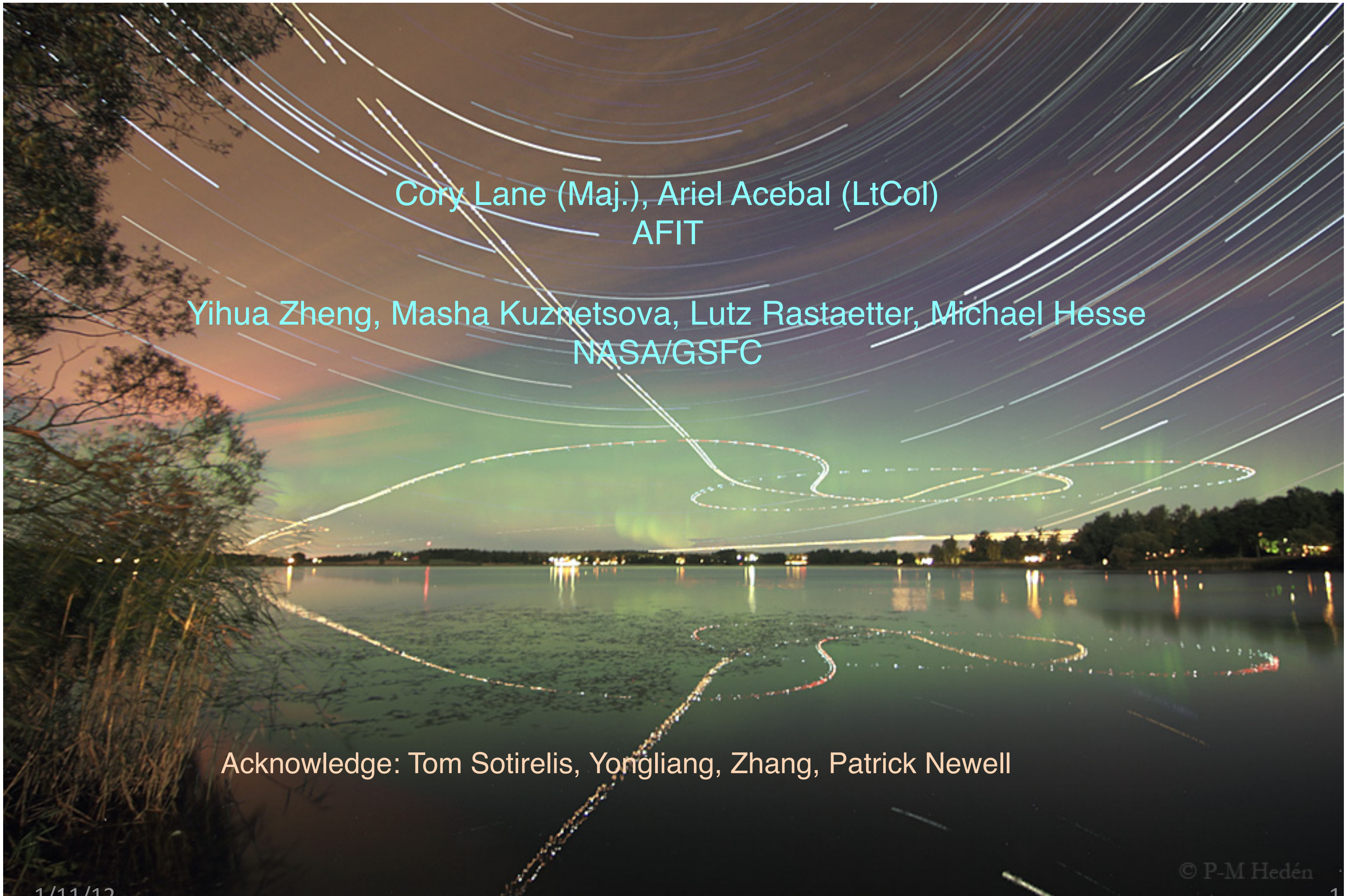
Auroral Model V& V Efforts



Cory Lane (Maj.), Ariel Acebal (LtCol)
AFIT

Yihua Zheng, Masha Kuznetsova, Lutz Rastaetter, Michael Hesse
NASA/GSFC

Acknowledge: Tom Sotirelis, Yongliang, Zhang, Patrick Newell

Overview

- Motivation
- What has been done (Cory)
- Future plan

Motivation

- Auroral precipitation models have been valuable both in terms of space weather applications and space science research.
- Aurora, as manifestation of SW-Magnetosphere coupling, can be used as a remote sensing tool for magnetospheric processes.
  - ionospheric conductance
  - Field-aligned currents (FACs)
  - Poynting flux – ion outflow
  - Joule Heating
- Yet very limited testing has been performed regarding model performance.
- A variety of auroral models are available, including empirical models that are parameterized by geomagnetic indices or upstream solar wind conditions, nowcasting models that are based on satellite observations, or those derived from physics-based, coupled global models.

