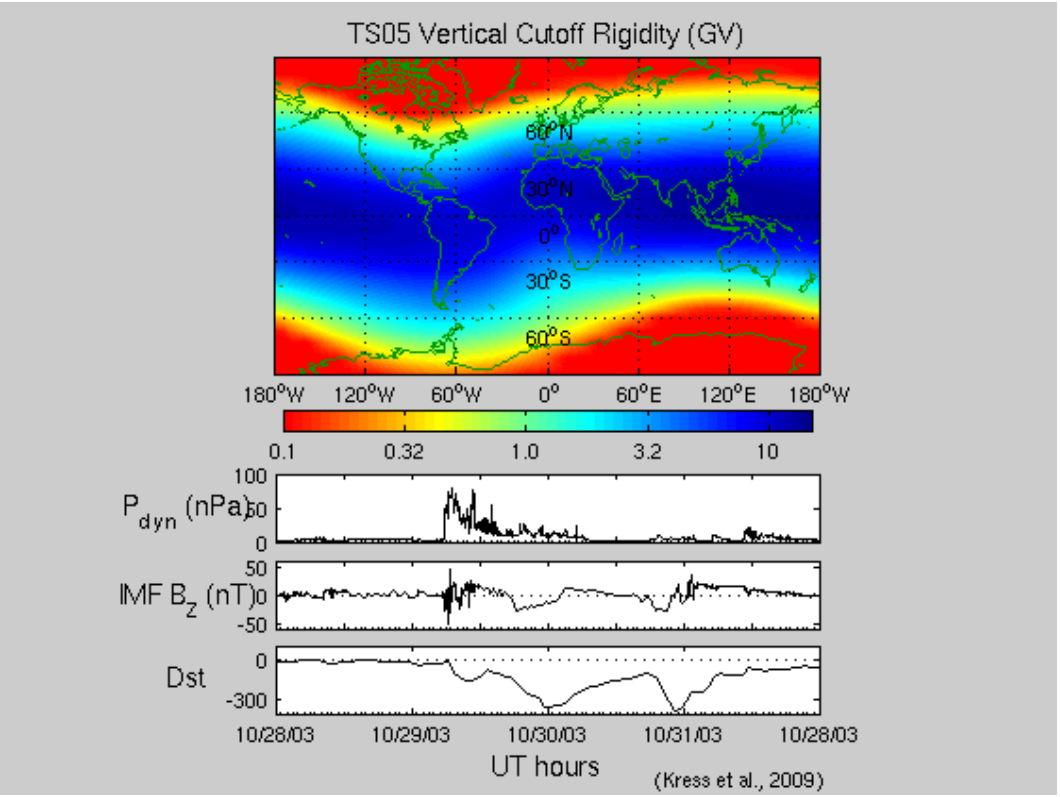


NCEP/GFS

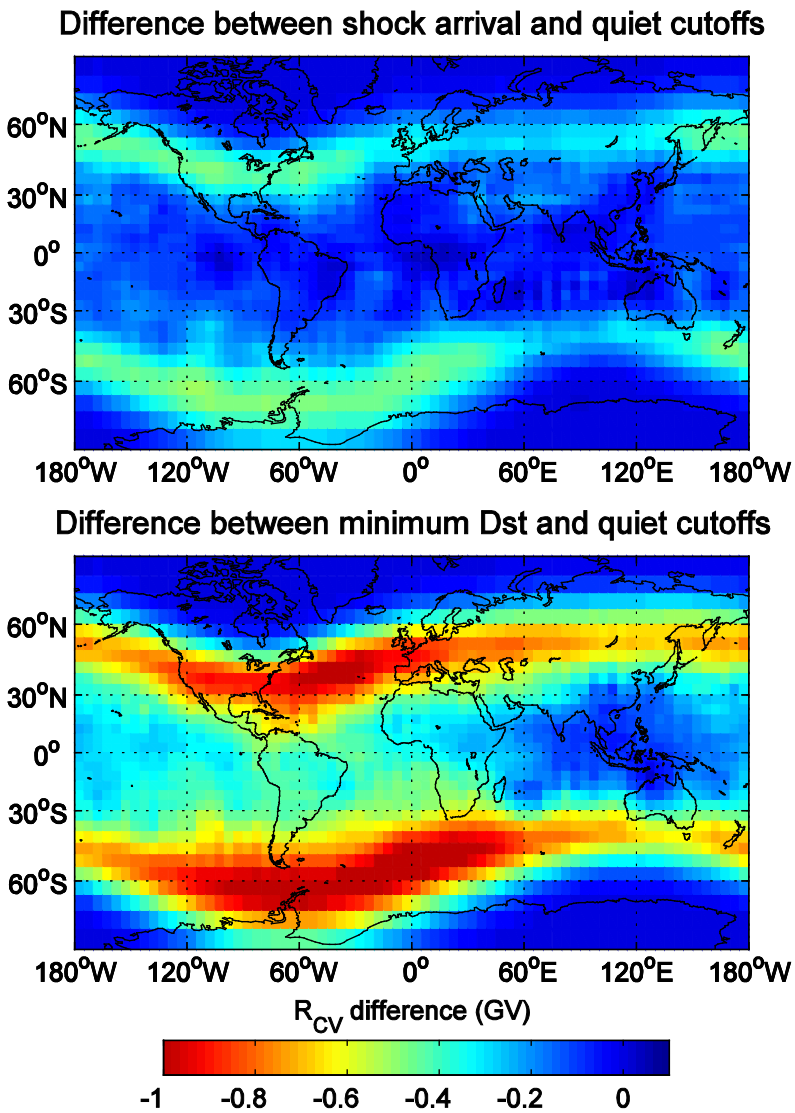


Atmospheric Dose and Dose Equivalent

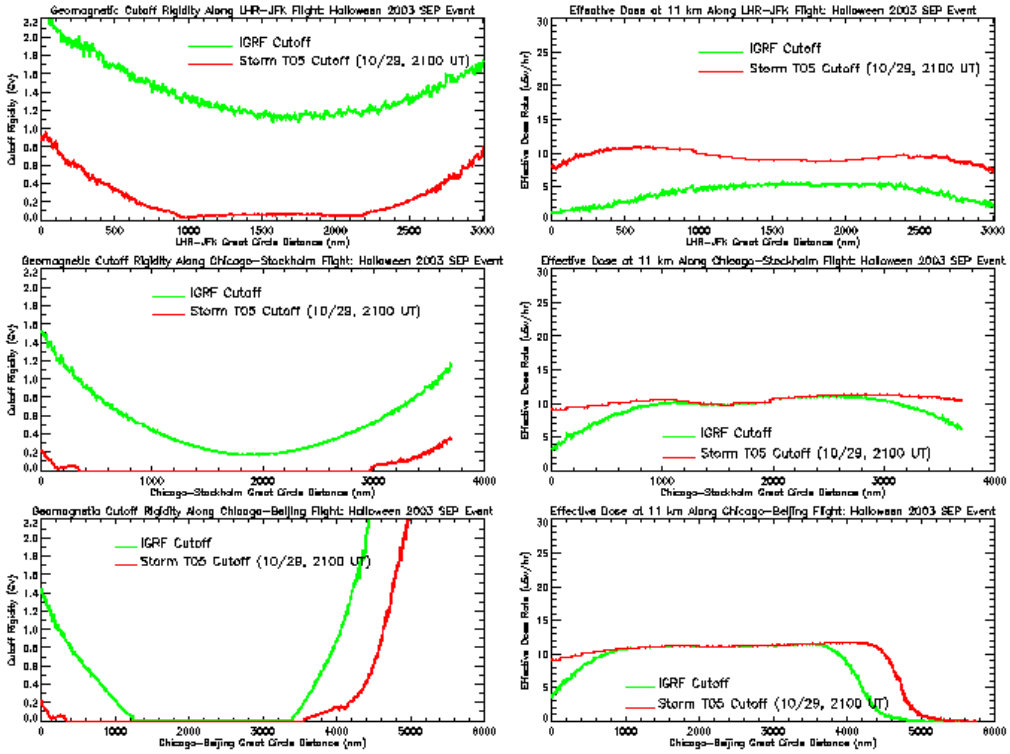
Geomagnetic Shielding



- **Severe geomagnetic storms suppress geomagnetic shielding allowing SEPs access to mid- latitudes.**
  - **Due primarily to a build up of the ring current**
  - **Shock arrival can also be significant**
- **Particles with rigidities below the a cutoff value cannot access that point in space**
  - **We compute these using the TS05 storm magnetic field model and a particle tracing code**
    - **During the Halloween storms we find 1 and 0.5 GV suppression during main phase and shock arrival, respectively**

