NAIRAS model and application to space weather effects for suborbital flights

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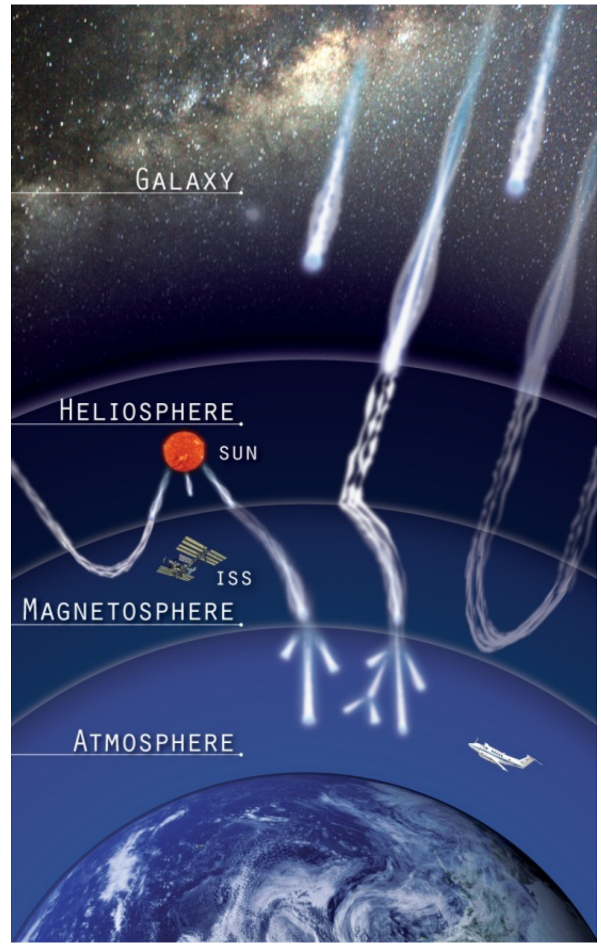
Outline

- NAIRAS Model Overview
  - Publically Available Products
  - Profile Information
- NAIRAS Model Components
  - GCR Model
  - SEP Spectral Fitting
  - Geomagnetic Shielding
    - Vertical Cutoffs
    - Directional Effects
  - Inner Proton Belt Model
- RaD-X Balloon Mission
- Wrap-Up

NAIRAS Model

- **NASA LaRC's Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) Model:**
  - Real-time physics-based, global model
  - Real-time inclusion of GCR and SEP radiation
  - Real-time solar-magnetospheric effects on radiation
  - Real-time meteorological data used



Public Web site: http://sol.spacenvironment.net/~nairas/ (or google NAIRAS)

NAIRAS Model Predictions During March 2012 Solar Storm Events

Effective Dose Rate[1](E) for 2012-03-07 11:00-12:00 GMT

5km (16,000 feet) Radiative Dose Rate (uSv/hr)

lat	90S-60S	60S-40S	40S-20S	20S-0	0-20N	20N-40N	40N-60N	60-90N
avg	12.01	8.51	3.77	1.06	0.88	2.58	8.21	11.74
max	13.67	12.35	8.81	3.03	3.64	8.71	12.45	13.61

11km (35,000 feet) Radiative Dose Rate (uSv/hr)

lat	90S-60S	60S-40S	40S-20S	20S-0	0-20N	20N-40N	40N-60N	60-90N
avg	63.79	43.36	15.16	2.69	2.14	9.45	41.37	66.03
max	69.41	66.18	47.22	10.15	13.08	45.58	67.98	72.08

15km (49,000 feet) Radiative Dose Rate (uSv/hr)

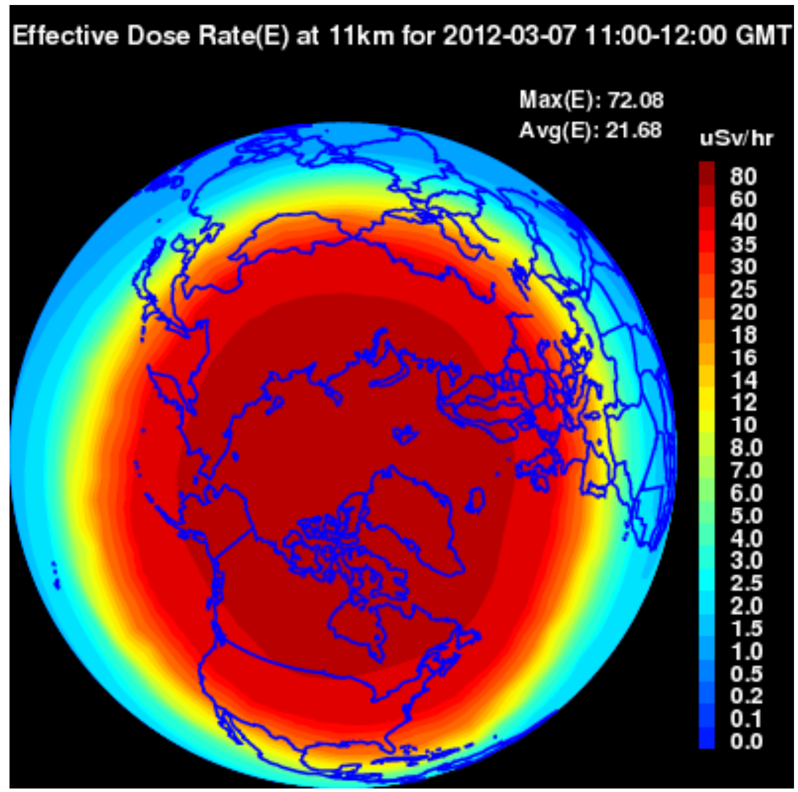
lat	90S-60S	60S-40S	40S-20S	20S-0	0-20N	20N-40N	40N-60N	60-90N
avg	133.91	84.70	22.91	3.21	2.51	13.33	76.84	142.45
max	144.86	140.66	94.98	13.45	17.59	90.36	147.34	152.19

Representative High-Latitude Flights

2012-03-07 11:00-12:00 GMT

Flight Name	Time	Rate[1]	Dose[1]	Safety Signal		
	hours	uSv/hr	mSv	Aircrew[2]	Public[3]	Prenatal[4]
London,GBR - New York,USA	5.50	51.52	0.283	yellow	green	yellow
Chicago,USA - Stockholm,SWE	8.50	63.09	0.536	yellow	yellow	red
Chicago,USA - Munich,DEU	8.50	56.35	0.479	yellow	yellow	red
Chicago,USA - Beijing,CHN	13.50	60.34	0.815	yellow	red	red

Signal	Aircrew[5] Max_Annual(800hrs)	Public[6] one_trip	Prenatal[6] one_trip
green	0-6.0mSv	0-0.330mSv	0-0.167mSv
yellow	6.0-12.0mSv	0.330-0.670mSv	0.167-0.333mSv
red	>12.0mSv	>0.670mSv	>0.333mSv



