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ISSCREM: International Space Station Cosmic Radiation Exposure Model

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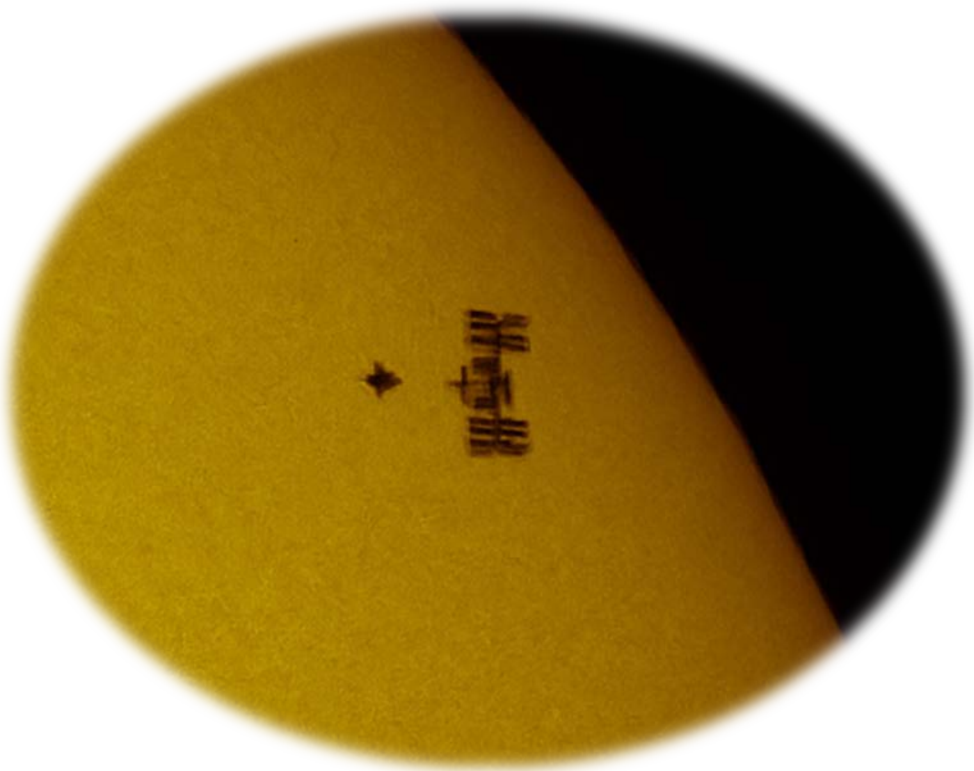
Outline

- Motivation
- Model Development
- Model Benchmarking
- Effective Dose Simulations
- Summary



Motivation

Radiation exposure assessment is part of mission planning aboard the ISS (Necessitated by the Radiation Health Working Group (RHWG))

ISS Low-Earth Orbit (LEO)

- 90 minute orbit
- 340 to 420 km altitude
- Inclination of 51.6˚

Main Sources of Radiation in LEO

- Trapped Radiation (TR)
- Galactic Cosmic Radiation (GCR)

Motivation

To develop a model to predict the radiation dose space-crew can expect to get for a given mission aboard the ISS.

Specifically:

- Give measure of the dose equivalent and the effective dose space-crew get from GCR and TR exposure.
    - Dose equivalent is an operational quantity (radiation weighted)
    - Effective dose is a protection quantity (radiation and tissue weighted)
- Base model on operational data collected aboard the ISS (empirical model)
- Correlate the model to physical phenomena occurring in LEO.

Model Development

Operational Data

- NASA has been operating a Tissue Equivalent Proportional Counter (TEPC).

- TEPC data available from 2000 to 2010.
- **2001 and 2008 data used in model development.**
- Rest of data used in model benchmarking.

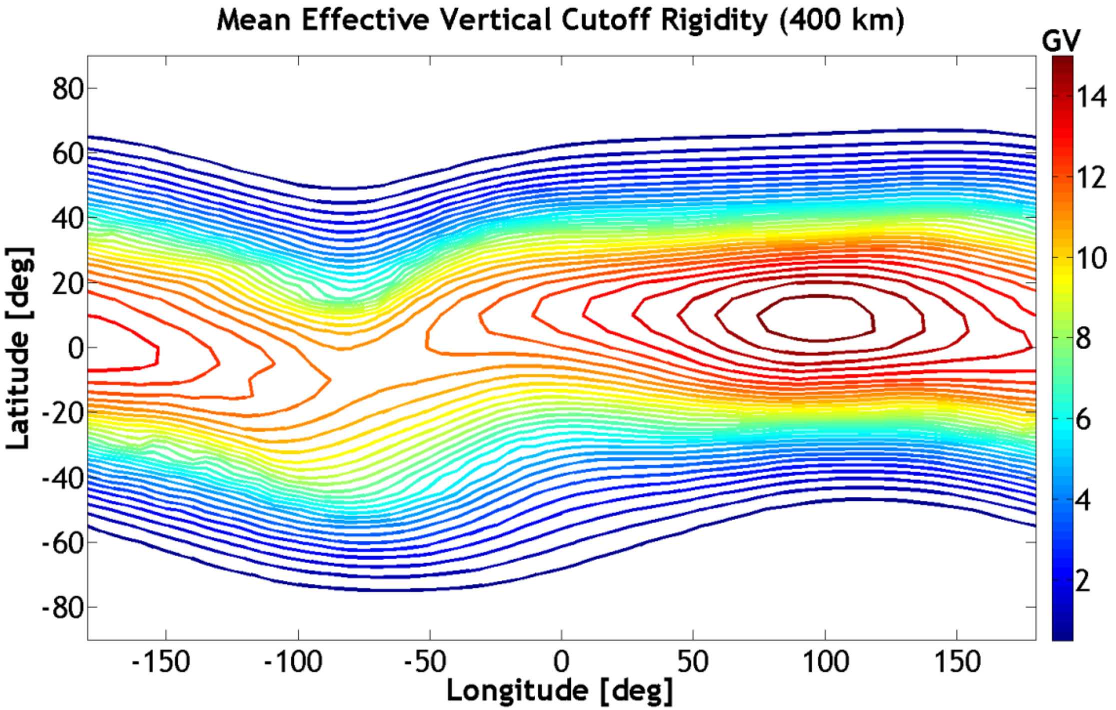
Data contains:

- Dose equivalent rate (µSv min^{-1})
- ISS position
- Radiation Flag (GCR or trapped radiation)
- TEPC detector location

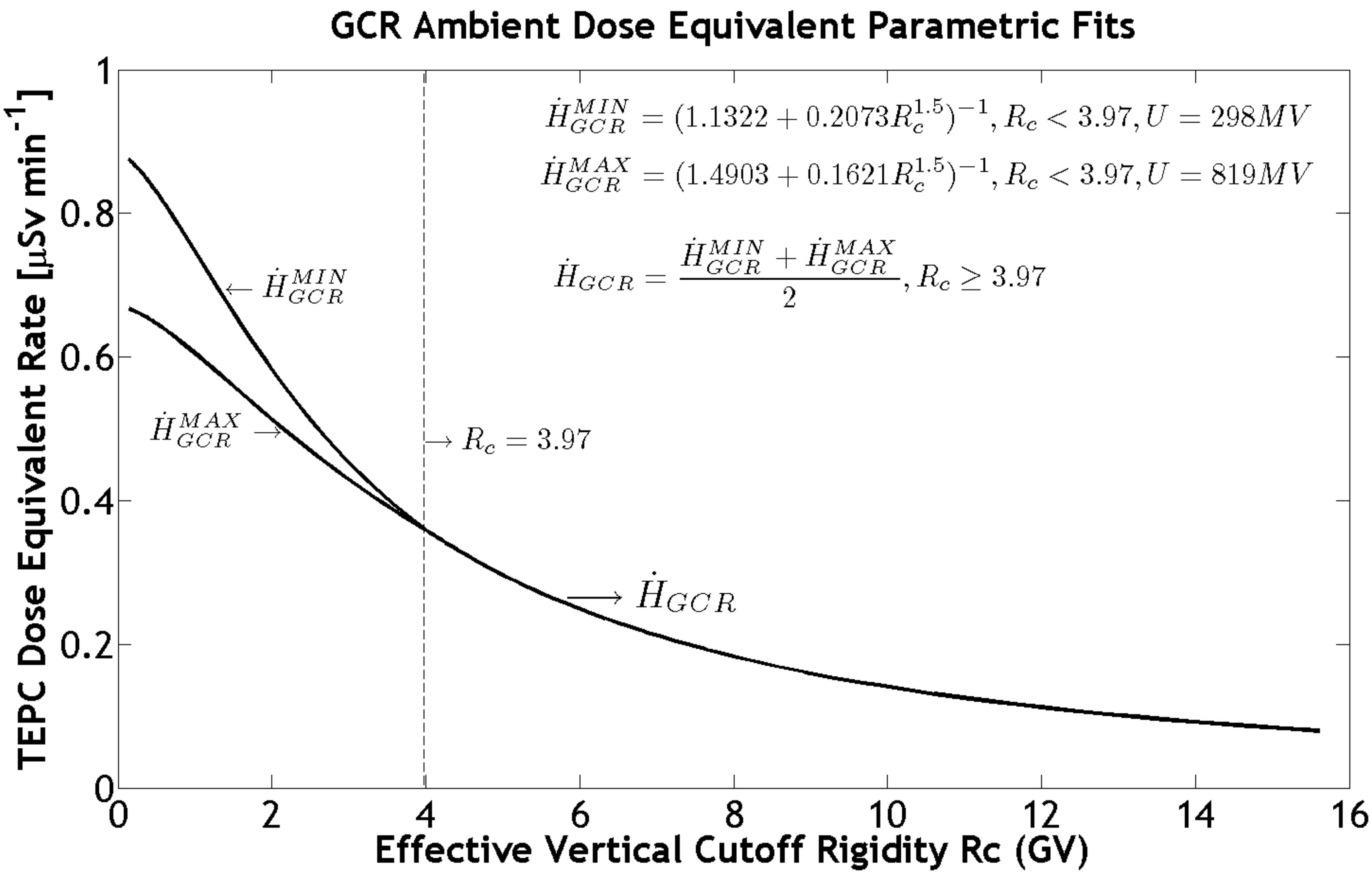
Model Development

GCR parametric model

- GCR dose is anti-coincident with solar-cycle and dependent on the ability of GCR ions to penetrate magnetosphere.
- The measured TEPC dose equivalent rate from GCR exposure was correlated to the cutoff rigidity parameter interpolated from ISS state vectors.
- Cutoff rigidity maps were obtained from Smart and Shea RCINUT3 code.



Model Development

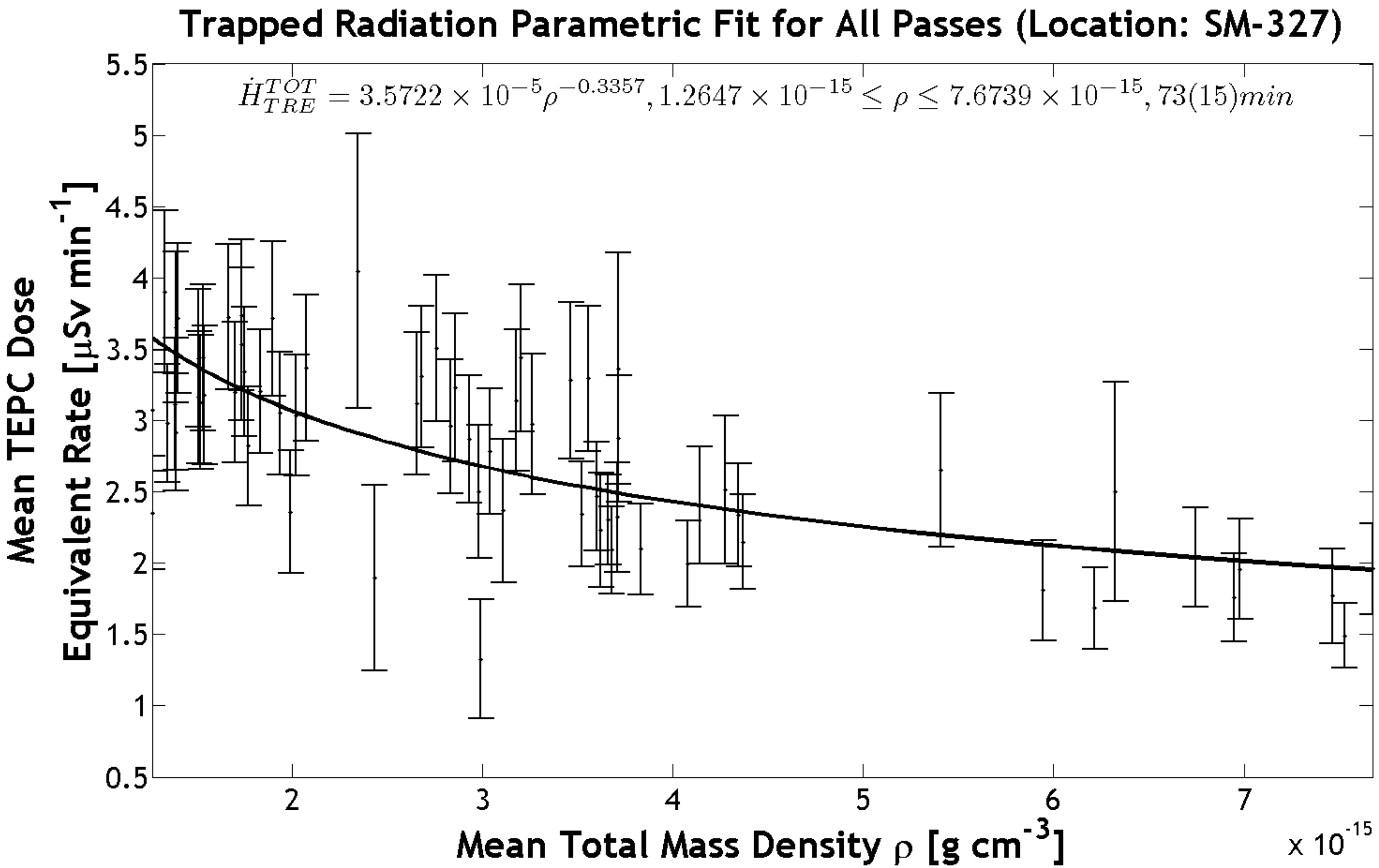


Model Development

Trapped radiation parametric model

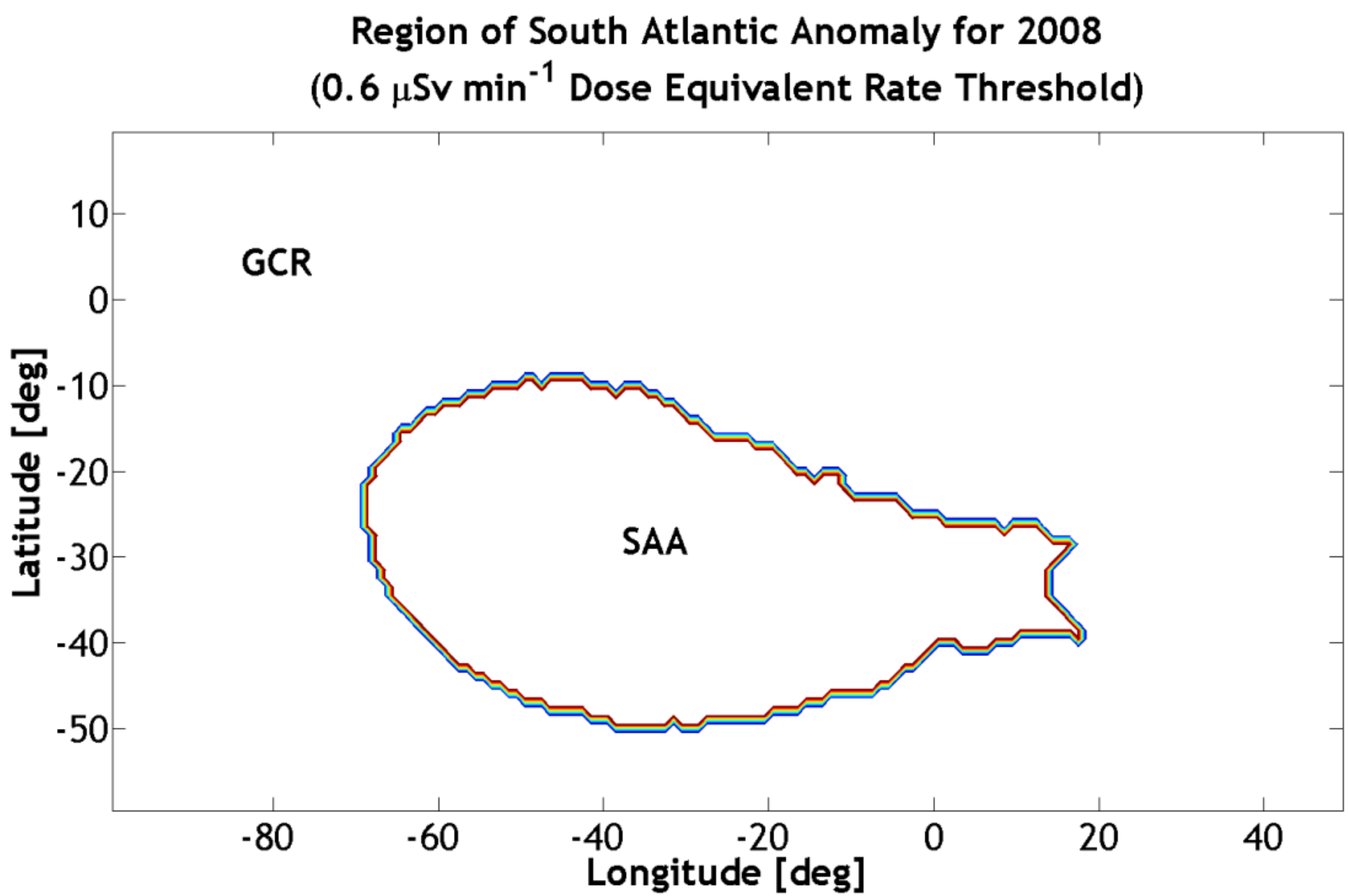
- TR dose is anti-coincident with solar activity due to atmospheric density effects inside the SAA.
- NRLMSIS-00 atmospheric density model was used.
- Solar activity was accounted for by solar radio flux at 10.7 cm (F10.7) and Ap magnetic index.
- Model was developed for the TEPC detector located at SM-327 with the detector orientated perpendicular to the velocity vector.

Model Development

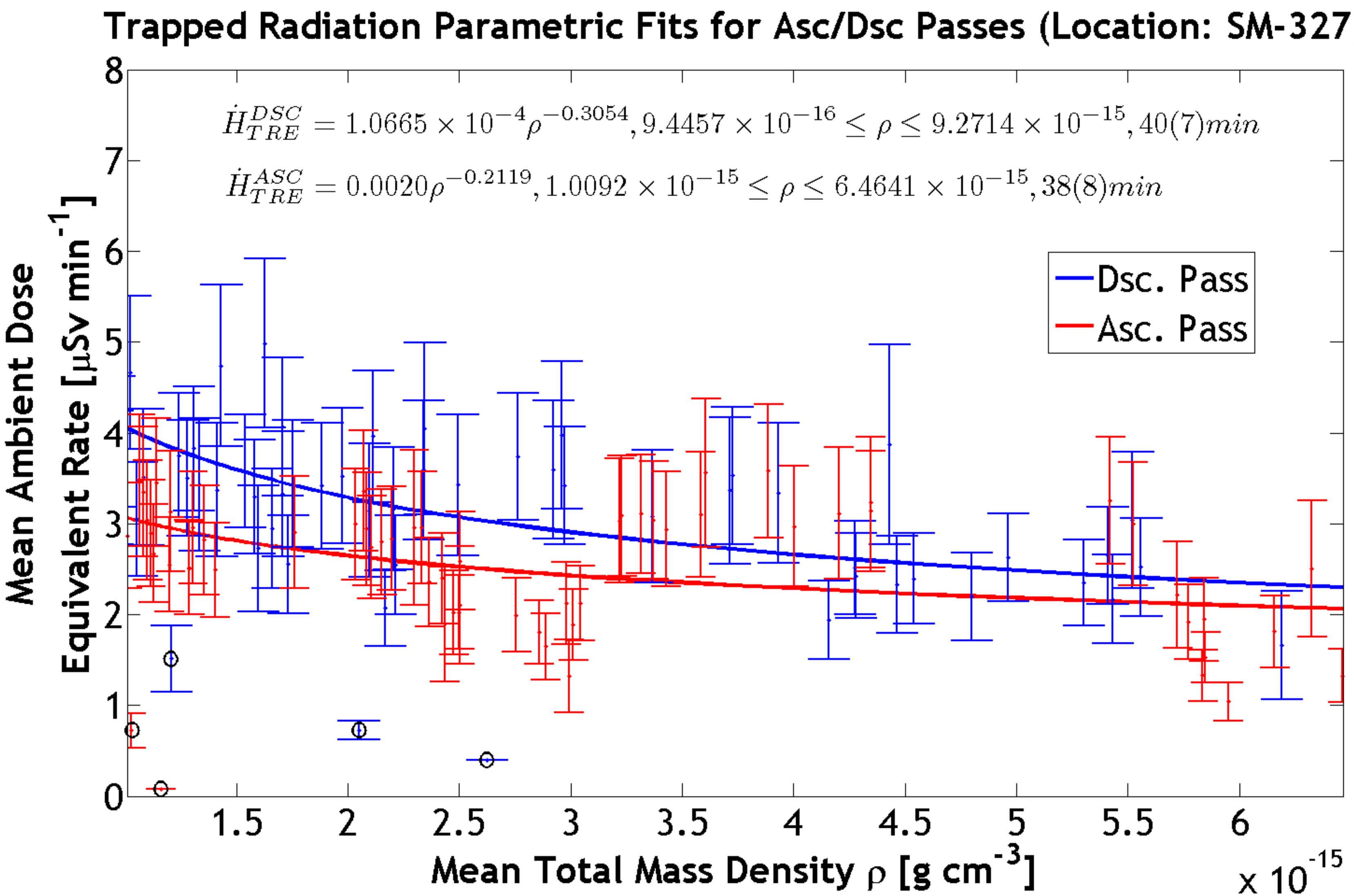


Model Development

South Atlantic Anomaly delineation



Model Development



Model Development

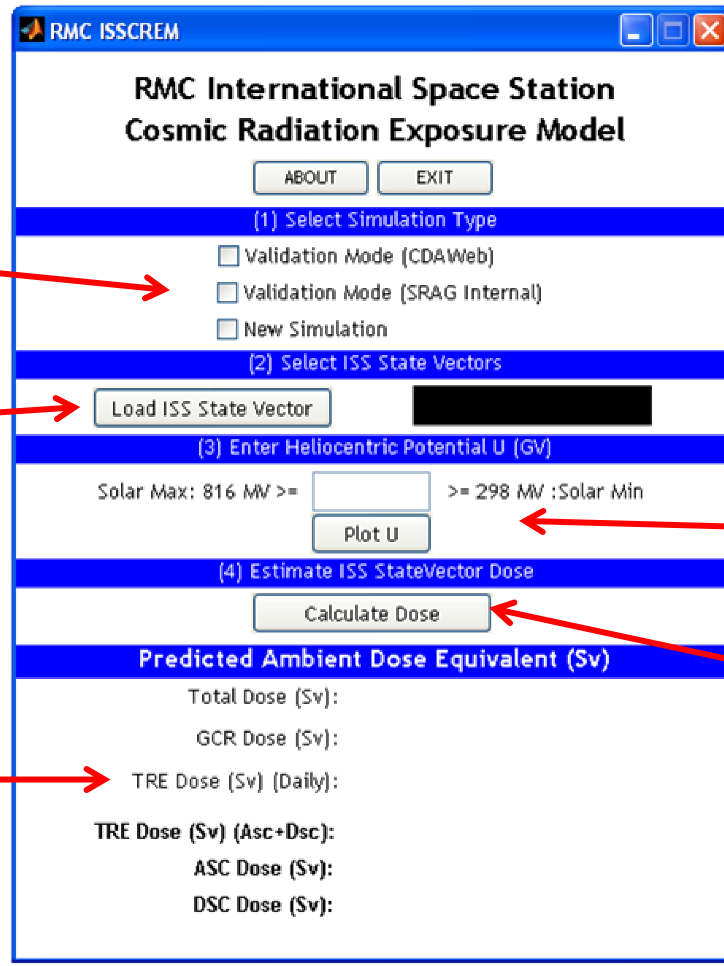
Graphical User Interface

- International Space Station Cosmic Radiation Exposure Model (ISSCREM)

(1) Select simulation type.

(2). Load ISS state-vectors and solar activity input parameters for trapped radiation model.

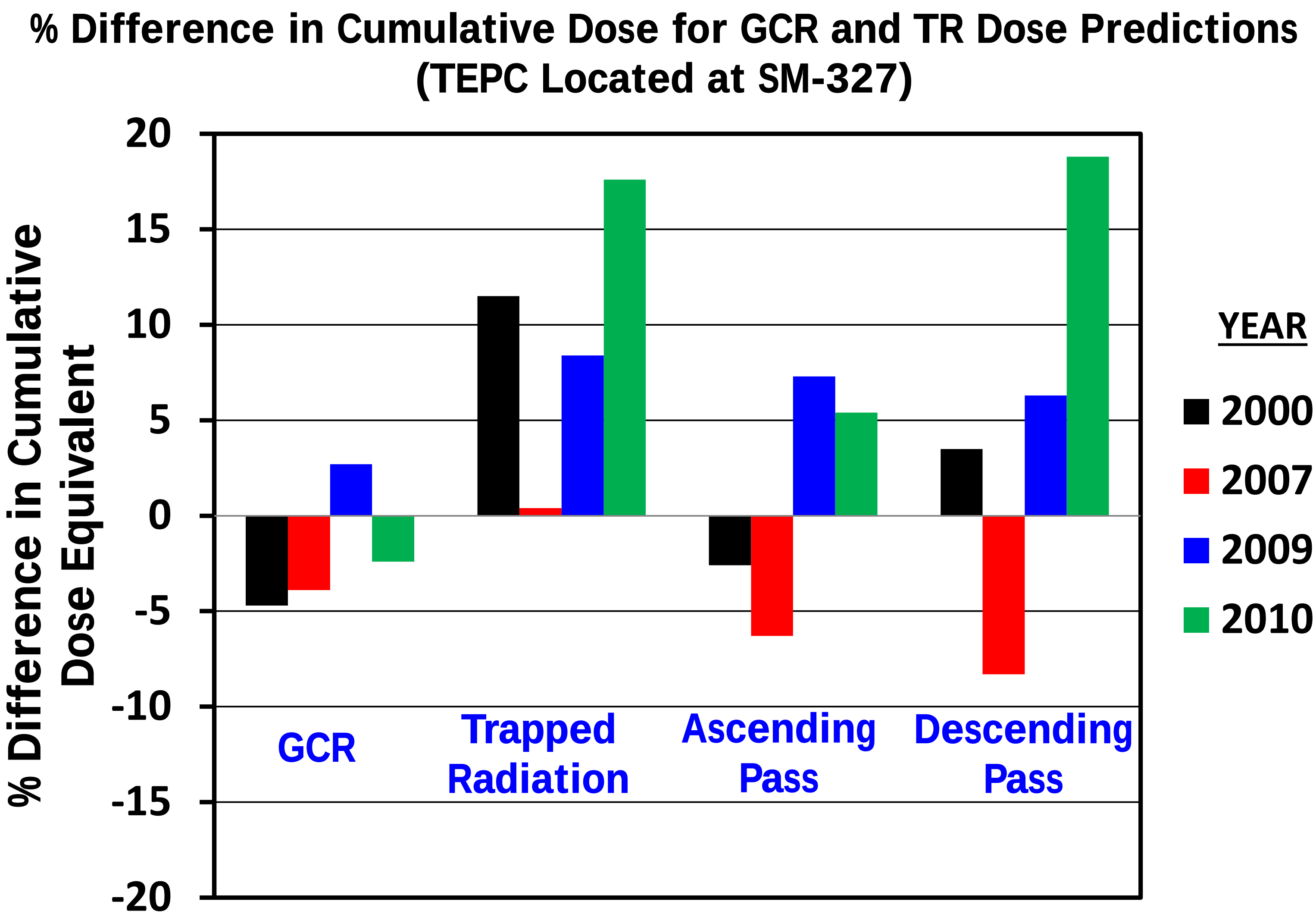
(5). View cumulative dose including output .txt files and figures.