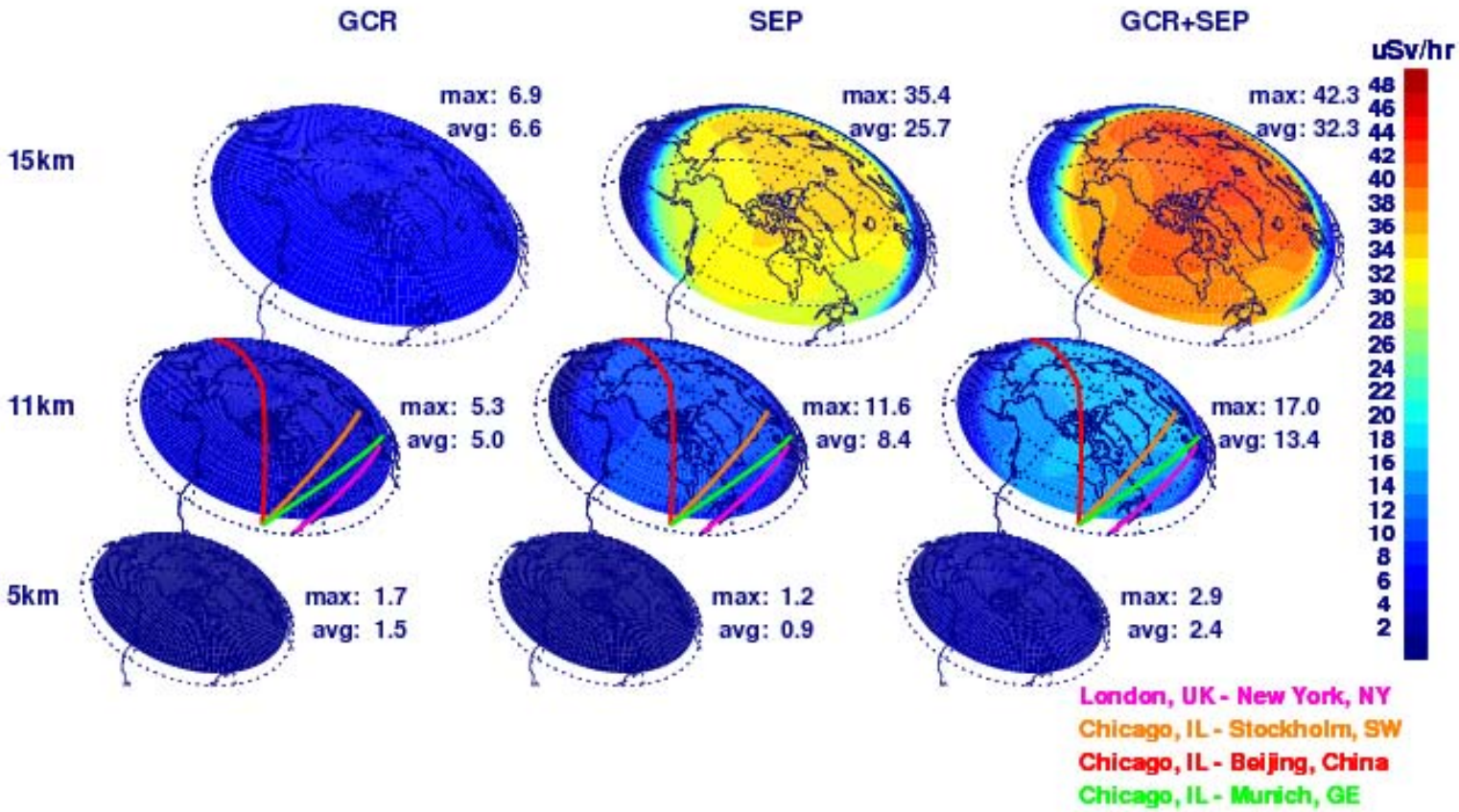

Difference between shock arrival and quiet cutoffs
60°N
30°N
0°
30°S
60°S
180°W
120°W
60°W
0°
60°E
120°E
180°W
Difference between minimum Dst and quiet cutoffs
