NAIRAS Model Predictions of Aircraft Radiation Exposure during the Halloween 2003 Storms

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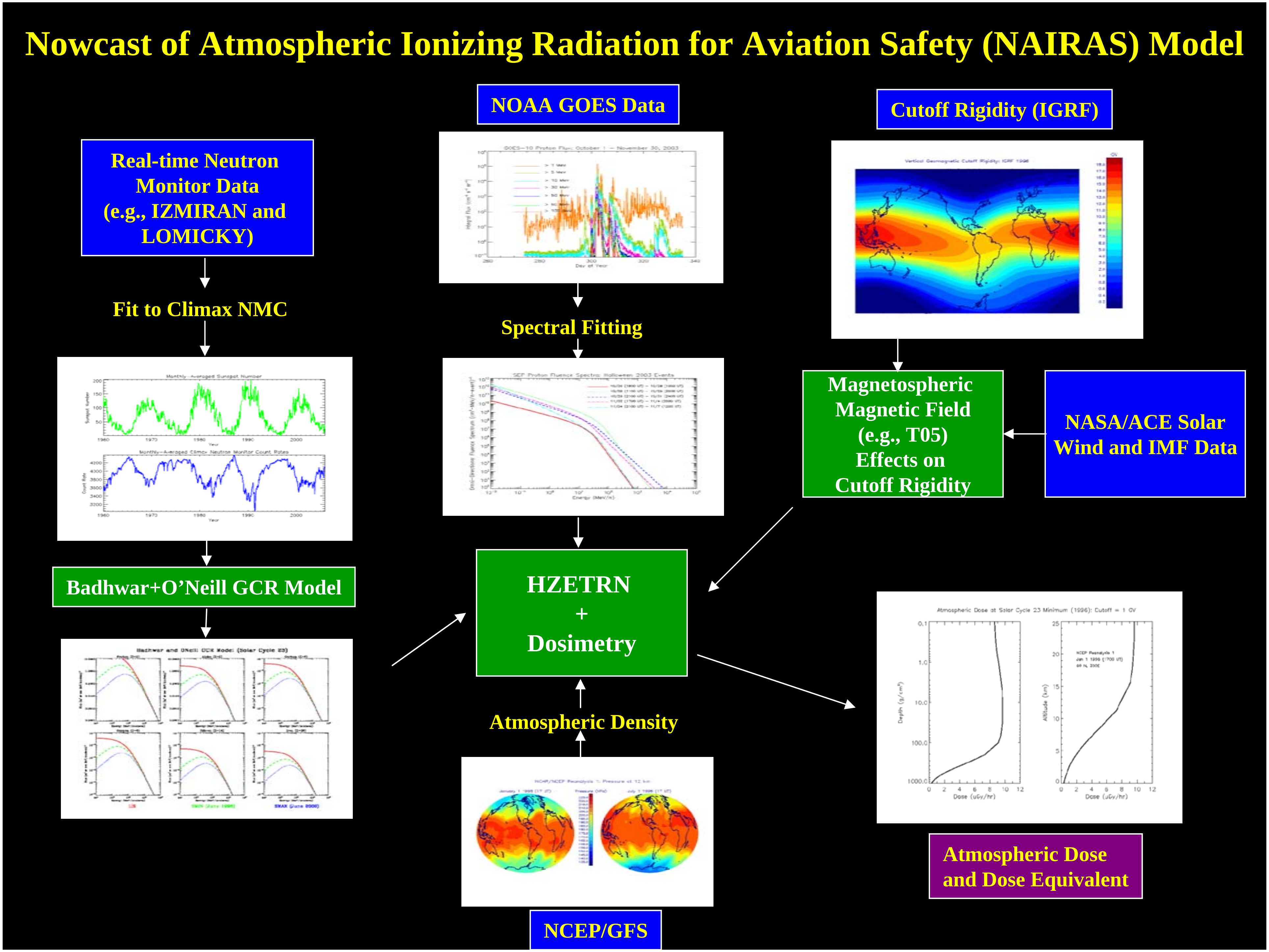
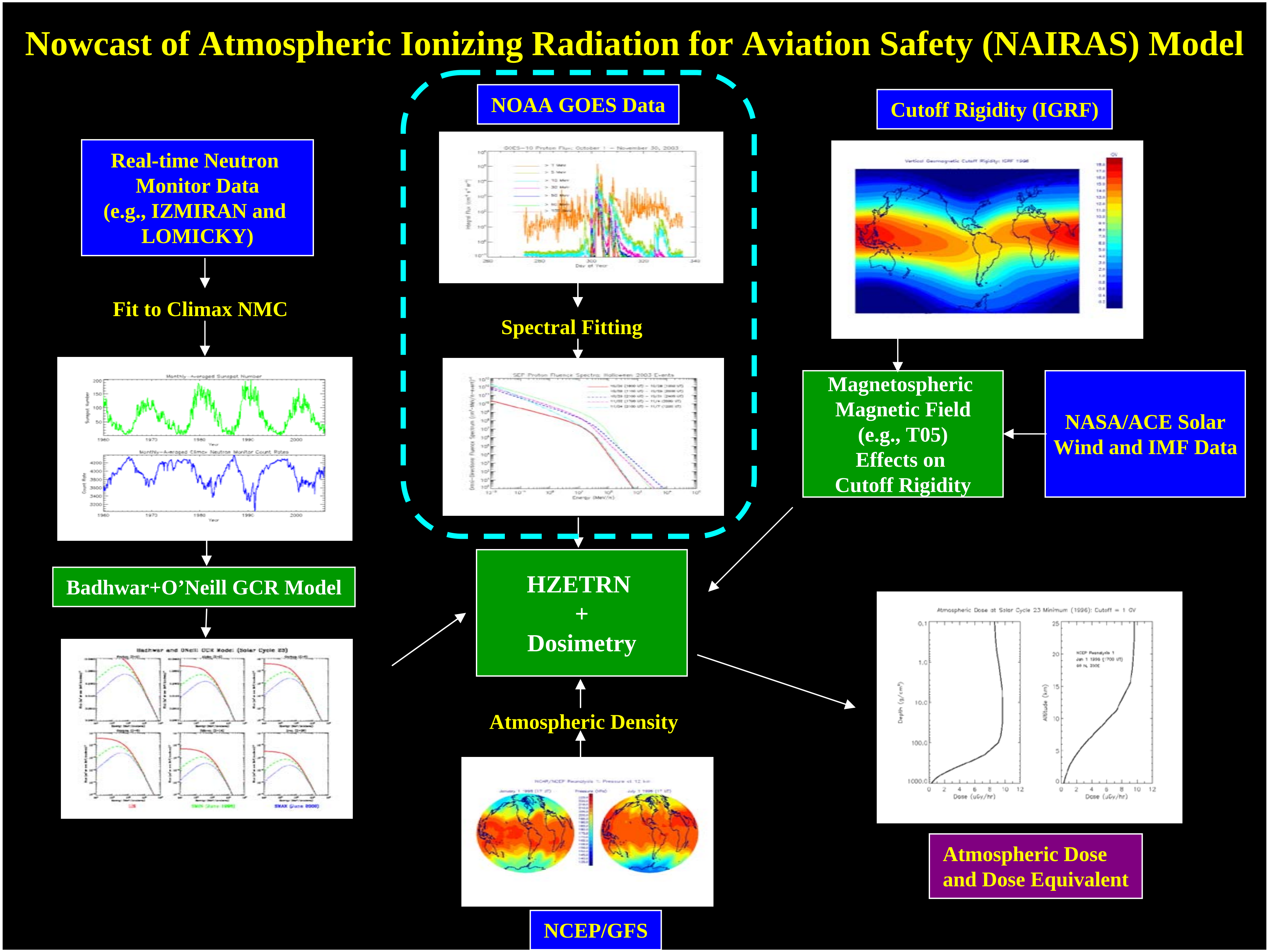
Outline

