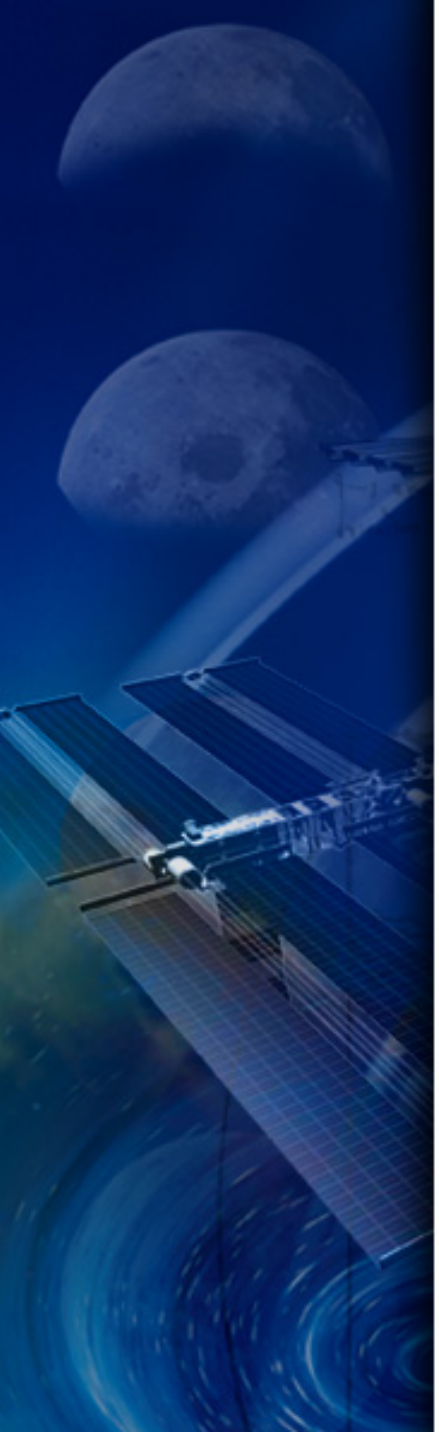

A Predictive Code for ISS Radiation Mission Planning

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Radiation Monitoring for the International Space Station
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OUTLINE

- Motivation
- Code Development
  - TEPC Data
  - R_c Maps
  - Interpolation Procedure
  - Solar Modulation Parameters
  - South Atlantic Anomaly
- Preliminary Results
  - Predicted vs. Actual
  - Diurnal Modulation
  - GUI Development
- Conclusions and Future Work

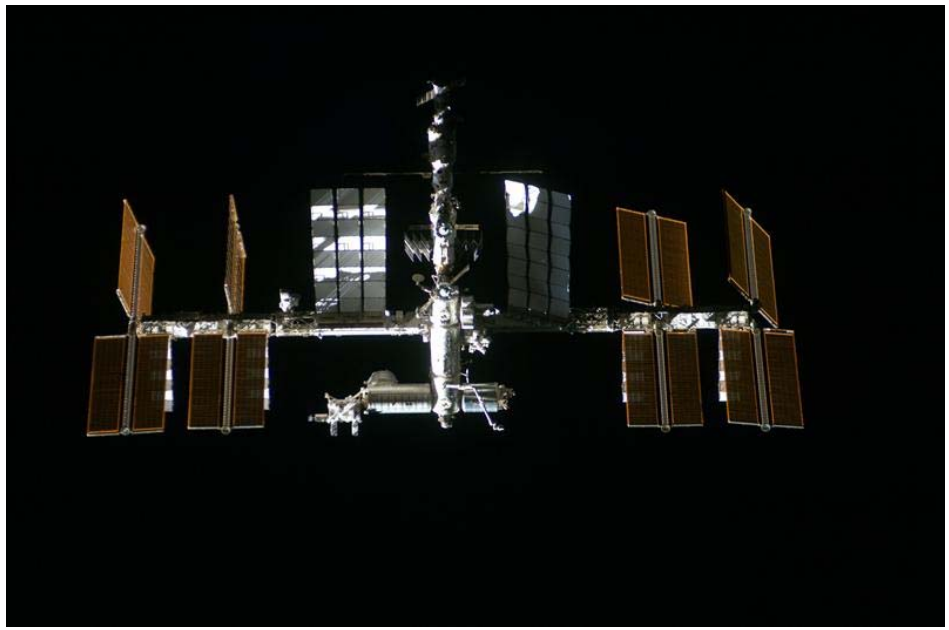


Image taken from Canadian Space Agency Website.

Motivation

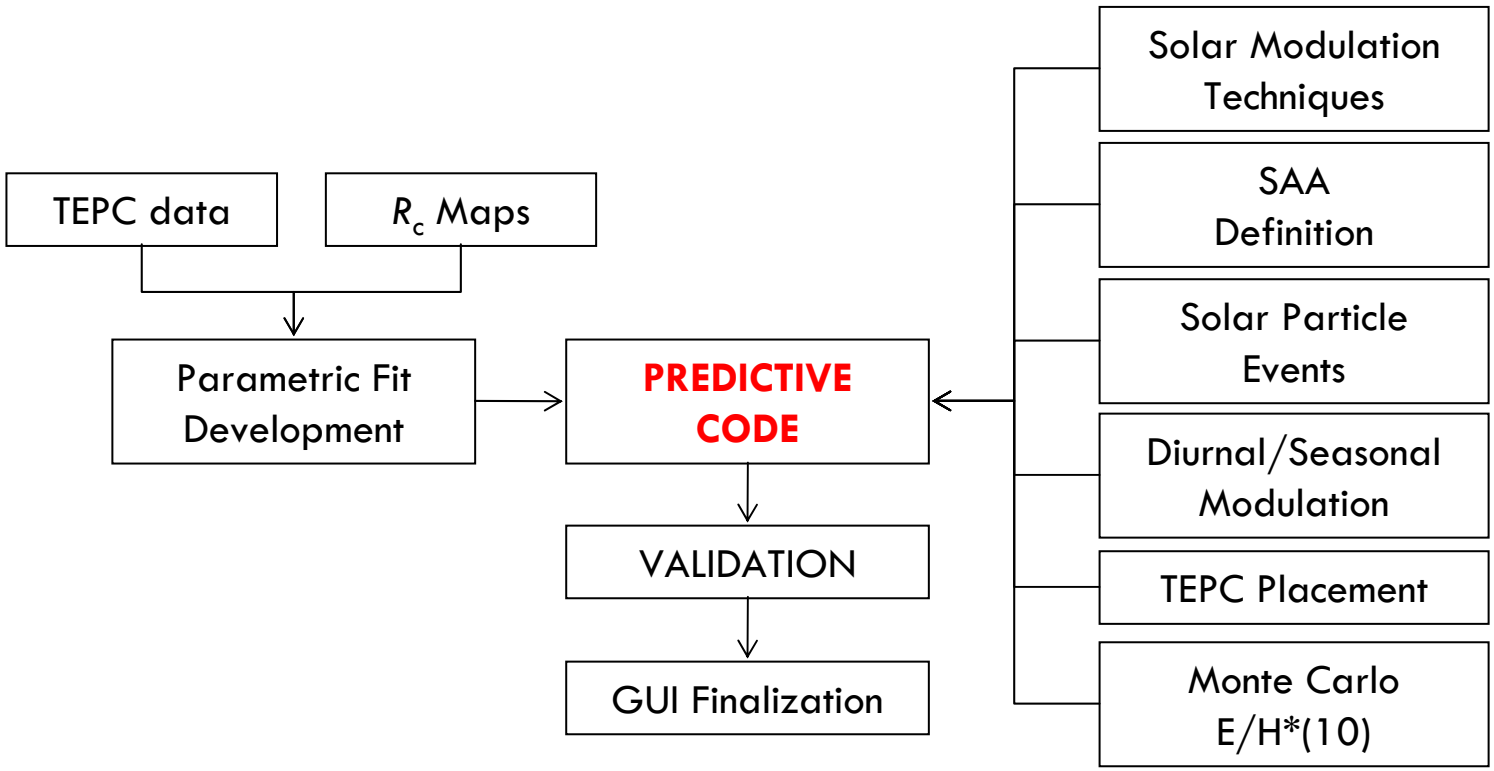
- US tissue equivalent proportional counter (TEPC) used to measure mixed radiation field and provide an absorbed dose and ambient dose equivalent.
  - extensive data sets have been taken over last 10 years (covers solar max/min for Solar Cycle 23).
  - correlated ISS position (latitude, longitude, altitude) provides well-characterized estimation of effective vertical cut-off rigidity.