(3). Enter in U for GCR model.

(4). Calculate dose.

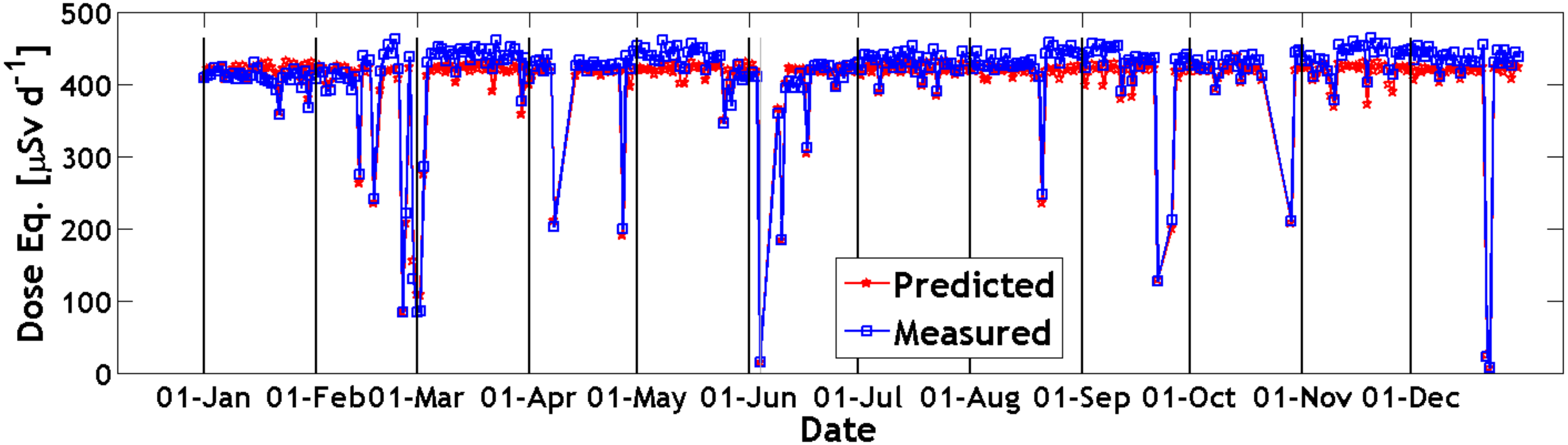
Benchmarking



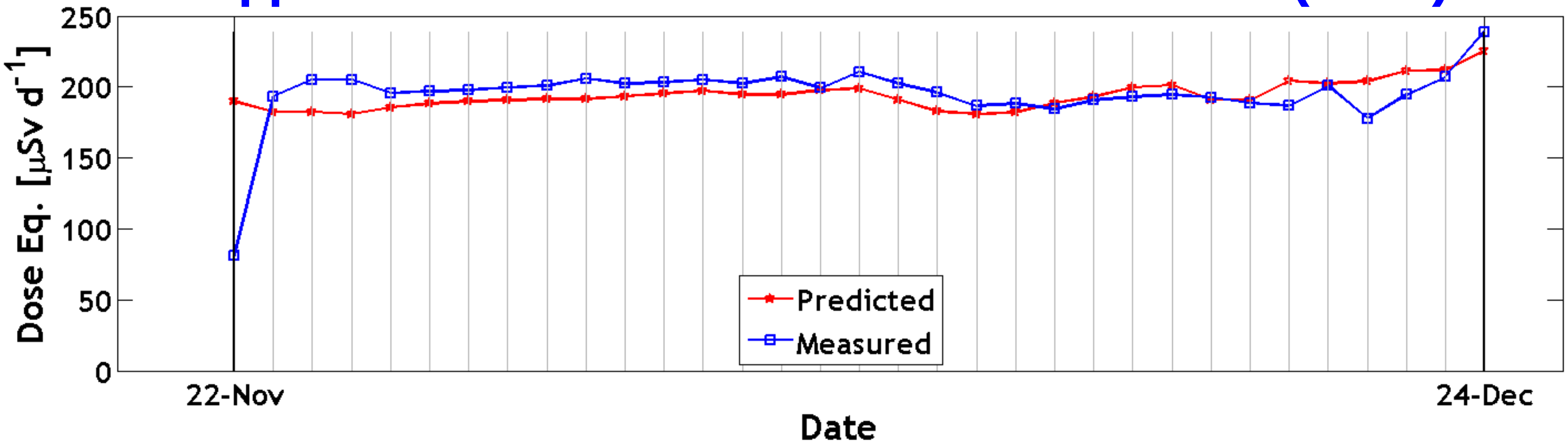
$$\% \text{ Difference} = \frac{\text{Measured Dose Eq.} - \text{Predicted Dose Eq.}}{\text{Measured Dose Eq.}} 100\%$$

Benchmarking

GCR Dose Predictions (2009)



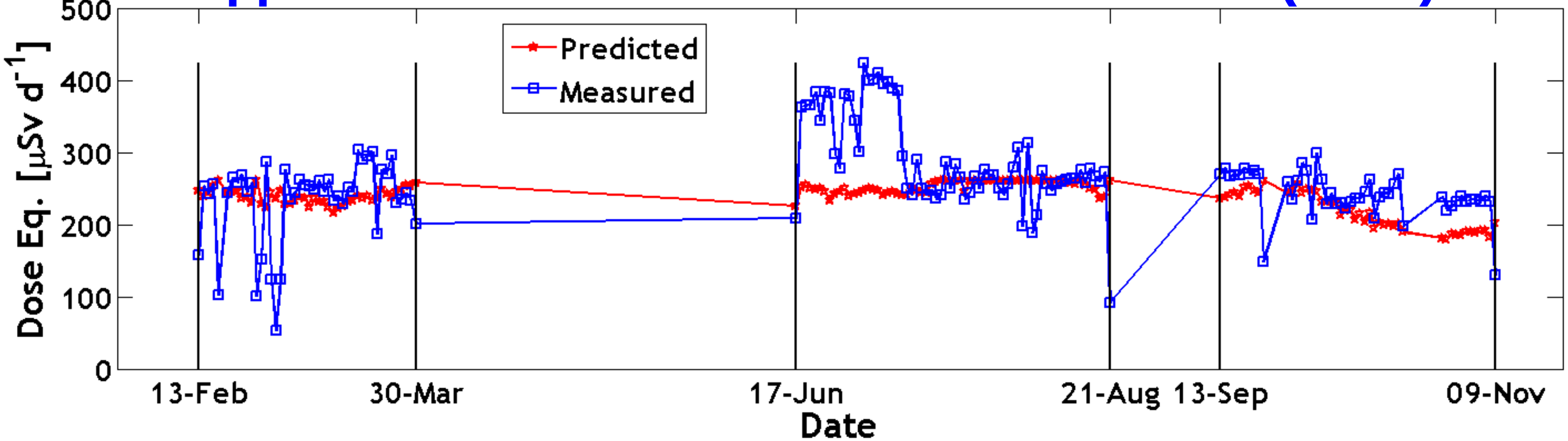
Trapped Radiation Dose Predictions at SM-327 (2007)



Benchmarking

Detector Orientation

Trapped Radiation Dose Predictions at SM-327 (2009)



TEPC detector orientation at SM-327 from February 13 to March 30, 2009

TEPC detector orientation at SM-327 from 17 June, 2009 to 8 July, 2009

TEPC detector orientation at SM-327 from July 9 to August 21, 2009

Effective Dose

- Want to get measure of the effective dose which is a protection quantity (biologically relevant dose).

Protection Quantity ← $E = \frac{\boldsymbol{E}}{\boldsymbol{H^*(10)}} H_{TEPC}$ → Operational Quantity

Space Radiation Environment
- AP8 model to simulate trapped protons
- CREME96 model to simulate GCR
- Examine solar maximum and minimum conditions

ISS Shielding Distribution
- Simple cylinder
- Complex geometry
- Examine wall thickness of 2 – 10 cm aluminum

PHITS Monte Carlo Simulations
- Transport radiation through ISS shielding

ICRP Fluence Conversion Factors
- Use ICRP-103 fluence conversion factors to find E/H*(10)

Effective Dose

How to calculate E/H*(10)?

- Particle and Heavy Ion Transport Code System (PHITS) Monte Carlo code used to transport radiation through a simple representation of the ISS.

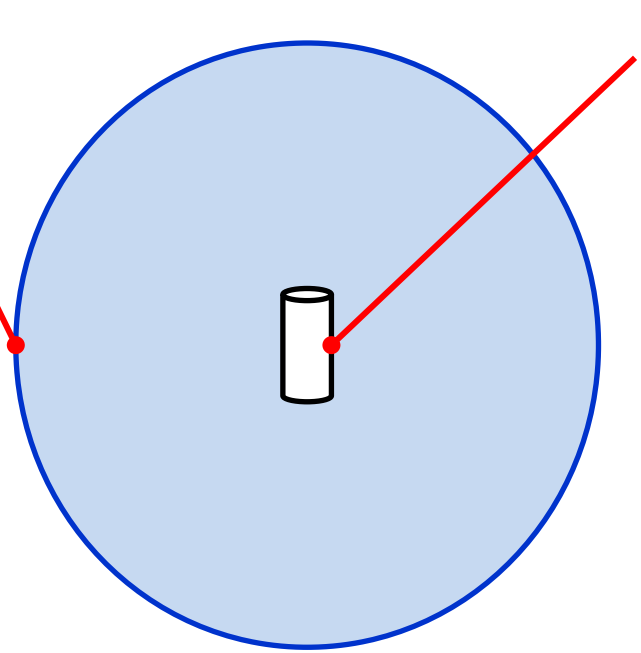
Simulating a spherical source with **isotropic** radiation environment inside

ISS Service Module approximated as a simple cylinder filled with air

Wall Thickness: 2, 4, 6, 10 cm Al

Length: 13 m

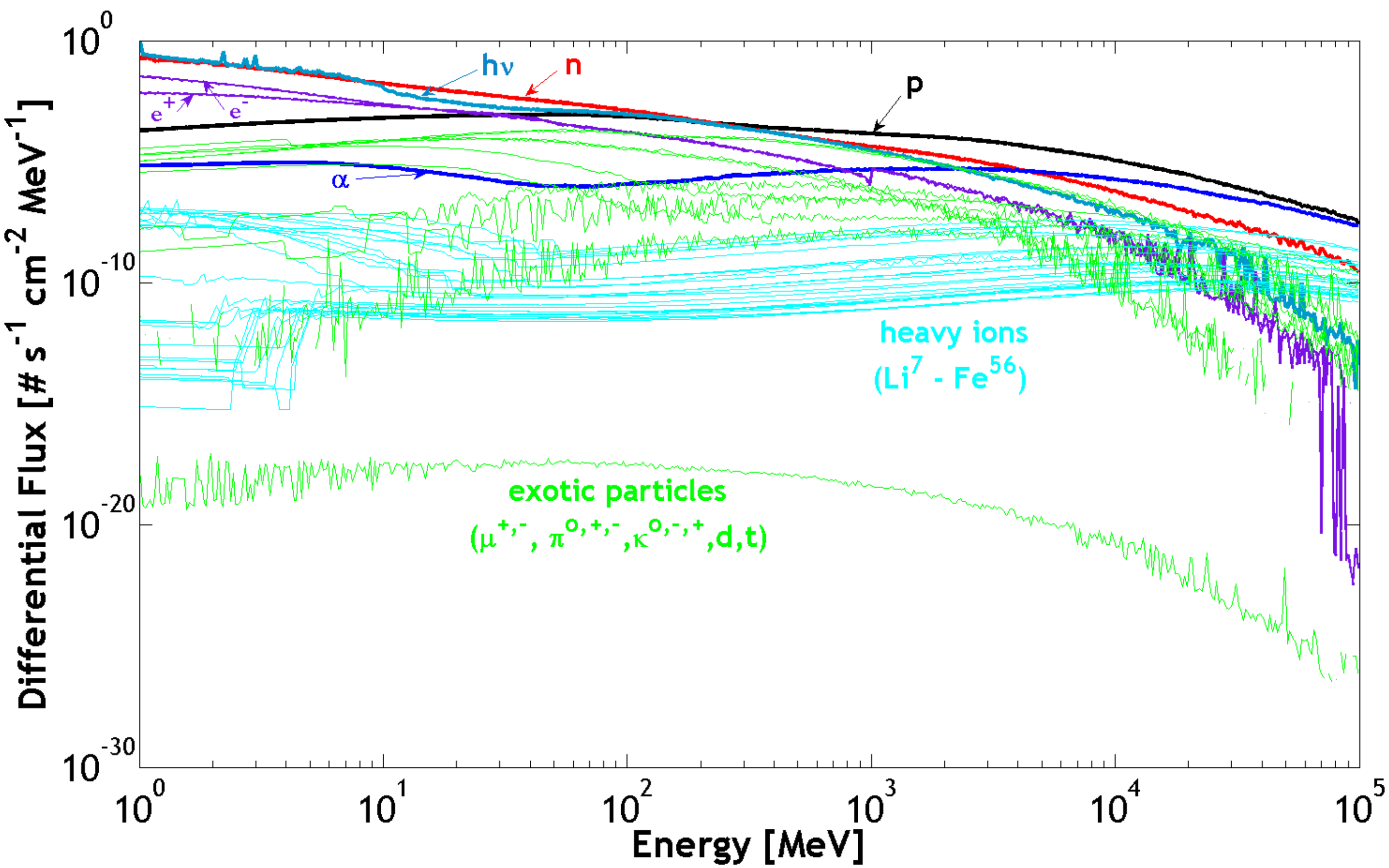
Diameter: 4.5 m



Effective Dose

How to calculate E/H*(10)?

- Primary and secondary particle flux distribution inside ISS modelled.
- Example flux distribution inside ISS (GCR at solar minimum incident on cylinder with 4 cm wall thickness).



Effective Dose

What was determined?

- Simulated trapped radiation H*(10) and E within factor of 2 of measured data and published works.
- Neglecting heavy-ion contribution from GCR exposures results in underestimation of H*(10) and E as confirmed before[1].
- Thicker shielding increases GCR H*(10) and E but decreases trapped radiation H*(10) and E.
- TEPC dose equivalent can be used as conservative estimate of effective dose based on simulations.

Trapped Radiation

$$\frac{E}{H^*(10)} = 0.25 \text{ to } 0.3$$

GCR

$$\frac{E}{H^*(10)} = 0.35 \text{ to } 0.65$$

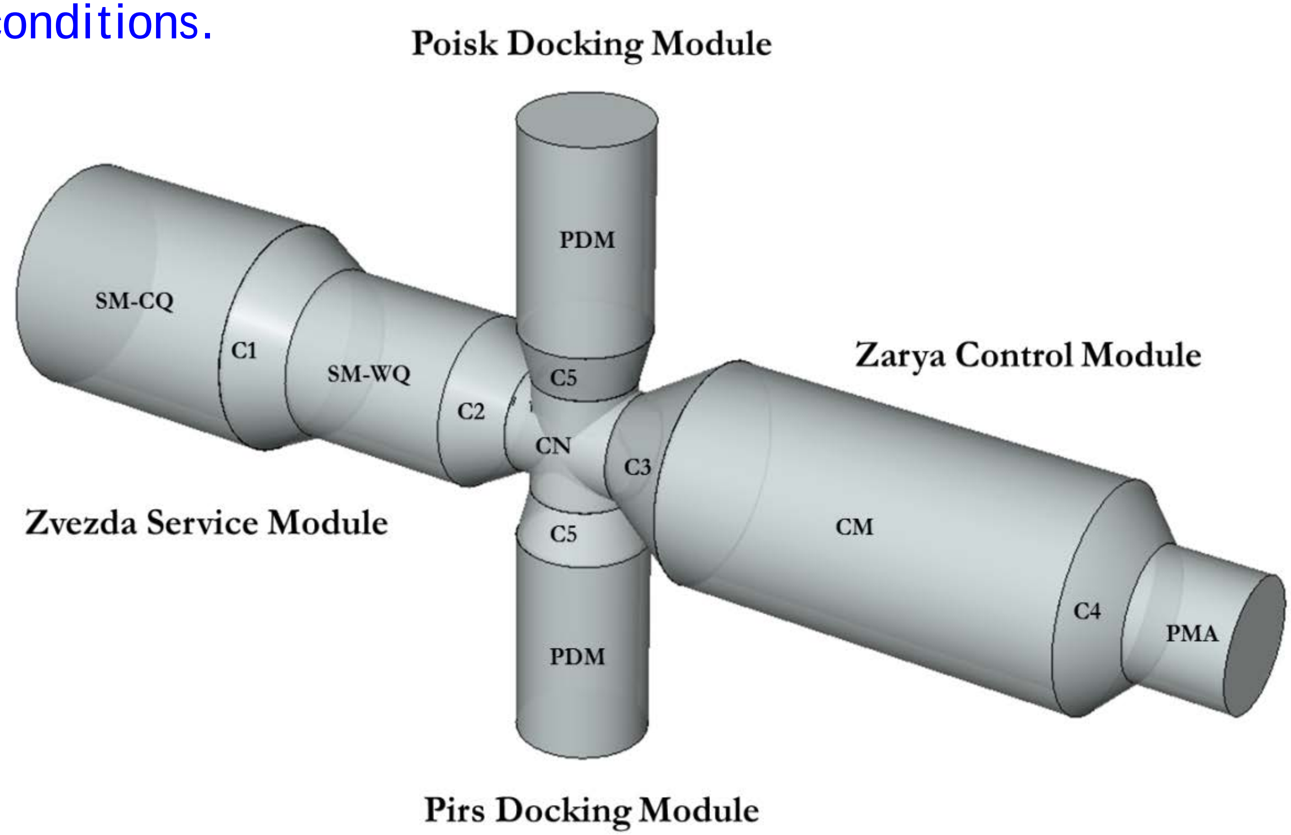
- Taking the ratio of the effective dose predicted by Sato[2] to the measured TEPC dose equivalent results in E/H(TEPC)= 0.5 to 0.6.

[1] Z. Kolísková (Mrázová), L. Sihver, I. Ambrožová, T. Sato, F. Spurný, and V. A. Shurshakov, Adv. Space Res. 49, 230-236 (2011
[2] T. Sato, A. Endo, L. Sihver, K. Niita, Radiat. and Environ. Biophysics, Vol. 50, pp. 115 – 123, 2011

Effective Dose

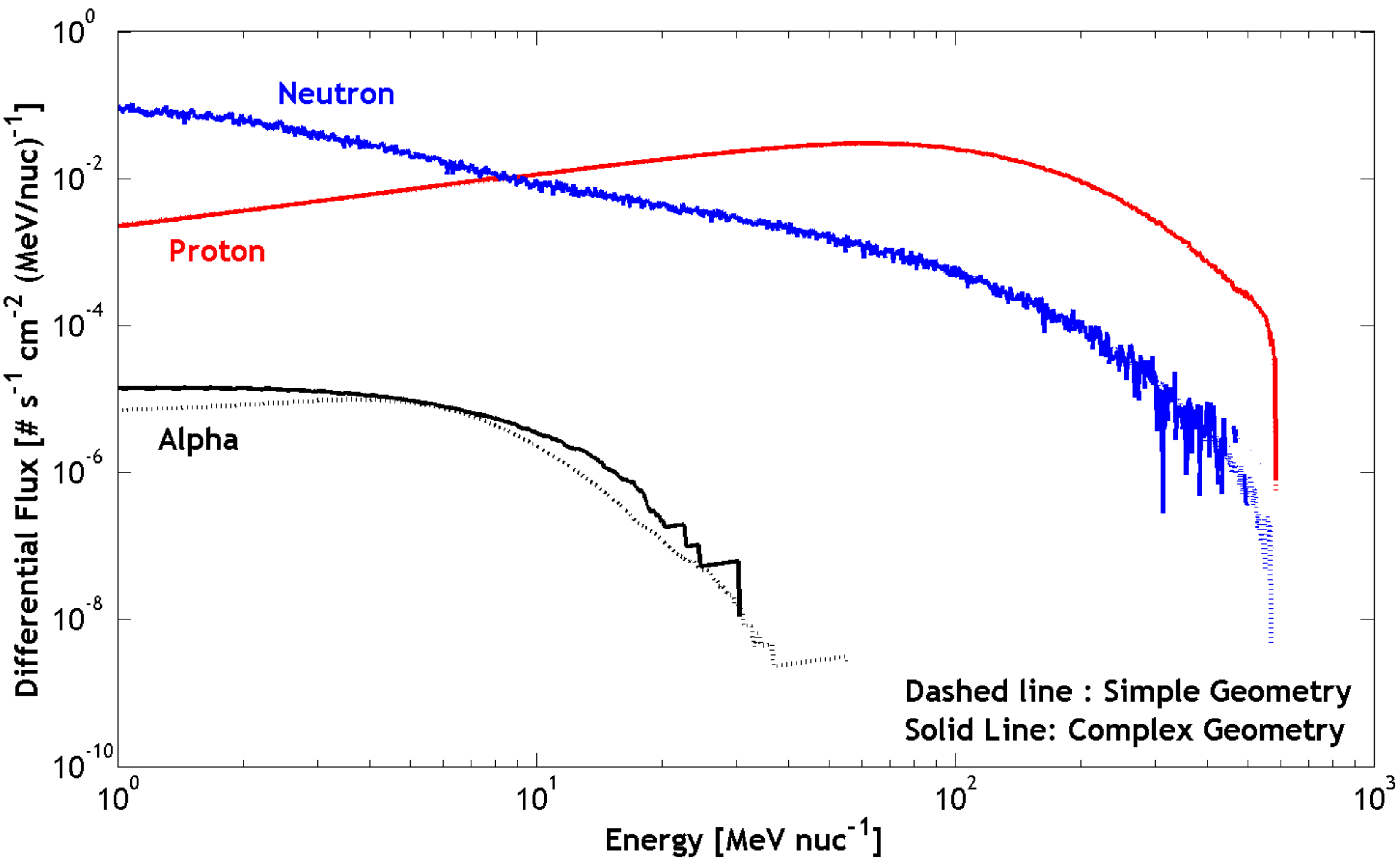
Comparisons made against a more complex geometry.

- Modeled complex geometry at 2 cm and 10 cm aluminum wall thicknesses.
- Simulated E/H*(10) for trapped radiation and GCR at solar minimum conditions.



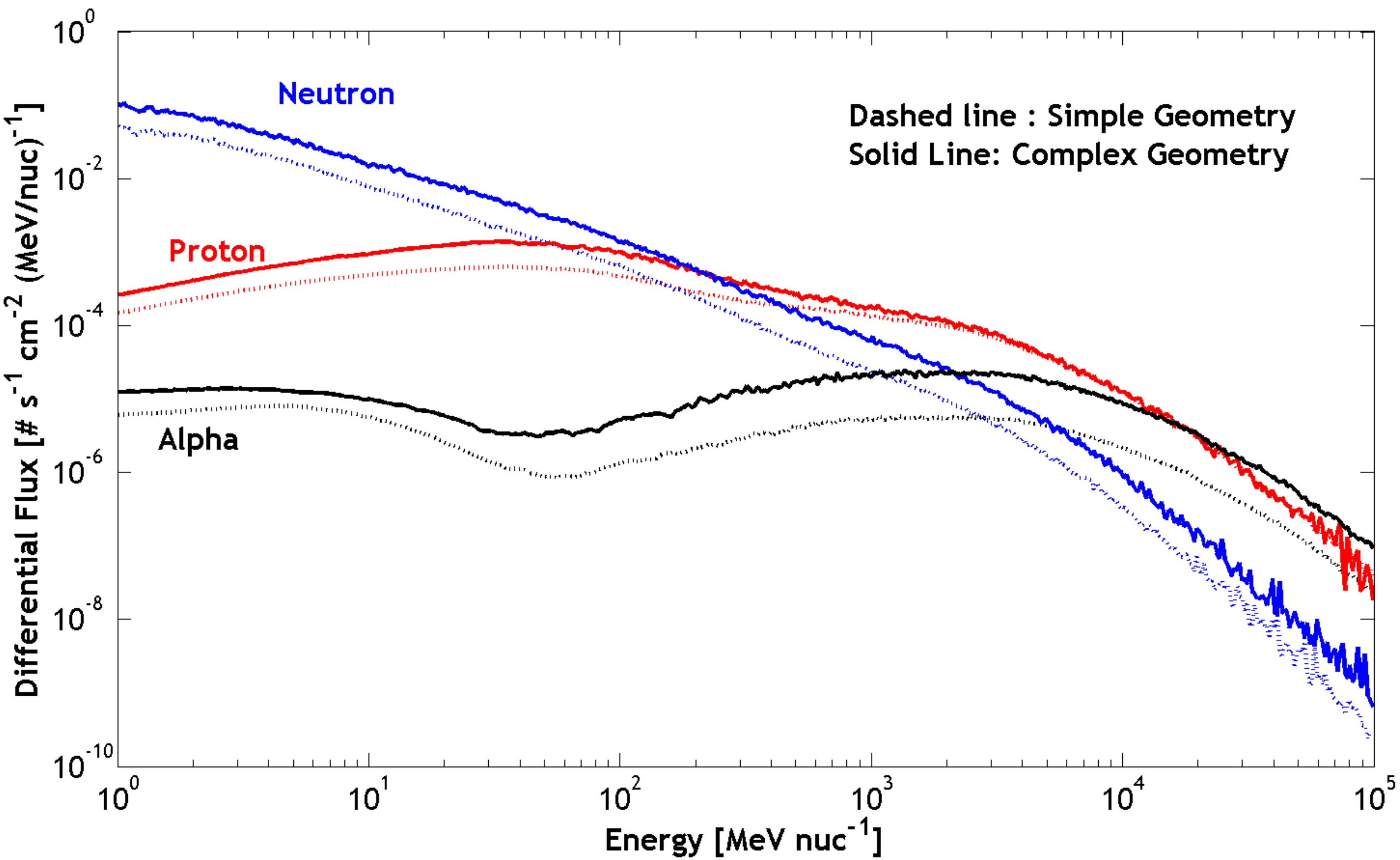
Effective Dose

Trapped radiation induced flux distribution at solar minimum incident on simple cylinder and complex representation of Service Module at 5.4 g cm^{-2} aluminum.