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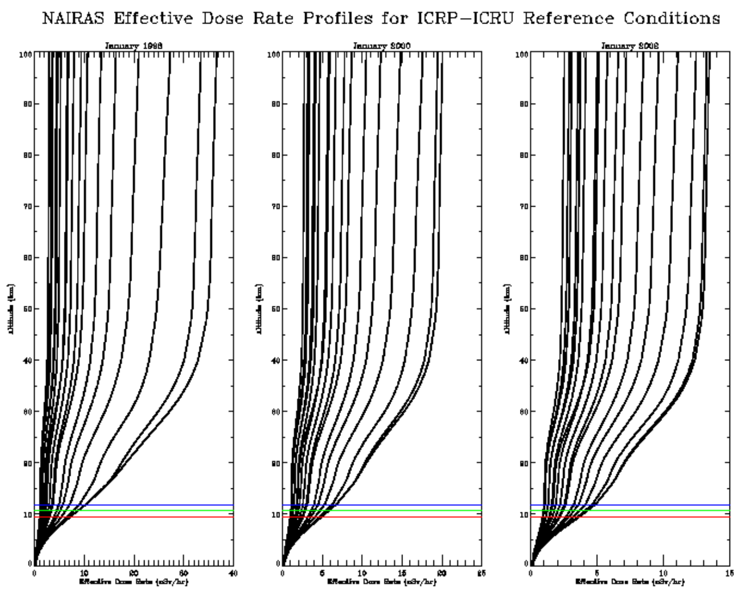
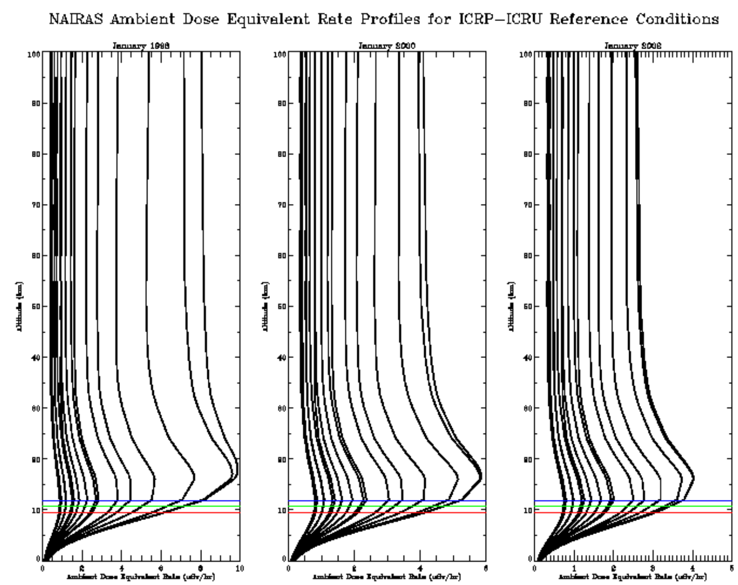
NAIRAS GCR Dose Profiles

(Mertens et al., 2013)



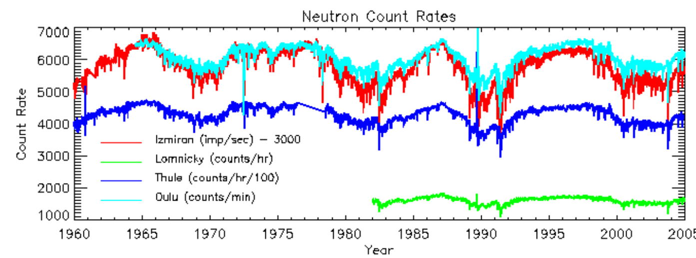
Effective Dose Rate

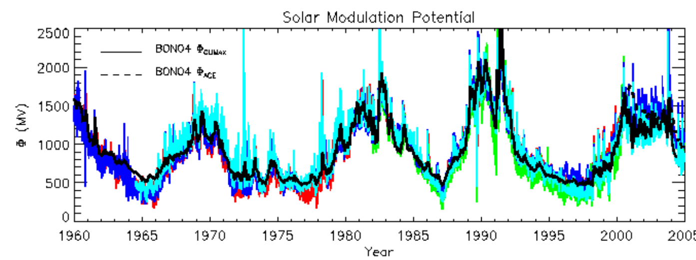


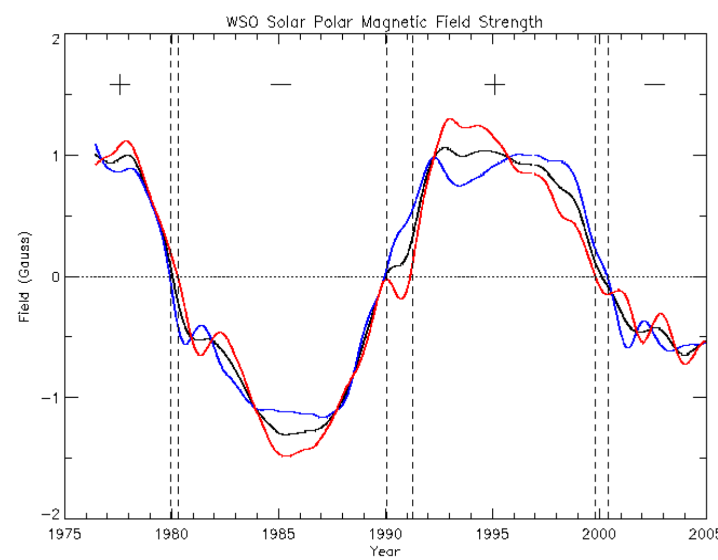
Ambient Dose Equivalent Rate

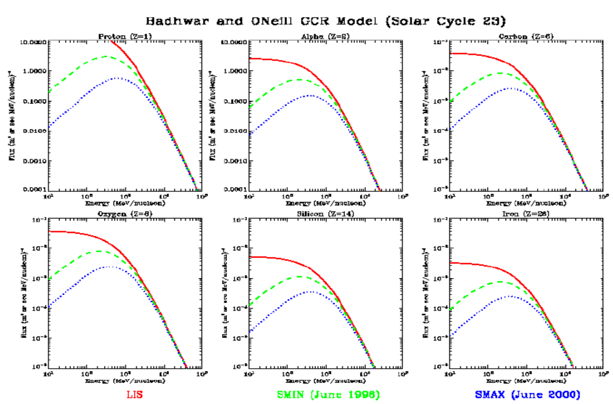
GCR Fluence Spectra

- 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 2010 GCR HP
  - Steady-state Fokker-Planck transport to 1 AU
  - HP embedded in diffusion coefficient
  - Validated by NASA/ACE