60°N
30°N
0°
30°S
60°S
180°W
120°W
60°W
0°
60°E
120°E
180°W
R_CV difference (GV)
-1
-0.8
-0.6
-0.4
-0.2
0

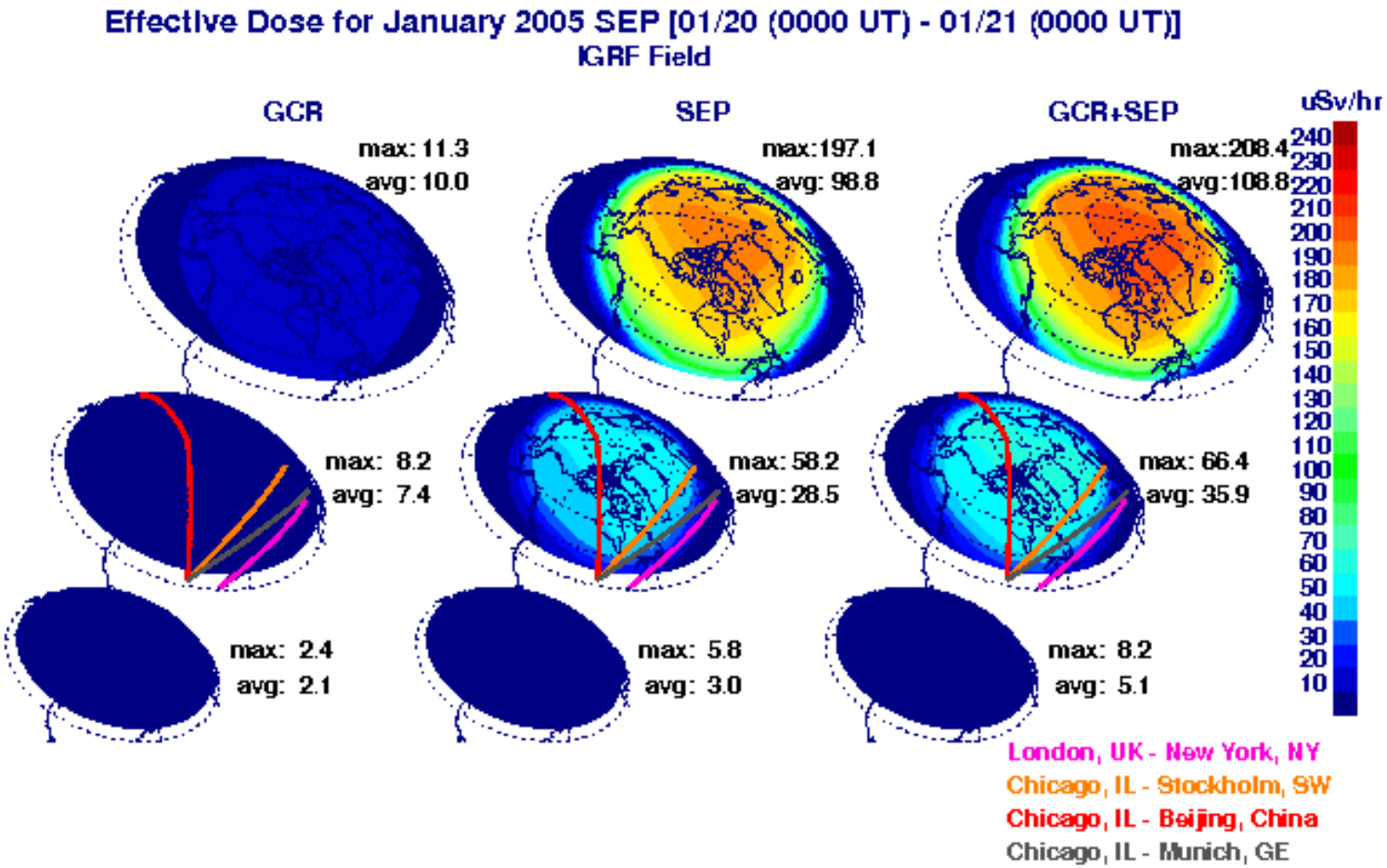
Flight Path Comparison
Geomagnetic Effects