Challenges

- What physical quantity/quantities to choose
- How to define the physical quantify/ quantities from model and data
- Which data sets to use

Validation already been done

Newell, P. T., T. Sotirelis, K. Liou, A. R. Lee, S. Wing, J. Green, and R. Redmon (2010), Predictive ability of four auroral precipitation models as evaluated using Polar UVI global images, Space Weather, 8, S12004, doi:10.1029/2010SW000604

Instantaneous

1. Brautigam IMF model (r=0.68)
2. Evans nowcast model (r=0.70)
3. Hardy Kp model (r=0.72)
4. Ovation Prime (r=0.75)

Hourly averages

1. Brautigam IMF model (r=0.69)
2. Hardy Kp model (r=0.74)
3. Ovation Prime (r=0.76)
4. Evans nowcast model (r=0.77)

better

Physical parameter: Precipitating power

Using Polar/UVI
during 1996 -1997

Validation Methodology

Physical quantities: Equatorward boundary

Poleward boundary

Define the boundary: not trivial

Method 1: a threshold in flux (50 eV - 20 keV) as in Hardy model

Method 2: Newell et al. approach, where different identified regions have physical meanings

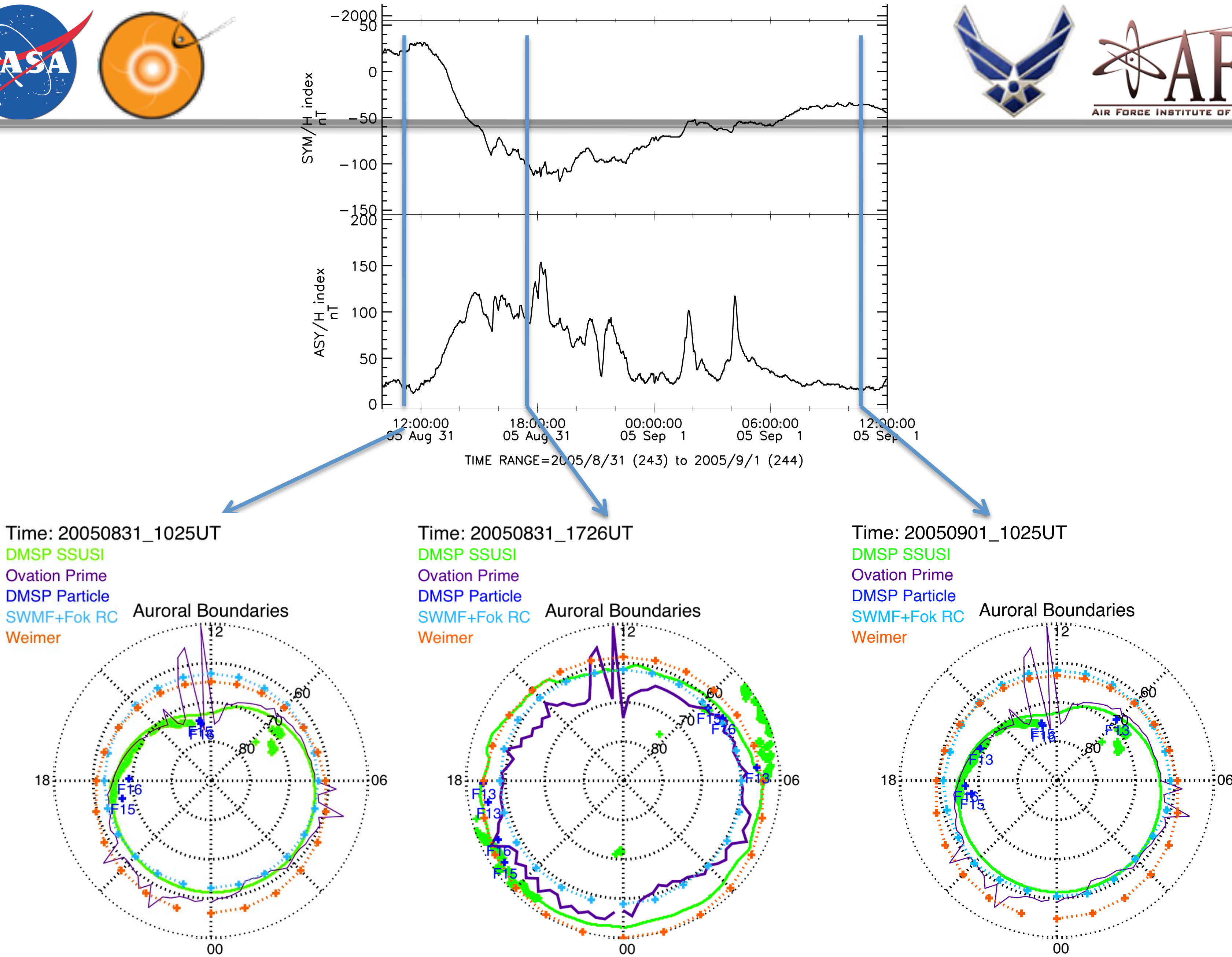
Method 3: Redmond et al approach, constant value in flux (sub energy range of DMSP: 1.39 keV -30 keV) as a threshold