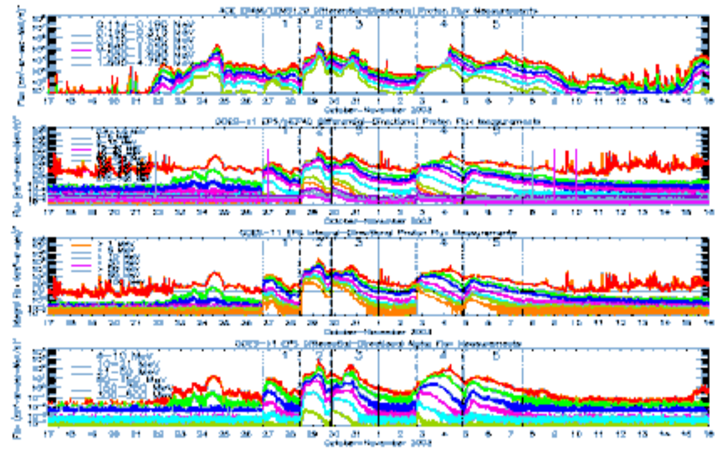


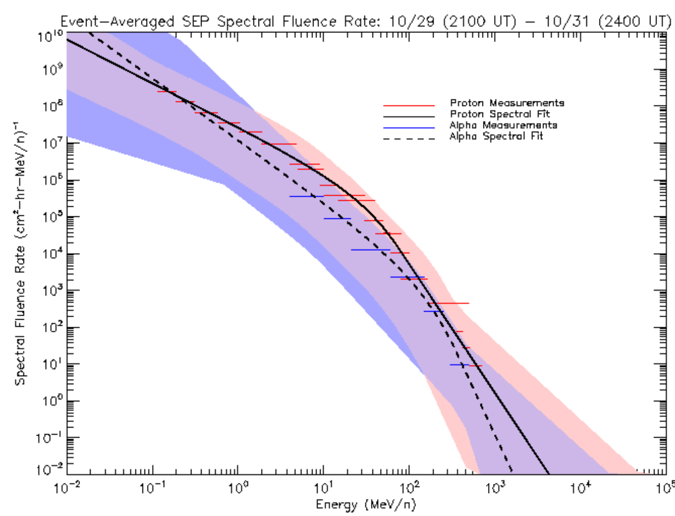




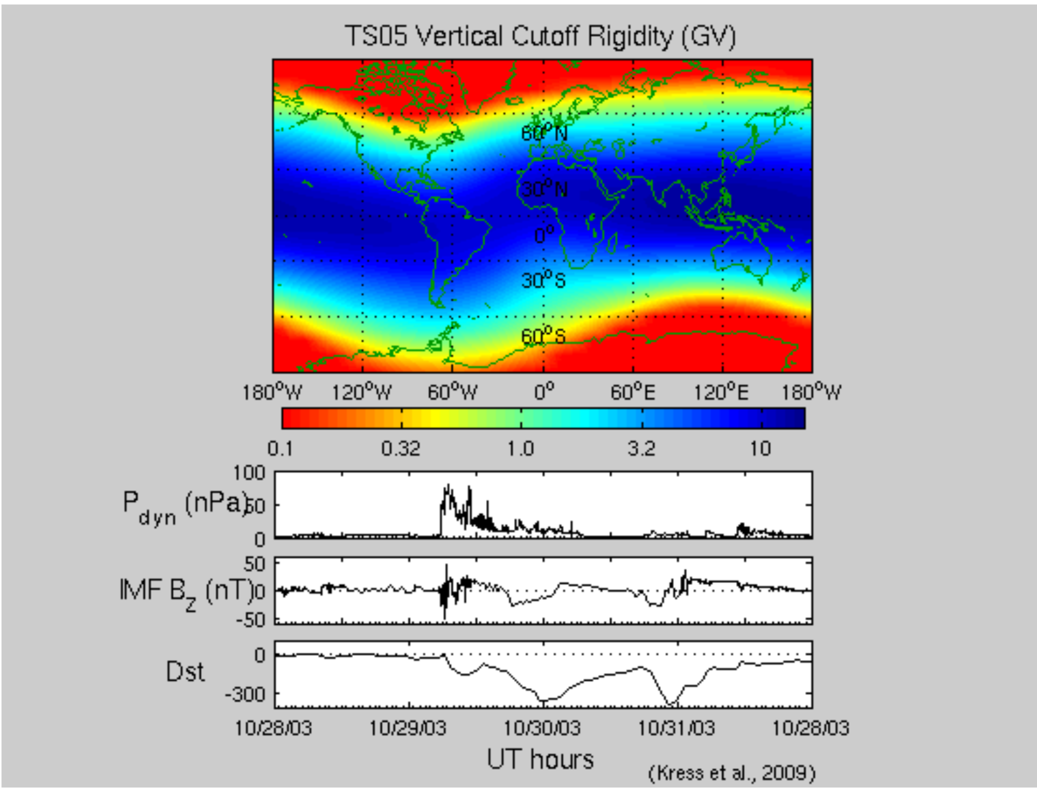
SEP Fluence Spectra

- GOES and ACE observes proton/alpha fluxes which we need to derive the incident fluence rates and spectral characteristics
- Fit measurements to analytical spectral fluence distributions
  - Require differential spectral flux measurements to decrease monotonically with increasing energy
  - Fit a single power-law, Ellison-Ramaty, double power-law, and Weibull distributions
  - Select spectral distribution with the minimum χ^2



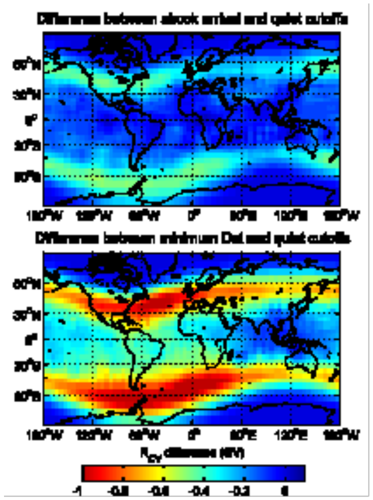


Geomagnetic Shielding

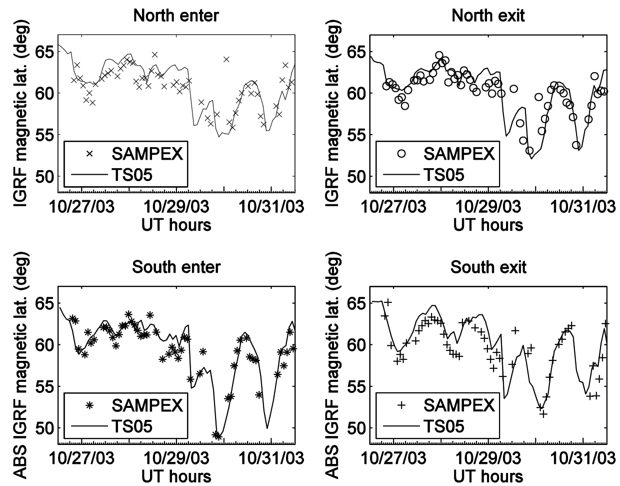


- Severe geomagnetic storms suppress geomagnetic shielding allowing SEPs access to mid-latitudes.
  - Due primarily to a build up of the ring current
  - Shock arrival can also be significant
- Particles with rigidities below the a cutoff value cannot access that point in space
  - We compute these using 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