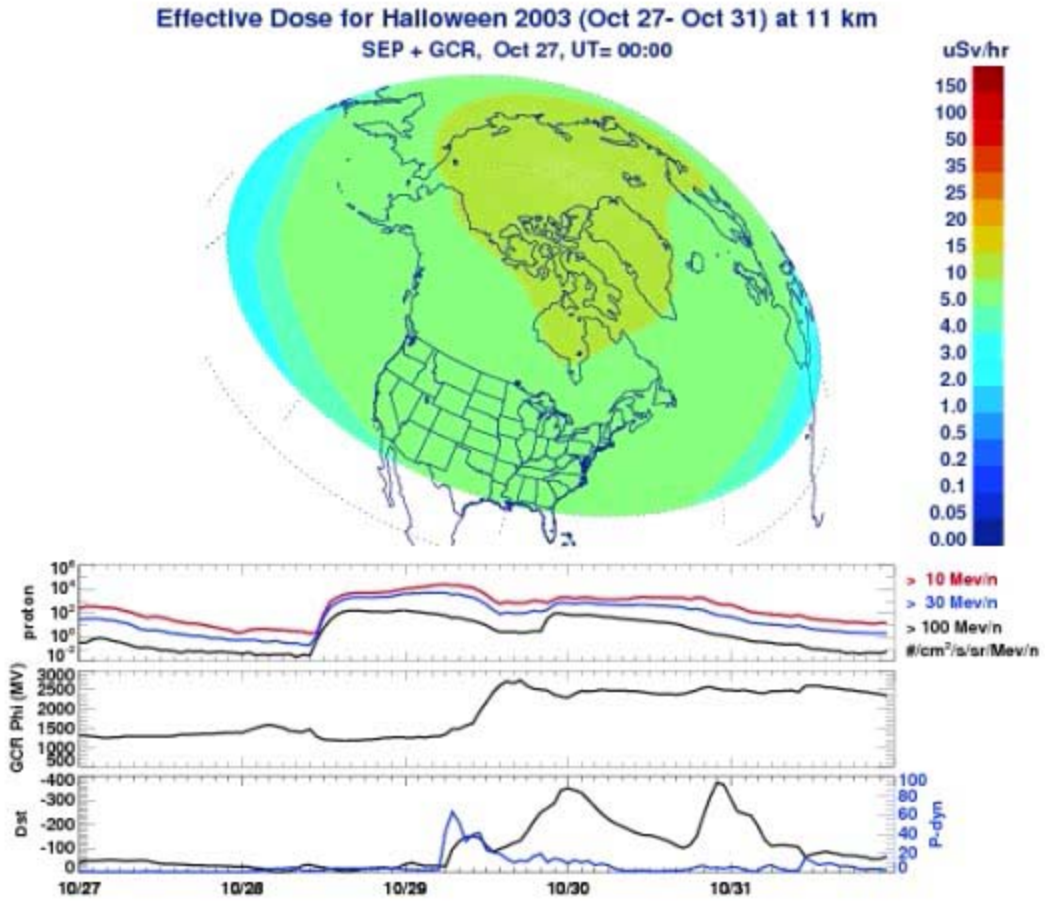


- **LHR-JFK flight path**
  - **Significant differences because flight nears or crosses the open/closed field line boundary**
- **ORD-PEK flight path**
  - **Limited differences since both models include passage into polar cap**
  - **Significant dosage is seen in both cases**

Effective Dose for Halloween 2003 SEP [10/29 (2100 UT) – 10/31 (2400 UT)]
T05 Storm Field: October 29, 2003 (2100 UT)