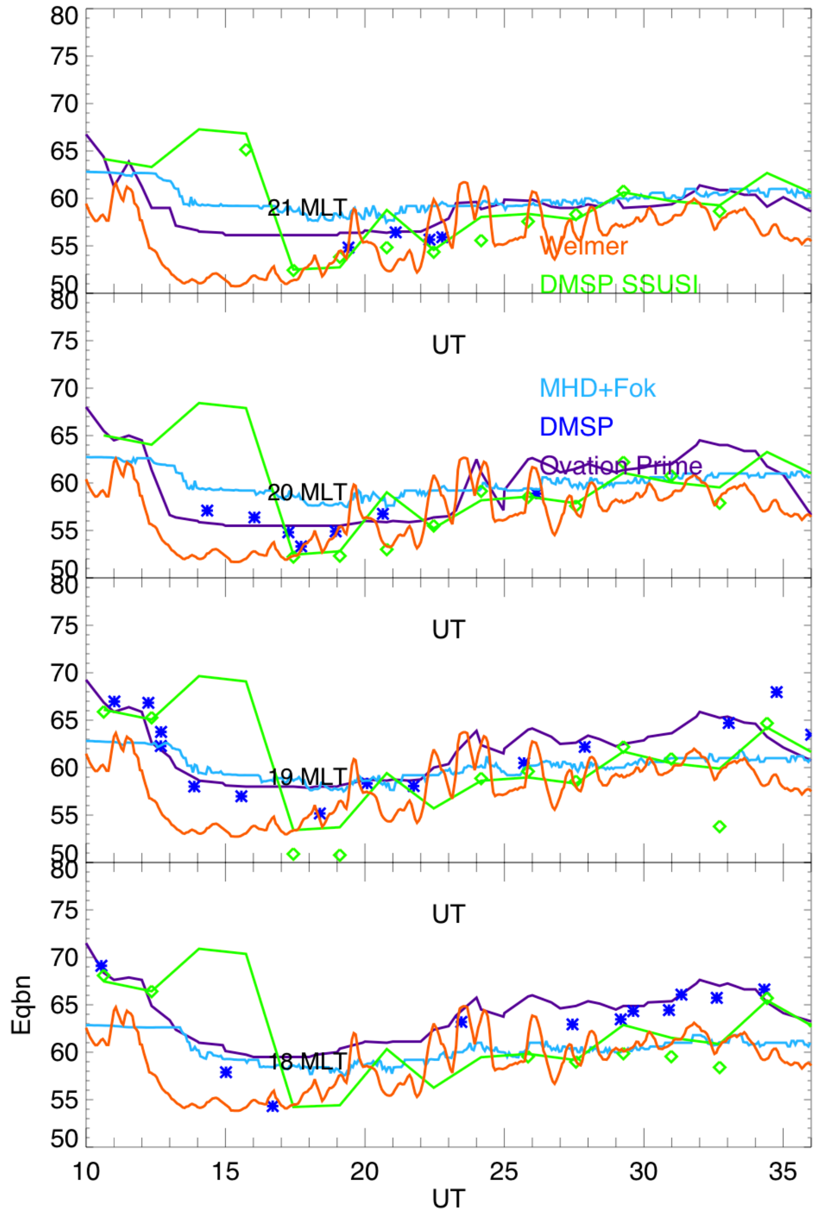
http://ccmc.gsfc.nasa.gov/RoR_WWW/presentations/boundary_options.pdf