Halloween 2003 Geomagnetic Storm

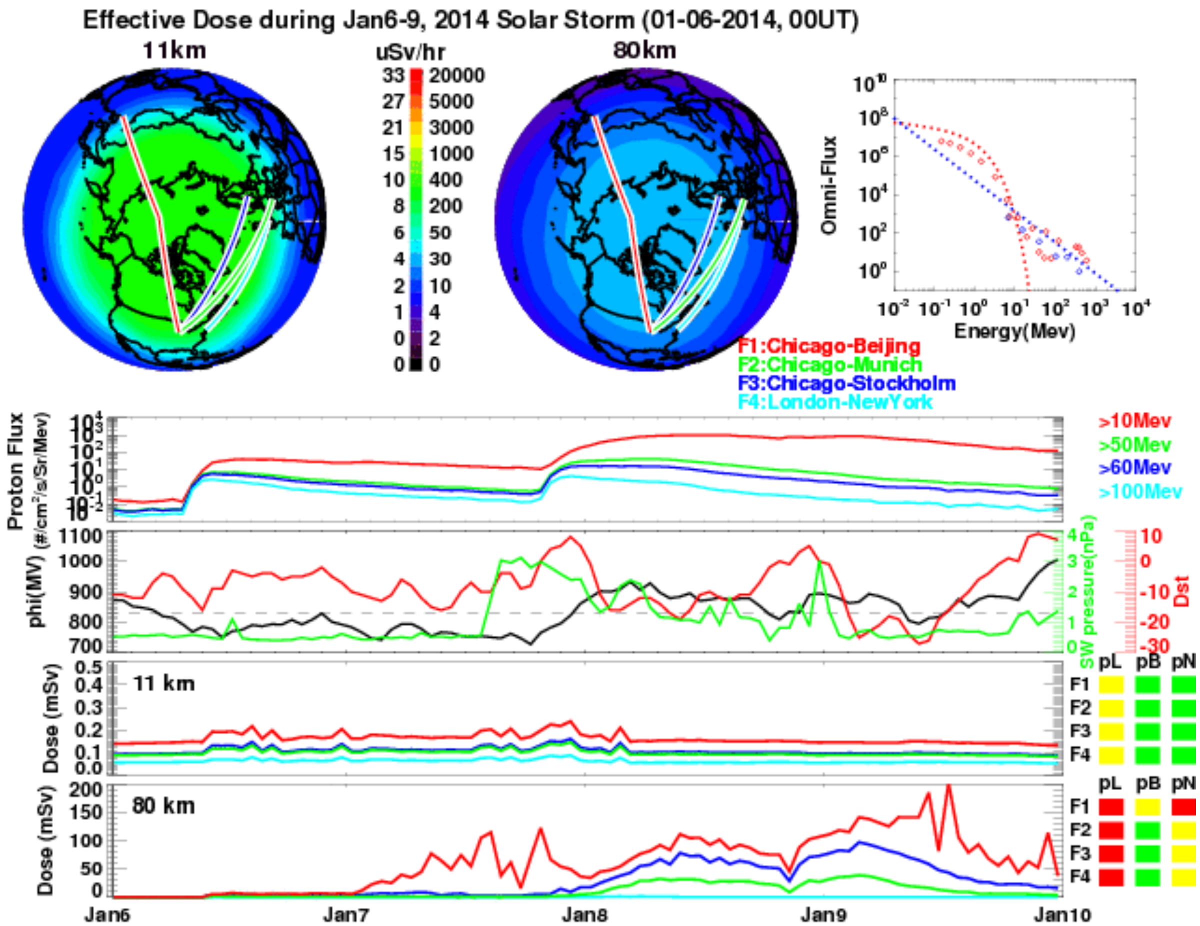


Cutoff Latitude of ~ 20 MeV protons

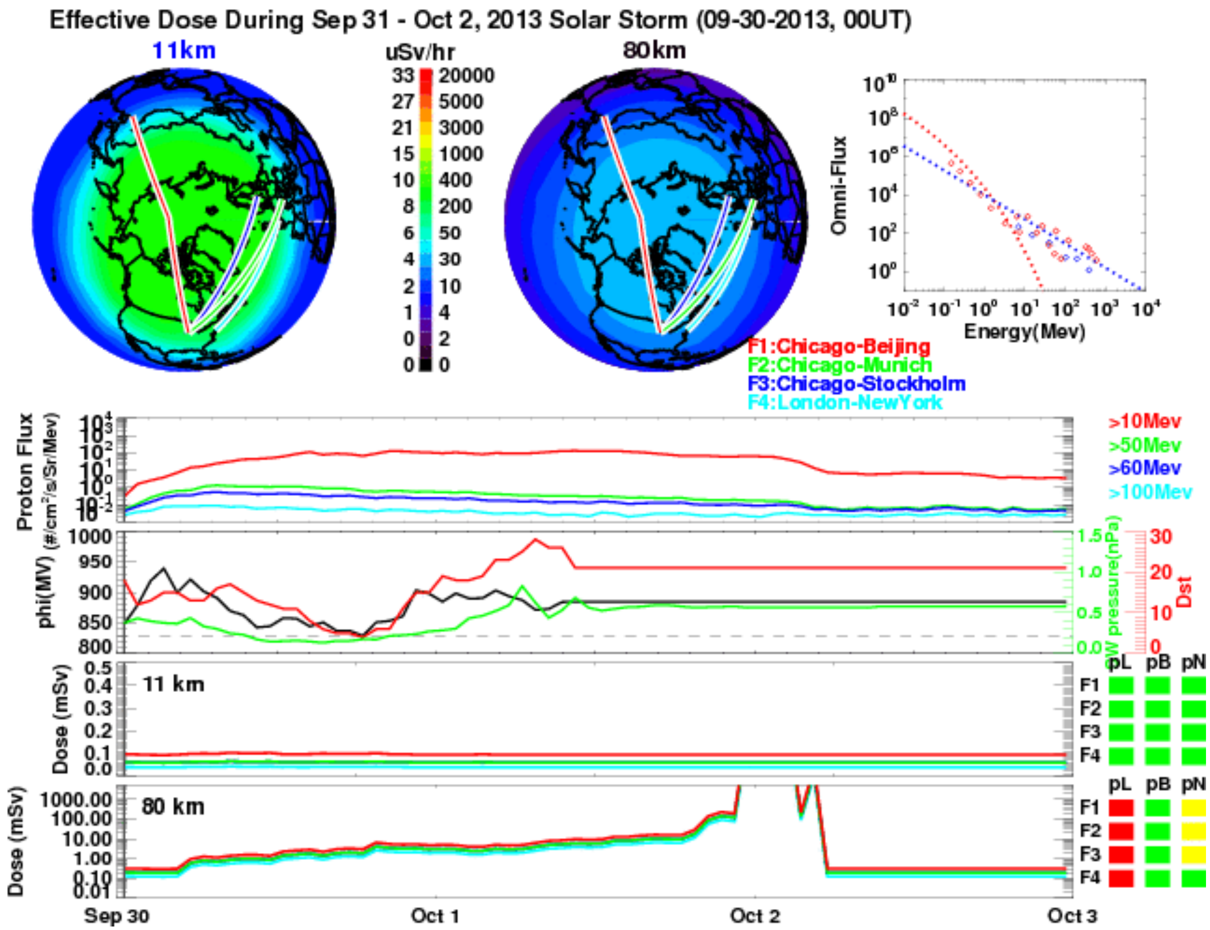


- TS05 cutoff latitude accuracy: ~ 2-degrees
- TS05 cutoff accuracy significantly better LFM/MHD code
- 2-degree cutoff uncertainty in latitude can translate into factor ~2 or greater aircraft dose uncertainty