- Predictive code (correlating ambient dose equivalent rate to cut-off rigidity) could be developed to estimate ISS crew exposure for mission planning.

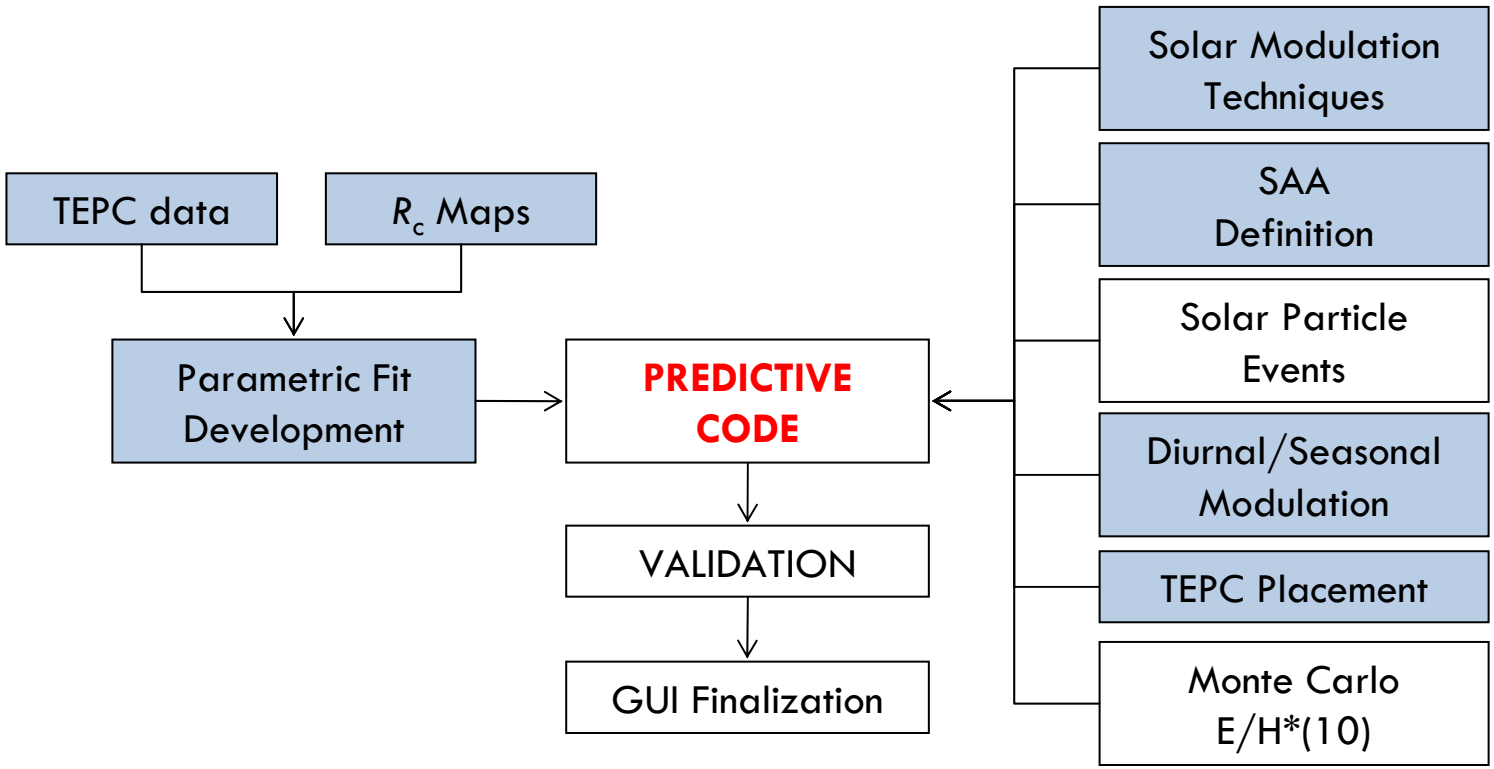
Image Shows TEPC in SM-327 (SRAG NASA Internal Site)

ISS023E009121

Code Development



Code Development



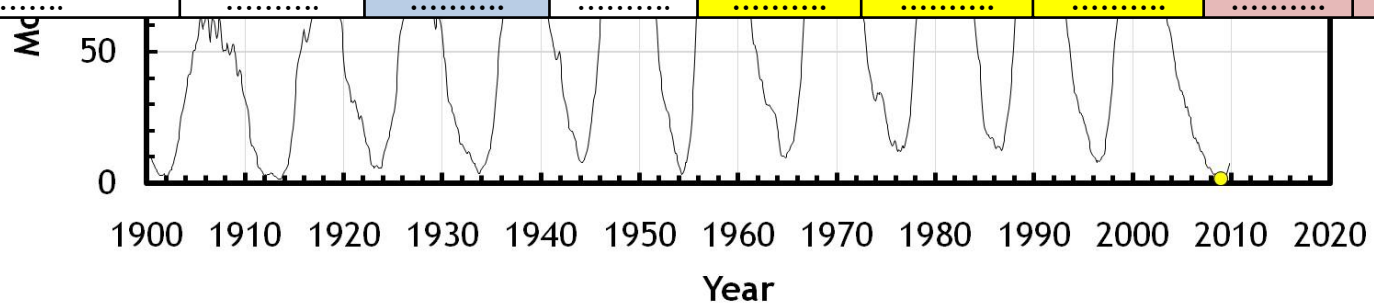
Code Development

TEPC Data

R_c Maps

- Space Radiation Analysis Group (SRAG) of NASA provided two sets of TEPC data from July 7-13, 2001 and December 10-16, 2008.

Date	Dose	DoseEq60	Time Interval	Longitude	Latitude	Altitude	Flag	Location
(GMT)	(μGy/min)	(μSv/min)	(min)	(deg.)	(deg.)	(km)		
12/10/2008 00:00:13	0.042	**0.049**	1	**-74.244**	**12.92**	**353.099**	**GCR**	**SM-327**
12/10/2008 00:01:13	0.043	**0.154**	1	**-71.954**	**9.857**	**353.428**	**GCR**	**SM-327**
12/10/2008 00:02:13	0.045	**0.218**	1	**-69.712**	**6.776**	**353.858**	**GCR**	**SM-327**
12/10/2008 00:03:13	0.038	**0.194**	1	**-67.502**	**3.682**	**354.394**	**GCR**	**SM-327**
12/10/2008 00:04:13	0.029	**0.046**	1	**-65.309**	**0.581**	**355.033**	**GCR**	**SM-327**
12/10/2008 00:05:13	0.037	**0.179**	1	**-63.119**	**-2.519**	**355.775**	**GCR**	**SM-327**
12/10/2008 00:06:13	0.034	**0.047**	1	**-60.919**	**-5.614**	**356.614**	**Trapped**	**SM-327**
12/10/2008 00:07:13	0.069	**0.421**	1	**-58.693**	**-8.698**	**357.547**	**Trapped**	**SM-327**
12/10/2008 00:08:13	0.341	**0.734**	1	**-56.427**	**-11.764**	**358.563**	**Trapped**	**SM-327**
.....	.....	.....	.....	.....	.....	.....	.....	.....