Measure of Performance

- PE for a fixed local time (PE)
  - How well model performs in terms of temporal revolution
- Divided into different local time sectors – such as the dusk side
- Whether the deviation in all local time is uniform or not – a measure of whether the model captures the MLT feature
  - How well models do

correlation in MLT binned by activity level or for a specific time - auroral imaging


SYM/H_index nT
ASY/H_index nT
12:00:00 05 Aug 31
18:00:00 05 Aug 31
00:00:00 05 Sep 1
06:00:00 05 Sep 1
12:00:00 05 Sep 1
TIME RANGE=2005/8/31 (243) to 2005/9/1 (244)
Time: 20050831_1025UT
Time: 20050831_1726UT
Time: 20050901_1025UT
DMSP SSUSI
Ovation Prime
DMSP Particle
SWMF+Fok RC
Weimer
Auroral Boundaries
12
06
00
18
60
70
80



21 MLT
Weimer
DMSP SSUSI
UT
MHD+Fok
DMSP
Ovation Prime
20 MLT
UT
19 MLT
UT
18 MLT
Eqbn
UT

Research Objective

- Develop and execute a meaningful comparison between DMSP energy flux measurements (in situ) and the calculated spatial and temporal energy outputs of various computational auroral models to include Ovation Prime, (Old & New) Hardy, SWMF/Fok-RC, and AMIE.
- Investigate the effect of geomagnetic activity and seasons on these results.
- From these comparisons, assign quantitative performance scores, utilizing various statistical measures (e.g., PE, Skill Score).

Validation Results

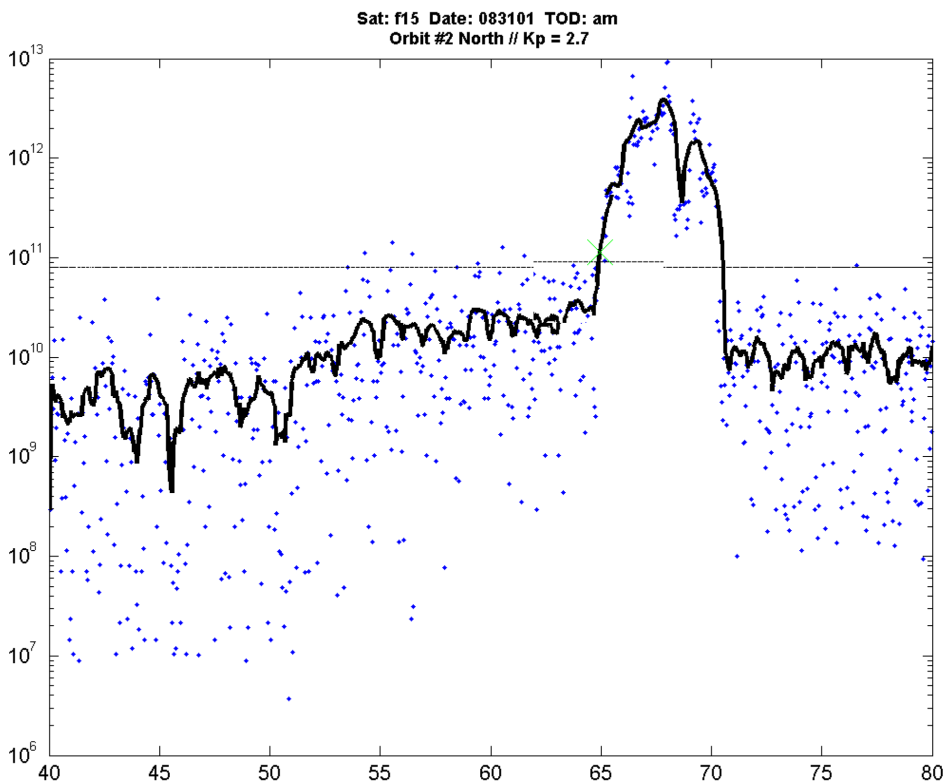
- A: 0.4 ergs/cm^2/s
- B: 0.6 ergs/cm^2/s
- C: 1.0 ergs/cm^2/s

A constant energy flux threshold is used for obtaining the equatorward boundary

1erg=10.^(-7) joule
1 eV=1.6*10.^(-19) joule
Threshold 0.4 ergs/cm^2/s =2.5*10^11 eV/cm^2/s