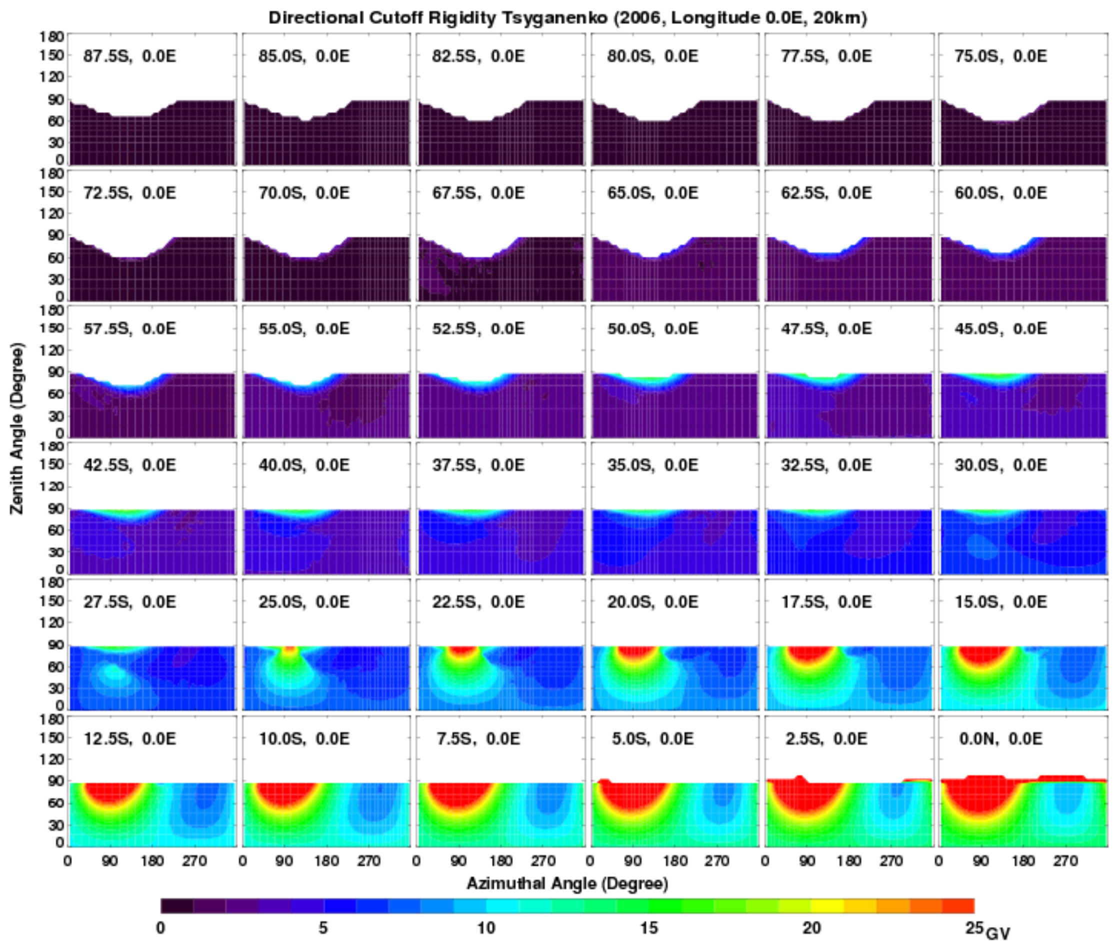
January 2014 Solar Storm Period



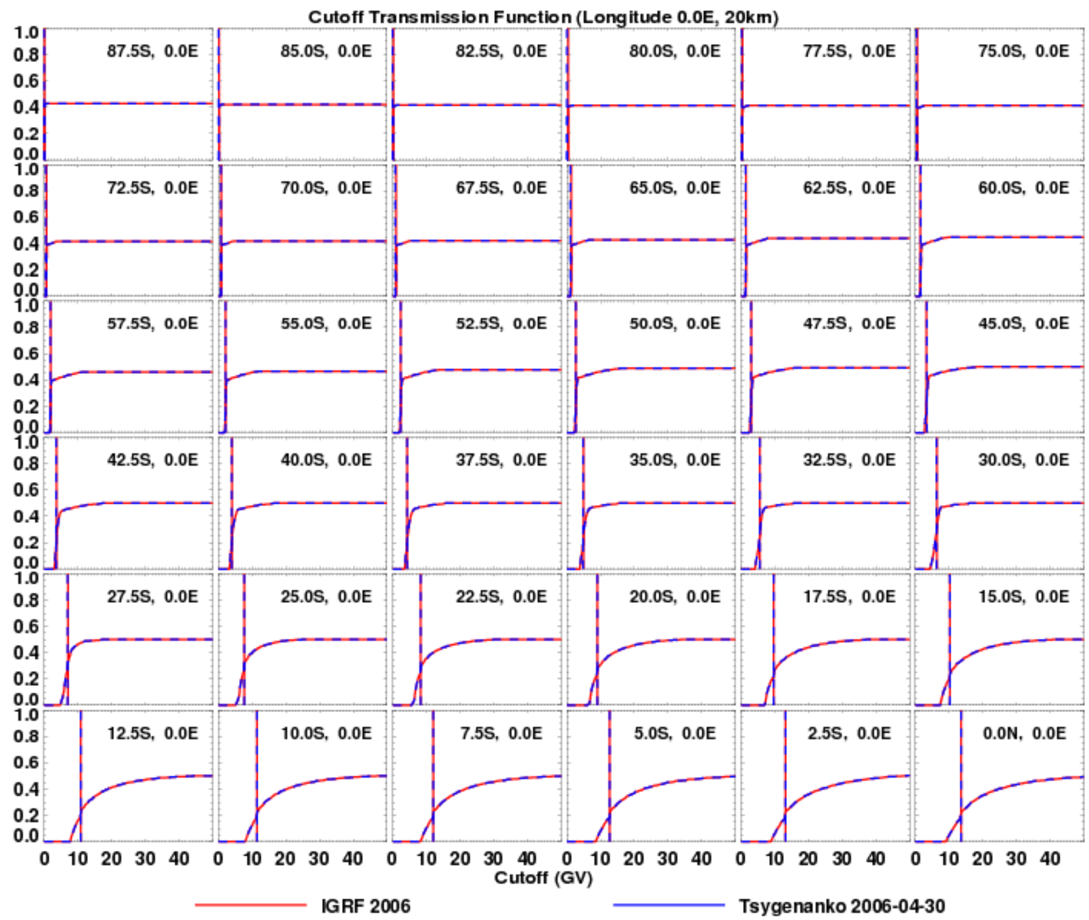
September-October 2013 Solar Storm Period