- Overview of the NAIRAS Model Concept
- Halloween 2003 Storm Case Study
- Summary and Conclusions


Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) Model
Real-time Neutron Monitor Data (e.g., IZMIRAN and LOMICKY)
Fit to Climax NMC
Badhwar+O'Neill GCR Model
NOAA GOES Data
Spectral Fitting
HZETRN + Dosimetry
Atmospheric Density
NCEP/GFS
Cutoff Rigidity (IGRF)
Magnetospheric Magnetic Field (e.g., T05) Effects on Cutoff Rigidity
NASA/ACE Solar Wind and IMF Data
Atmospheric Dose and Dose Equivalent

Analysis of Halloween 2003 Event

- Complexity of simultaneous processes
  - Largest geomagnetic storm of solar cycle 23
  - Forbush decreases
  - Ground Level Events (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 analysis
  - Full time-dependent SEP radiation exposure
  - GCR component including Forbush decrease



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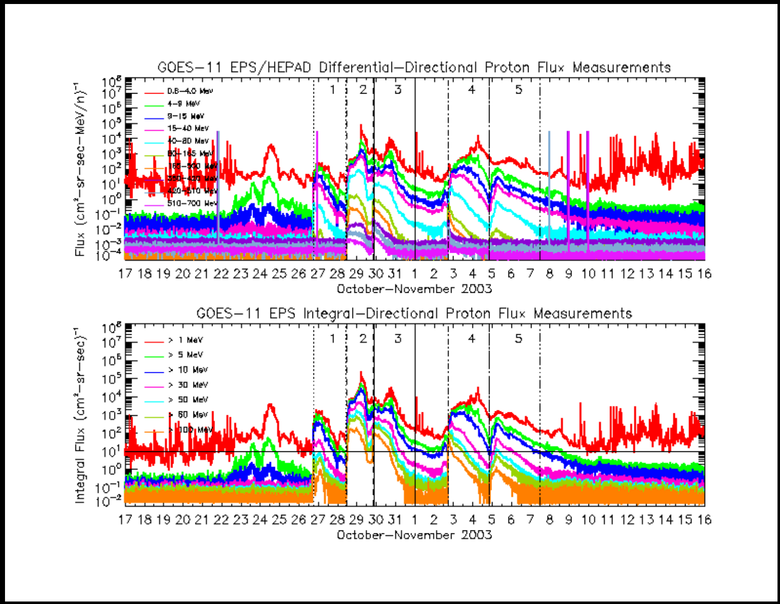
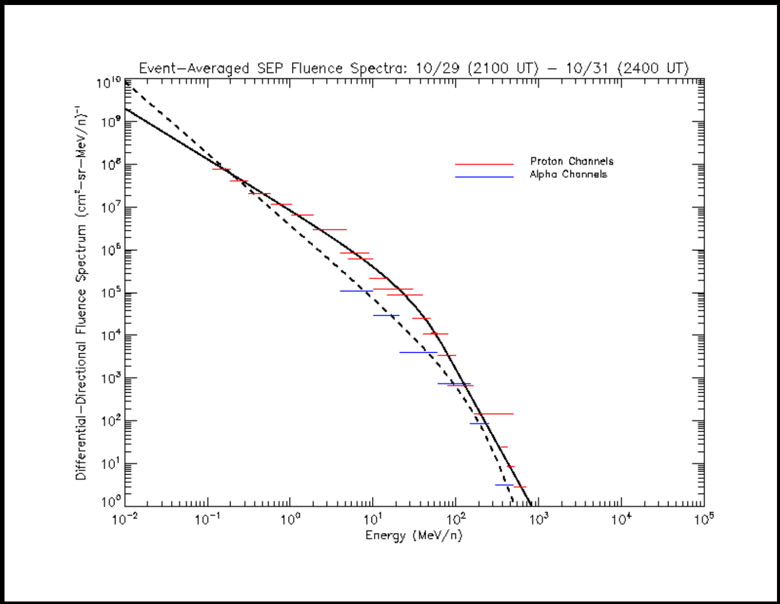
SEP Fluence and Spectra

- GOES observes proton fluxes and we need the fluence and spectral characteristics of these events
- 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