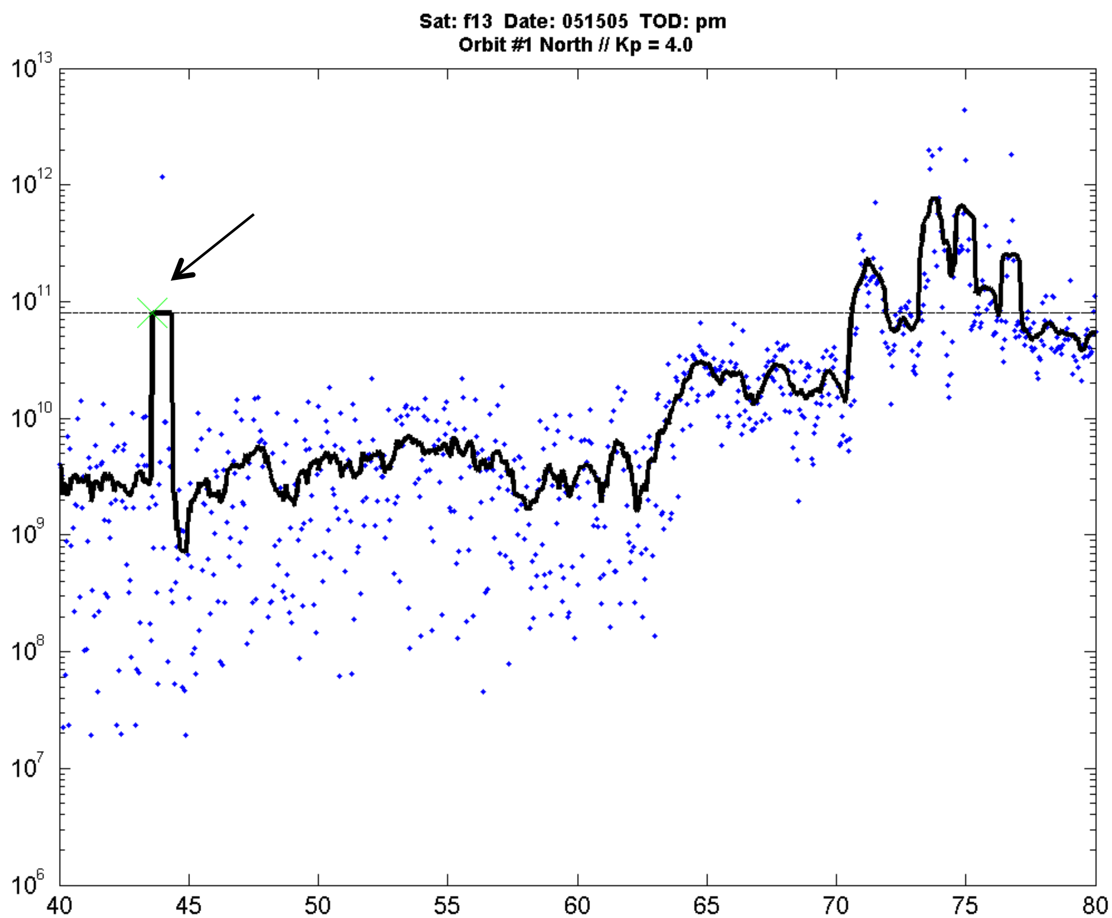
DMSP unit: eV/cm^2/s/sr
Limit= 8.0*10^10 eV/cm^2/s/sr