TS05 Directional Geomagnetic Cutoffs Quiet-Time

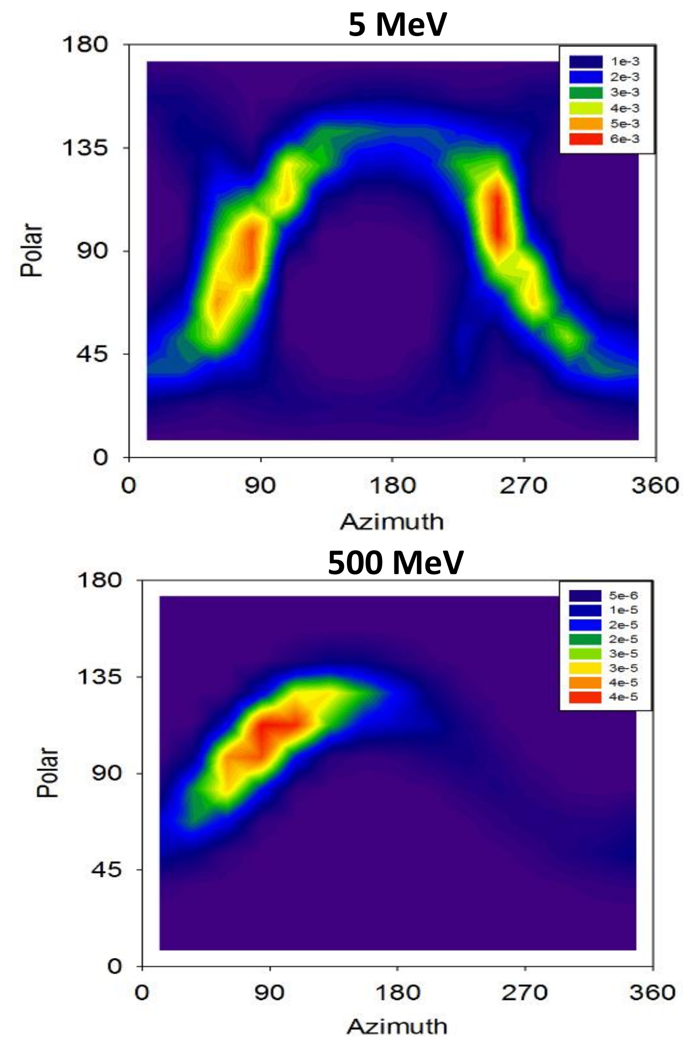


Quiet-Time Geomagnetic Transmission TS05 & IGRF



Inner Proton Radiation Belt

- Under quiet conditions, inner zone protons with energies > 100 MeV represent most the important contributions to radiation exposure in LEO
- AP-8 model extended to include temporal, spatial and directional effects
  - SAA north-west temporal/ spatial drift
  - Solar cycle variation using F10.7 and NM data
  - Trapped protons sample large altitude region in LEO, which introduces prominent east-west asymmetry in atmospheric loss rate, requiring a vector trapped proton model
- Same extensions to AP-8 will be applied to AP-9



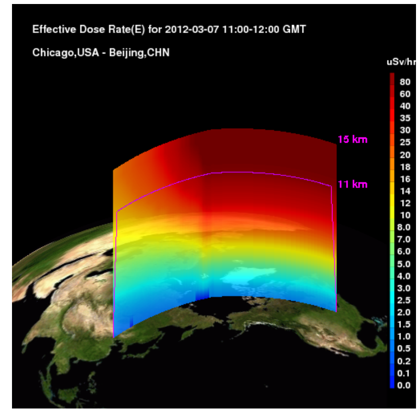
Directional dependency of the trapped protons as viewed in the center of the SAA at 400 km. Contour units in (MeV-cm²-sr-s)⁻¹

RaD-X : Radiation Dosimetry Experiment

Science Goals and Objectives

- Improve predictive atmos. ionizing dose tools by characterizing energy deposition by cosmic ray primaries
    - Measure dosimetric quantities in upper atmos
    - Separate cosmic ray primary contributions
- Identify and characterize low-cost atmos. radiation dose measurement solutions for continuous, global monitoring

RaD-X Measures Radiobiological Dose and CR Primary Proton and HZE Contributions



Mission and Instrument Parameters

- Platform: High-Altitude Balloon
- Launch Site: Fort Sumner, NM
- Mission Duration: 24-hours
- Temporal Sampling: 1-5 minutes
- Launch Readiness Date: September 2015
- Instruments: (1) TEPC, (2) TID detector, (3) LET spectrometer, and (4) microdosimeter emulator
- Measurement uncertainty: < 30 %
- All instrument components at TRL 6 or higher

Science Team and Partners

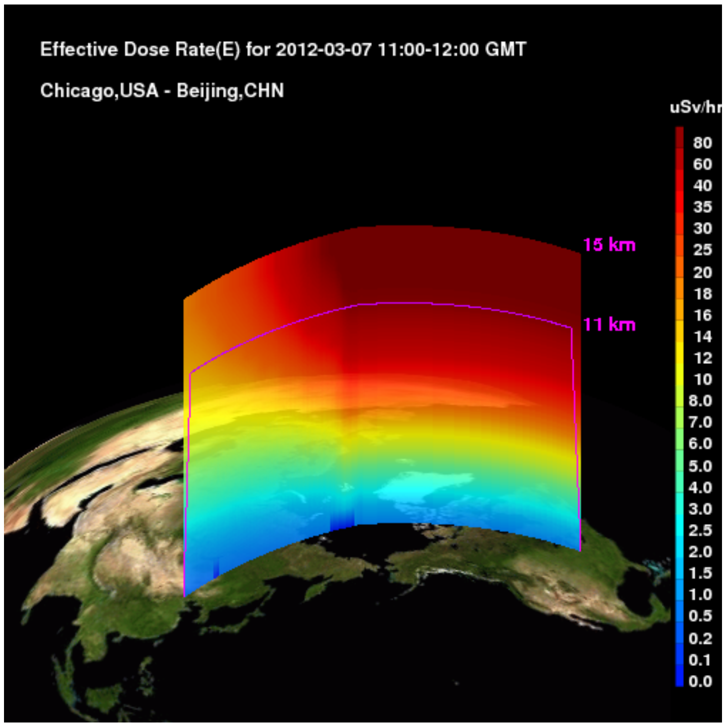
NASA Langley
NASA ARC
NASA GSFC/WFF
Prairie View A & M University (PVAMU)
  Center for Radiation Engineering
  and Science for Space Exploration (CRESSE)
University of Virginia
Space Environment Technologies, Inc.

Wrap-Up

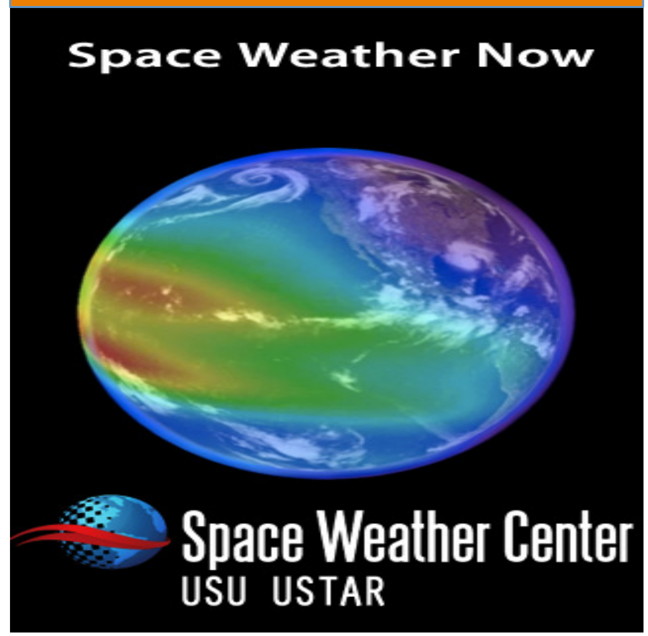
- NAIRAS Computed Output Products
  - Dosimetric Quantities
    - Effective dose, ambient dose equivalent, silicon absorbed dose, tissue absorbed dose, and tissue dose equivalent
  - Flux Quantities
    - Spectral flux (total and by particle), total flux (by particle and particle sum), atmospheric ionization rate, >10 MeV neutron flux (microelectronic effects)
  - Differential flux and differential absorbed dose LET Spectra (tissue and silicon)
- NAIRAS Studies/Updates for LEO
  - Continue to assess directional cutoff rigidity effects
  - Integrate inner proton belt radiation model