Code Development

R_c Maps

Parametric Fit

- Several estimations of the cut-off rigidity have been used in the analysis:
  - International Geomagnetic Reference Field (IGRF 2000)
  - RCINTUT3 code (Smart + Shea 2001)
  - An effective vertical cutoff rigidity table (Nymmik et al.) utlizing the IGRF internal source field for epoch 2005.

Smart, D. F., Shea., M.A., World Grid of Calculated Cosmic Ray Vertical Cutoff Rigidities for Epoch 2000.0, ICRC 2007, 2008

Nymmik et al., A method of claculation of vertical cutoff rigidity in the geomagnetic field, Cosmic Research, Vol. 47, No. 3, pp. 191-197, 2009

Code Development

R_c Maps

Parametric Fit

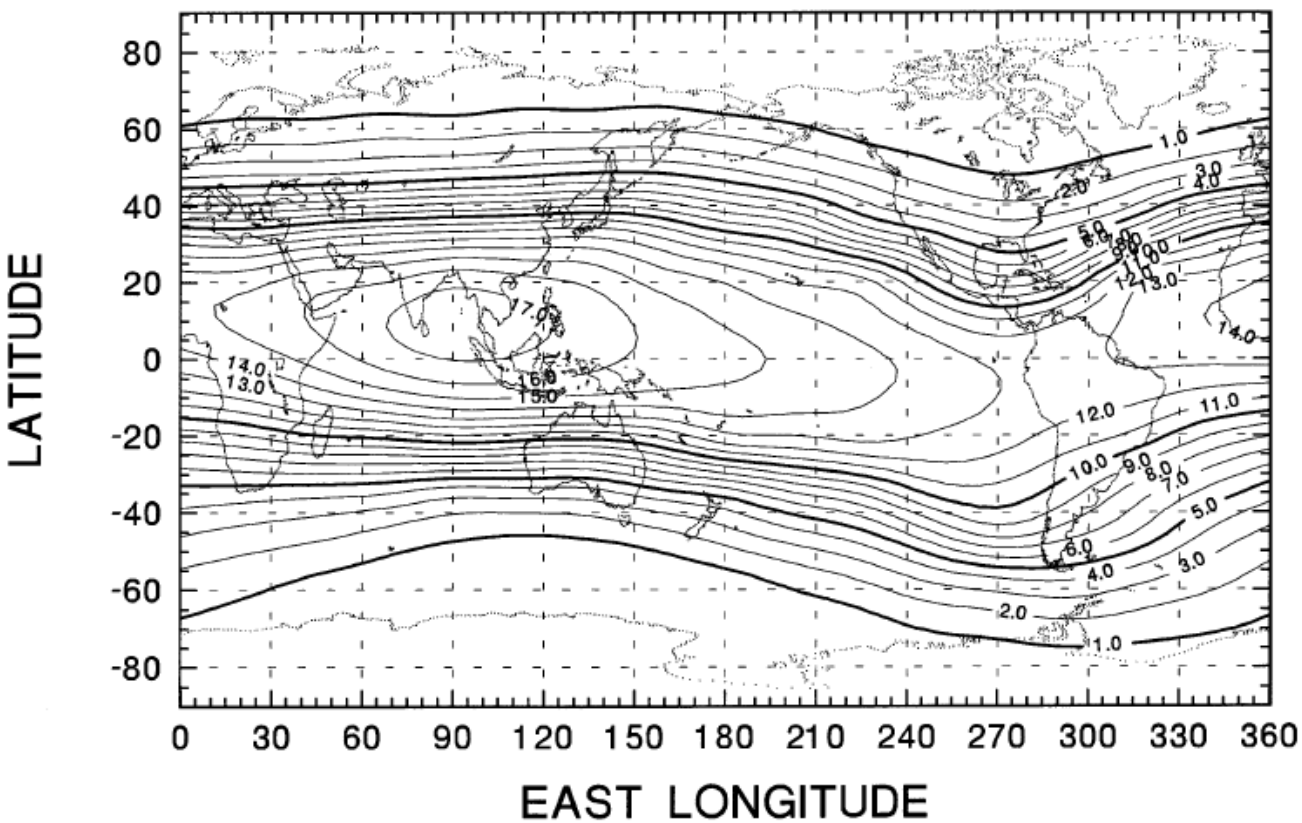


Figure 1: Iso-rigidity contours for vertical geomagnetic cutoff rigidities for epoch 2000.

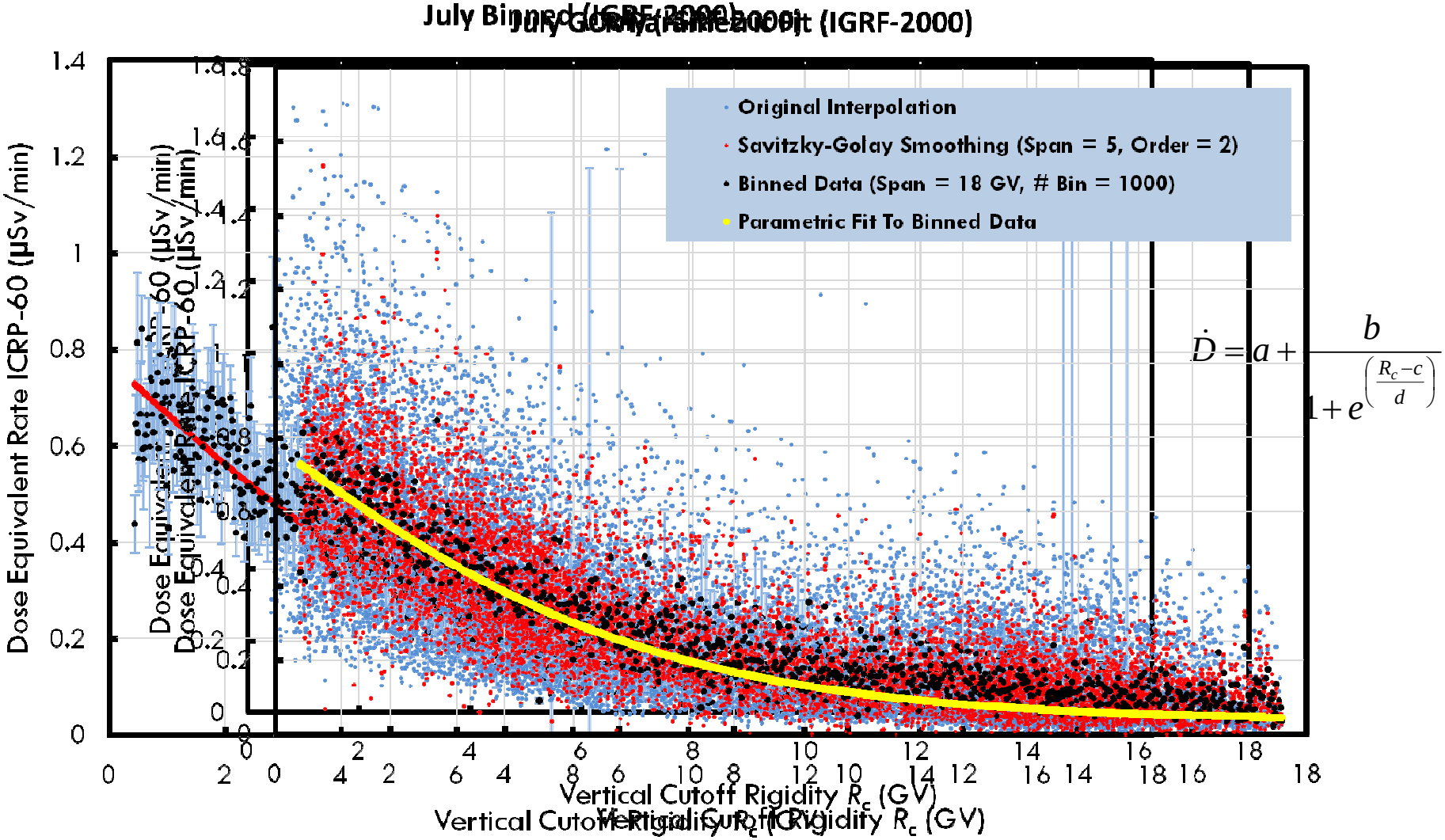
Smart, D. F., Shea., M.A., World Grid of Calculated Cosmic Ray Vertical Cutoff Rigidities for Epoch 2000.0, ICRC 2007, 2008