DMSP



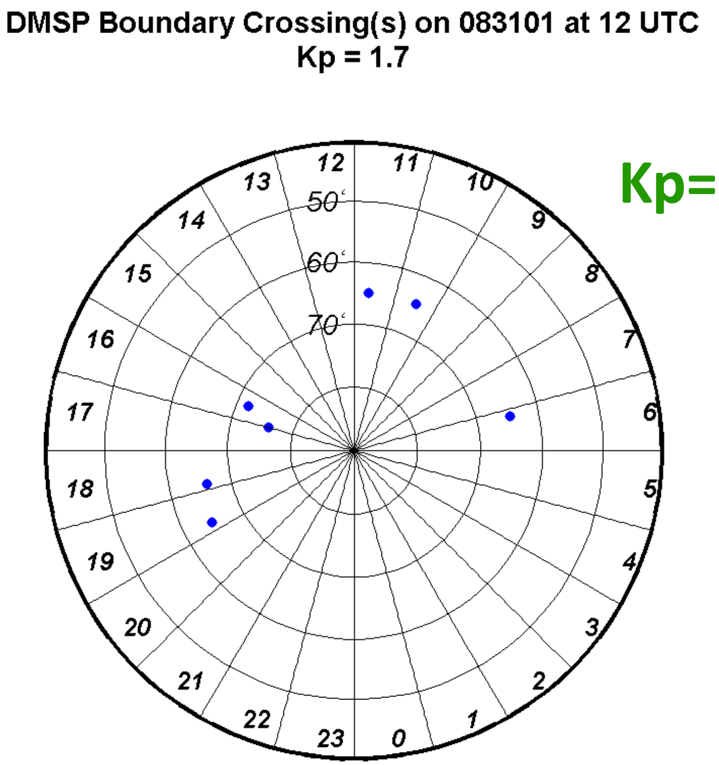
- DMSP satellite "pass"
- Northern Hemisphere
- Threshold is set to ~8.0×10^{10}, ~1.2×10^{11}, and ~2.0×10^{11} eV/cm^2/sec/sr
- 15-sec moving average is used (black line) for smoothing (all 0's removed)
- Green X represents crossing point
- More than 5800 of these passes have been collected…

DMSP



…and individually validated “by hand.”