Effective Dose

GCR flux induced distribution at solar minimum incident on simple cylinder and complex representation of Service Module at 5.4 g cm^{-2} aluminum.



Effective Dose

Comparisons made against a more complex geometry.

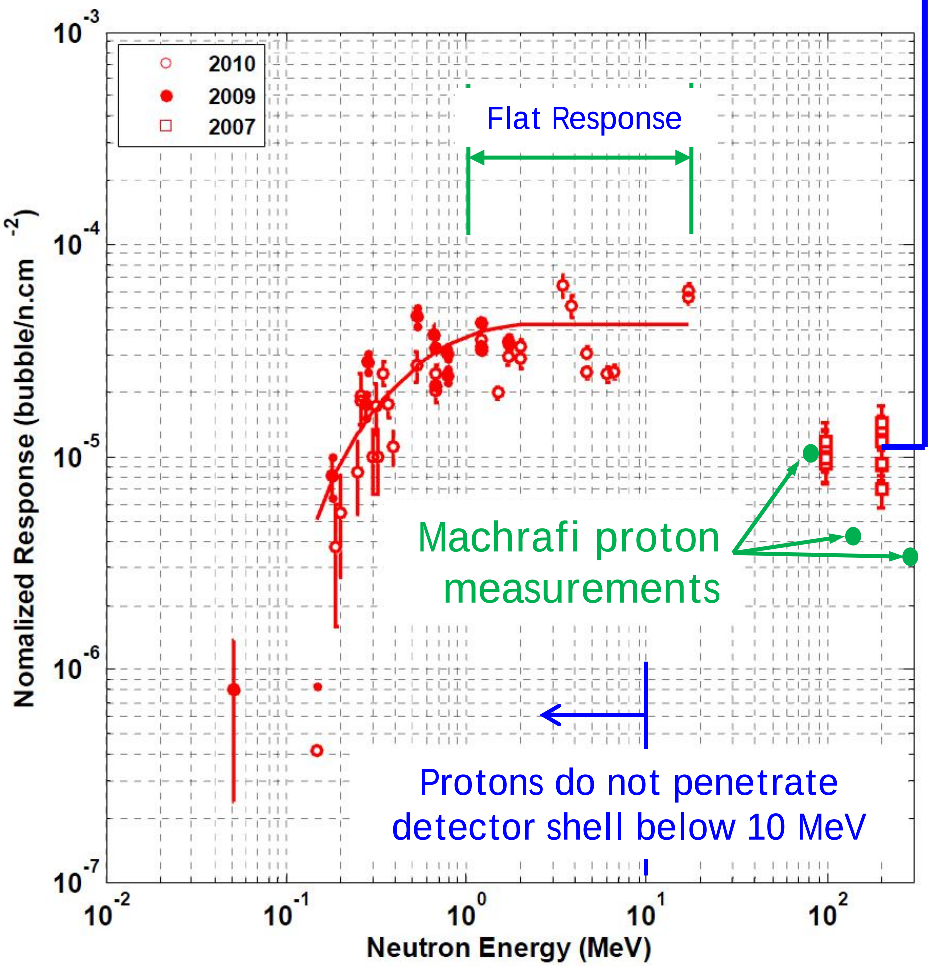
Wall Thickness (g cm^{-2})	Geometry	Trapped Proton H*(10) (Sv d^{-1})	Trapped Proton E (Sv d^{-1})	Trapped Proton E/H*(10)	Galactic Cosmic Radiation H*(10) (Sv d^{-1})	Galactic Cosmic Radiation E (Sv d^{-1})	Galactic Cosmic Radiation E/H*(10)
5.40	Complex	8.6e-04	2.2e-04	0.25	2.0e-04	1.3e-04	0.63
	Simple	8.5e-04	2.2e-04	0.25	1.0e-04	6.3e-05	0.63
27.0	Complex	1.5e-04	4.3e-05	0.29	4.3e-04	1.5e-04	0.36
	Simple	1.4e-04	4.1e-05	0.29	2.1e-04	7.4e-05	0.36

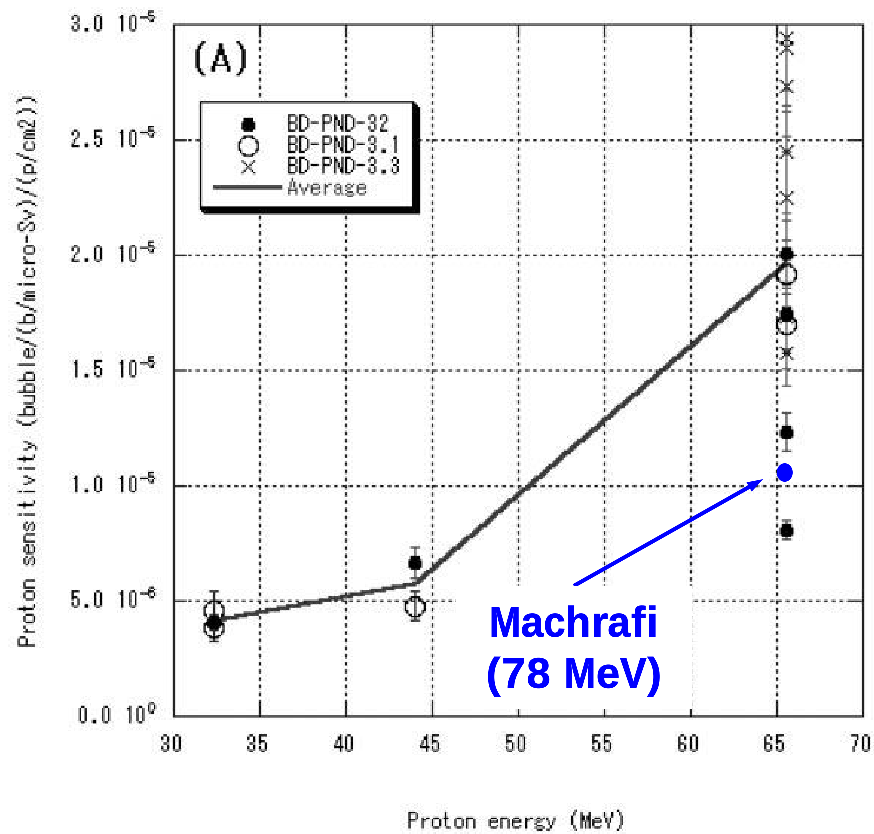
- E/H*(10) for GCR and TR remained same.
- Trapped radiation doses (ambient and effective) remained the same with complex geometry but GCR doses (ambient and effective) increased.
- Demonstrates that local shielding effects and module geometry play a role in modeling the amount of dose received (most work is done with simple geometries!)

Bubble Detector

Neutron and Proton Response Function

High energy data collected at iThemba (2007)



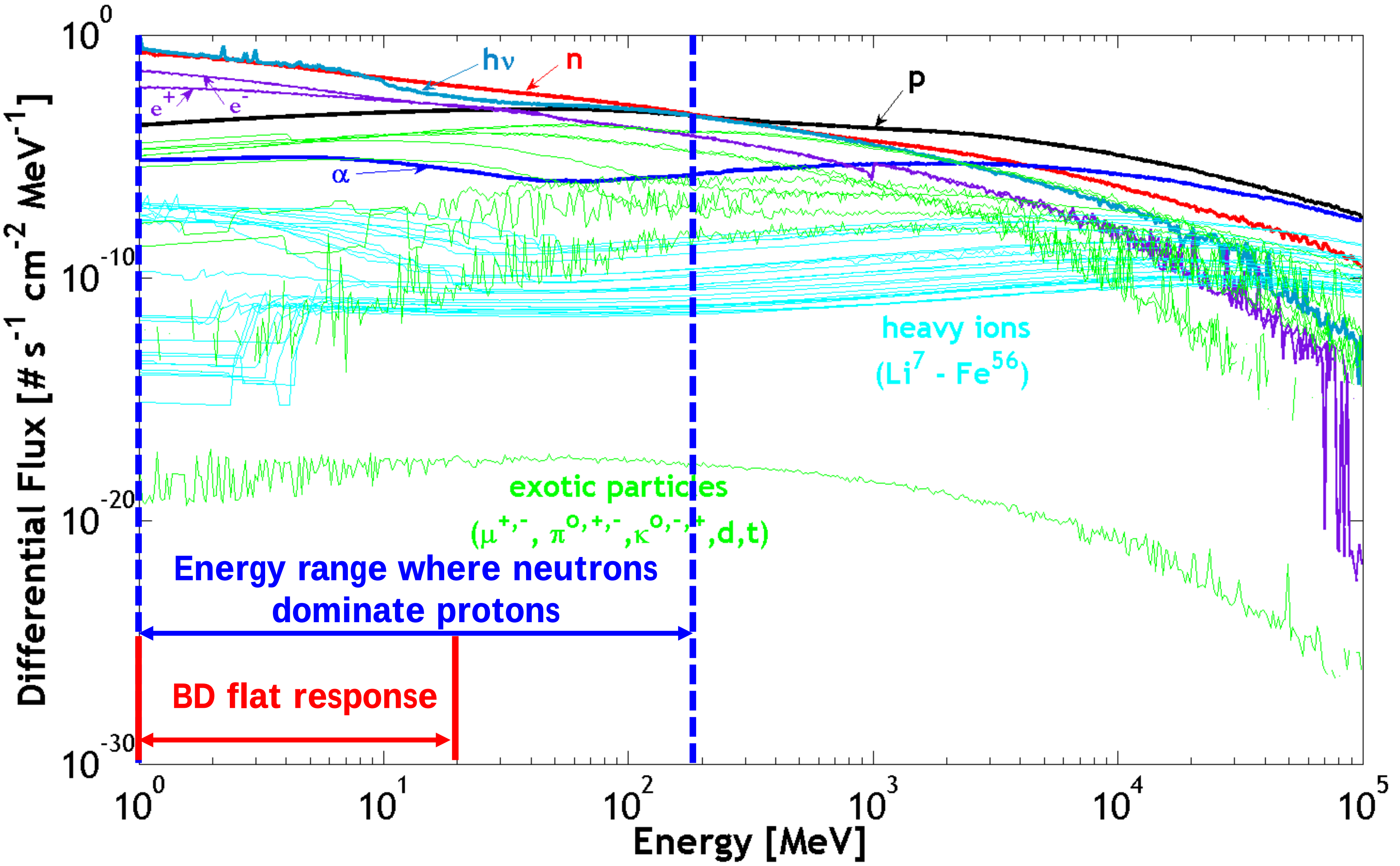


***Bubble Technology Industries, Report on Characterization of the Space Bubble Detector Spectrometer, March 31st 2010 (Detector sensitivity of 0.1 bubble μSv^{-1})**

***Takada et al, *Measured Proton Sensitivities of Bubble Detectors*, Radiation Protection Dosimetry, Vol. 111 (2), 181-189)**

Bubble Detector

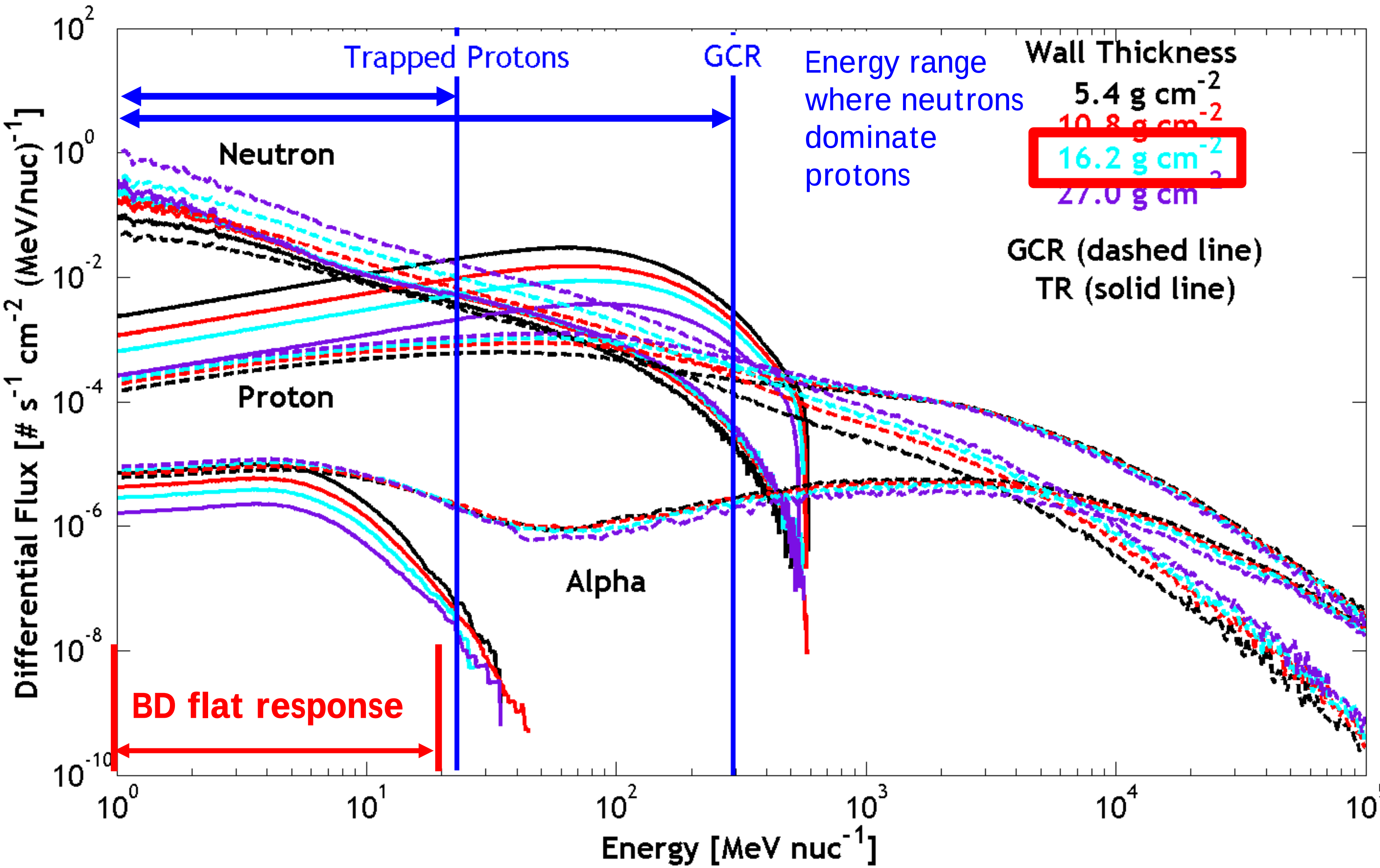
PHITS Analysis: Application to BD Interpretation



GCR induced flux distribution at solar minimum incident on simple cylinder representation of Service Module at 10.8 g cm^{-2} aluminum.

Bubble Detector

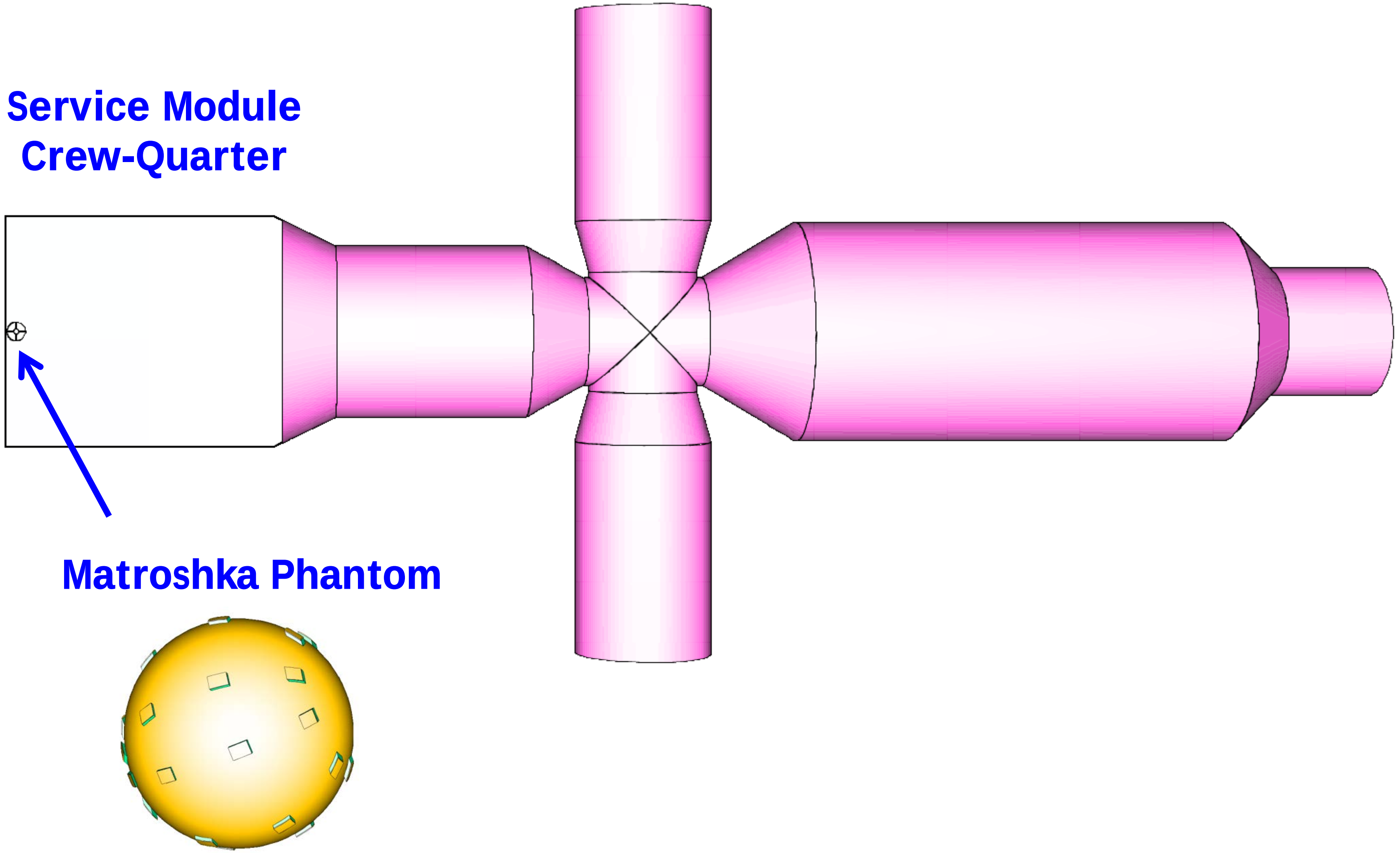
PHITS Analysis: Application to BD Interpretation



GCR and TR flux induced distribution at solar minimum inside simple cylinder geometry of Service Module at 2, 4, 6, and 10 cm wall thicknesses.

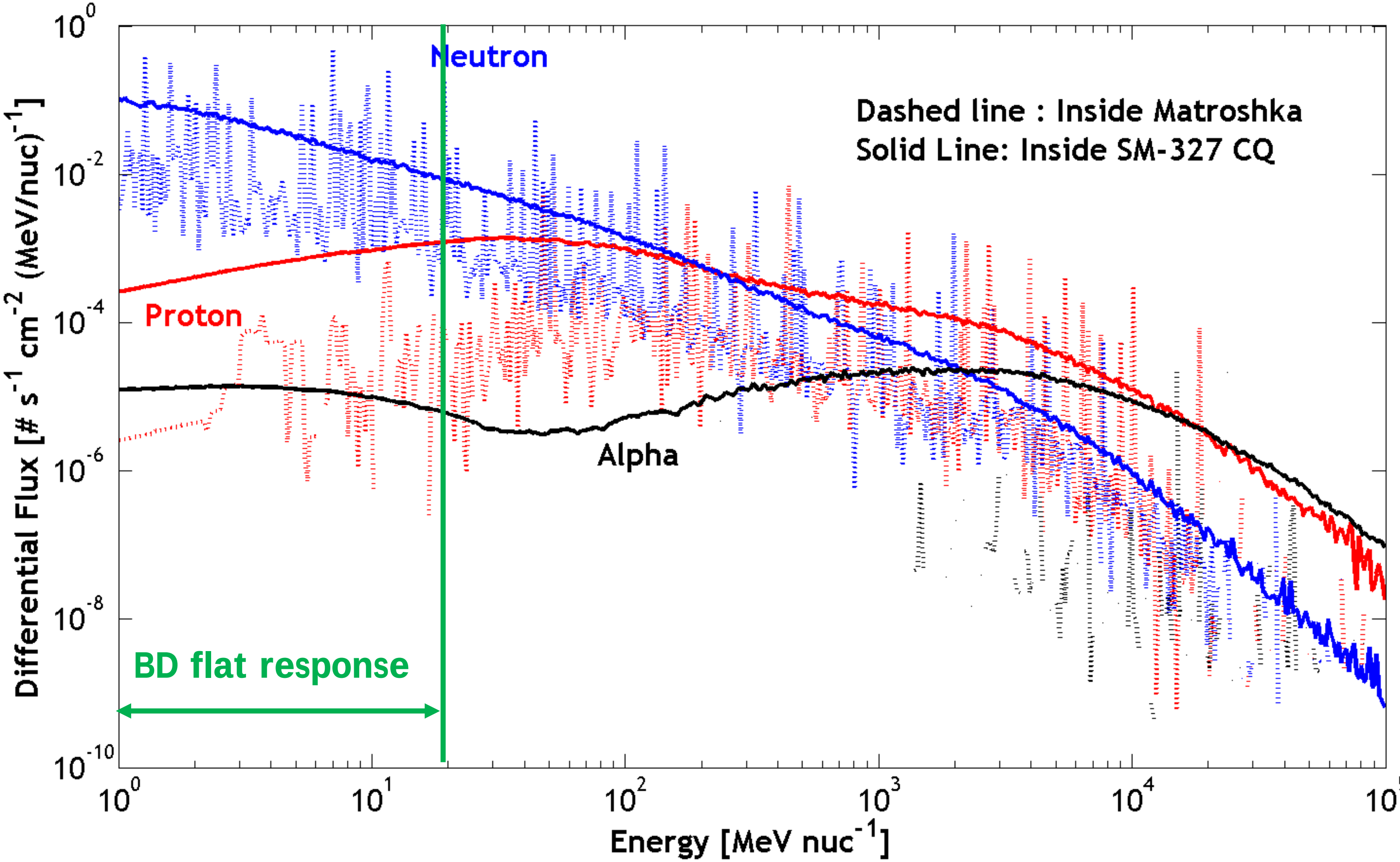
Bubble Detector

PHITS Analysis: Application to BD Interpretation



Bubble Detector

PRELIMINARY RESULTS



GCR flux induced distribution at solar minimum inside SM-327 CQ (complex geometry) and inside the air-cavity of the Matroshka phantom.

Conclusions

Principle Code

- Developed a predictive model which relates ISS crew dose rate to physical phenomena in LEO.
- Can predict GCR and trapped radiation TEPC dose equivalents to within ±10% and ±20% on a daily basis and for a total mission.
- Accuracy is robust over a solar cycle and shown to behave well given variations in solar activity input parameters (based on a sensitivity analysis).
- Model has been implemented into a user-friendly software.

Protection Quantity

- PHITS Monte Carlo simulations have demonstrated that the TEPC dose equivalent is an excellent operational quantity.
- Complex geometry and shielding shown to be significant modifier of effective doses but not $E/H^{*}(10)$ ratio.

Conclusions

Bubble Detector Response

- Over the operating energy-response range of the BD, neutrons are the principle component observed in the device (as supported by PHITS calculations)

- Preliminary results for GCR induced flux distribution inside Matrohska air cavity at solar minimum also suggest neutrons are still the dominant component.
    - This point is also detailed in proton and heavy ion calculations performed in: B. J. Lewis, M. B. Smith, H. Ing, H.R. Andrews, R. Machrafi, L. Tomi, T. J. Matthews, L. Veloce, V. Shurshakov, I. Tchernykh and N. Khoshooniy, **"Review of Bubble Detector Response Characteristics and Results from Space",** Radiation Protection Dosimetry, doi: 10.1093/rpd/ncr358, September 1, 2011.

- On-going work includes:
    - Model experimental setup of Matroshka setup (BD placement) and compare to measurements.
    - Model target fragmentation in Matroshka phantom and BD

Future Work

- Implement ISSCREM into lower-level computer language.
- Implement SPEs into model.
- As new TEPC is collecting data, scale the current and new TEPC to determine localized shielding conditions.
- Improve trapped model as more data is gathered.
- Model response of TEPC to mixed radiation field (heavy-ions).
- Improve model of the ISS shielding distribution for use into Monte Carlo simulations.