Code Development

Parametric Fit (GCR)

Solar Modulation Techniques

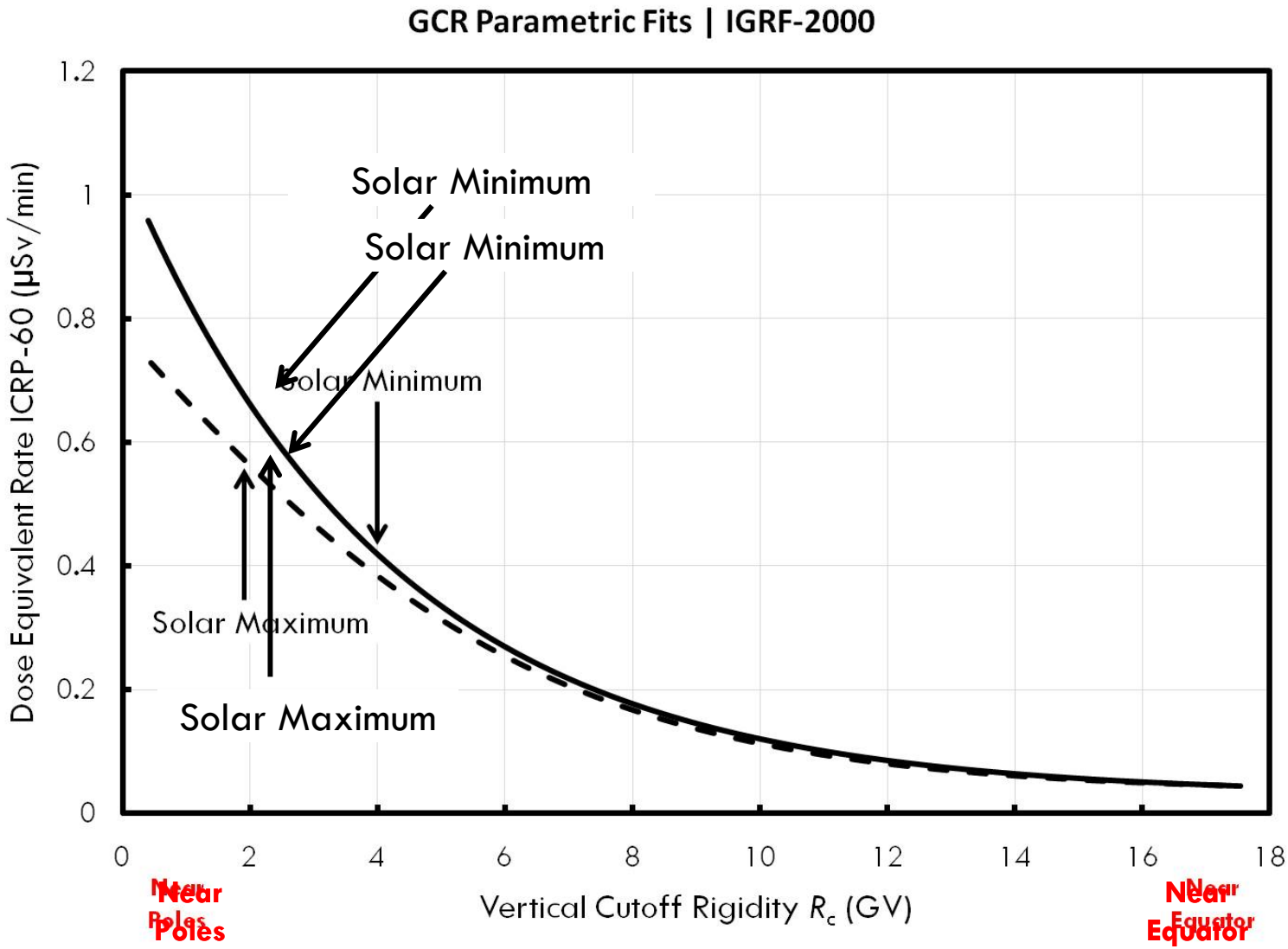
GCR Data binned July solar maximum conditions compared to the IGRF-2000.



Code Development

Parametric Fit (GCR)

Solar Modulation Techniques

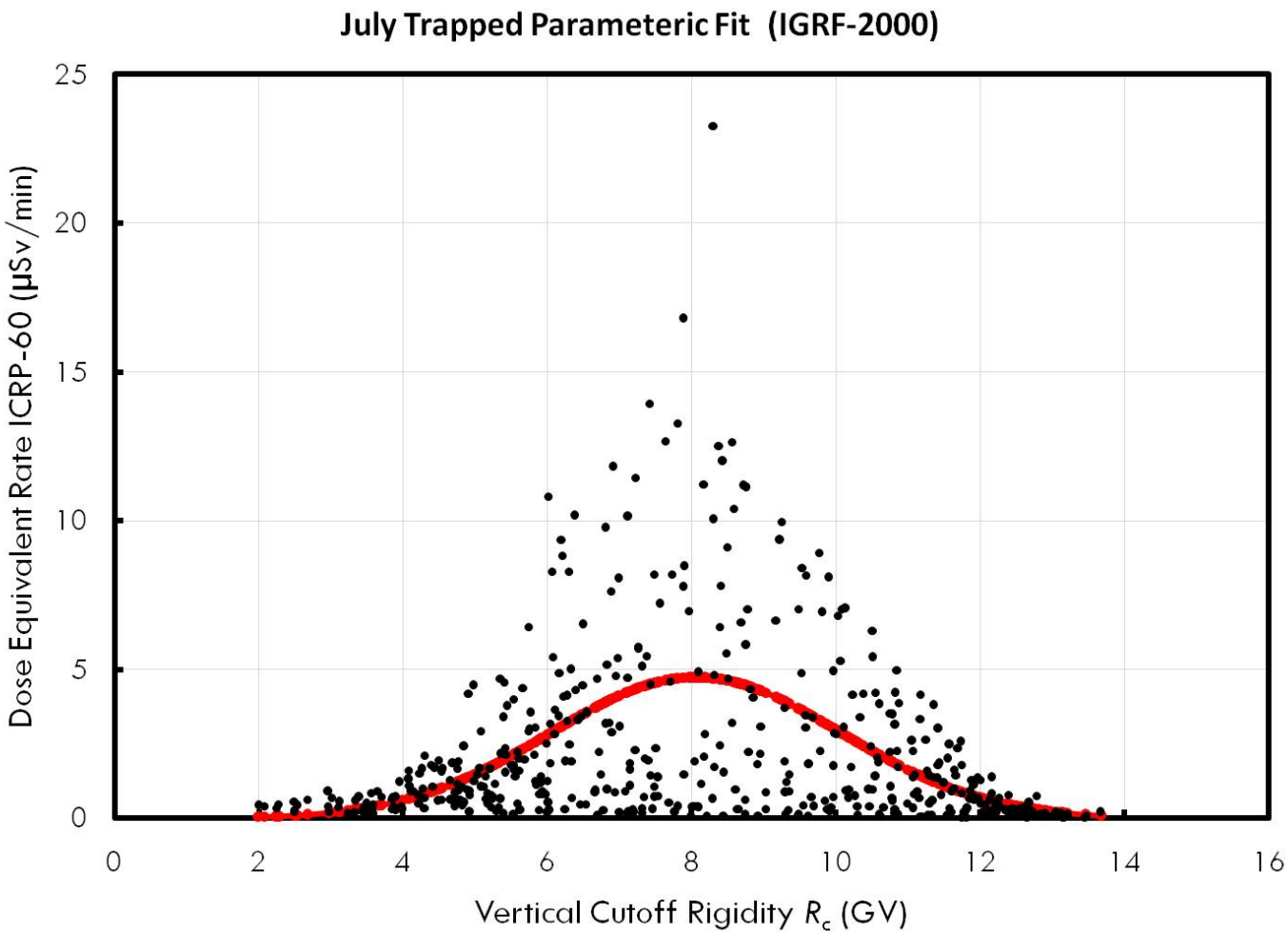


Code Development

Parametric Fit (Trapped Radiation)

Solar Modulation Techniques

Trapped Data for July (solar max.) interpolated using IGRF-2000.