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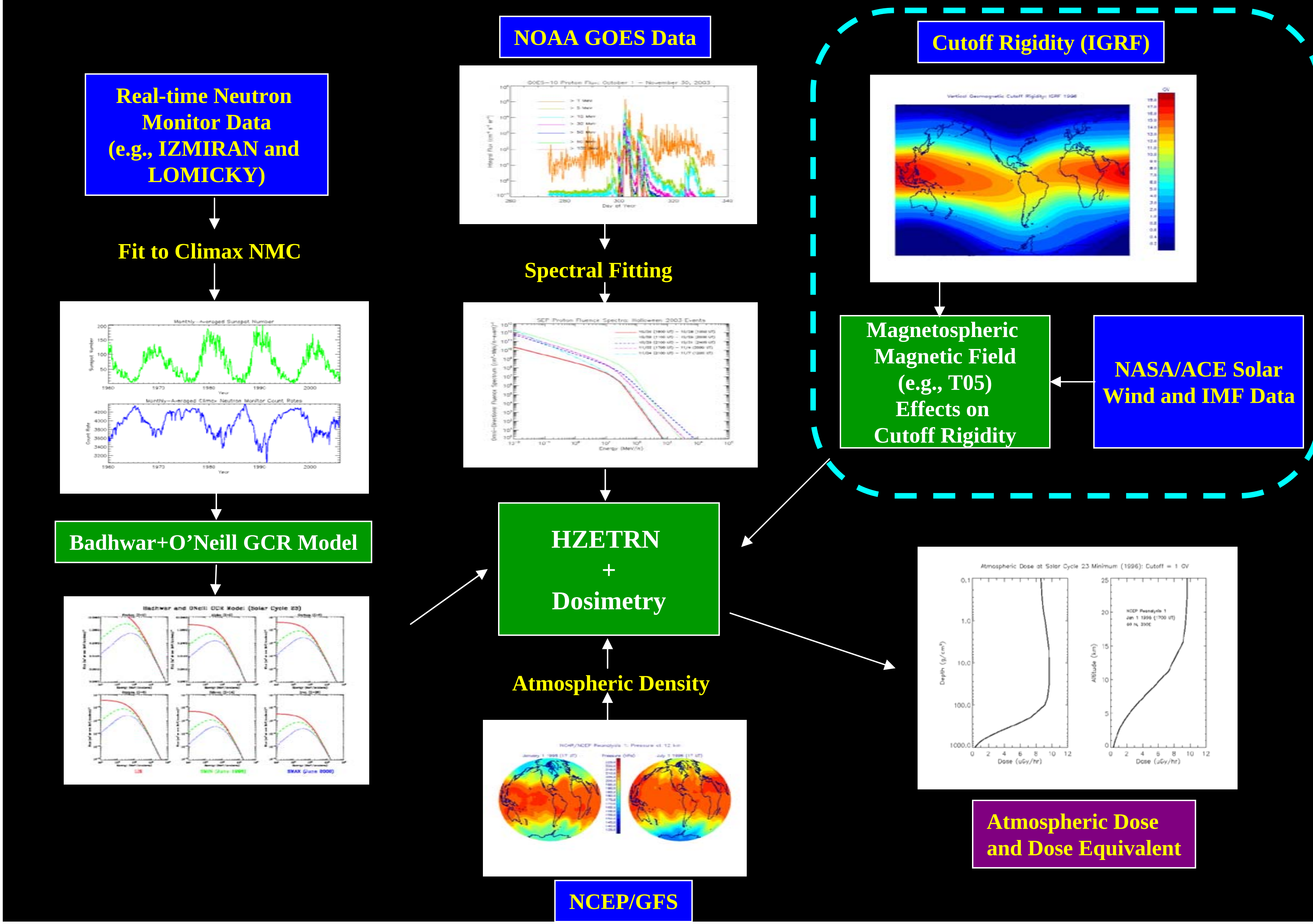
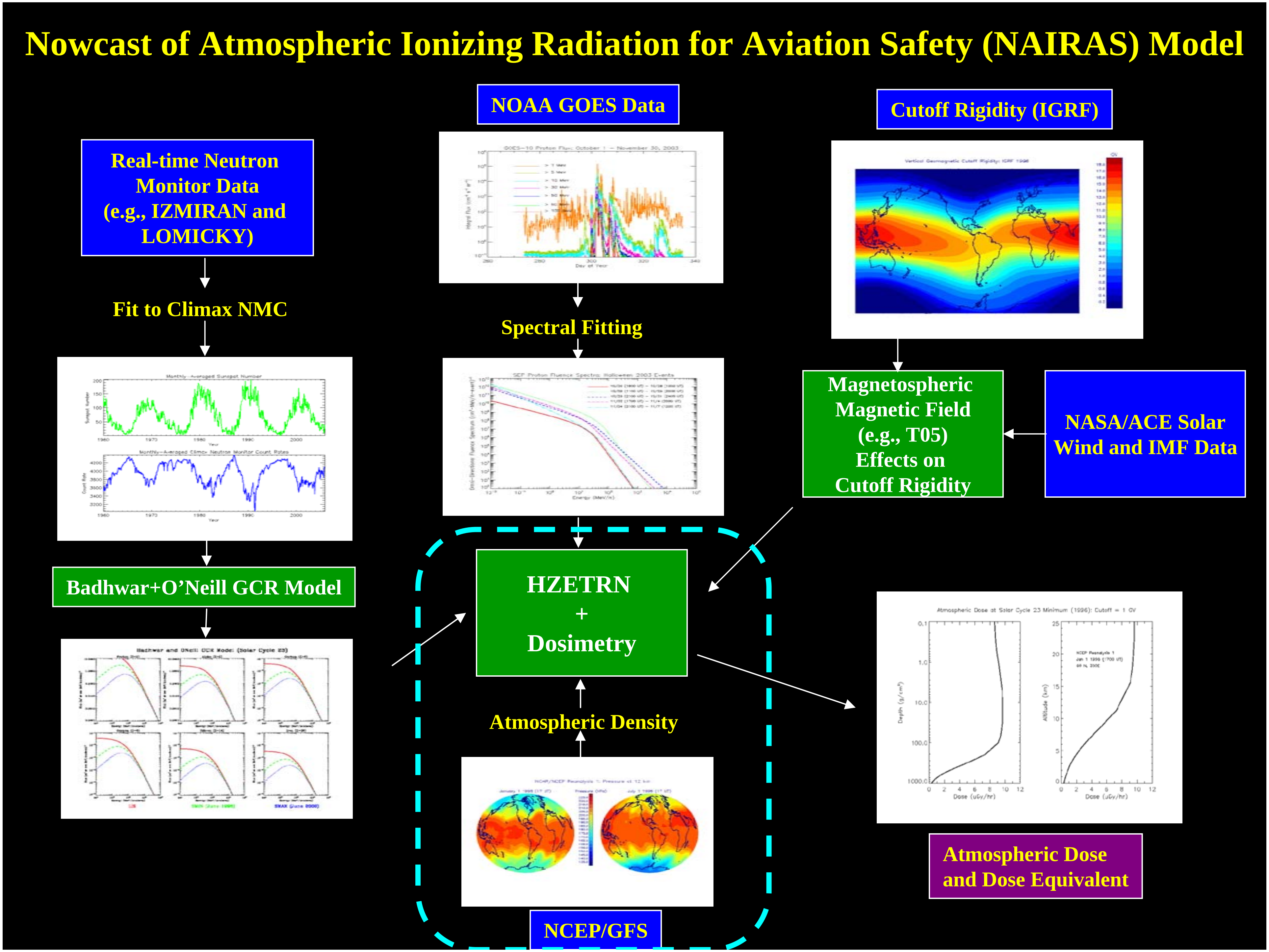