Backup Slides

NAIRAS Graphical Products
March 2012 Solar Storm Event



iPhone app
Search "SpaceWx"



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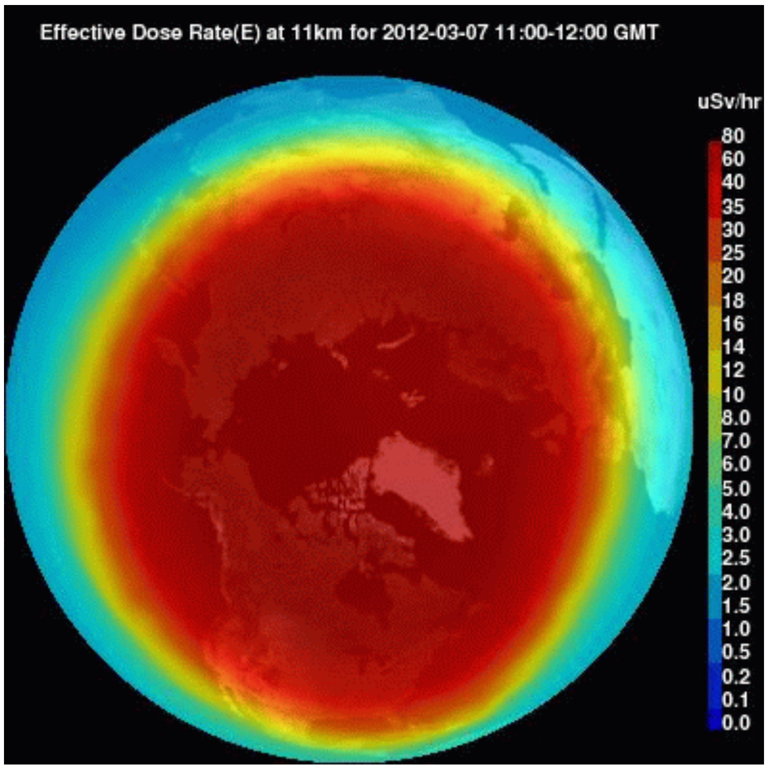