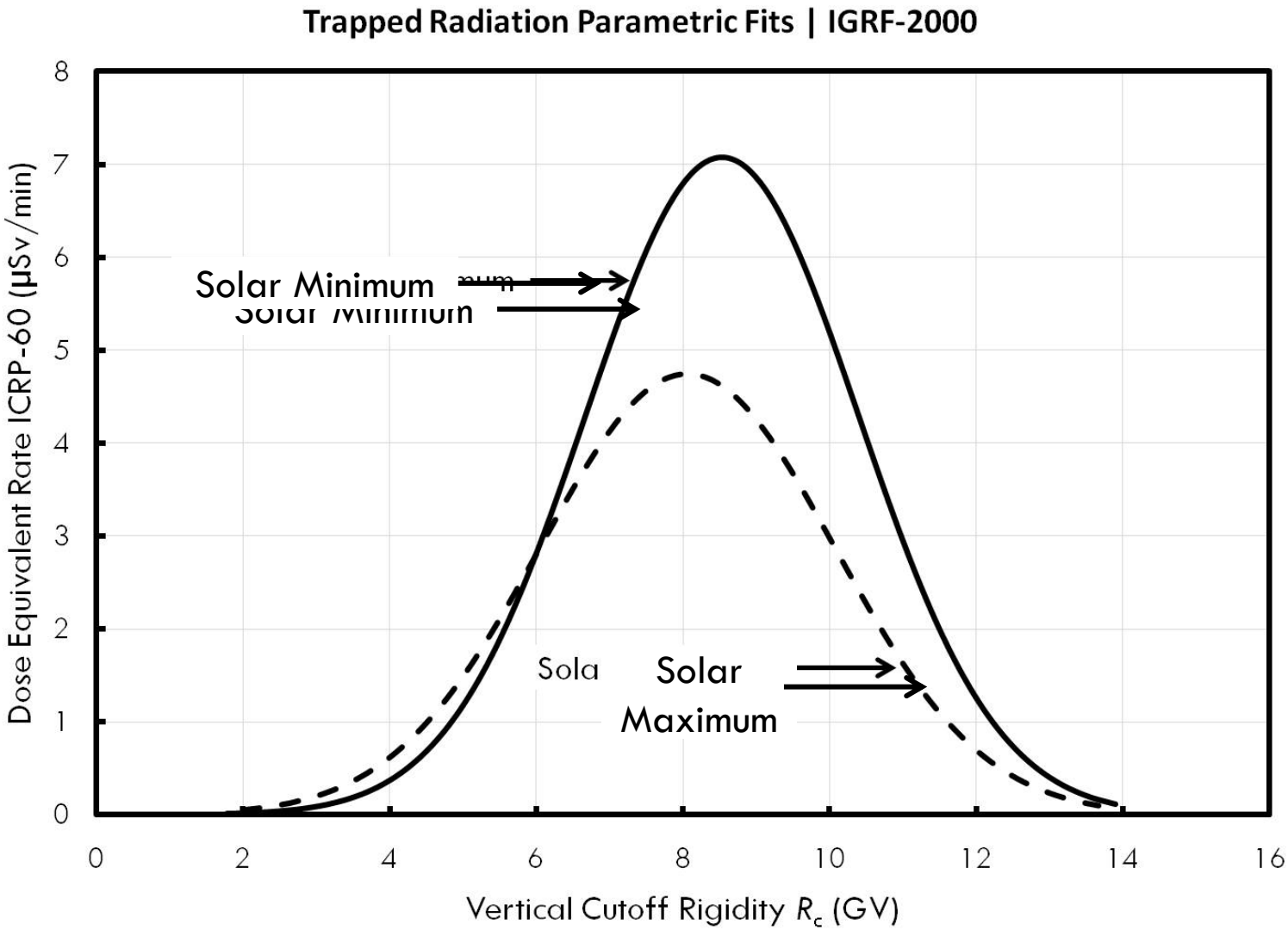


$$\dot{D} = \frac{a}{e^{\left(\frac{R_c - b}{c}\right)^2}}$$

Code Development

Parametric Fit (Trapped Radiation)

Solar Modulation Techniques



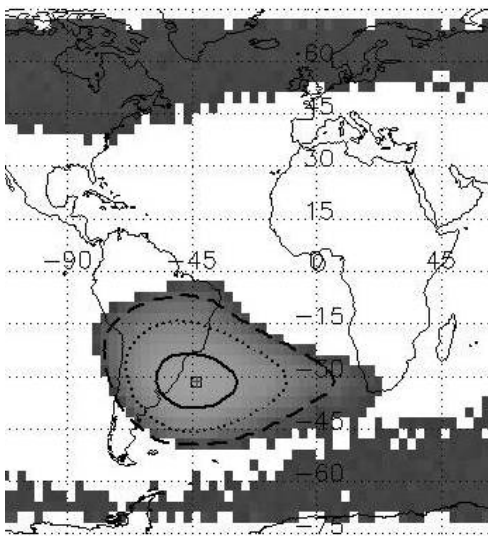
Code Development

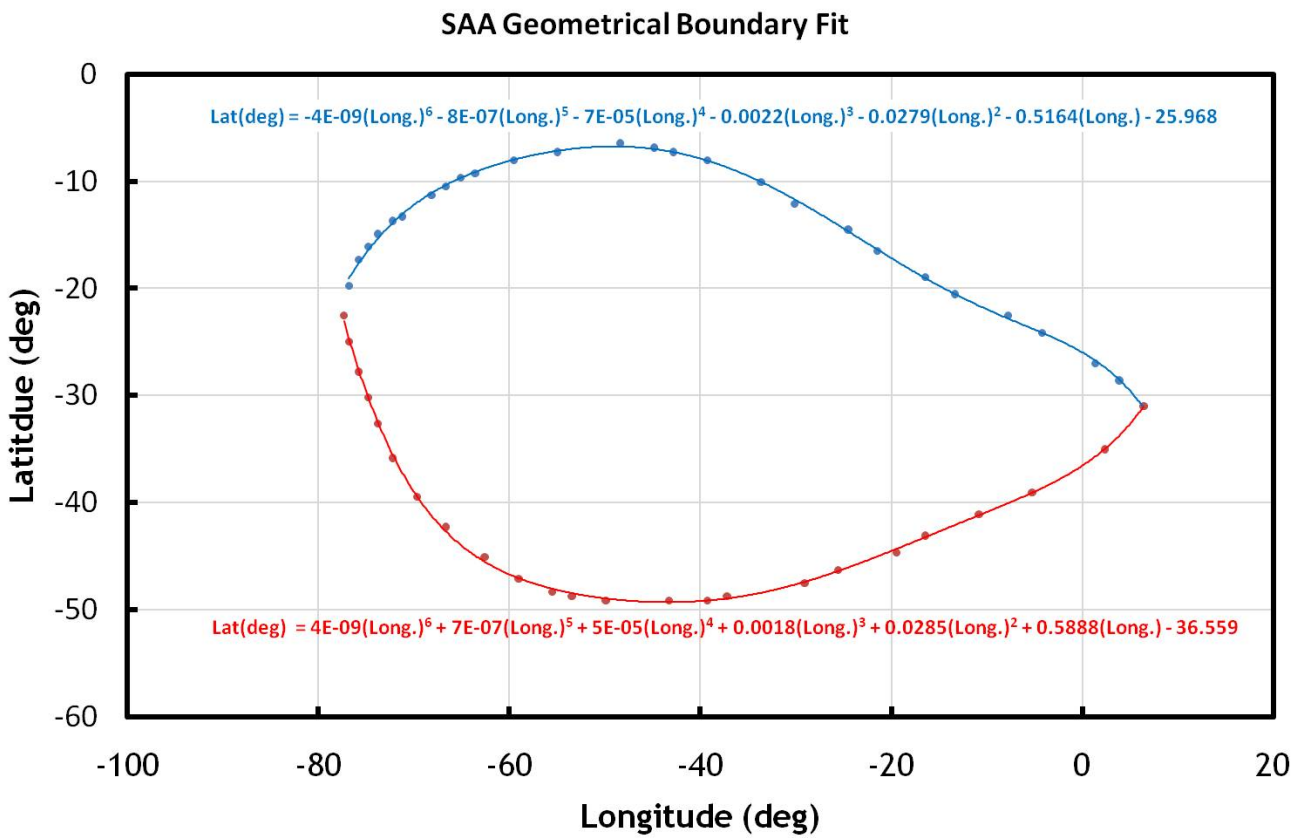
- Parametric fits developed envelope the extremes of Solar Cycle 23.
- To predict the ambient dose equivalent rate in between the extremes of the solar cycle, interpolation parameters must be used.
- Solar modulation parameters utilized to adjust the parametric fits include:
  - 12 month running mean of the monthly smoothed sunspot number
  - F10.7 cm solar radio flux
  - heliocentric potential