Geomagnetic Shielding

- Severe geomagnetic storms suppresses geomagnetic shielding allowing SEPs access 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 codes
    - During the Halloween storms we find 1 and 0.5 GV suppression during main phase and shock arrival



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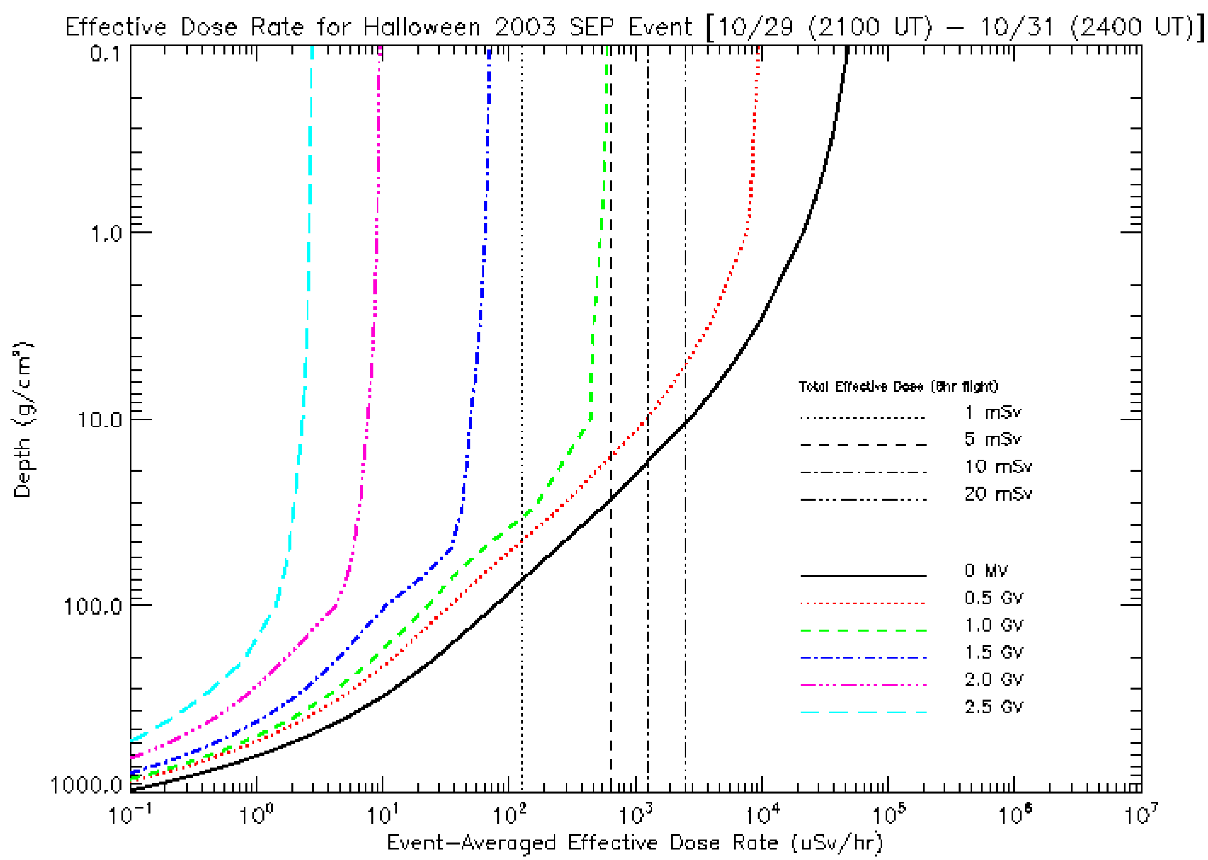
HZETRN Dose Calculations



- High Z Transport code solves the linear Boltzmann equation including
  - Ion-Electron Scattering
  - Elastic nucleon scattering
  - Nuclear reactions