Supplemental Slides

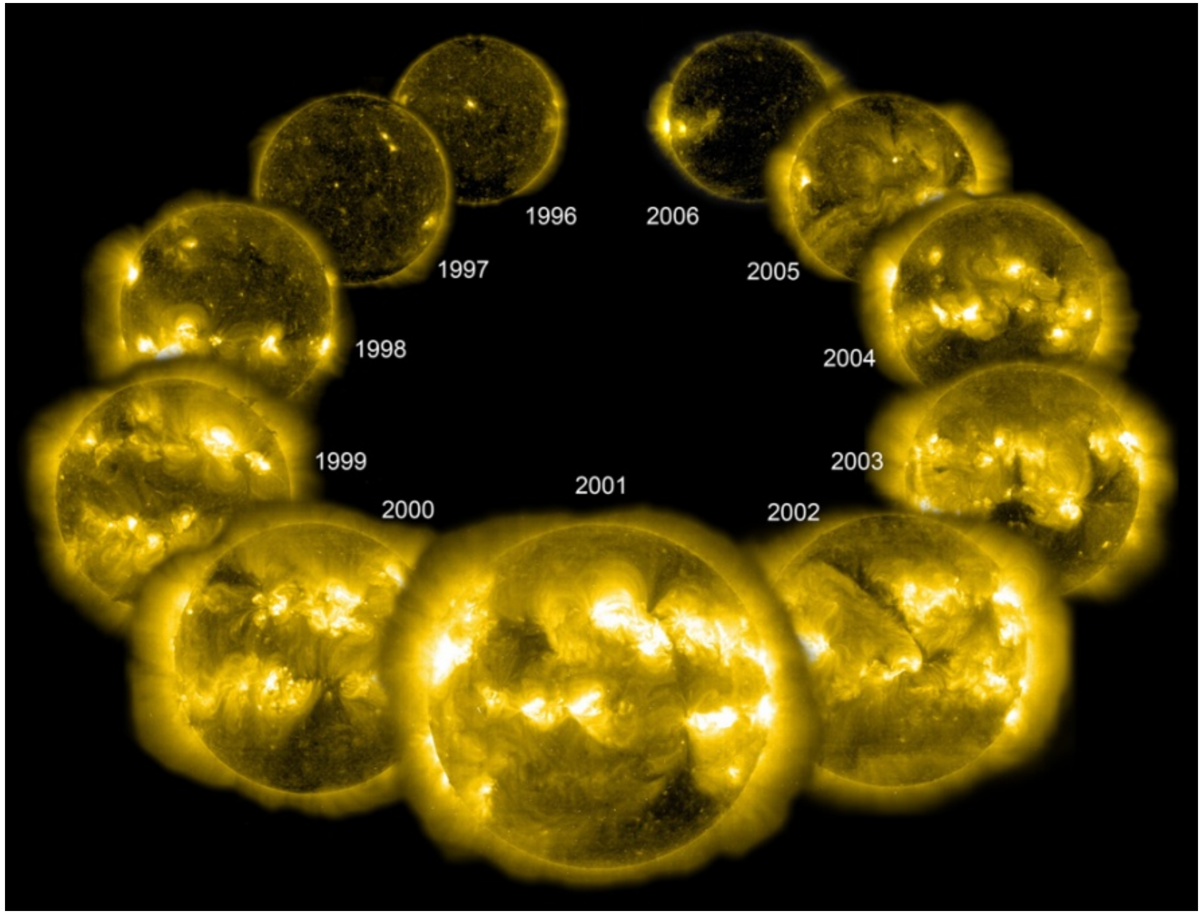
Motivation

State-of-the-Art Models

- A qualitative approach is taken to predict the expected dose space-crew are to receive aboard ISS.
- Current efforts are focused on modelling the radiation environment outside and inside the ISS.
    - HZETRN
    - SHIELDOSE
    - EVADOSE
    - DESIRE
    - CREME (GCR Environment)
    - AP8/AE8 (Trapped Environment)
- Empirical models have been developed for predicting dose aboard U.S. Space Shuttle and Mir Space Station.
- No truly predictive model exists for ISS mission planning.

Model Development

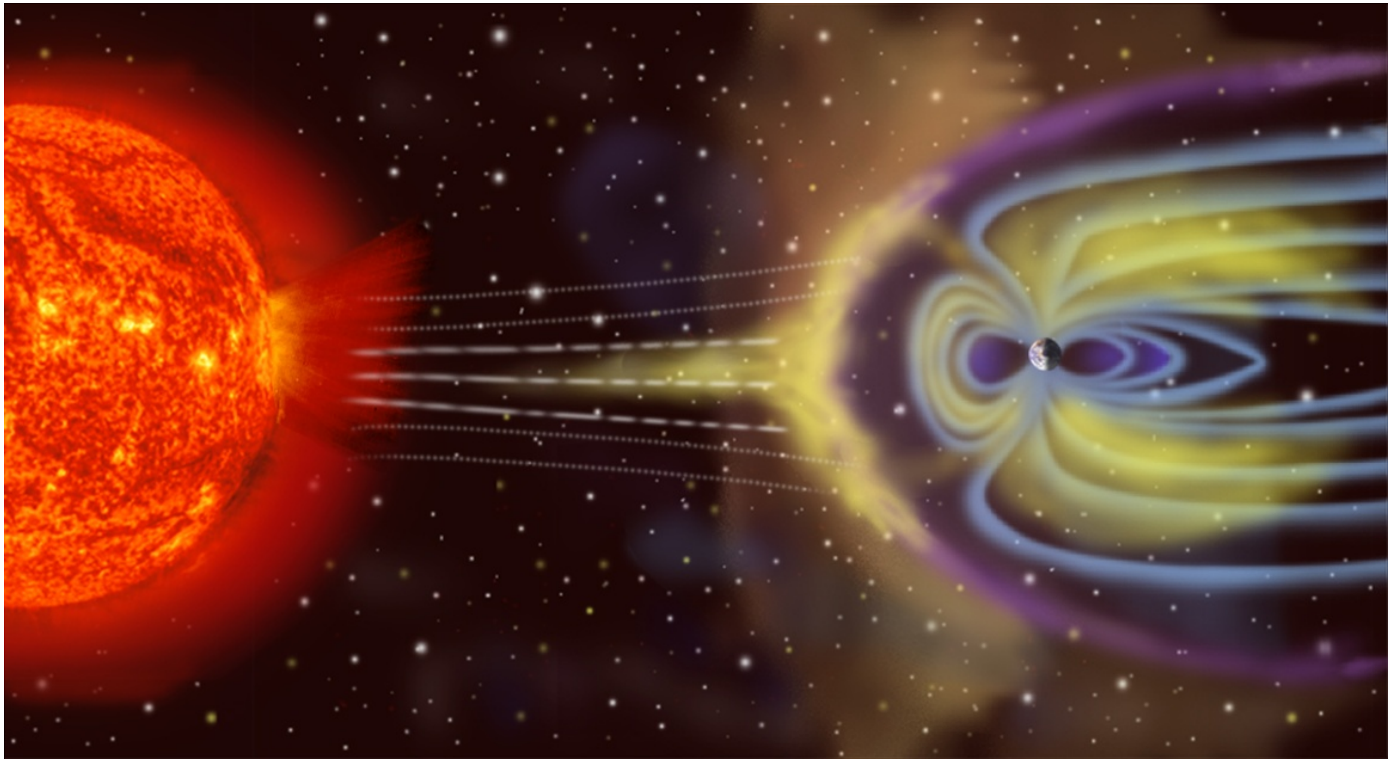
Why use 2001 and 2008 TEPC data for model development?



- Sun follows 11 year cycle of solar activity.
- 2001 represents solar maximum conditions while 2008 represents solar minimum conditions.

Model Development

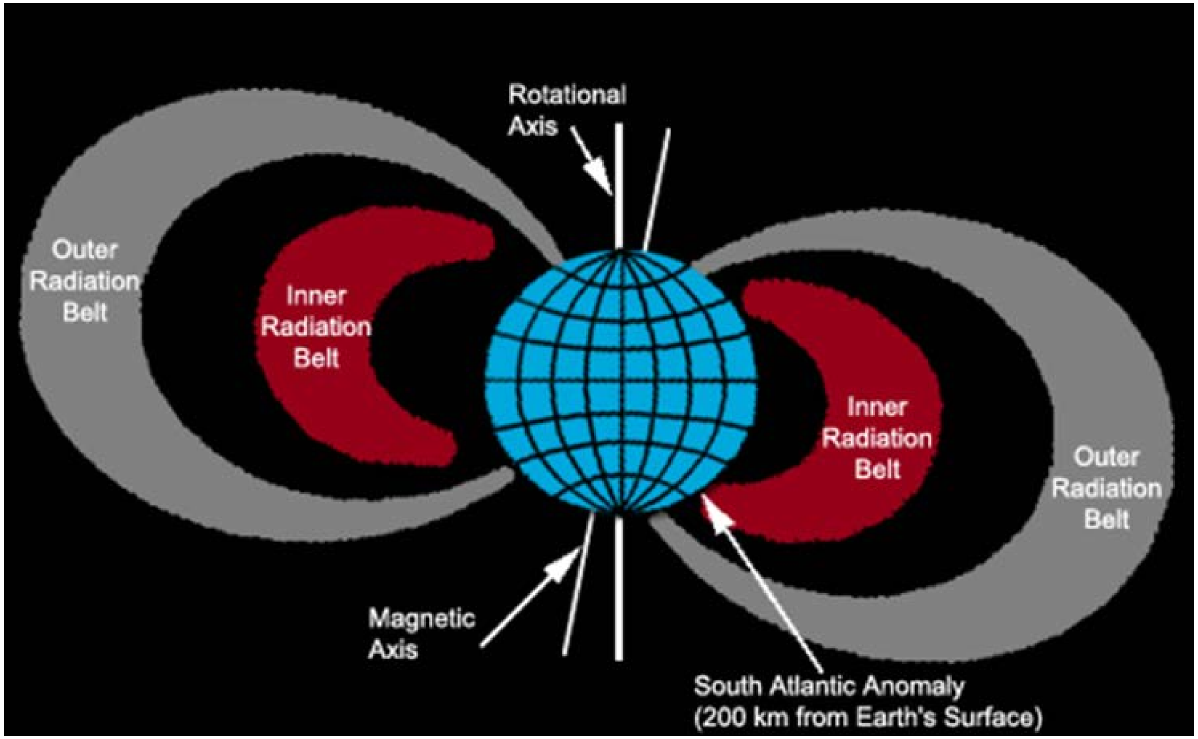
Why is solar activity important for GCR dose?



- Solar wind extends beyond the solar system and acts as barrier for GCR ions.
- The Earth's magnetosphere deflects incoming ions.

Model Development

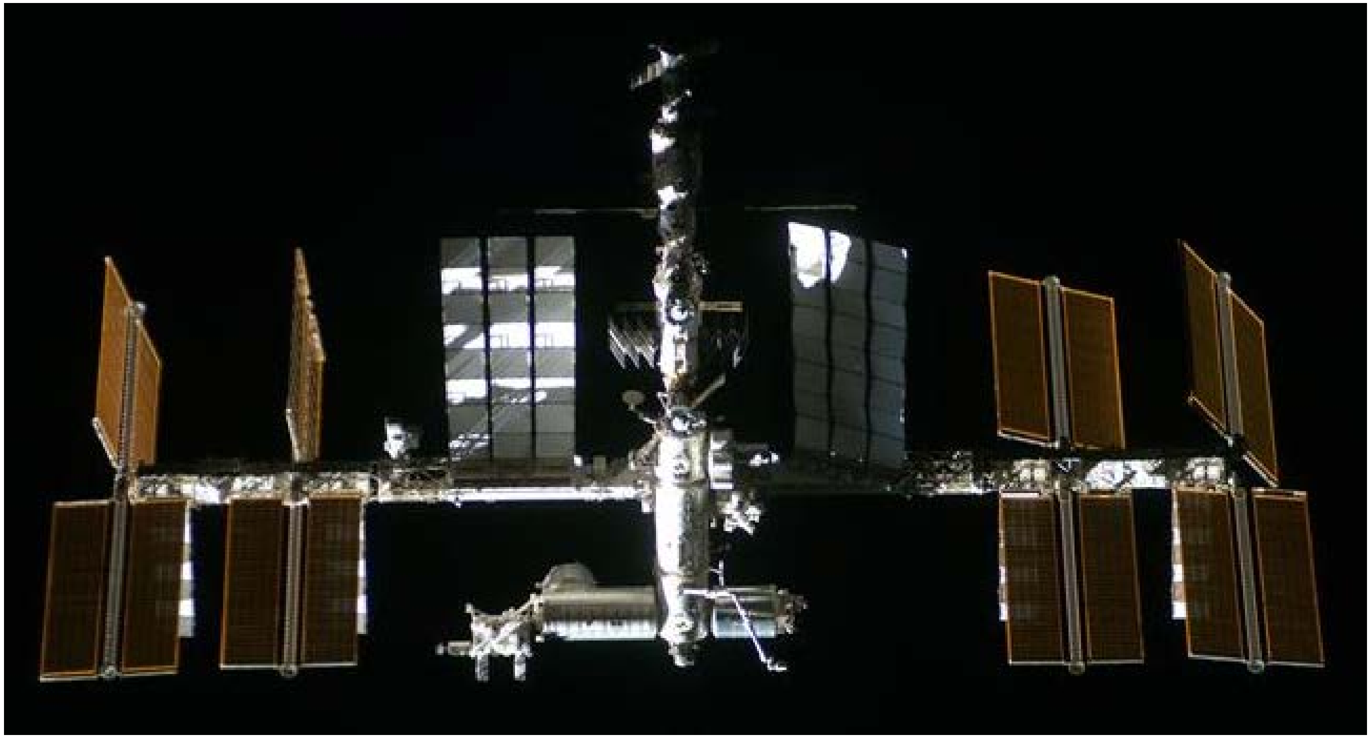
Why is solar activity important for trapped radiation dose?



- South Atlantic Anomaly (SAA) is a dip in the Earth's magnetic field.
- Trapped radiation exposure is limited to within the SAA.
- Increase in solar activity results in increased atmospheric density and less trapped radiation dose.

Model Development

What other factors do we need to consider?



- ISS modules have different shielding distributions due to different construction and distribution of equipment inside them.
- Adjacent modules can also influence shielding.

Benchmarking

Sensitivity Analysis

- Varied solar activity input parameters to test the effect on predicted dose.
    - Varied F10.7 by up to ±50%.
    - Varied Ap magnetic index from quiet to very disturbed conditions.
    - Varied U by up to ±20% as well as extreme conditions (i.e. solar max. or min.).
    - Varied the extent of SAA.
- Space Weather Prediction Center offers 45 day lead-time predictions of F10.7 and Ap magnetic index.
- ISS orbit is well defined.

Benchmarking

Dose Type	% Variation from True F107	% Difference from Measured Dose			
		2000	2007	2009	2010
Total TR	-50	-43	-34	0	-10
	-20	-5	-14	2	4
	-10	5	-6	4	12
	+10	10	5	13	22
	+20	10	9	18	26
	+50	10	20	30	36
Ascending Pass TR	-50	-30	-29	-1	-13
	-20	-10	-14	2	-7
	-10	0	-7	4	0
	+10	0	0	11	7
	+20	0	4	14	13
	+50	0	7	22	20
Descending Pass TR	-50	-70	-41	-9	-21
	-20	-30	-22	-3	8
	-10	-20	-14	2	13
	+10	0	-3	12	23
	+20	0	3	16	26
	+50	0	14	27	36

Benchmarking

		% Difference from Measured Dose			
Dose Type	**Ap Index**	**2000**	**2007**	**2009**	**2010**
Total TR	400	14	27	43	41
	100	14	16	25	29
	50	14	11	20	25
	25	14	6	16	22
	0	5	-6	6	12
Ascending Pass TR	400	0	7	31	23
	100	0	4	19	17
	50	0	0	15	10
	25	0	0	12	10
	0	0	-7	6	0
Descending Pass TR	400	0	30	41	38
	100	0	11	23	28
	50	0	5	18	26
	25	-10	0	14	23
	0	-10	-14	3	15

Benchmarking

	% Difference from Measured Dose				
% Variation from True U	2000	2002	2007	2009	2010
-20	-9	-5	N/A		N/A
-10	-7	-4	3		2
+10	0	0	0	N/A	0
+20	N/A	N/A	4		3
Previous Year	N/A	N/A	4		2
Solar Maximum	-7	-3	11	11	11
Solar Minimum	-17	-13	3	3	2

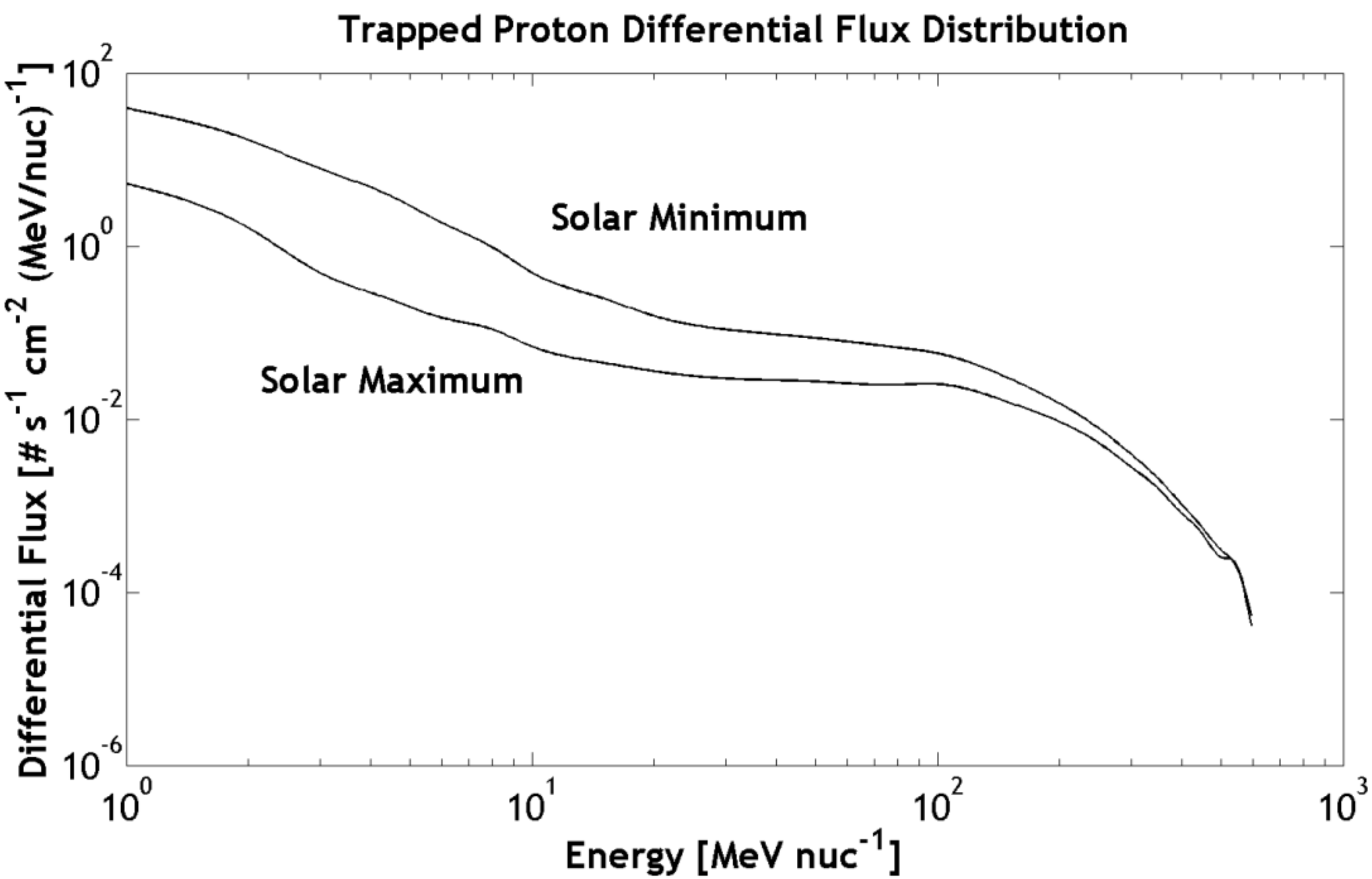
Benchmarking

		% Difference from Measured Dose			
Dose Type	**SAA Contour Line ($\mu Sv\ min^{-1}$)**	**2000**	**2007**	**2009**	**2010**
GCR	0.6	-4	-4	3	-3
	0.3	0	1	7	2
	0	2	3	9	4
Total TR	0.6	10	0	9	17
	0.3	10	-2	7	16
	0	10	0	8	14
Ascending Pass TR	0.6	0	-4	7	3
	0.3	0	-7	4	3
	0	0	-4	4	3
Descending Pass TR	0.6	0	-8	6	18
	0.3	0	-8	6	18
	0	0	-11	6	18

Effective Dose

Input Trapped Radiation Flux Distribution

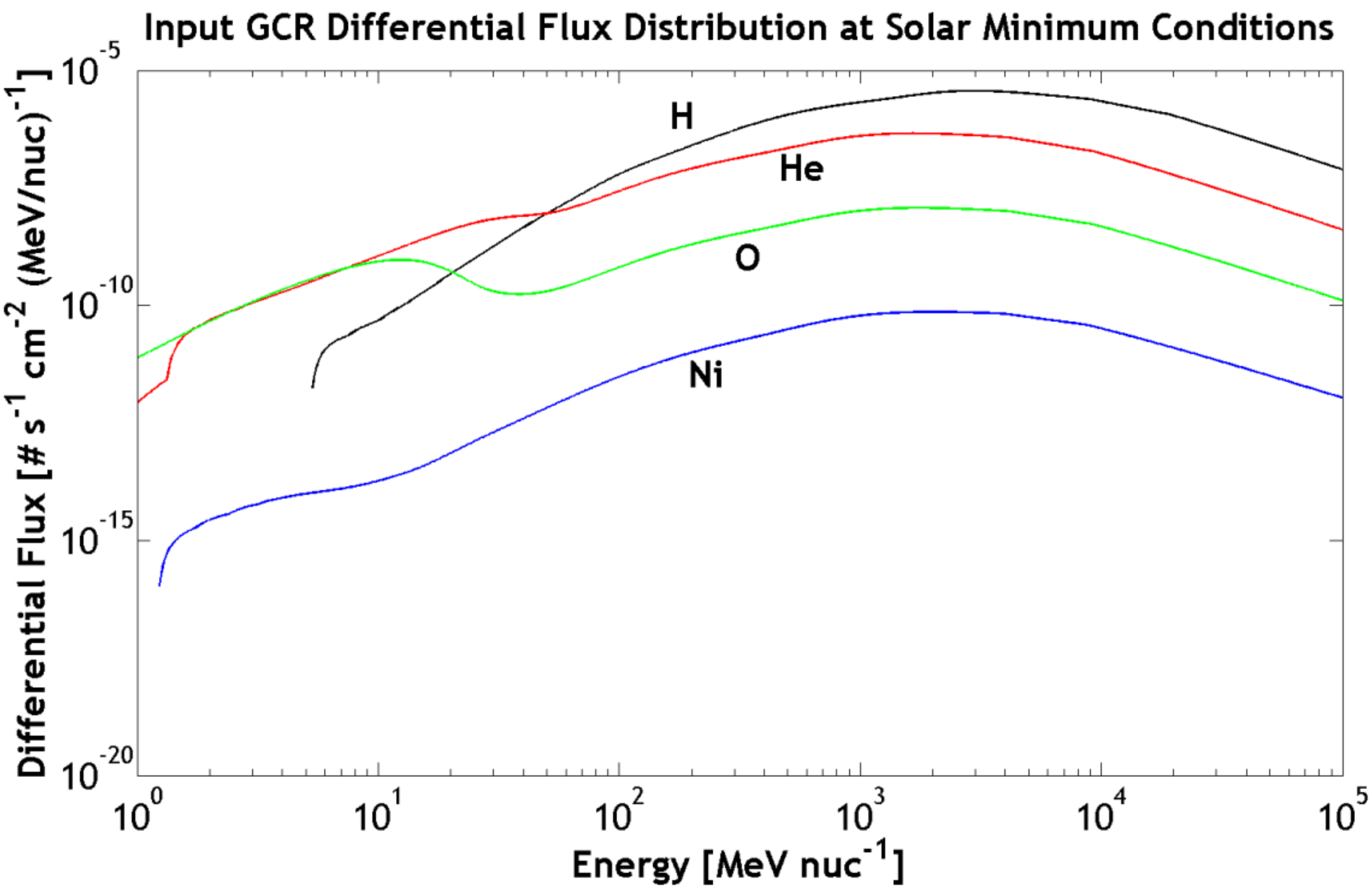
- AP8 model used to simulate trapped protons at solar maximum and minimum conditions.



Effective Dose

Input GCR Flux Distribution

- CREME96 model used to simulate GCR at solar maximum and minimum conditions.



Effective Dose

Trapped radiation effective-to-ambient dose equivalent conversion factors at solar maximum and solar minimum conditions incident on a simple aluminum cylinder as a function of wall thickness.

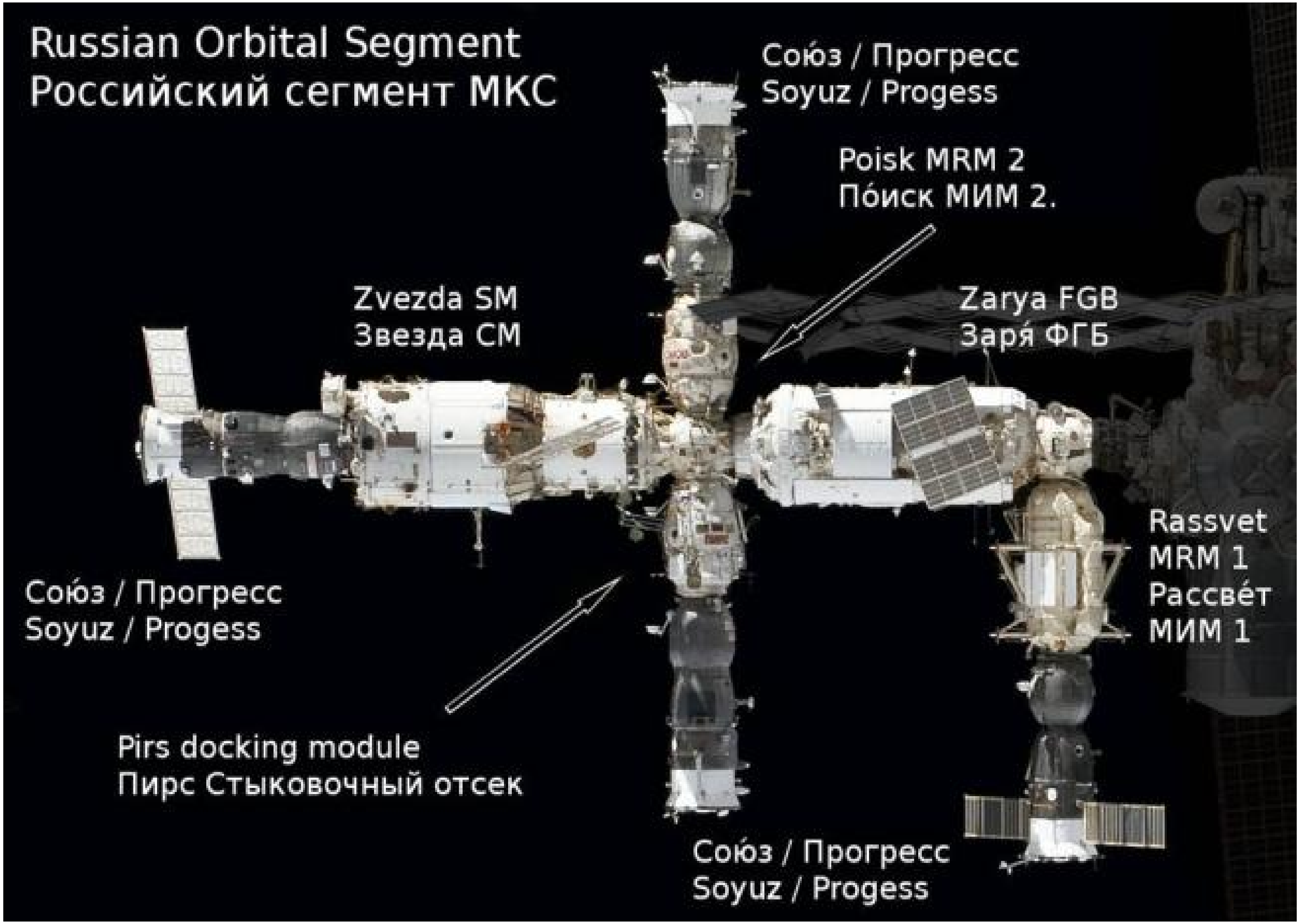
	Solar Maximum			Solar Minimum		
Wall Thickness (g cm^{-2})	H*(10) (Sv d^{-1})	E (Sv d^{-1})	E/H*(10)	H*(10) (Sv d^{-1})	E (Sv d^{-1})	E/H*(10)
5.40	4.23e-04	1.26e-04	0.30	8.52e-04	2.17e-04	0.25
10.8	2.63e-04	8.21e-05	0.31	4.69e-04	1.31e-04	0.28
16.2	1.76e-04	5.65e-05	0.32	2.92e-04	8.52e-05	0.29
27.0	9.40e-05	2.93e-05	0.31	1.43e-04	4.13e-05	0.29

Effective Dose

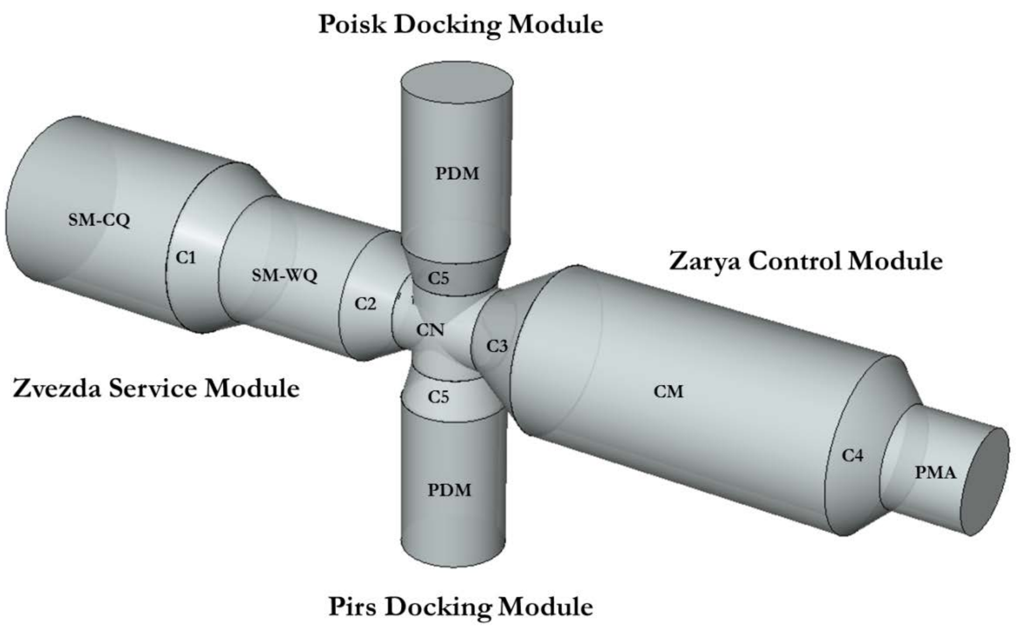
GCR effective-to-ambient dose equivalent conversion factors at solar maximum and solar minimum conditions incident on a simple aluminum cylinder as a function of wall thickness.