Code Development

Solar Modulation Techniques

- Proton flux intensity map (2001 - 2006) @ 400 – 450 km.
- Decrease in intensity (0.05%/y) and drifting towards West Pacific (3 km/y).





Ginet et al., Energetic Proton Maps for the South Atlantic Anomaly

Preliminary Results

Predictive code compared against historical TEPC measurements:

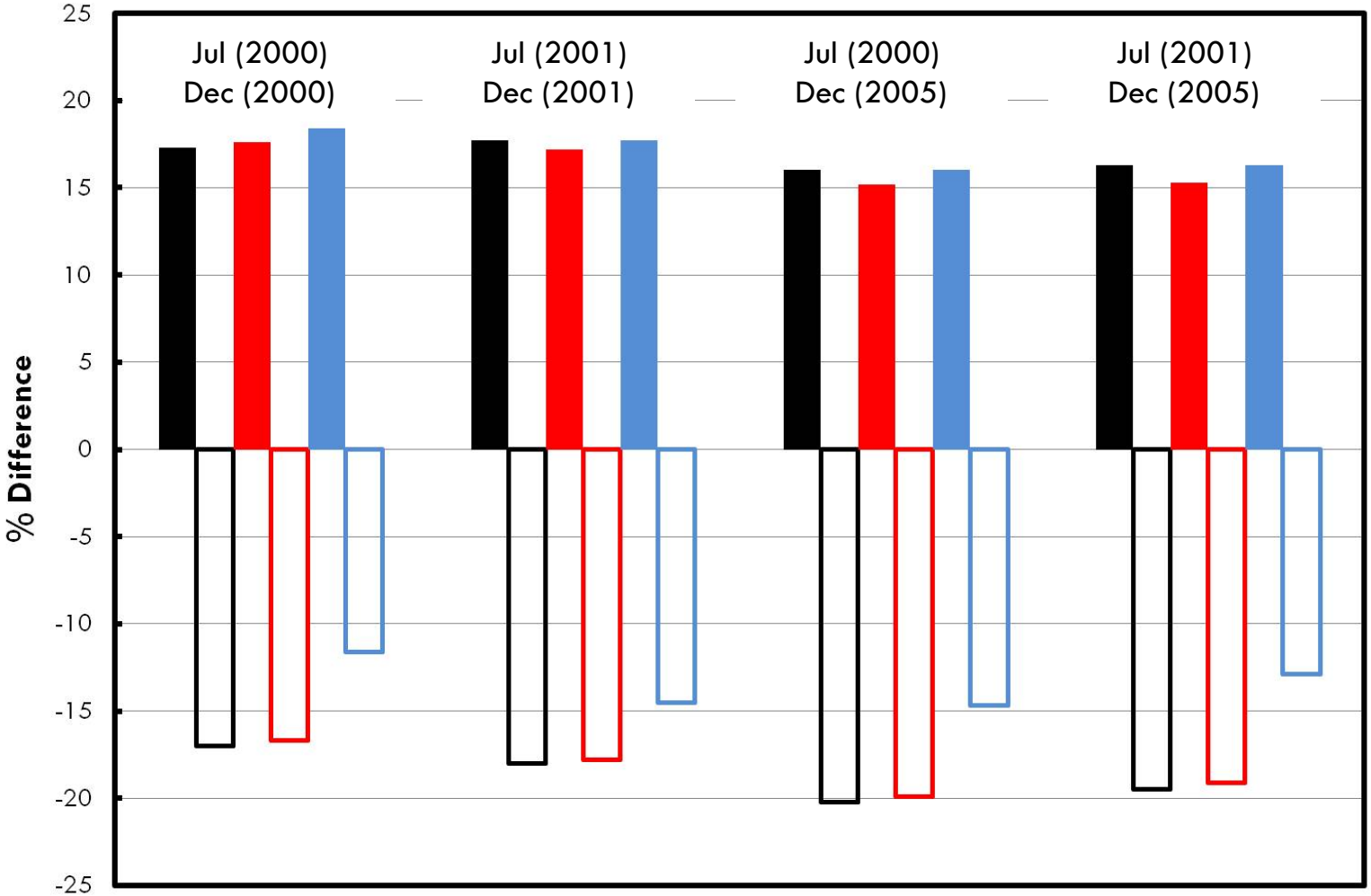
April 1-21, 2010 Location = SM P327-Pointed FWD , +X
Total Dose = 1346.8 mrem (GCR = 843.4, TRAP = 503.4)

Jun. 4-20, 2005 Location = SM P327
Total Dose = 777.8 mrem (GCR = 532.9, TRAP = 244.8)