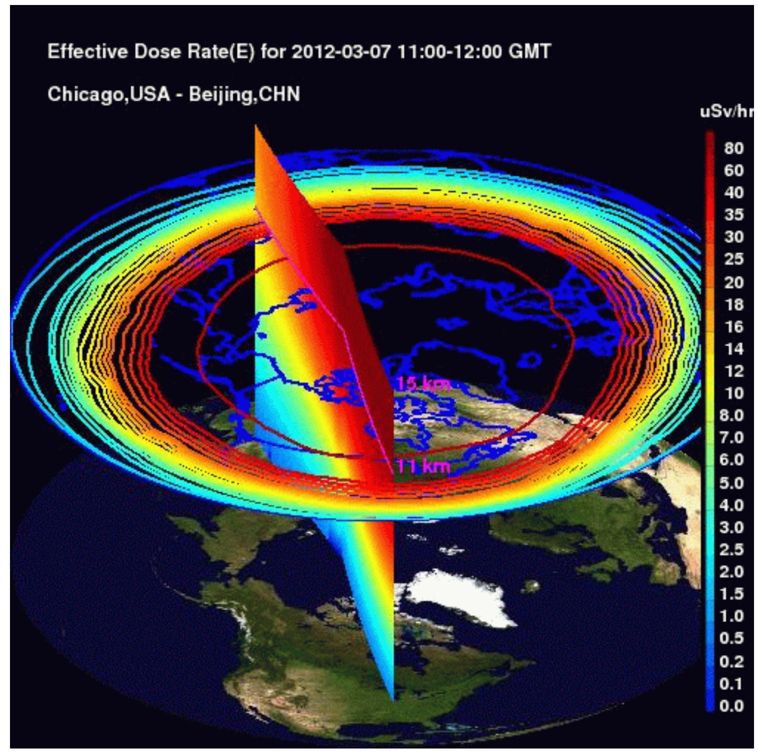

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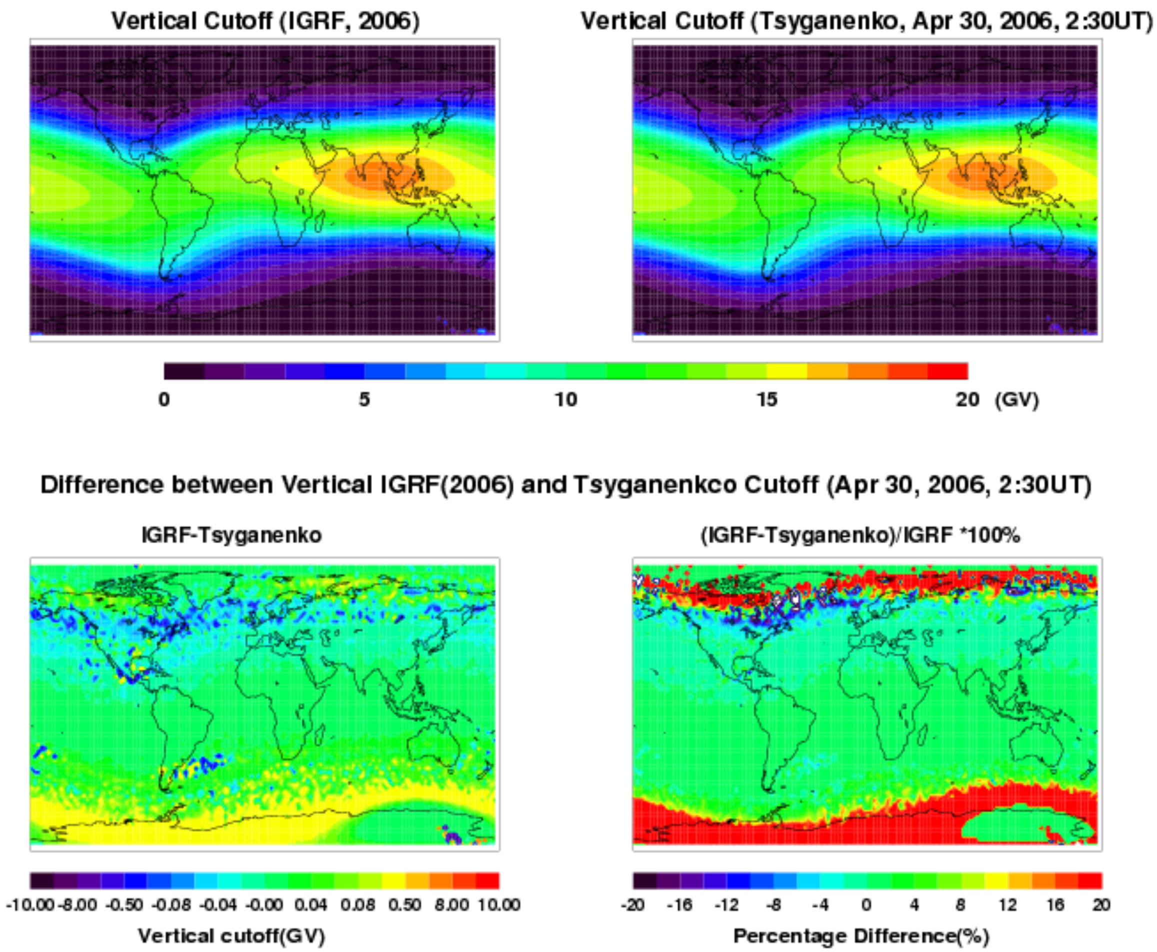
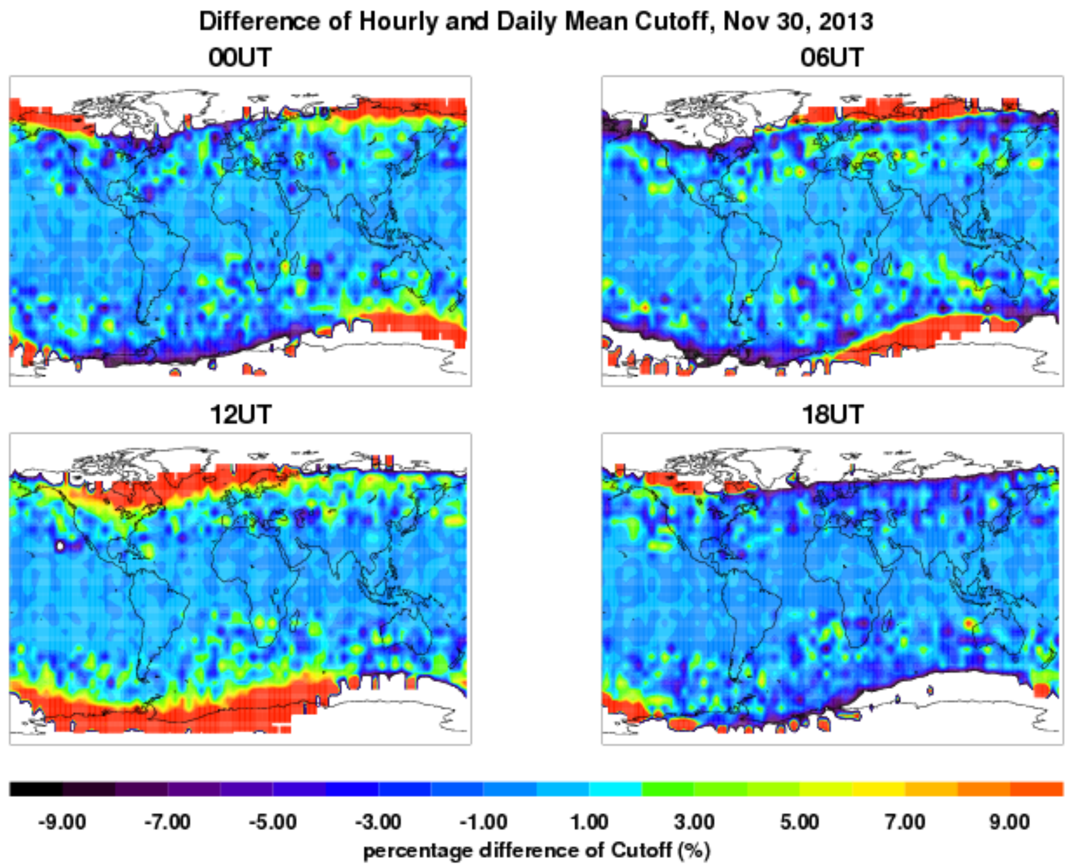
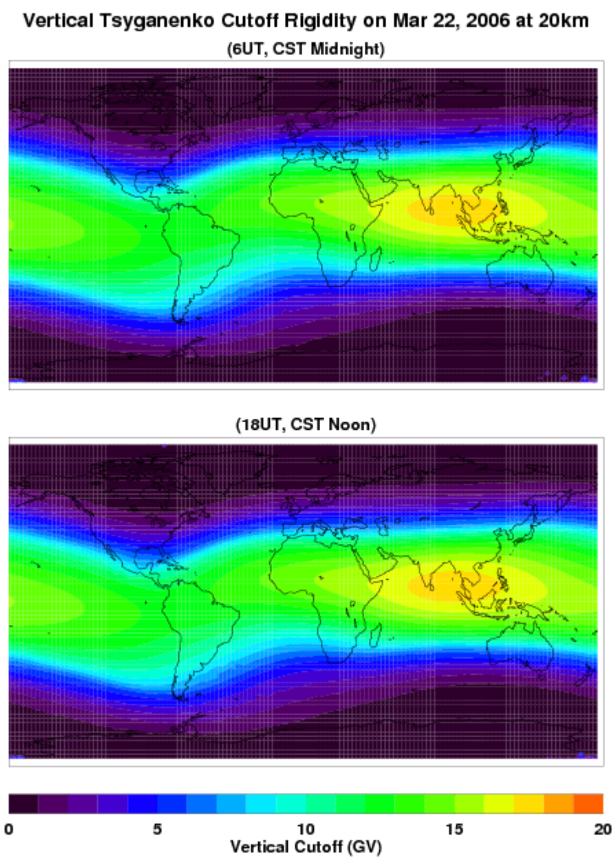
Vertical Cutoff Rigidity (2006)
TS05 & IGRF

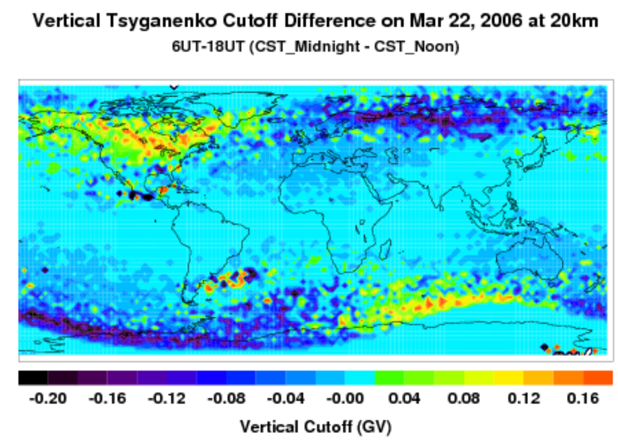


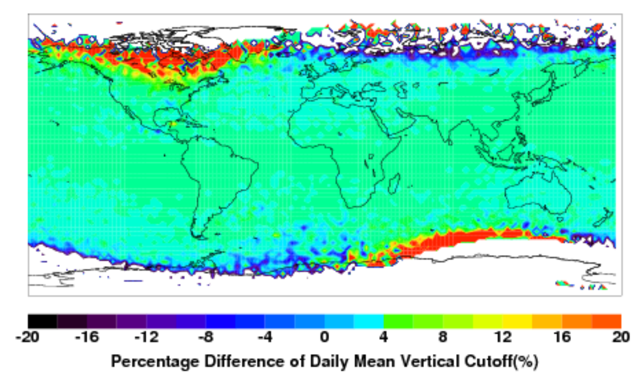
Daily Variation in TS05 Vertical Cutoffs Quiet-Time



Diurnal Variation in TS05 Vertical Cutoffs Quiet-Time







Quiet-Time Directional Cutoffs TS05 & IGRF Differences