	Solar Maximum			Solar Minimum		
Wall Thickness (g cm^{-2})	H*(10) (Sv d^{-1})	E (Sv d^{-1})	E/H*(10)	H*(10) (Sv d^{-1})	E (Sv d^{-1})	E/H*(10)
5.40	5.98e-5	3.92e-5	0.65	1.00e-4	6.34e-5	0.63
10.8	7.94e-5	4.22e-5	0.53	1.28e-4	6.71e-5	0.52
16.2	9.90e-5	4.47e-5	0.45	1.56e-4	7.01e-5	0.45
27.0	1.37e-4	4.84e-5	0.35	2.07e-4	7.42e-5	0.36

Effective Dose

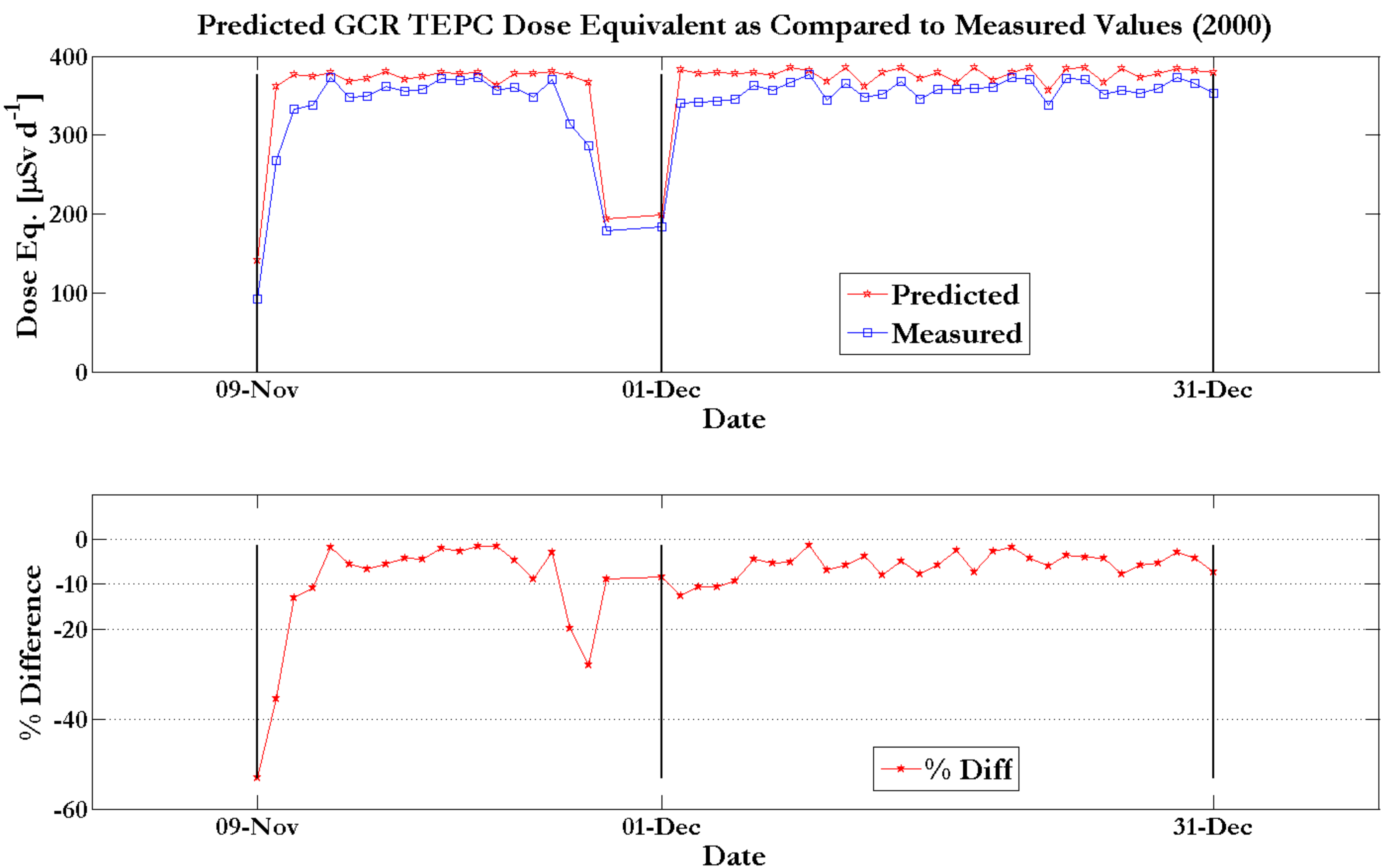


Effective Dose



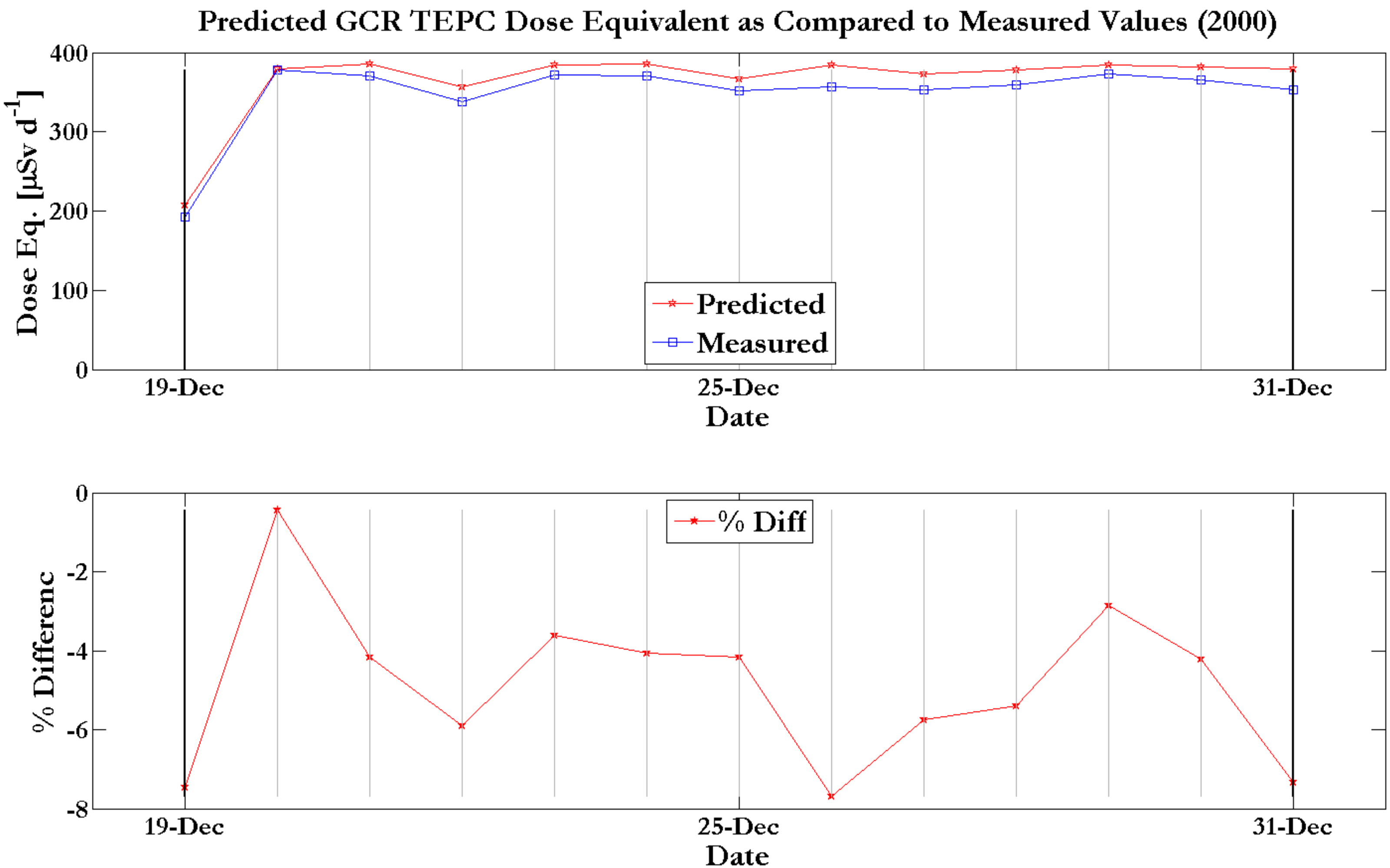
Complex representation of Zvezda Service Module (SM)[65] including Crew Quarters (SM-CQ) and Working-Quarters (SM-WQ) and neighboring Zarya Control Module (CM) [66], and Poisk and Pirs Docking Modules (PDM) [67]. Dimensions of modules in meters (length l, diameter d): SM-CQ (5.07,4.34), SM-WQ (3.57,3.22), CN (2.23,2.02), CM(7.98,4.1), PMA(1.91,2.4), PDM(3.96,2.54). Length of connecting cones in meters: C1(1.15), C2(1.09), C3(1.74), C4(0.87), C5(0.95).

2000



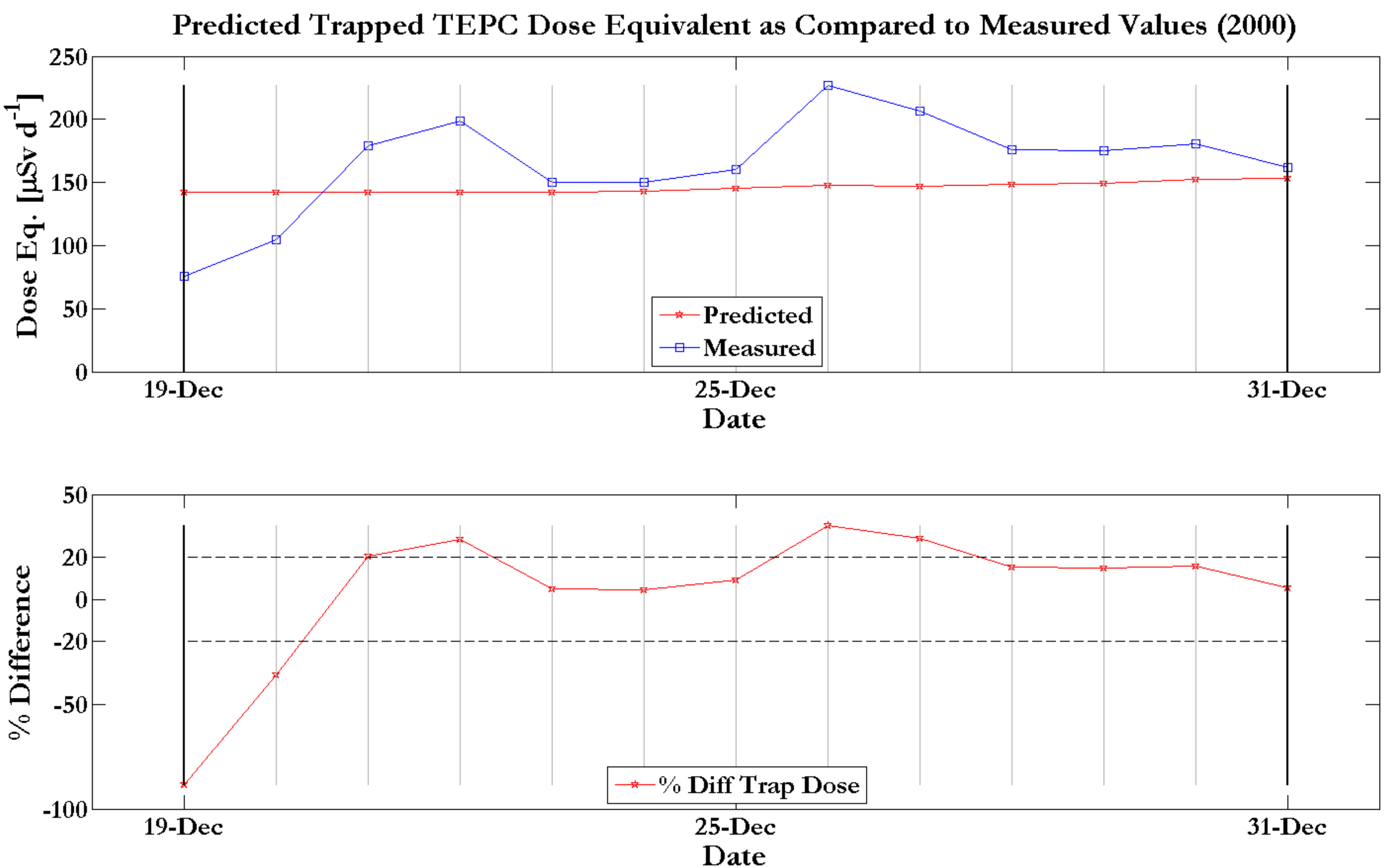
Predicted GCR TEPC Dose Equivalent as Compared to Measured Values (2000)
Dose Eq. [µSv d^{-1}]
400
300
200
100
0
Predicted
Measured
09-Nov
01-Dec
31-Dec
Date
% Difference
0
-10
-20
-40
-60
% Diff
09-Nov
01-Dec
31-Dec
Date

2000 SM-327



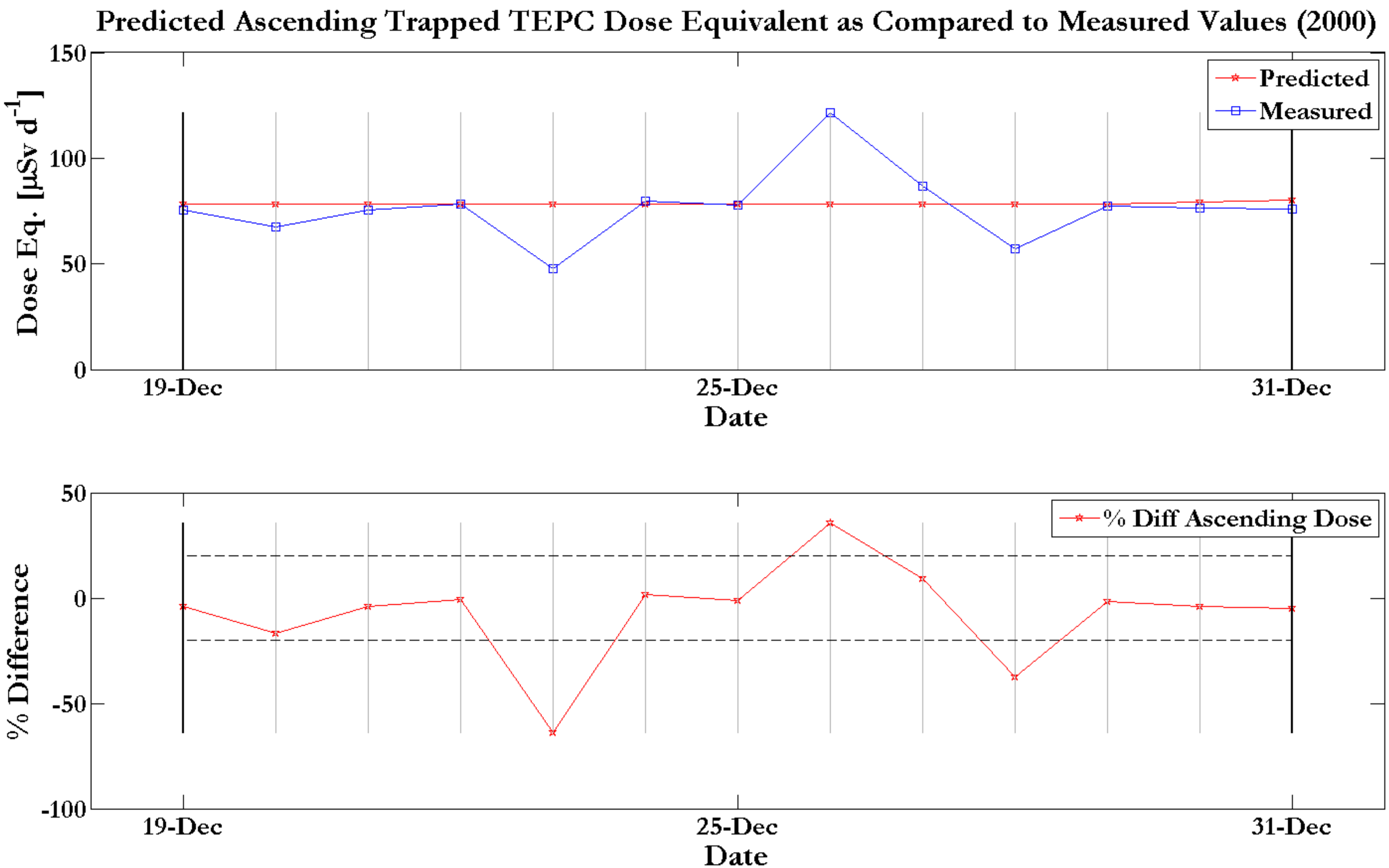
Predicted GCR TEPC Dose Equivalent as Compared to Measured Values (2000)
Dose Eq. [μSv d-1]
400
300
200
100
0
Predicted
Measured
19-Dec
25-Dec
31-Dec
Date
0
-2
-4
-6
-8
% Differenc
% Diff
19-Dec
25-Dec
31-Dec
Date

2000 SM-327



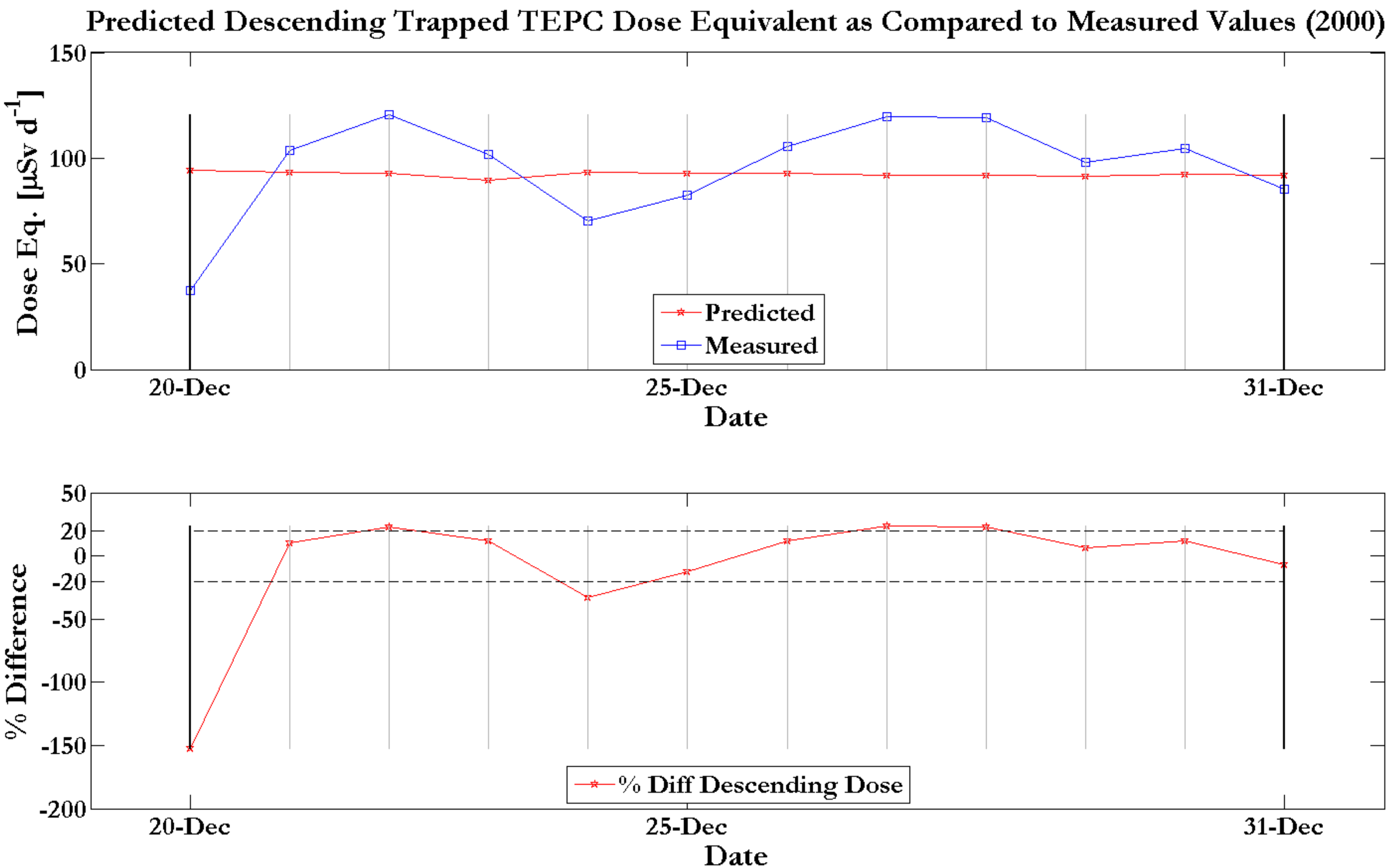
Predicted Trapped TEPC Dose Equivalent as Compared to Measured Values (2000)
Dose Eq. [µSv d-1]
250
200
150
100
50
0
19-Dec
25-Dec
31-Dec
Date
Predicted
Measured
% Difference
50
20
0
-20
-50
-100
19-Dec
25-Dec
31-Dec
Date
% Diff Trap Dose

2000 SM-327



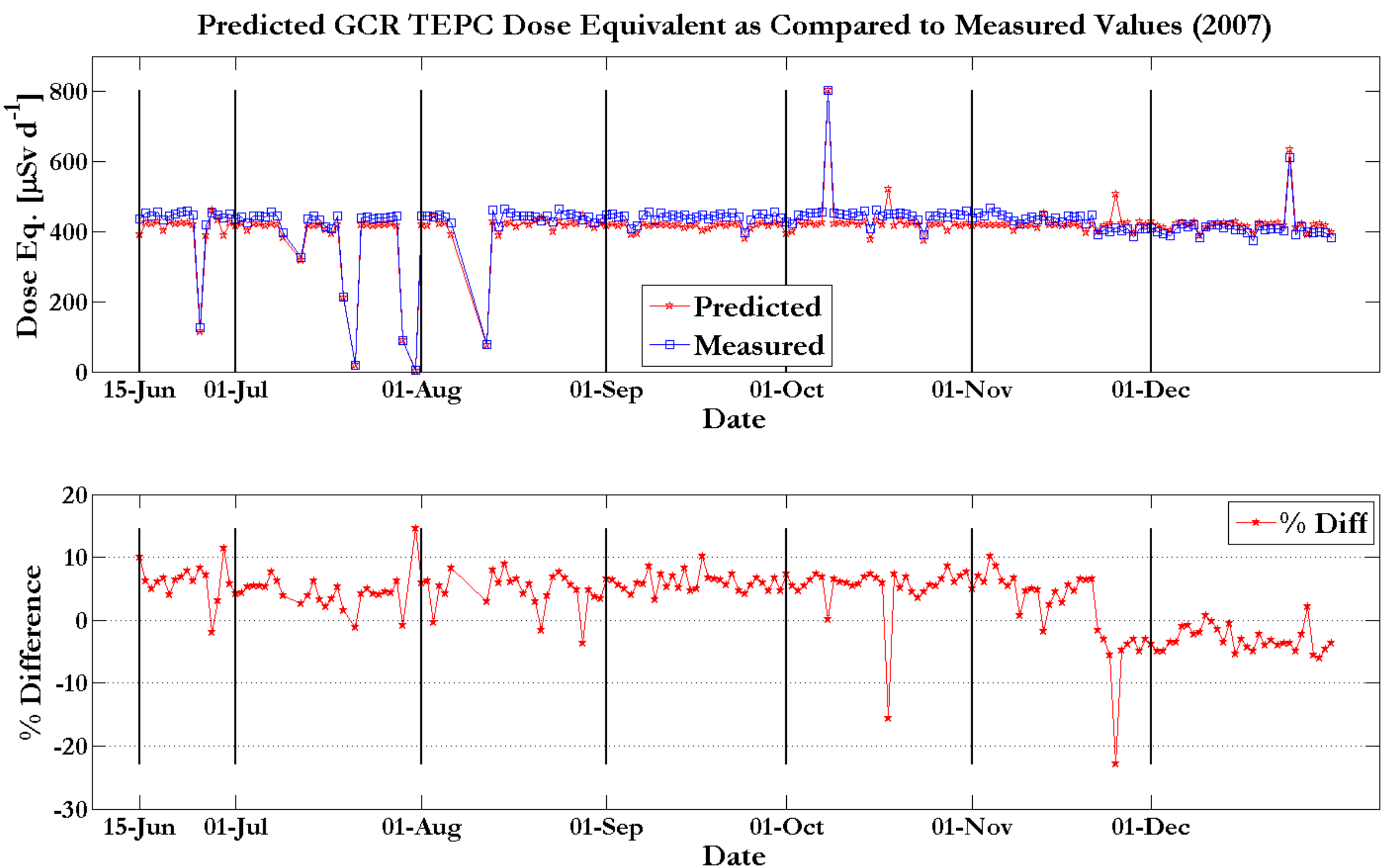
Predicted Ascending Trapped TEPC Dose Equivalent as Compared to Measured Values (2000)
Predicted
Measured
Dose Eq. [µSv d-1]
150
100
50
0
19-Dec
25-Dec
31-Dec
Date
% Diff Ascending Dose
% Difference
50
0
-50
-100
19-Dec
25-Dec
31-Dec
Date