Preliminary Results

Total Dose

GCR Dose



April 1-21, 2010

June 4-20, 2005

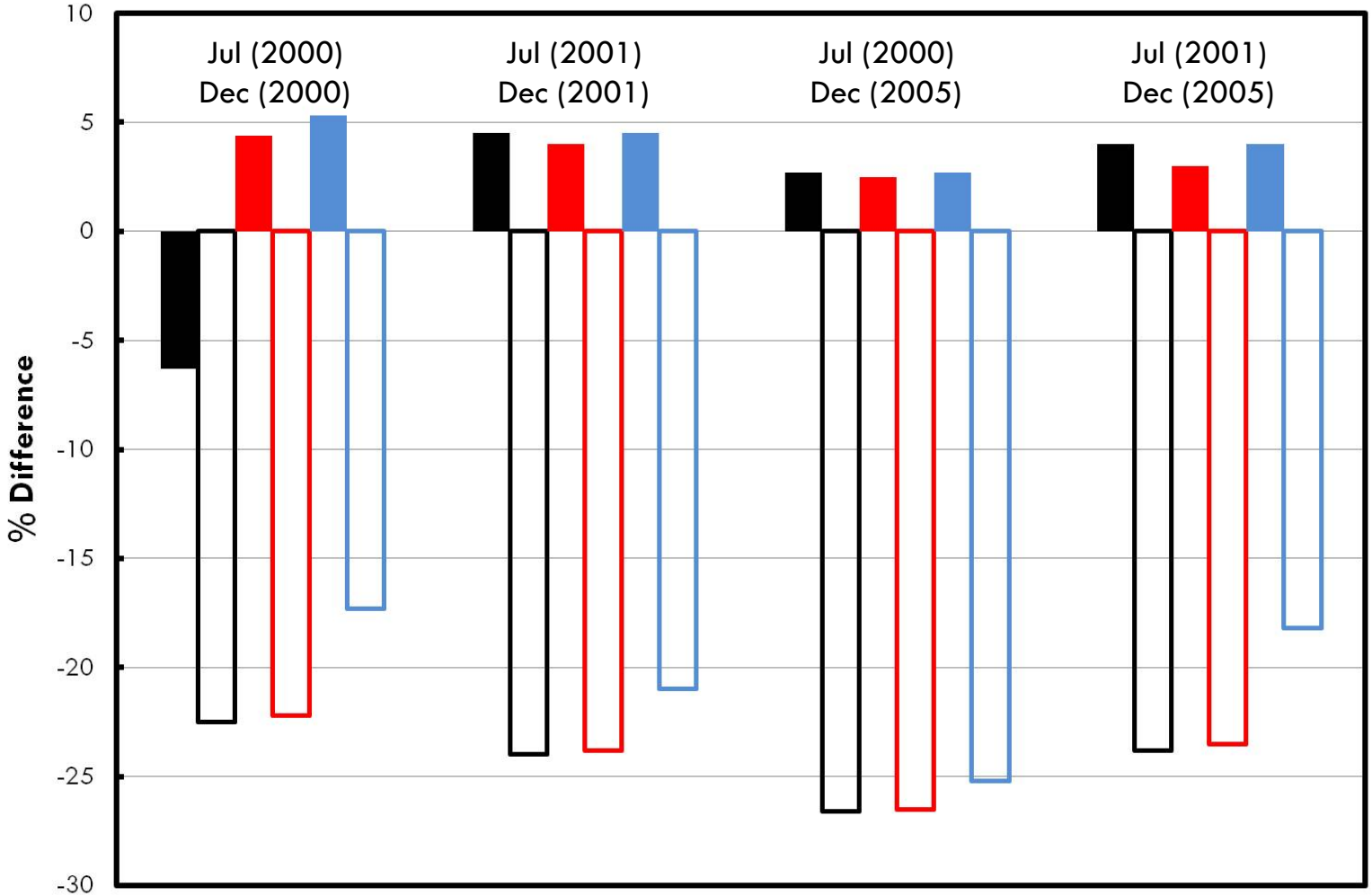
Solar Modulation Parameter

F10.7cm **SSN** **Heliocentric Potential**

Preliminary Results

GCR Dose

Trapped Dose



April 1-21, 2010

June 4-20, 2005

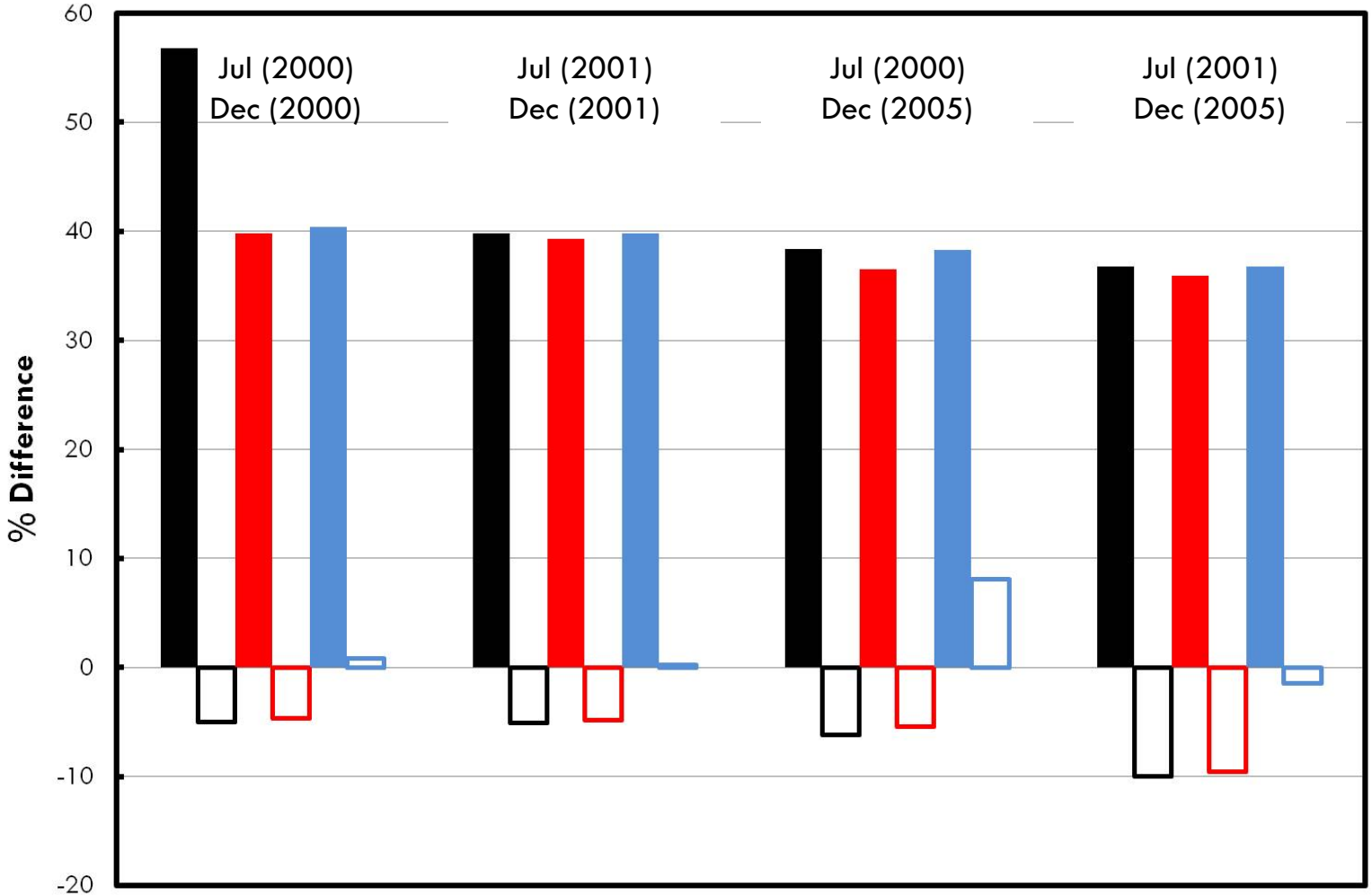
Solar Modulation Parameter

F10.7cm **SSN** **Heliocentric Potential**

Preliminary Results

Trapped Dose

Diurnal Modulation



April 1-21, 2010

June 4-20, 2005

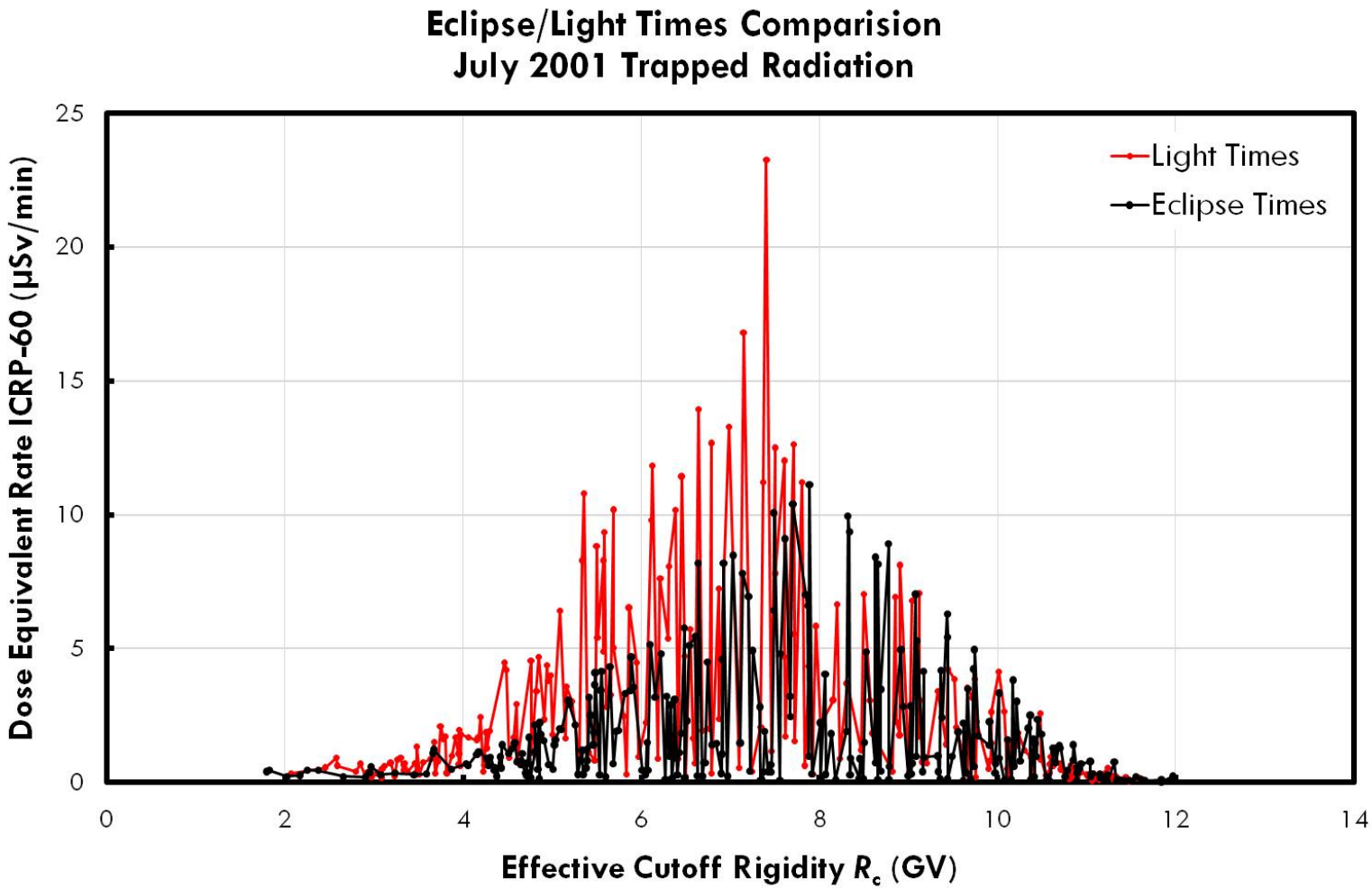
Solar Modulation Parameter

F10.7cm **SSN** **Heliocentric Potential**

Preliminary Results

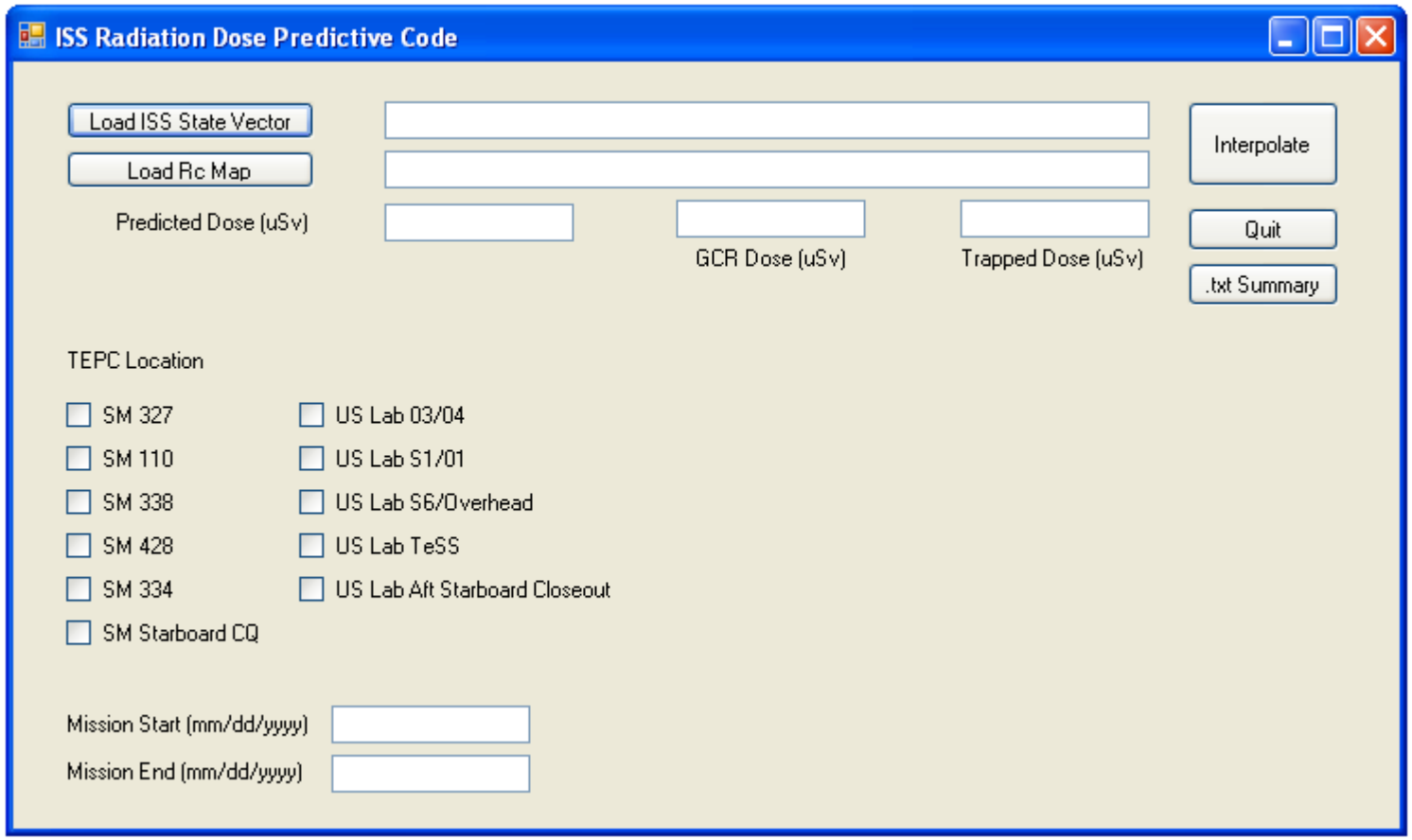
Diurnal Modulation

GUI Development



Preliminary Results

GUI Development



Conclusions

1. Overall, predicted ambient dose equivalent within 20% of measured. Uncertainty in TEPC measurement is ~30%.

2. Heliocentric potential offers the most robust and consistent solar modulation parameter.

3. Predicted trapped radiation contribution to ambient dose equivalent for the 2010 run within 30% – 40% of measured result while for 2005 run is <10% of measured. Sensitive to the SAA map!

4. Predicted GCR contribution to ambient dose equivalent for 2010 run <10% of measured and for 2005 run <25% of measured.

5. From previous two points, it is clear a happy medium is needed to optimize the GCR and Trapped doses.

Future Work

1. Improve SAA definition. Important for minimizing percent difference of GCR and trapped components.

2. Improve Rc maps (include disturbances as a parameter)

3. Diurnal + seasonal modulation effects (this includes density effects for trapped radiation).

4. Correlation factor dependent on ISS TEPC placement.

5. Solar Particle Events.

6. Compare current RMC code to NASA code for mission exposure prediction.

7. Perform Monte Carlo Transport Calculation through the ISS to get an effective-to-ambient dose equivalent E/H*(10) ratio to convert measured doses to a protection quantity.

8. Complete GUI for robust use and ease of use.

Acknowledgements

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