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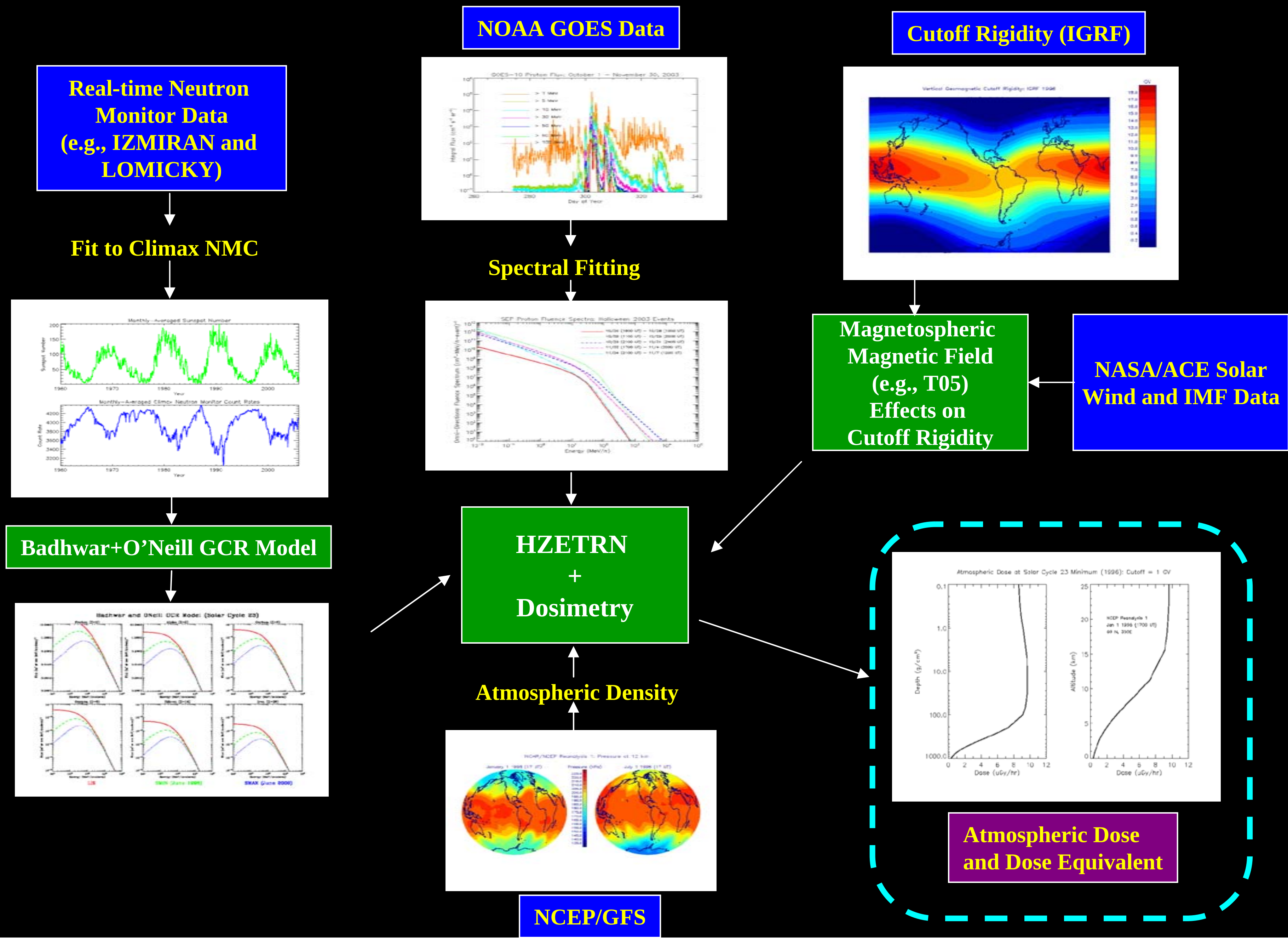
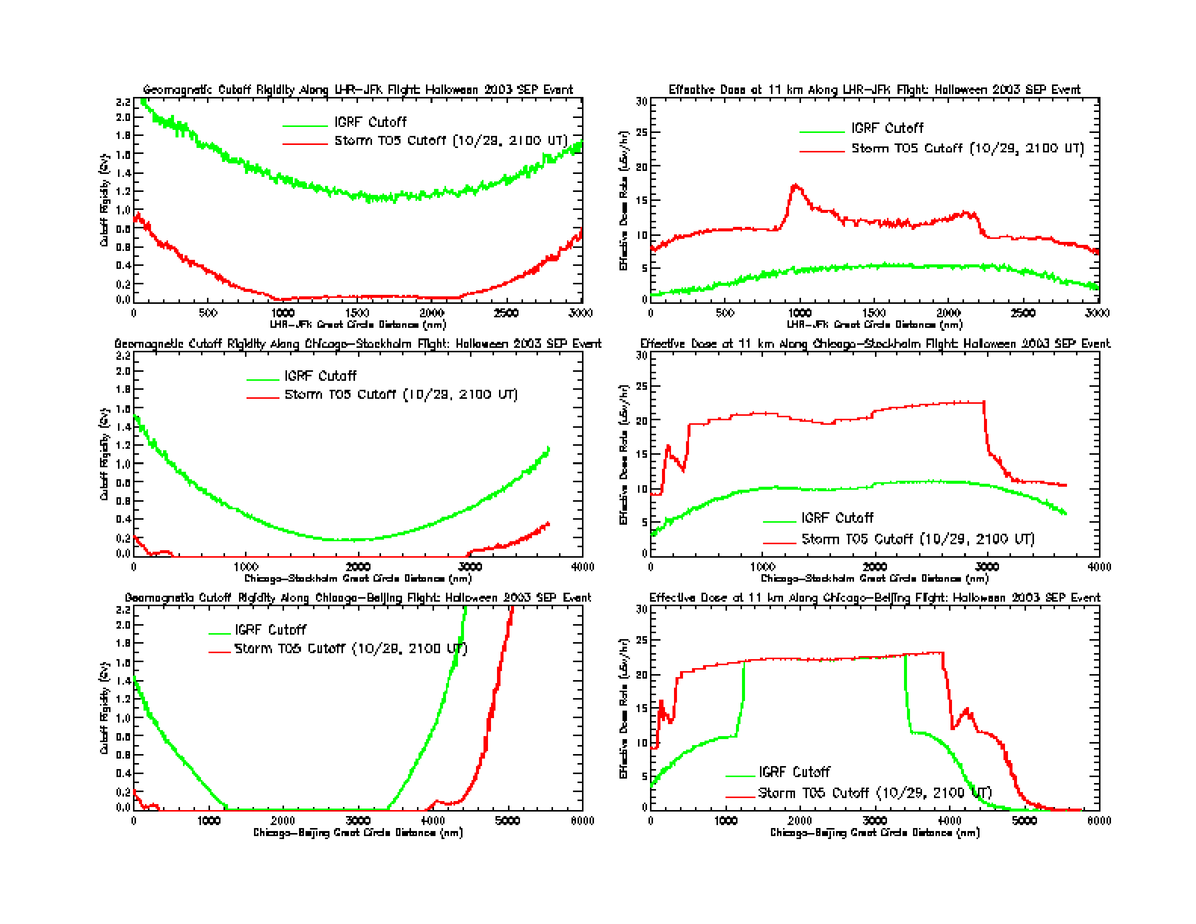