DMSP

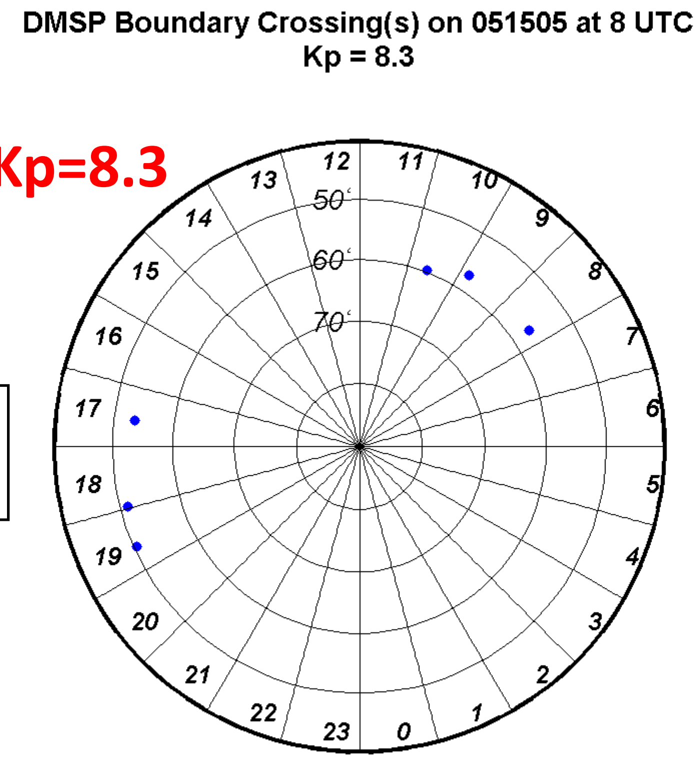


Kp=2

MLT Sectors

MLAT coordinates

Kp=8.3



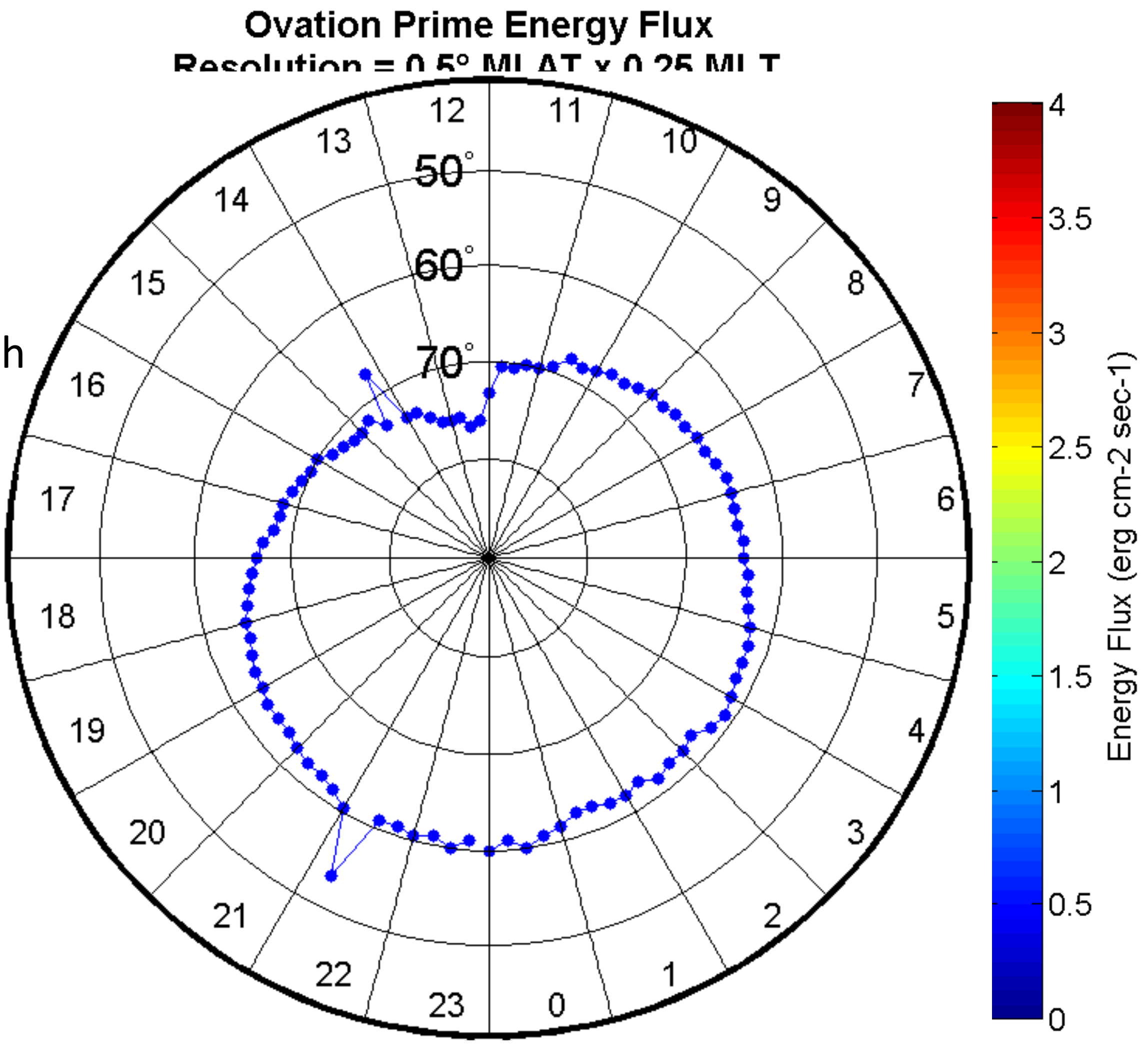
- Up to 4 satellites contribute up to 8 points per 60 minute period
- Increased geomagnetic storming results in threshold crossings moving equatorward

Five Models for Comparison

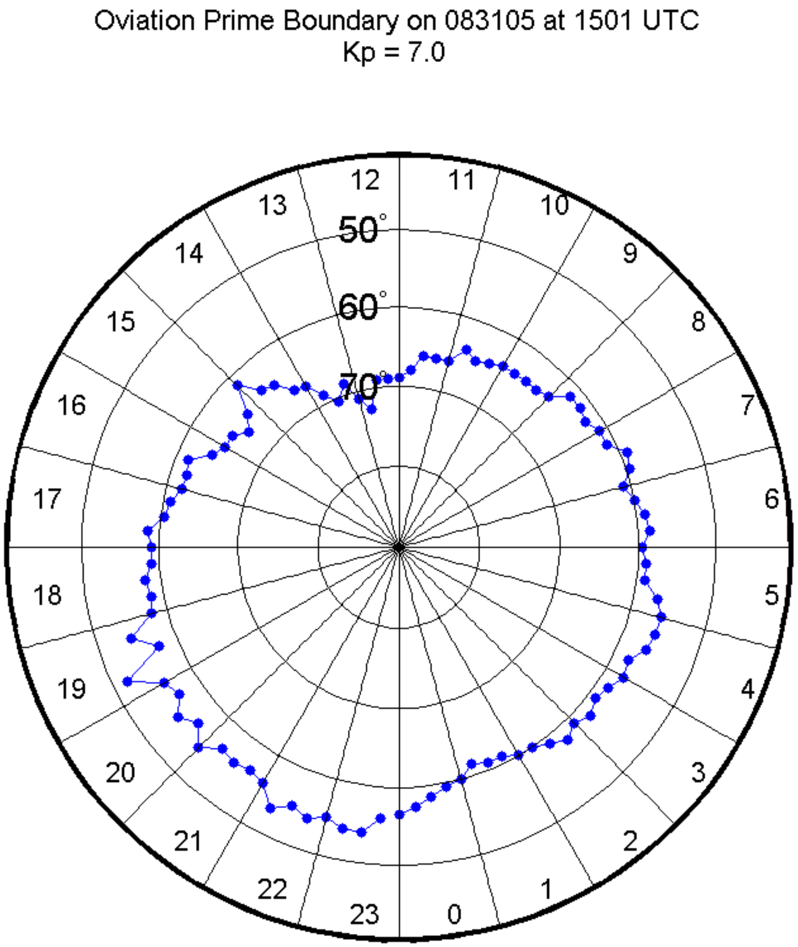
- Ovation Prime (OP)
- New Hardy (NH)
- Old Hardy (OH)
- SWMF – Fok-RC (SWMF)
- AMIE – (AMIE)