Effective Dose for January 2005 SEP [01/20 (0000 UT) - 01/21 (0000 UT)]
IGRF Field
GCR
SEP
GCR+SEP
uSv/hr
max: 11.3
avg: 10.0
max:197.1
avg: 98.8
max:208.4
avg:108.8
max: 8.2
avg: 7.4
max: 58.2
avg: 28.5
max: 66.4
avg: 35.9
max: 2.4
avg: 2.1
max: 5.8
avg: 3.0
max: 8.2
avg: 5.1
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
London, UK - New York, NY
Chicago, IL - Stockholm, SW
Chicago, IL - Beijing, China
Chicago, IL - Munich, GE


Effective Dose for Halloween 2003 (Oct 27- Oct 31) at 11 km
SEP + GCR, Oct 27, UT= 00:00
uSv/hr
150
100
50
35
25
20
15
10
5.0
4.0
3.0
2.0
1.0
0.5
0.2
0.1
0.05
0.00
proton
> 10 Mev/n
> 30 Mev/n
> 100 Mev/n
#/cm²/s/sr/Mev/n
GCR Phi (MV)
Dst
P-dyn
10/27
10/28
10/29
10/30
10/31

NAIRAS Project: Outlook from Year 2/3

- Prototype completion anticipated in mid-2011
- Preparing first real-time demo
- Require additional application of neutron monitor measurements
  - Reduce uncertainty in fitting high-energy tail of SEP ion fluence spectrum
  - Application of mid- and low-latitude neutron monitors
- Step towards SEP radiation exposure forecast
  - Application of mid- and low-latitude neutron monitors
  - Respond to high-energy SEP ions which can arrive up to 1 hour before satellites detect an SEP event
- Need storm-time airborne TEPC measurements
- Need > 1 GeV ion flux satellite measurements to complement neutron monitor data