2000 SM-327

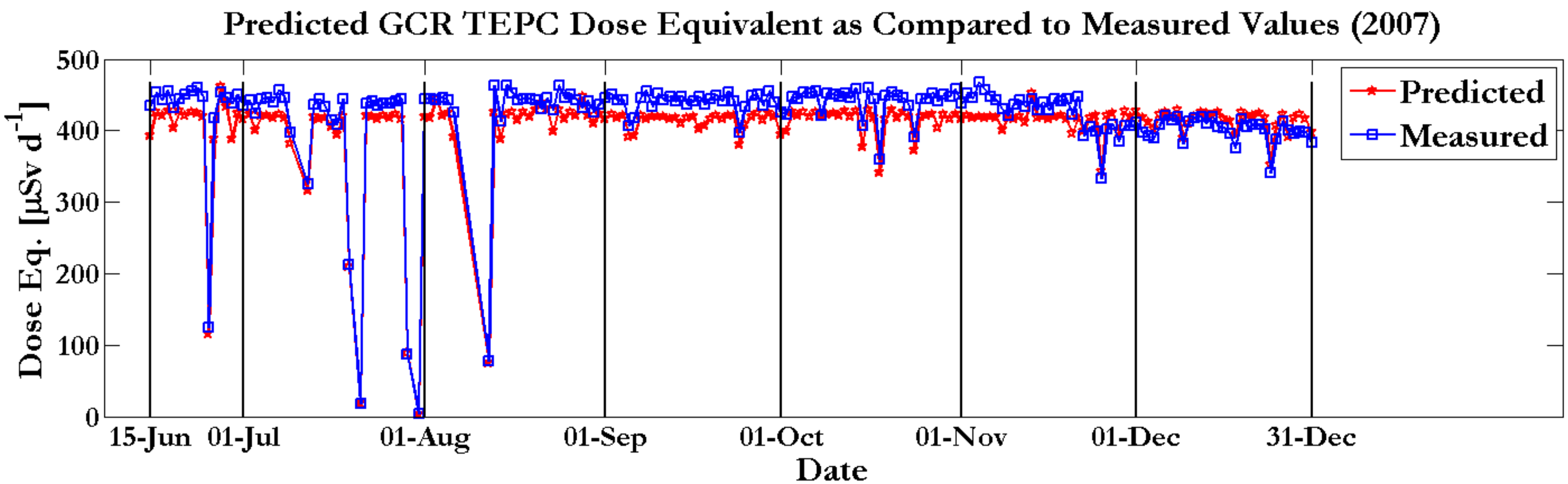


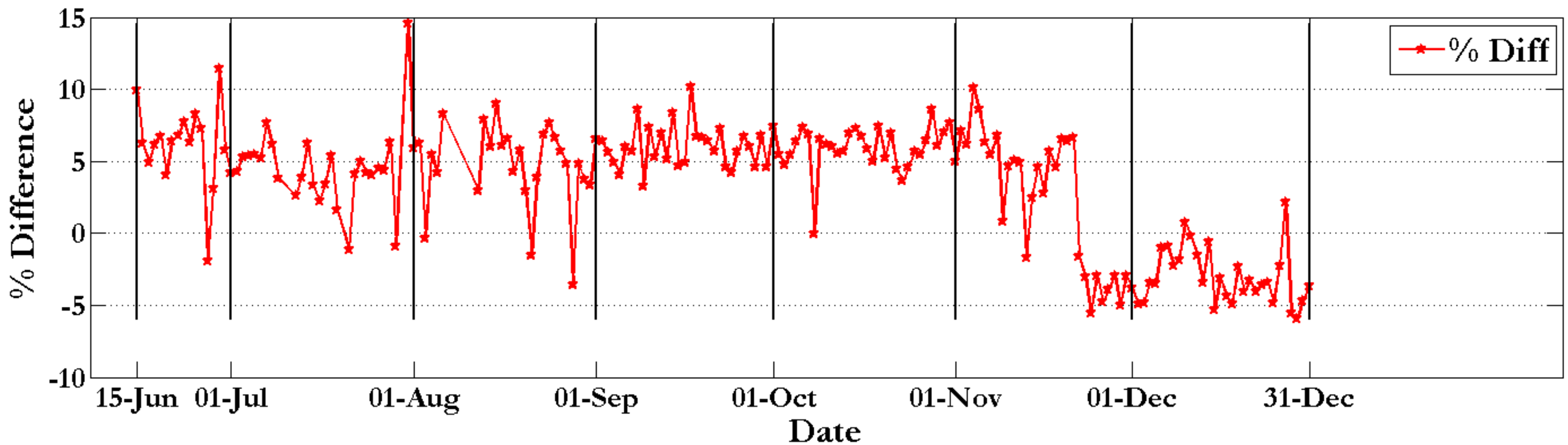
Predicted Descending Trapped TEPC Dose Equivalent as Compared to Measured Values (2000)
Dose Eq. [μSv d-1]
150
100
50
0
20-Dec
25-Dec
31-Dec
Date
Predicted
Measured
% Difference
50
20
0
-20
-50
-100
-150
-200
% Diff Descending Dose

2007 Original

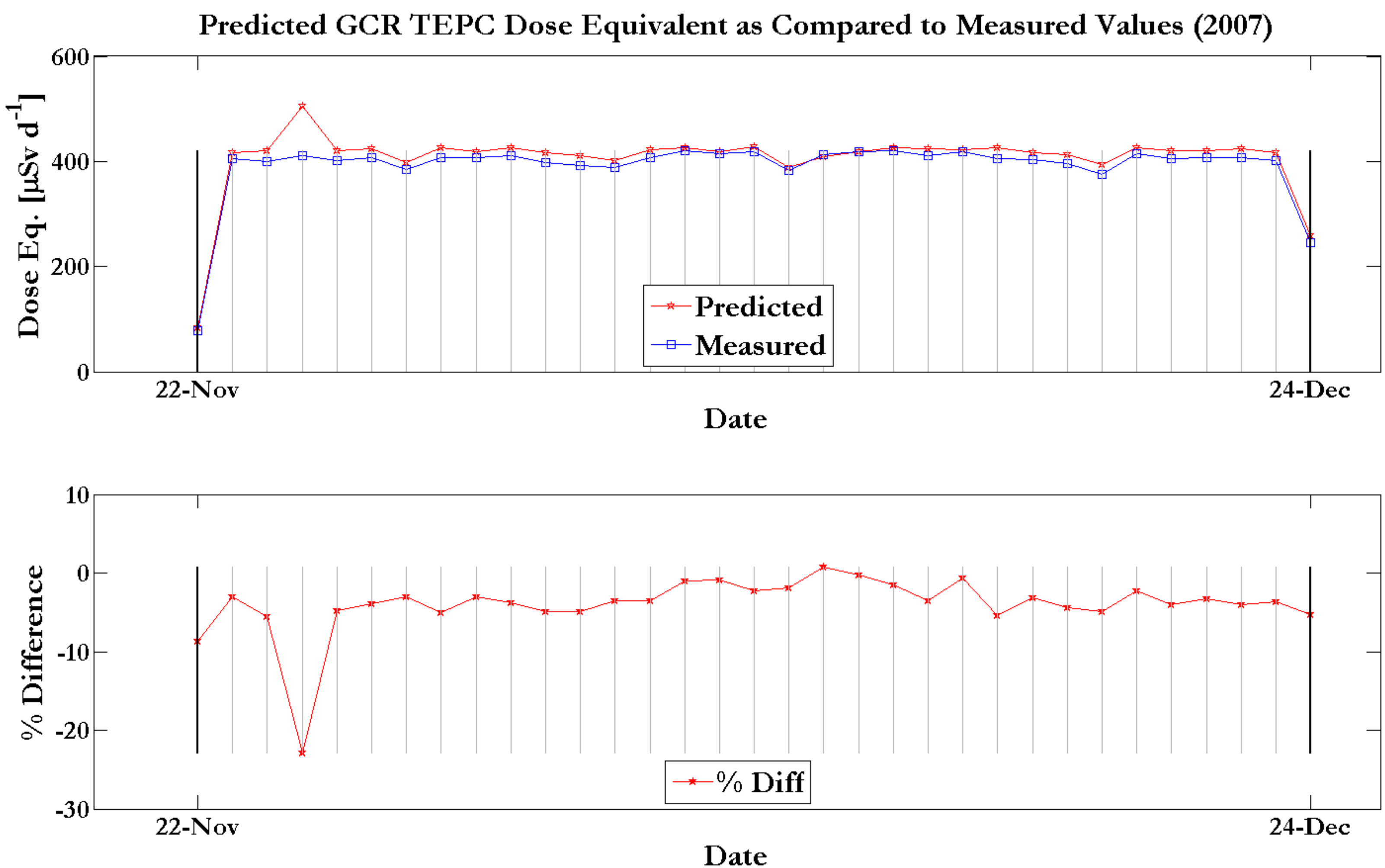


2007 Adjusted



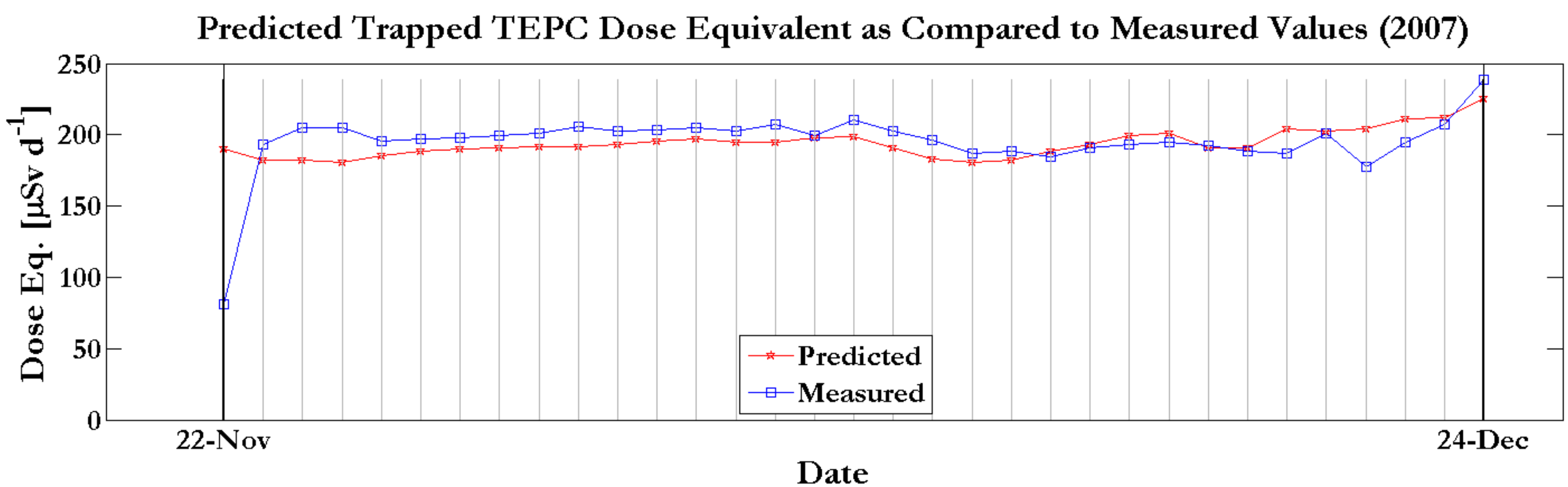


2007 SM-327

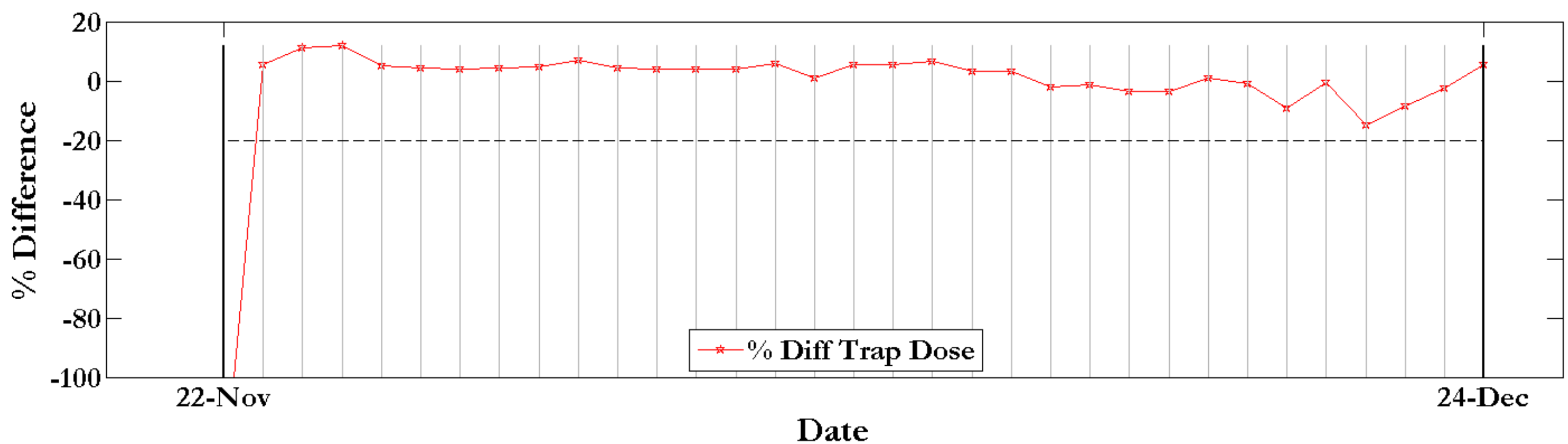


Predicted GCR TEPC Dose Equivalent as Compared to Measured Values (2007)
600
400
200
0
Dose Eq. [µSv d-1]
Predicted
Measured
22-Nov
24-Dec
Date
10
0
-10
-20
-30
% Difference
% Diff
22-Nov
24-Dec
Date

2007 SM-327

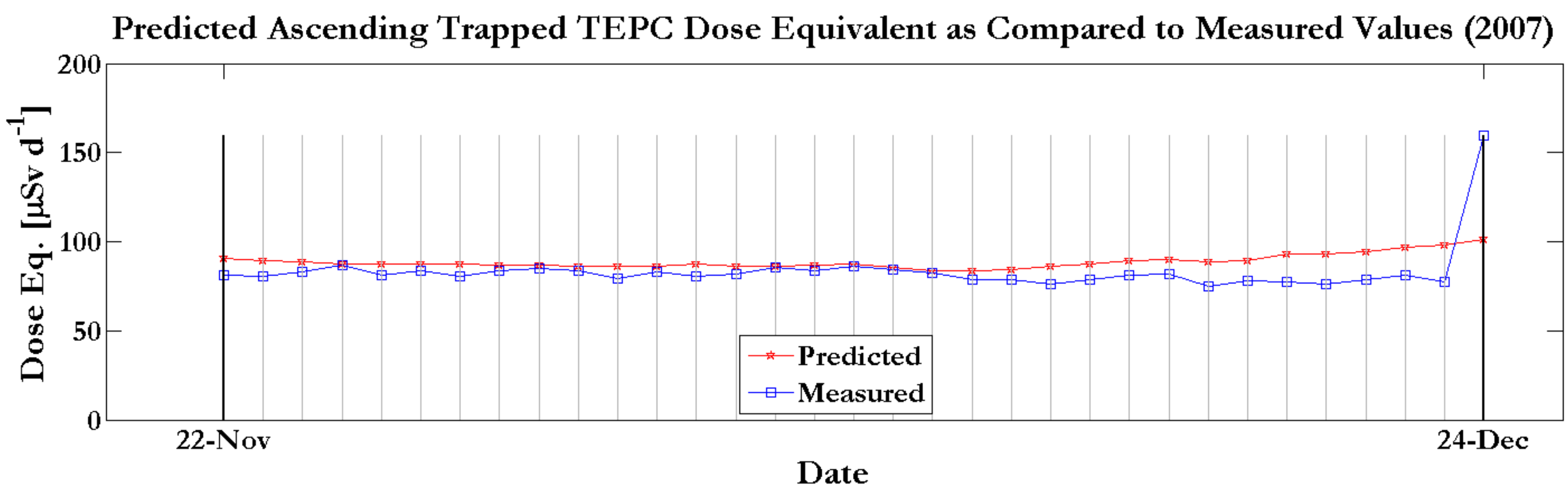


Predicted Trapped TEPC Dose Equivalent as Compared to Measured Values (2007)
Dose Eq. [µSv d-1]
250
200
150
100
50
0
22-Nov
24-Dec
Date
Predicted
Measured

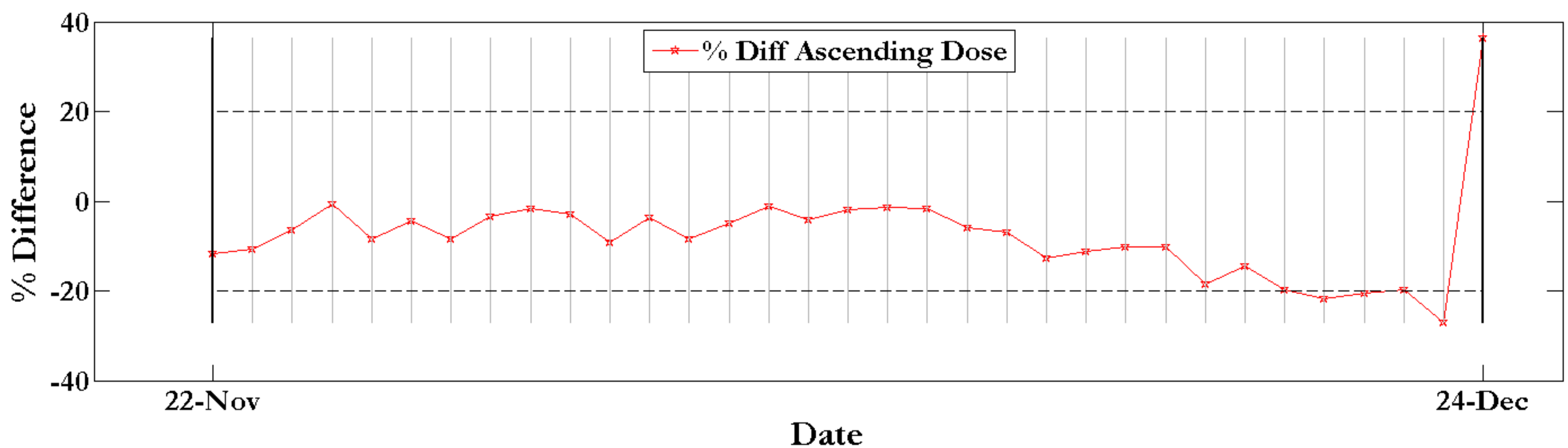


% Difference
20
0
-20
-40
-60
-80
-100
22-Nov
24-Dec
Date
% Diff Trap Dose

2007 SM-327

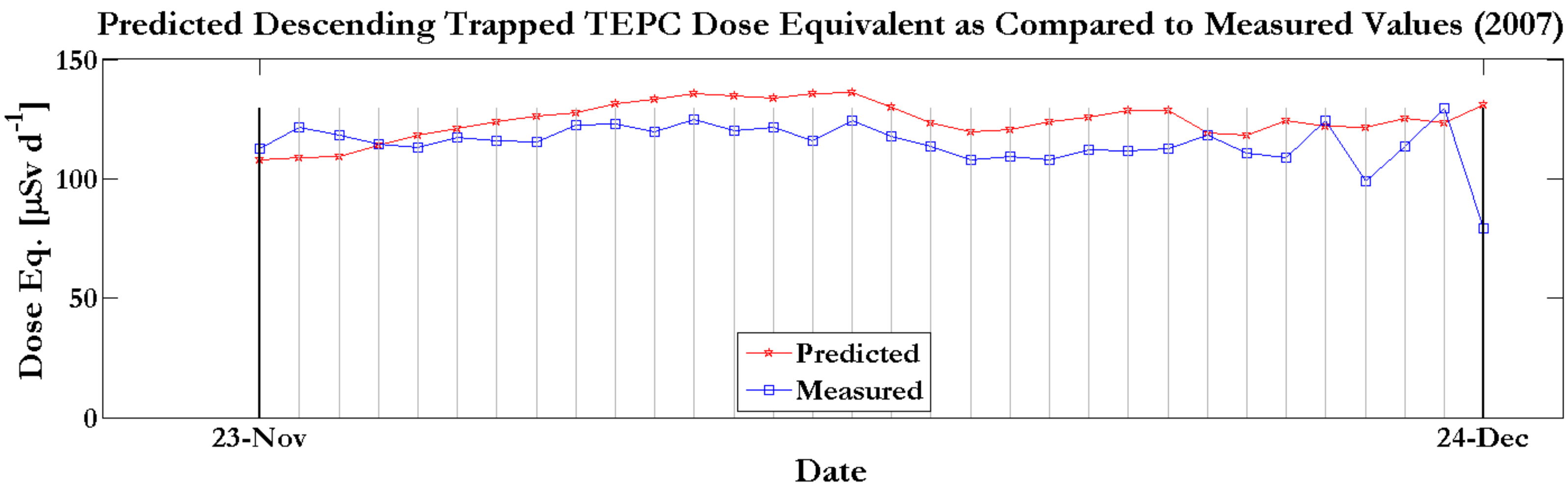


Predicted Ascending Trapped TEPC Dose Equivalent as Compared to Measured Values (2007)
Dose Eq. [μSv d-1]
200
150
100
50
0
22-Nov
24-Dec
Date
Predicted
Measured

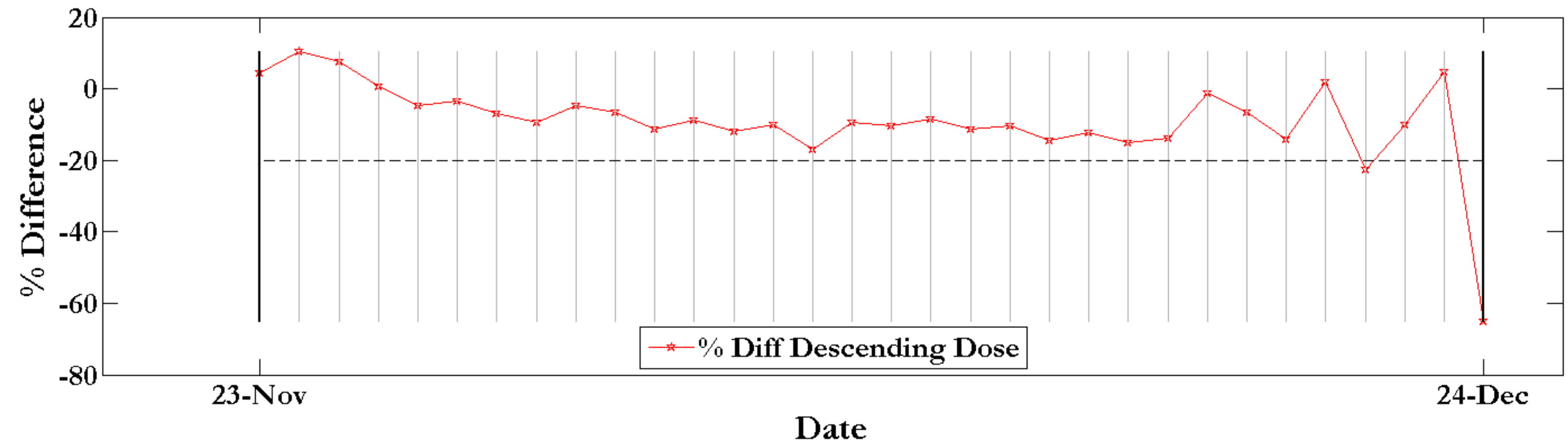


% Difference
40
20
0
-20
-40
% Diff Ascending Dose
22-Nov
24-Dec
Date

2007 SM-327

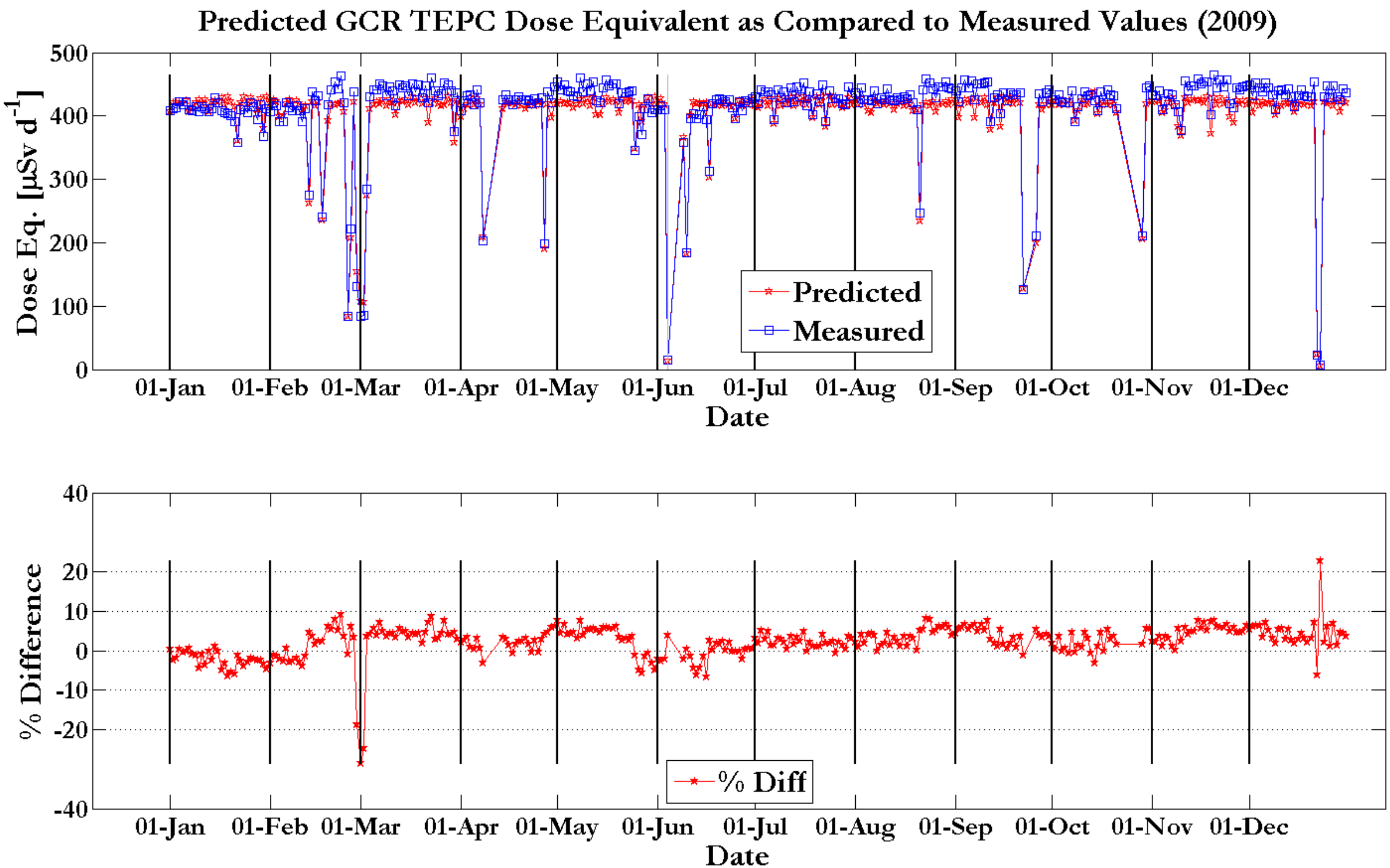


Predicted Descending Trapped TEPC Dose Equivalent as Compared to Measured Values (2007)
Dose Eq. [µSv d-1]
150
100
50
0
23-Nov
24-Dec
Date
Predicted
Measured