Effective Dose for Halloween Storm

- Using the all aspects of the SEP portion of NAIRAS we are able to calculate the effective dose at various altitudes and then include typical flight paths
  - We are also able to consider the role of the magnetic field model by varying which method is used to calculate the cutoff rigidity

Flight Path Comparison



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

Summary of Total Dose Equivalent Effects

Neglect geomag effects underestimates dose by ~ factor 3

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	0.063	0.030	0.024	2.62	2.10	1.25
ORD-ARN	0.155	0.104	0.078	1.99	1.49	1.33
ORD-PEK	0.210	0.195	0.160	1.31	1.08	1.22

IGRF underestimates geomag quiet condition by ~ 30%

SEP Variability

- We have recently completed runs which include the variability of SEP fluence
  - Note the levels seen during the storm exceed the typical GCR dose rates

Conclusions

- Programmatic
  - NAIRAS has adopted a terrestrial weather prediction paradigm to space weather generated radiation field
    - Year 1 work has been completed beginning year 2 including GCR effects
  - Prototype model completion expected in 2011
- Halloween 2003 SEP Case Study results
  - Atmospheric radiation exposure during event may have exceed 22% of ICRP recommend prenatal limit for a typically polar route
    - Passengers and crew did not come close to approaching ICRP exposure limits
  - Neglecting time-dependent geomagnetic storm influences on cutoff rigidity may significantly underestimate exposure
  - IGRF field can result in underestimation of ~30% even with storm effects

[redacted]

Radiation Exposure Quantities Overview

- **Unit of absorbed dose from particle R (D_R):**
  - **Unit: 1 Gray == 1 J/kg**
- **Equivalent Dose in Tissue (H_T):**
  - **Unit: Sievert = Gray x w_R**
  - **w_R: radiation weighting factor**

$$H_T = \sum_R w_R \cdot D_R$$

- **Effective Dose (E):**
  - **Unit: Sievert: Sievert X w_T**
  - **w_T: tissue weighting factor**

$$E = \sum_T w_T \cdot H_T$$

- **ICRP estimate:**
  - **1 in 20,000 risk of fatal cancer per 1mSv dose (lifetime)**