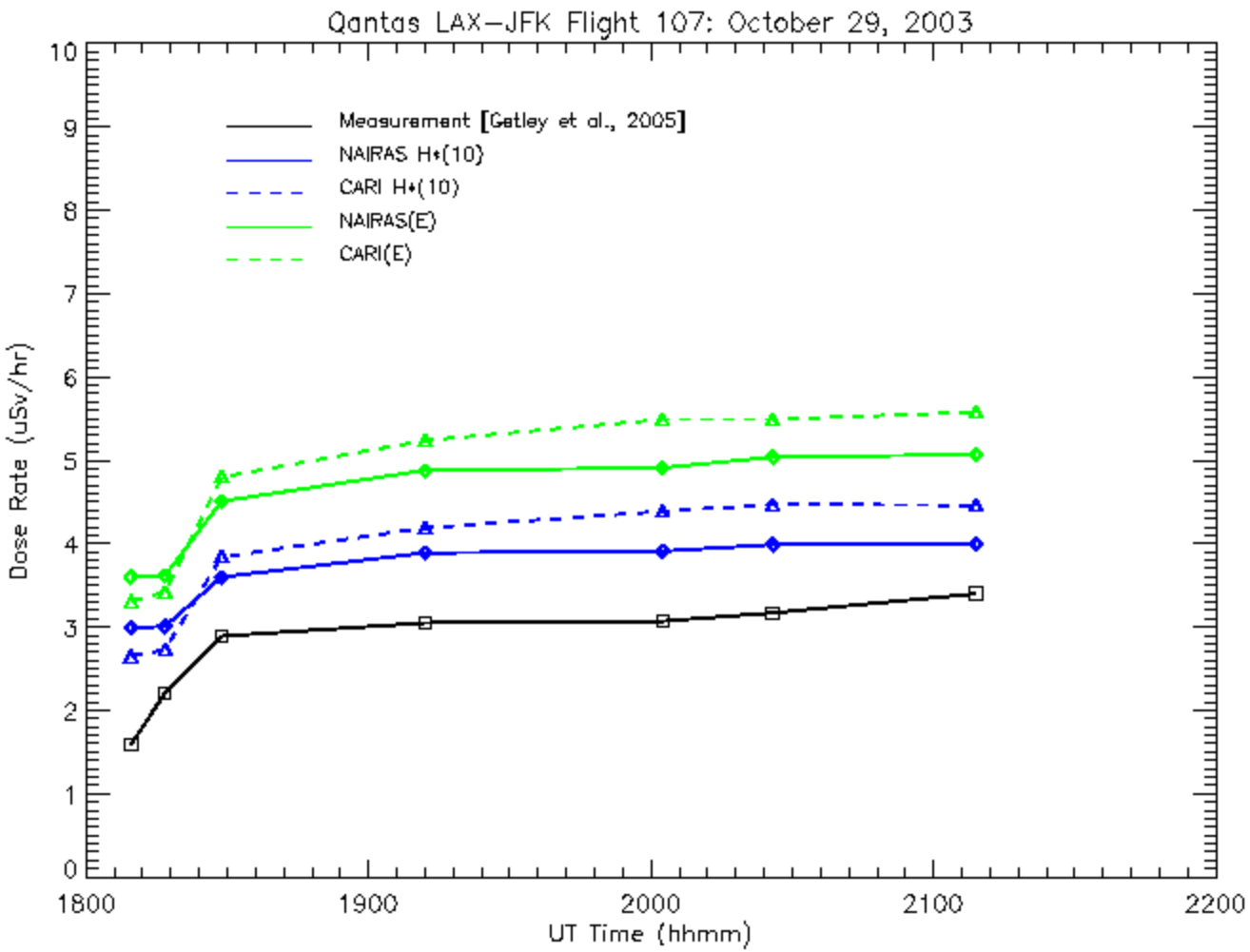
Backup Slides

Nowcast of Atmospheric Ionizing Radiation for Aviation Safety
Step 1 in NAIRAS Transition to Operations

- Experimental Data Products for Community Evaluation
  - 4-D Effective Dose (netcdf)
  - Global Effective Dose Graphics
  - Routine Flight Planning tools
  - Browsers and Google Earth
- Initial Data Availability
  - NOAA Aviation Digital Data Service (ADDS) experimental data products web interface
    - Commitment from NOAA NWS Aviation Services Branch
  - Space Environment Technologies (SET) (iphone product)
- Transition-to-Operations
  - Discussions with NOAA SWPC
  - Interest from Air Force Weather Agency (AFWA)
  - FAA NextGen Air Transportation System

Analysis of Halloween 2003 SEP Event

- Complexity of simultaneous processes
  - Largest geomagnetic storms of solar cycle 23
  - Forbush decreases
  - Ground Level Enhancements (GLE)
  - Anisotropic SEP distribution
- Initial analysis
  - Case study to assess geomagnetic storm influences on radiation exposure
  - Compute SEP event-averaged flux and let geomagnetic effects vary in time
- Current (on-going) analysis
  - Full time-dependent SEP radiation exposure
  - GCR component (including Forbush decrease)
  - Assessing SEP high-energy tail and anisotropy using neutron monitors


Qantas LAX–JFK Flight 107: October 29, 2003
Measurement [Getley et al., 2005]
NAIRAS H*(10)
CARI H*(10)
NAIRAS(E)
CARI(E)
Dose Rate (uSv/hr)
UT Time (hhmm)
0
1
2
3
4
5
6
7
8
9
10
1800
1900
2000
2100
2200

Summary of Total Effective Dose and Influence of Geomagnetic Effects

Neglect geomag effects underestimates dose by ~ factor 2

Flight Path	Dose Eq. T05S (mSv)	Dose Eq. T05Q (mSv)	Dose Eq. IGRF (mSv)	Dose Ratio T05S/IGRF	Dose Ratio T05S/T05Q	Dose Ratio T05Q/IGRF
JFK-LHR	0.054	0.030	0.024	2.25	1.18	1.25
ORD-ARN	0.088	0.084	0.078	1.13	1.05	1.08
ORD-PEK	0.122	0.166	0.102	1.20	1.05	1.14

T05S: Tsyganenko (T05) Storm Field
T05Q: Tsyganenko (T05) Quiet Field

IGRF underestimates geomag quiet condition by ~ 10-20%