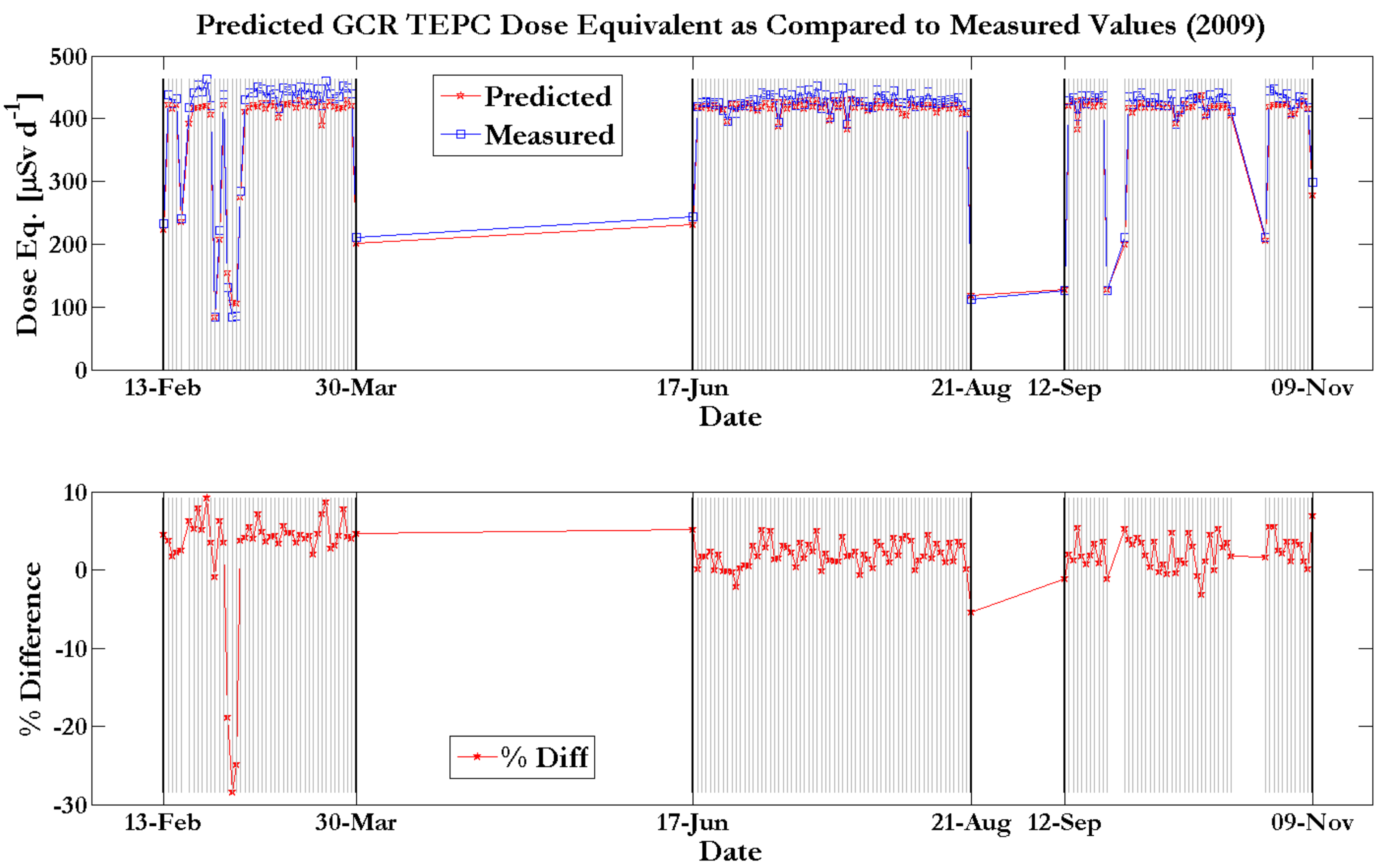
% Difference
20
0
-20
-40
-60
-80
23-Nov
24-Dec
Date
% Diff Descending Dose

2009



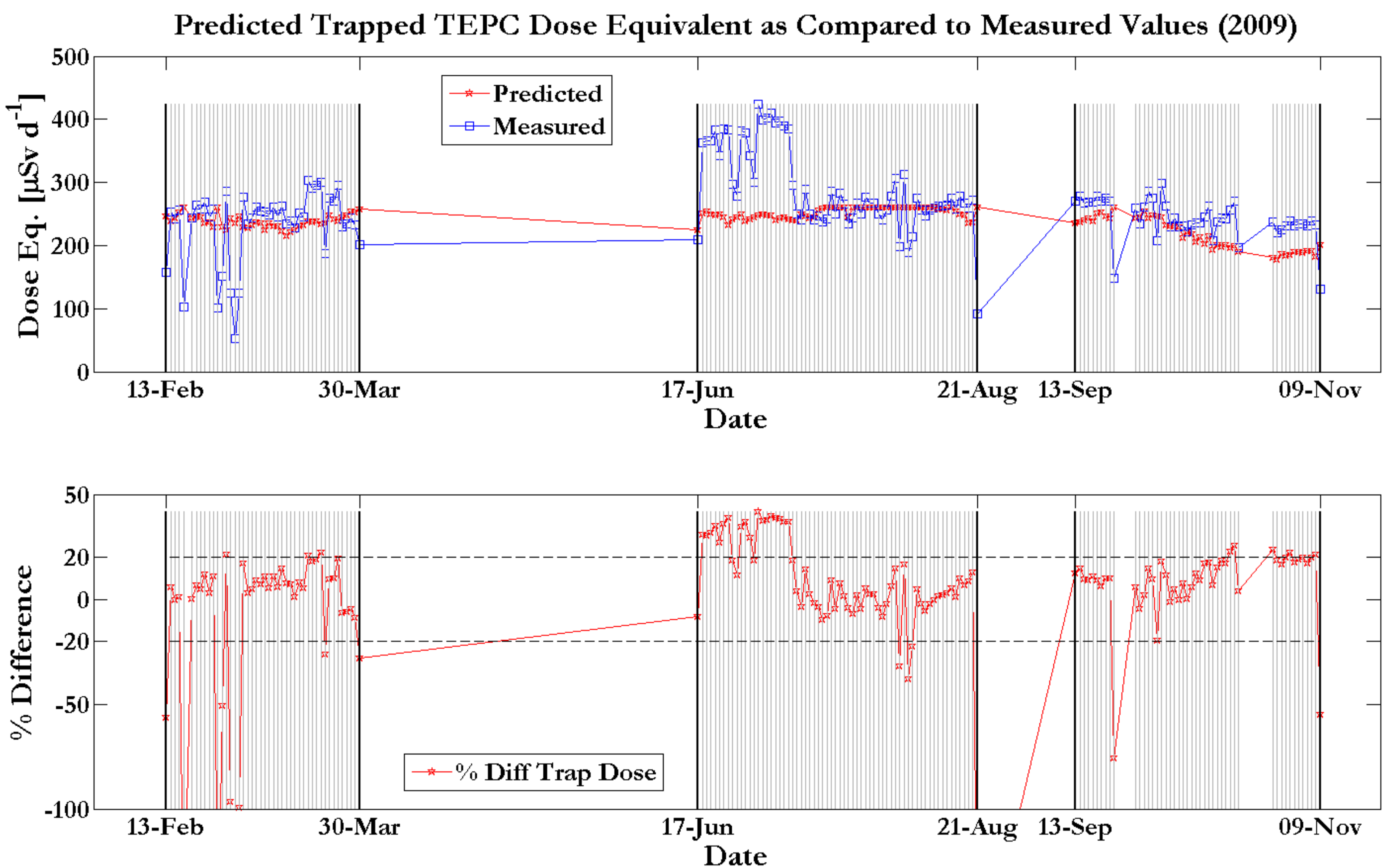
Predicted GCR TEPC Dose Equivalent as Compared to Measured Values (2009)
Dose Eq. [μSv d-1]
500
400
300
200
100
0
Predicted
Measured
01-Jan
01-Feb
01-Mar
01-Apr
01-May
01-Jun
01-Jul
01-Aug
01-Sep
01-Oct
01-Nov
01-Dec
Date
% Difference
40
20
10
0
-10
-20
-40
% Diff
01-Jan
01-Feb
01-Mar
01-Apr
01-May
01-Jun
01-Jul
01-Aug
01-Sep
01-Oct
01-Nov
01-Dec
Date

2009 SM-327



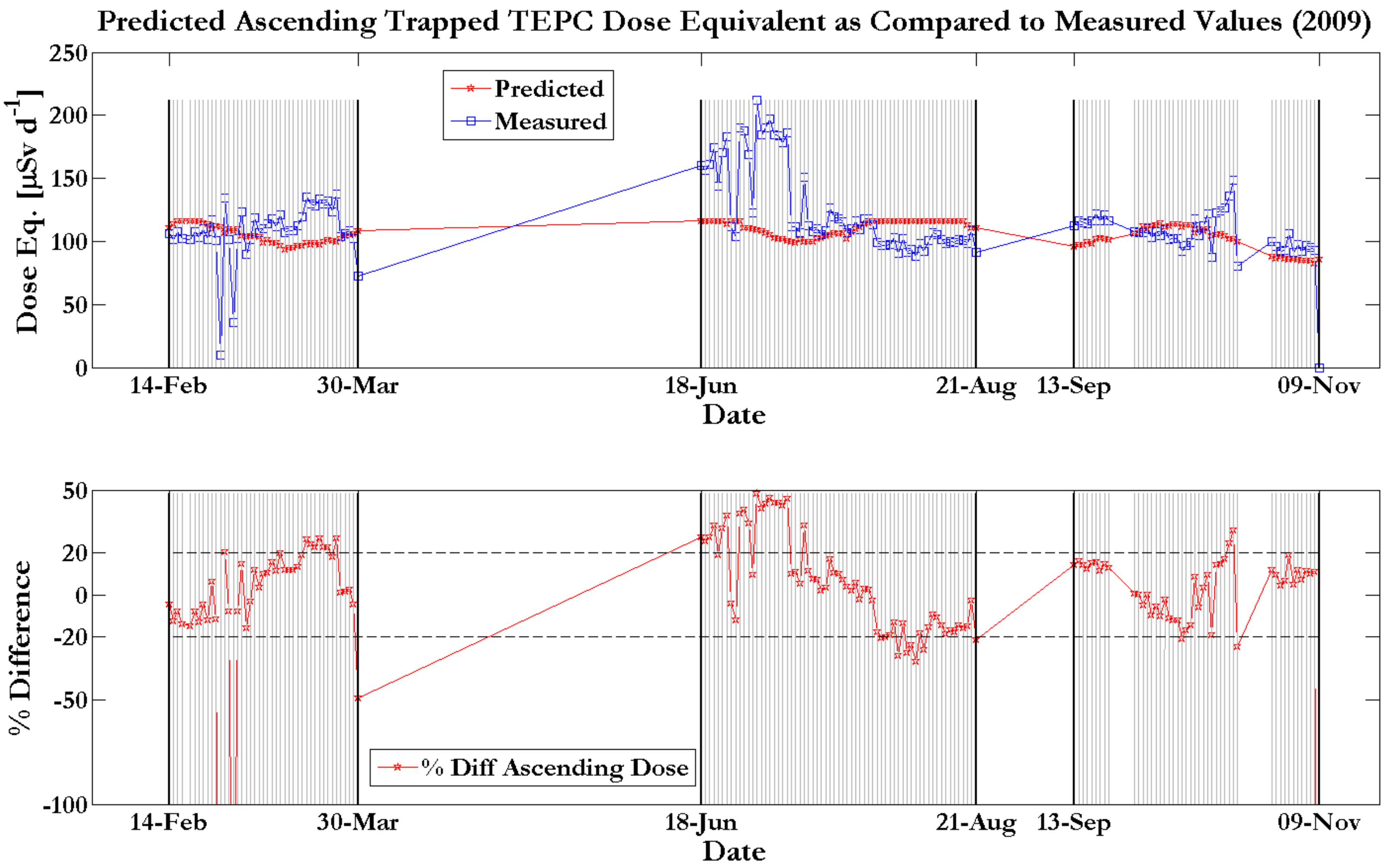
Predicted GCR TEPC Dose Equivalent as Compared to Measured Values (2009)
Dose Eq. [μSv d-1]
500
400
300
200
100
0
Predicted
Measured
13-Feb
30-Mar
17-Jun
21-Aug
12-Sep
09-Nov
Date
% Difference
10
0
-10
-20
-30
% Diff
13-Feb
30-Mar
17-Jun
21-Aug
12-Sep
09-Nov
Date

2009 SM-327



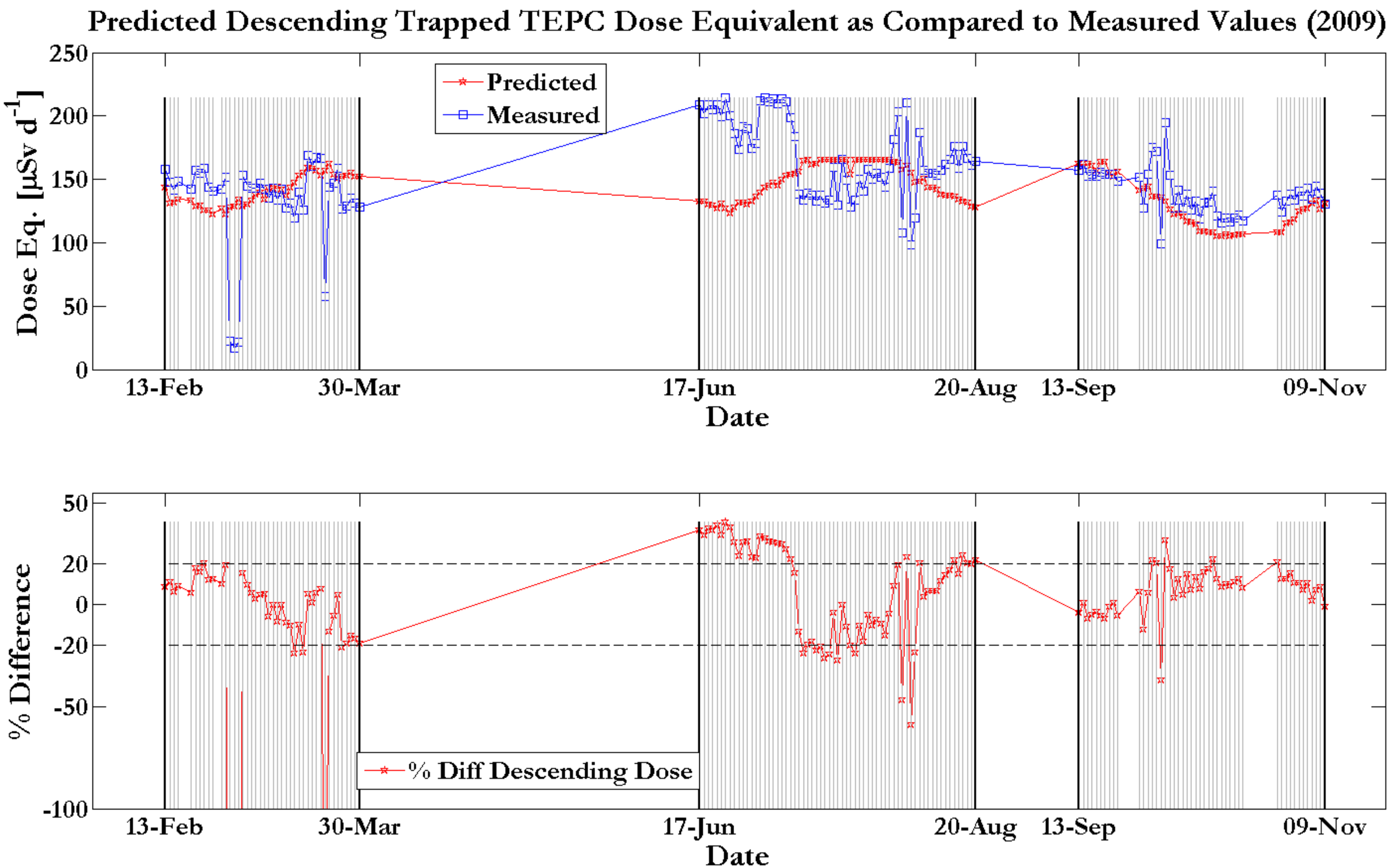
Predicted Trapped TEPC Dose Equivalent as Compared to Measured Values (2009)
Predicted
Measured
Dose Eq. [μSv d-1]
500
400
300
200
100
0
13-Feb
30-Mar
17-Jun
21-Aug
13-Sep
09-Nov
Date
% Difference
50
20
0
-20
-50
-100
% Diff Trap Dose
13-Feb
30-Mar
17-Jun
21-Aug
13-Sep
09-Nov
Date

2009 SM-327



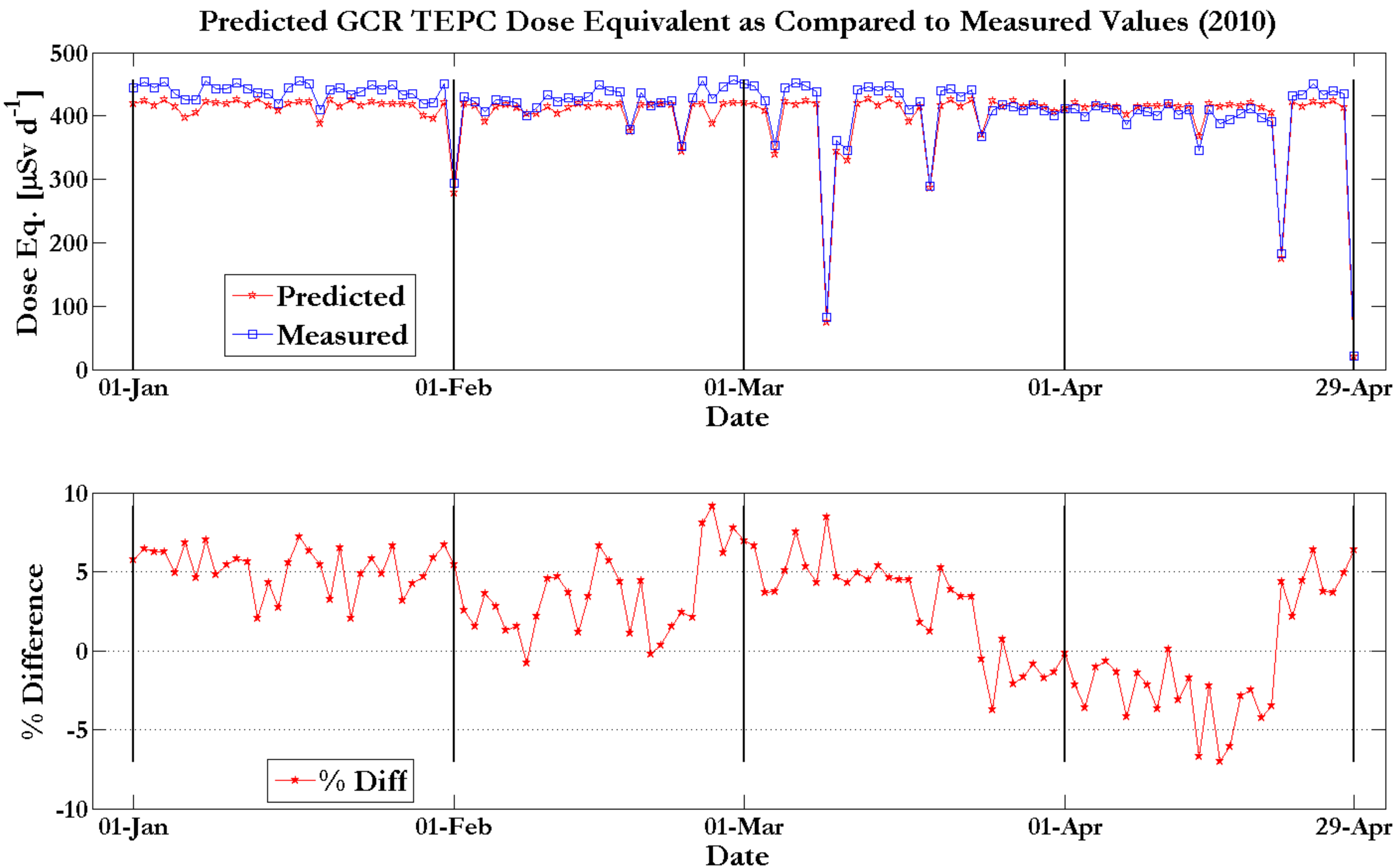
Predicted Ascending Trapped TEPC Dose Equivalent as Compared to Measured Values (2009)
Predicted
Measured
Dose Eq. [μSv d^{-1}]
250
200
150
100
50
0
14-Feb
30-Mar
18-Jun
21-Aug
13-Sep
09-Nov
Date
% Diff Ascending Dose
% Difference
50
20
0
-20
-50
-100
14-Feb
30-Mar
18-Jun
21-Aug
13-Sep
09-Nov
Date

2009 SM-327

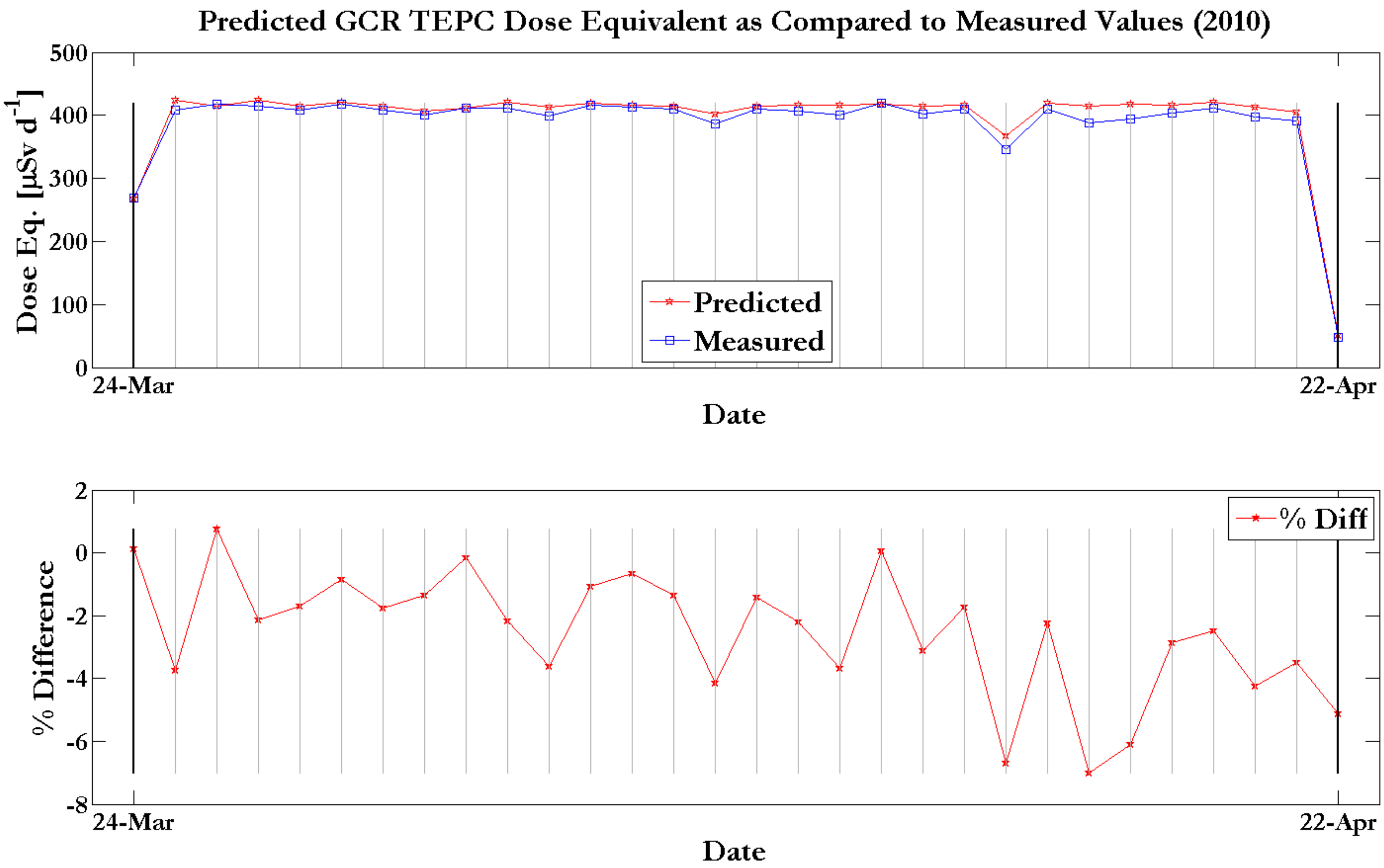


Predicted Descending Trapped TEPC Dose Equivalent as Compared to Measured Values (2009)
Predicted
Measured
Dose Eq. [μSv d-1]
250
200
150
100
50
0
13-Feb
30-Mar
17-Jun
20-Aug
13-Sep
09-Nov
Date
% Diff Descending Dose
% Difference
50
20
0
-20
-50
-100
13-Feb
30-Mar
17-Jun
20-Aug
13-Sep
09-Nov
Date

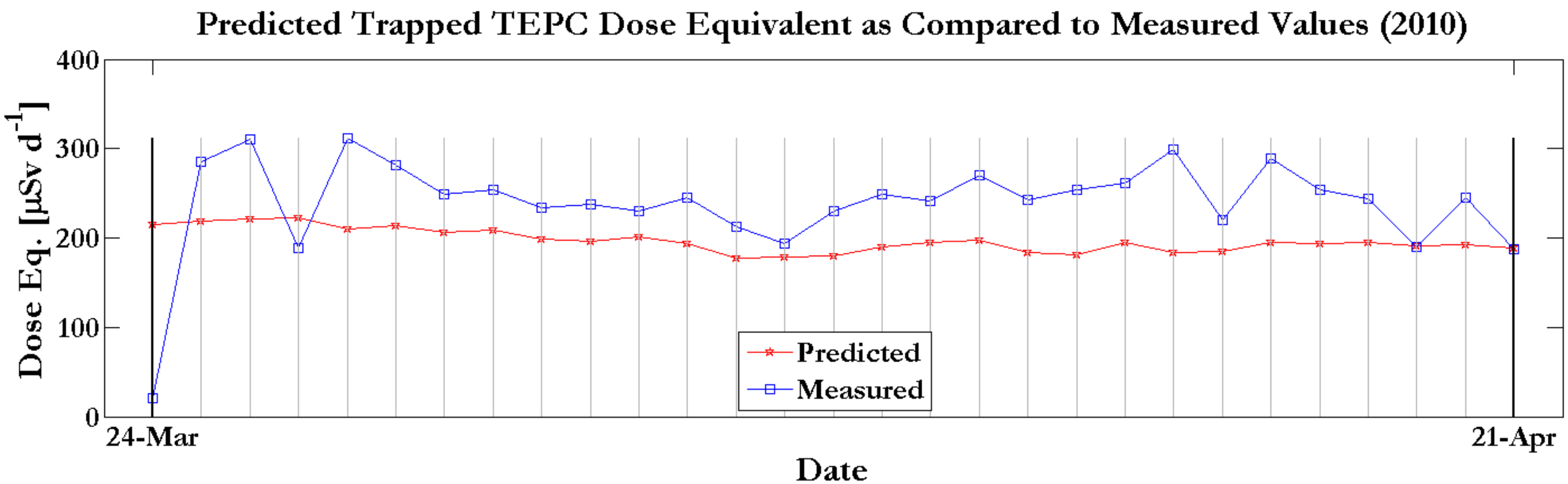
2010


Predicted GCR TEPC Dose Equivalent as Compared to Measured Values (2010)
Dose Eq. [μSv d-1]
Predicted
Measured
01-Jan
01-Feb
01-Mar
01-Apr
29-Apr
Date
% Difference
% Diff

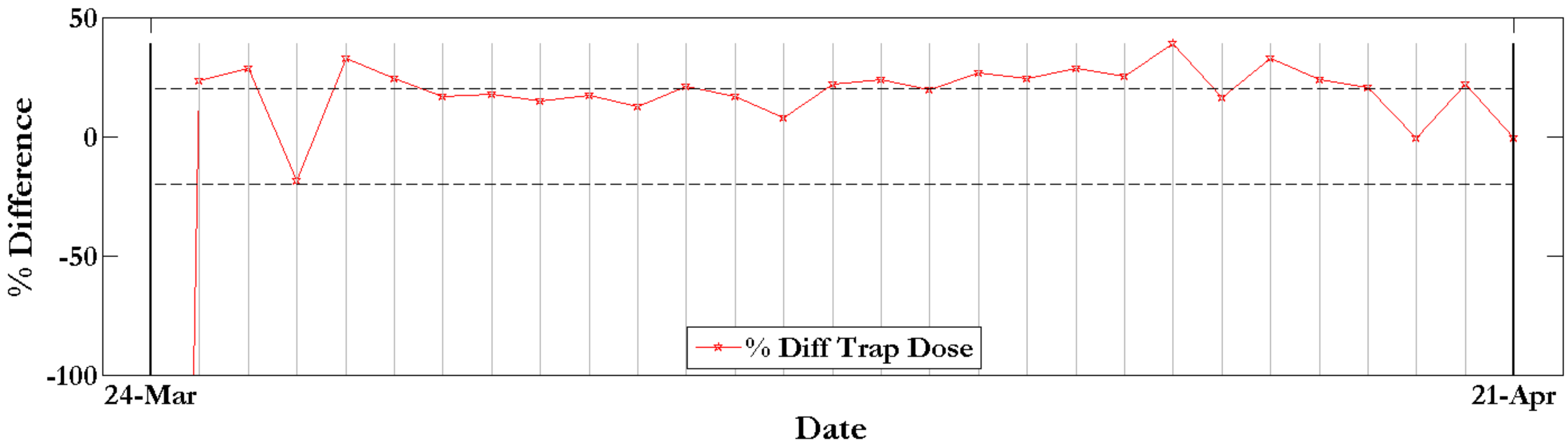
2010 SM-327


Predicted GCR TEPC Dose Equivalent as Compared to Measured Values (2010)
Dose Eq. [µSv d⁻¹]
500
400
300
200
100
0
Predicted
Measured
24-Mar
22-Apr
Date
% Difference
2
0
-2
-4
-6
-8
% Diff
24-Mar
22-Apr
Date

2010 SM-327

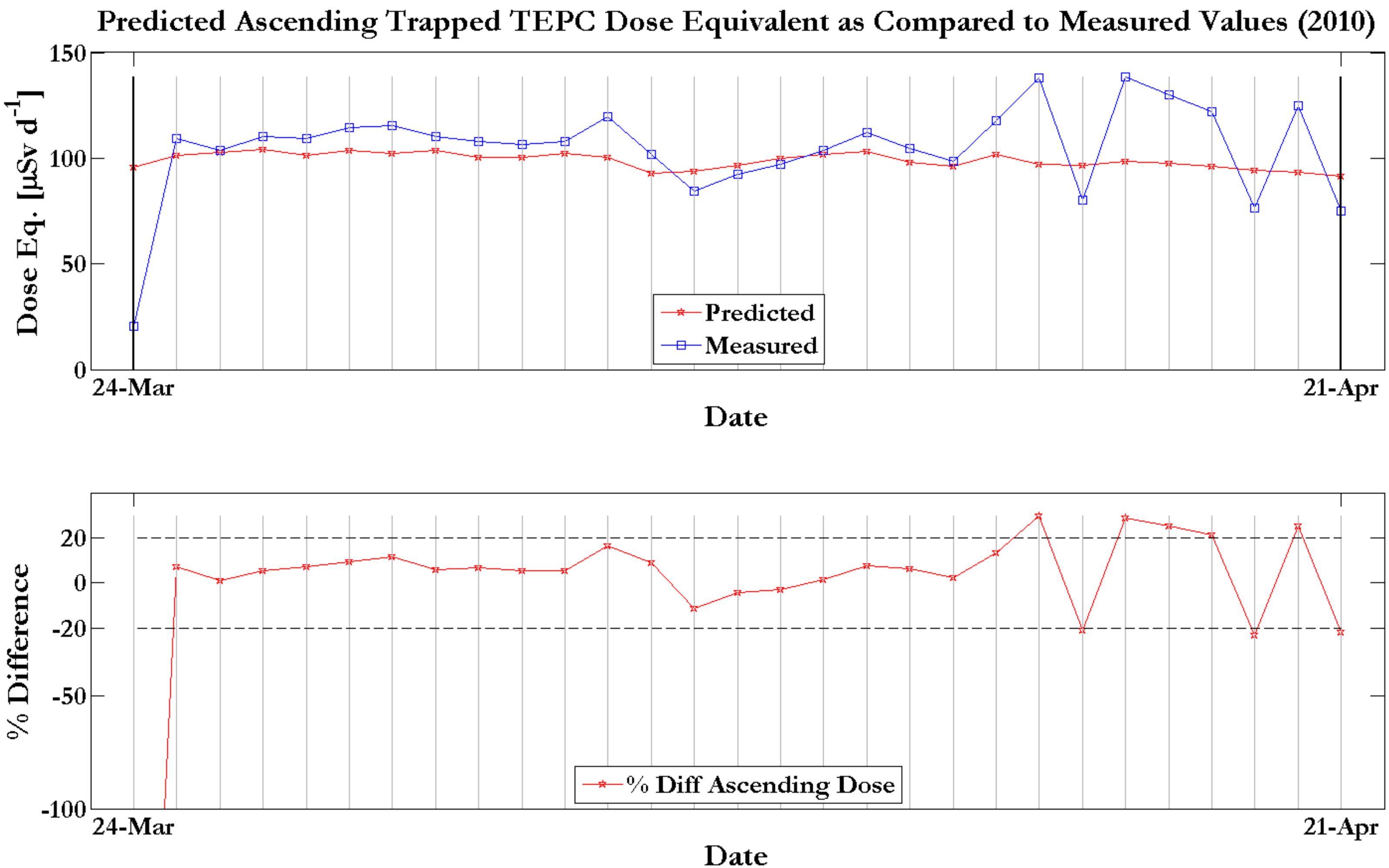


Predicted Trapped TEPC Dose Equivalent as Compared to Measured Values (2010)
Dose Eq. [µSv d-1]
400
300
200
100
0
24-Mar
21-Apr
Date
Predicted
Measured



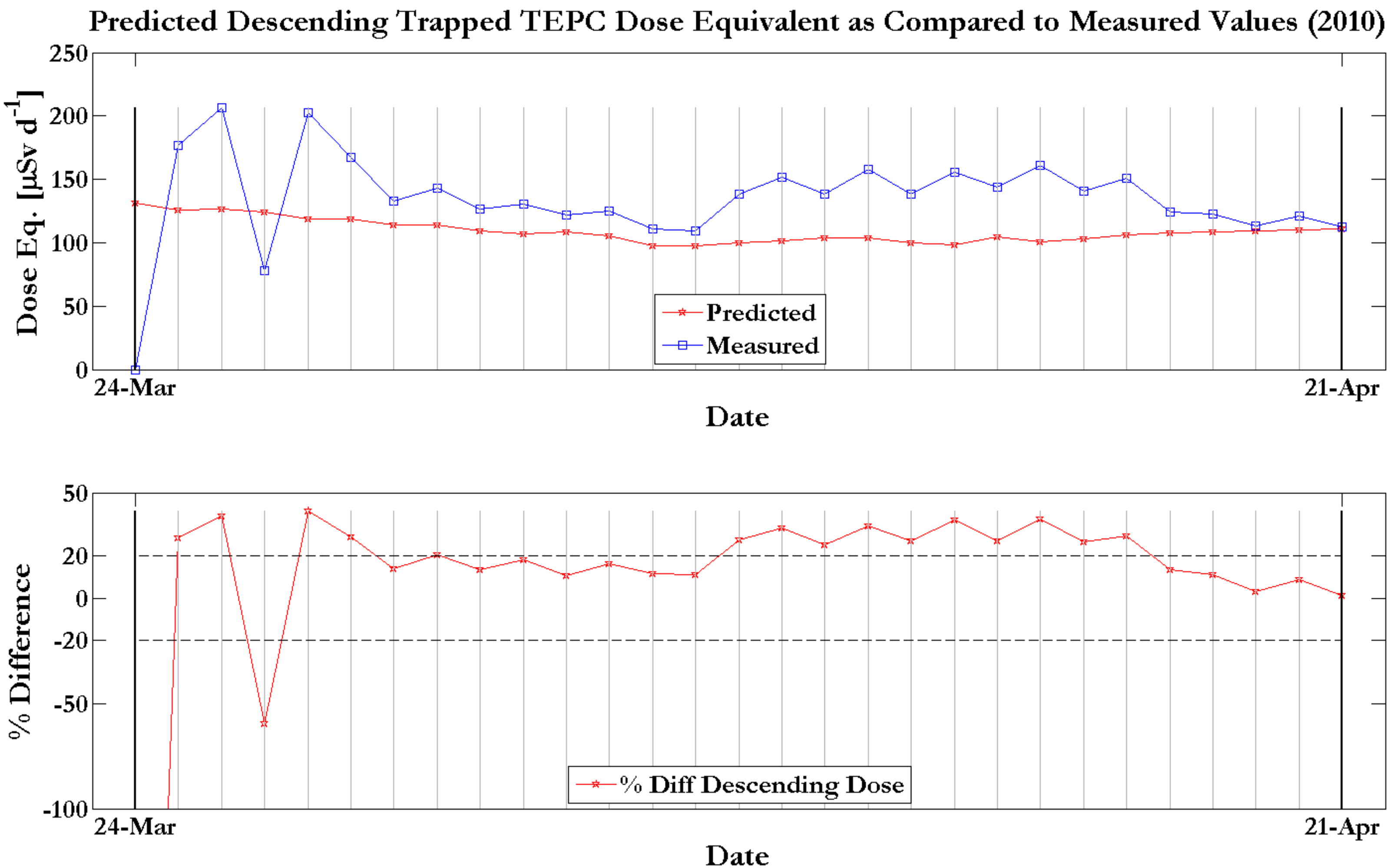
% Difference
50
0
-50
-100
24-Mar
21-Apr
Date
% Diff Trap Dose

2010 SM-327

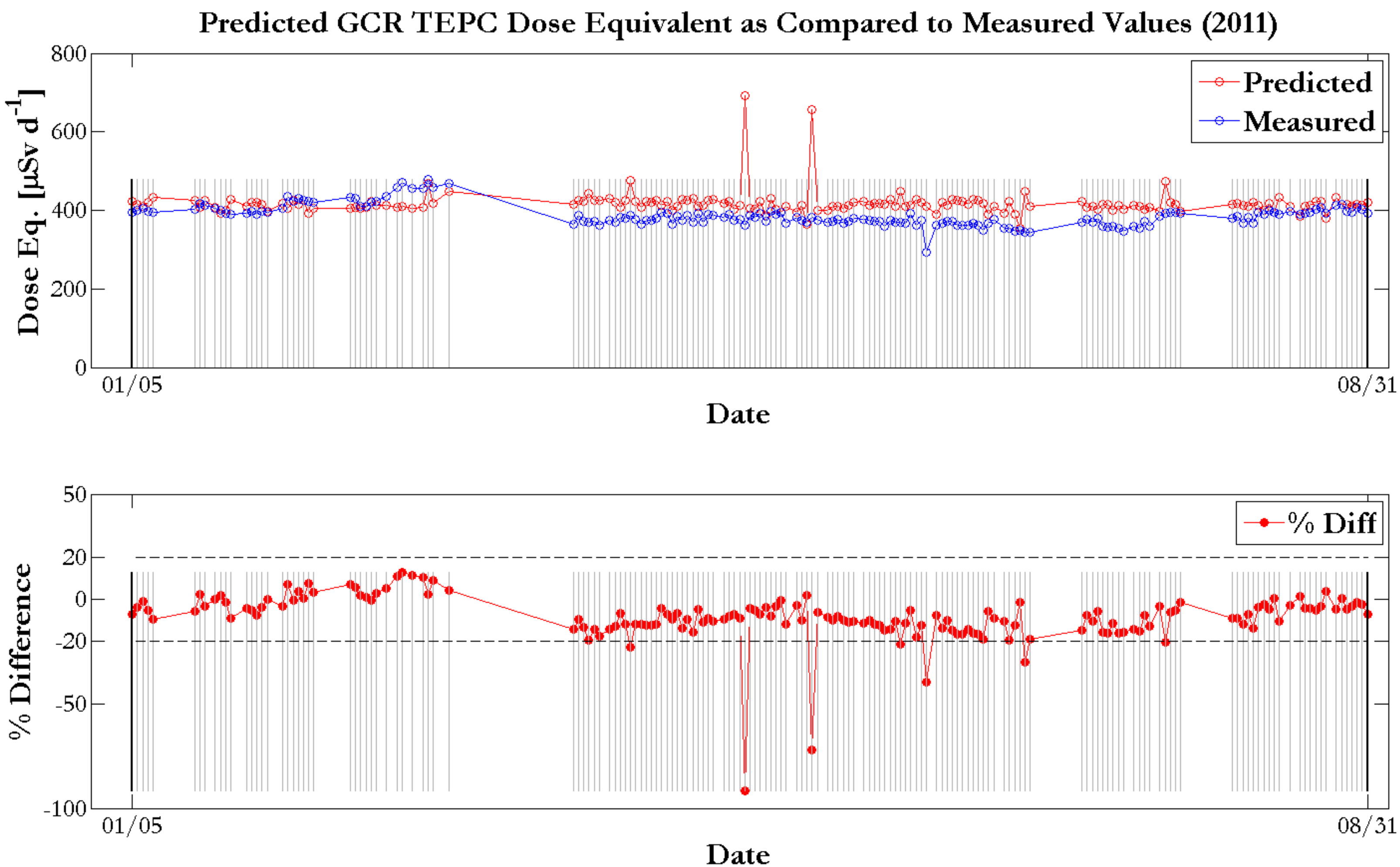


Predicted Ascending Trapped TEPC Dose Equivalent as Compared to Measured Values (2010)
Dose Eq. [µSv d-1]
150
100
50
0
24-Mar
21-Apr
Date
Predicted
Measured
% Difference
20
0
-20
-50
-100
24-Mar
21-Apr
Date
% Diff Ascending Dose

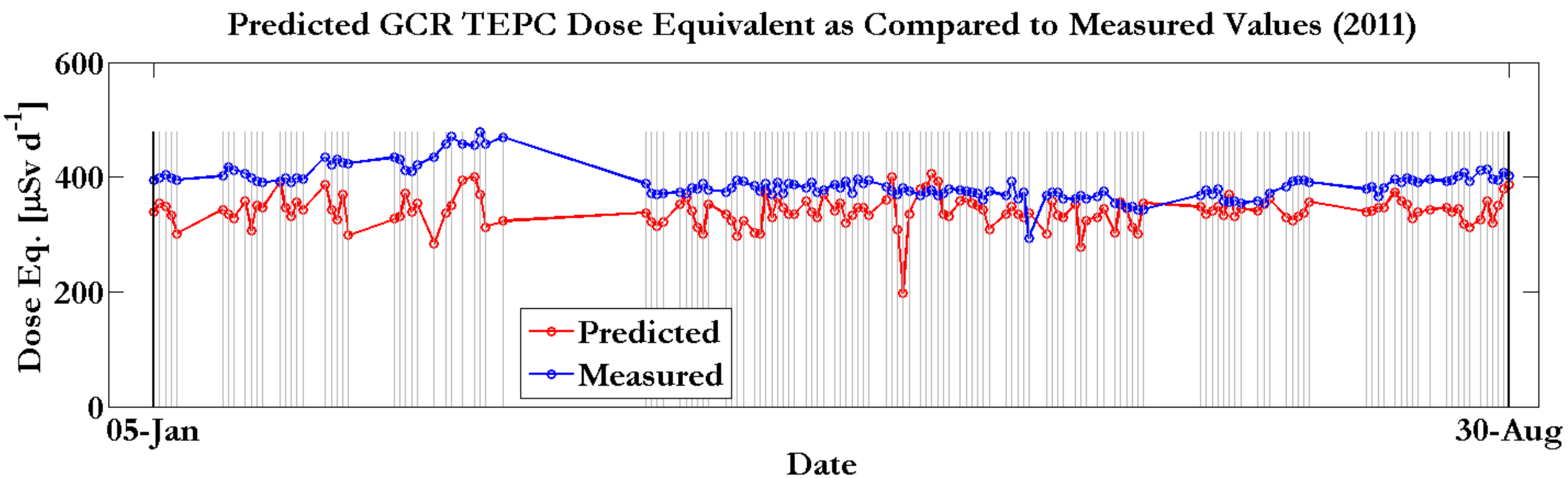
2010 SM-327

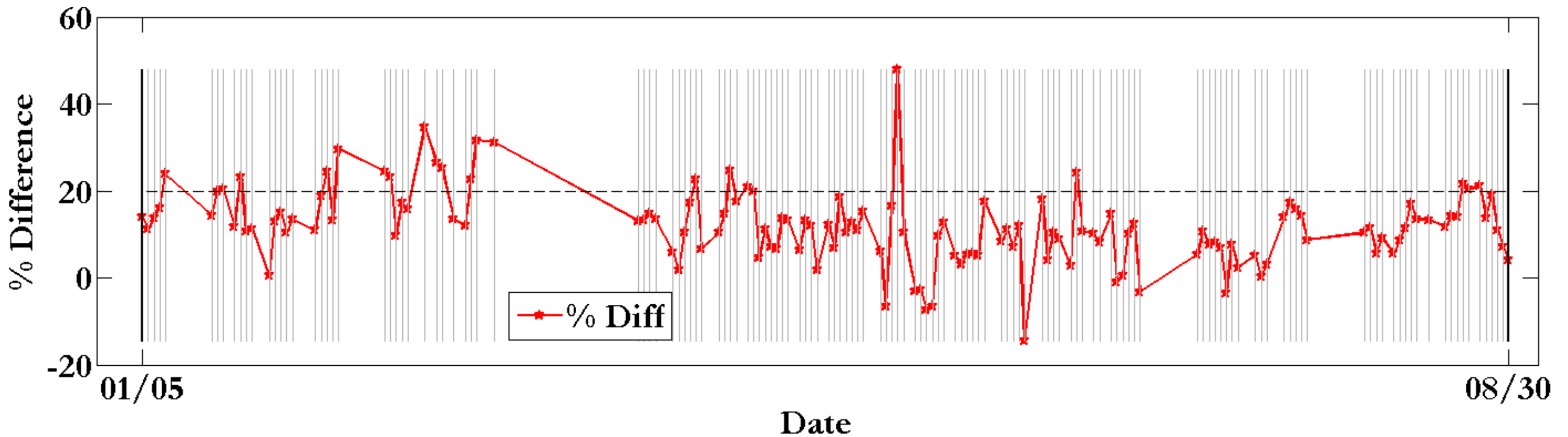

Predicted Descending Trapped TEPC Dose Equivalent as Compared to Measured Values (2010)
Dose Eq. [μSv d⁻¹]
250
200
150
100
50
0
24-Mar
21-Apr
Date
Predicted
Measured
% Difference
50
20
0
-20
-50
-100
24-Mar
21-Apr
Date
% Diff Descending Dose

2011 SM-327

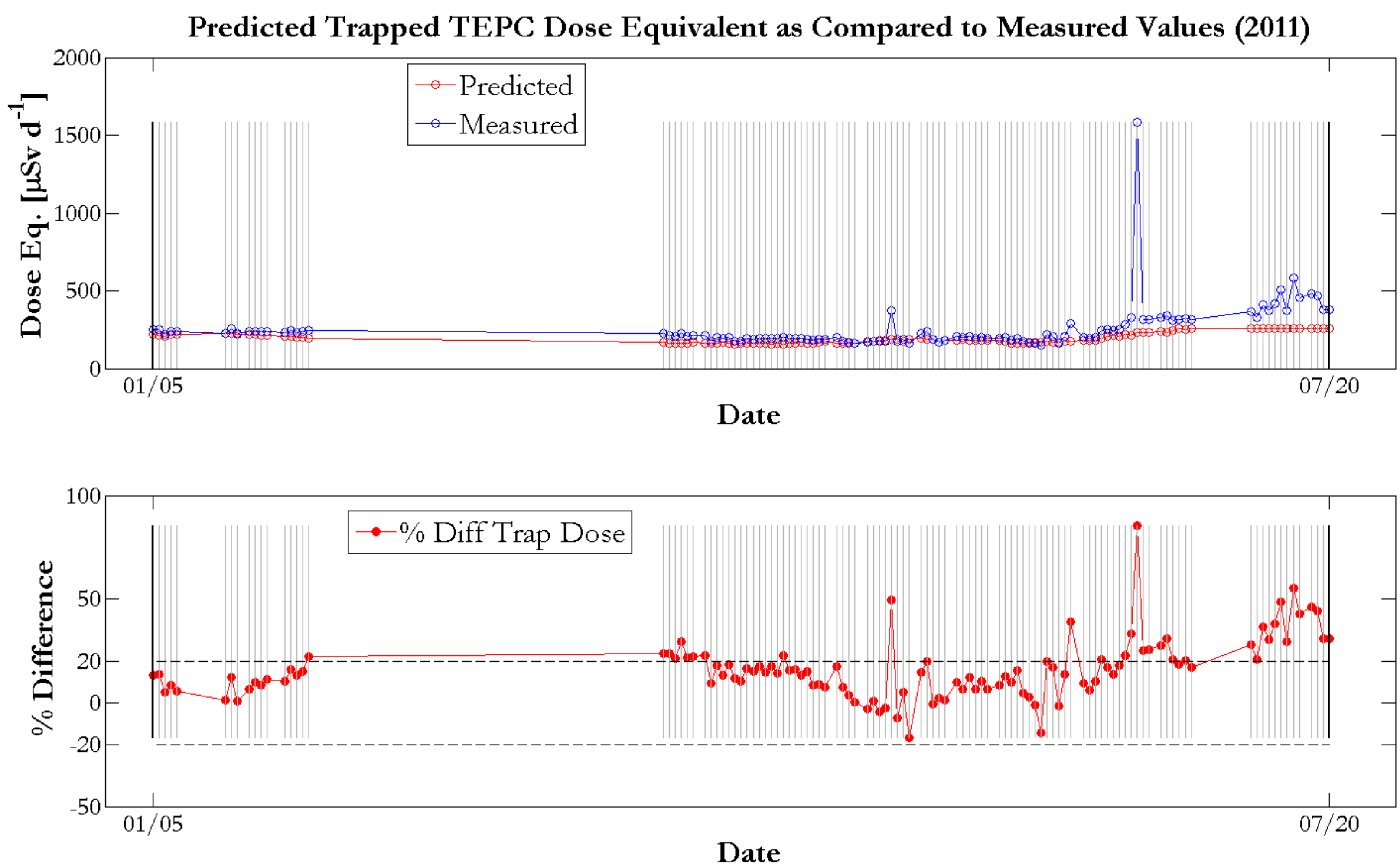

Predicted GCR TEPC Dose Equivalent as Compared to Measured Values (2011)
Predicted
Measured
Dose Eq. [µSv d-1]
800
600
400
200
0
01/05
08/31
Date
% Diff
% Difference
50
20
0
-20
-50
-100
01/05
08/31
Date

2011 SM-327 Adjusted





2011 SM-327


Predicted Trapped TEPC Dose Equivalent as Compared to Measured Values (2011)
Predicted
Measured
Dose Eq. [μSv d-1]
2000
1500
1000
500
0
01/05
07/20
Date
% Diff Trap Dose
% Difference
100
50
20
0
-20
-50
01/05
07/20
Date

2011 SM-327 Adjusted