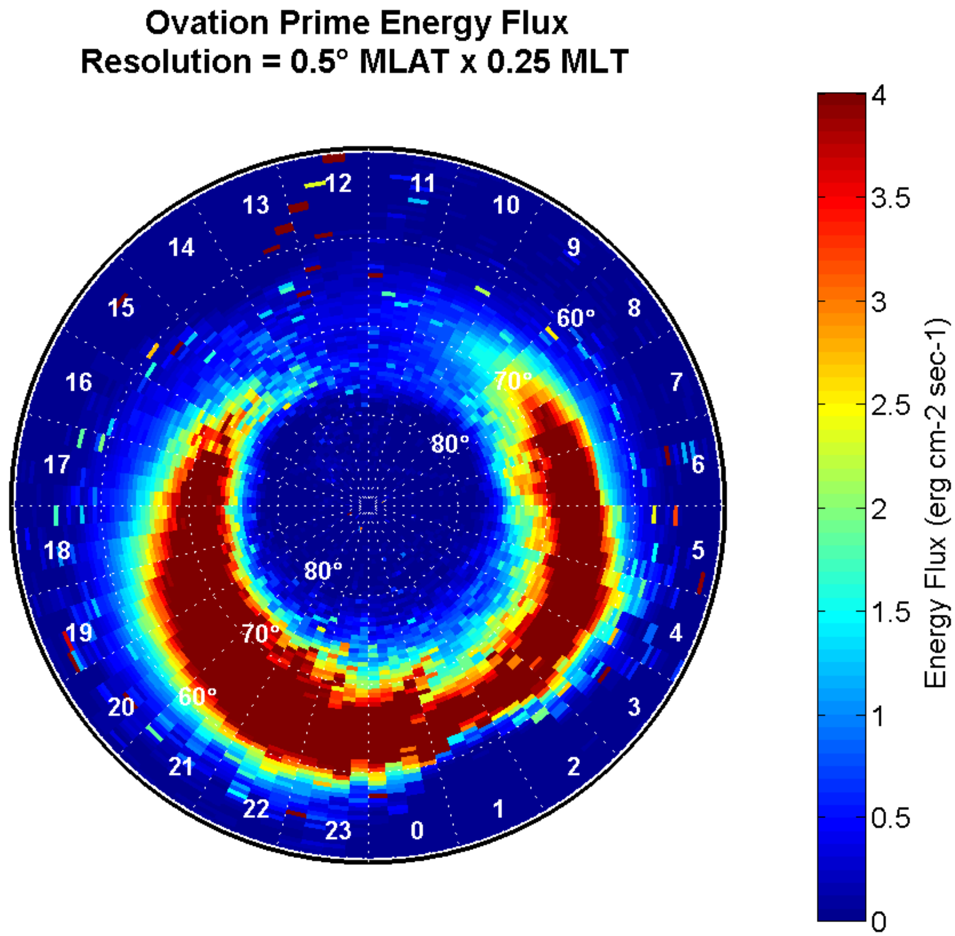
Ovation Prime

- <u>Ovation Prime Boundary Plot</u>
- 4 data points per MLT (3.75° spacing)
- In each MLT wedge, boundary is obtained with <u>three consecutive</u> values exceeding 0.4 erg/cm^2/s
- Observe:
  - Asymmetric
  - <u>Anomalous</u>
  - Small variations per minute
  - Strong Kp dependence



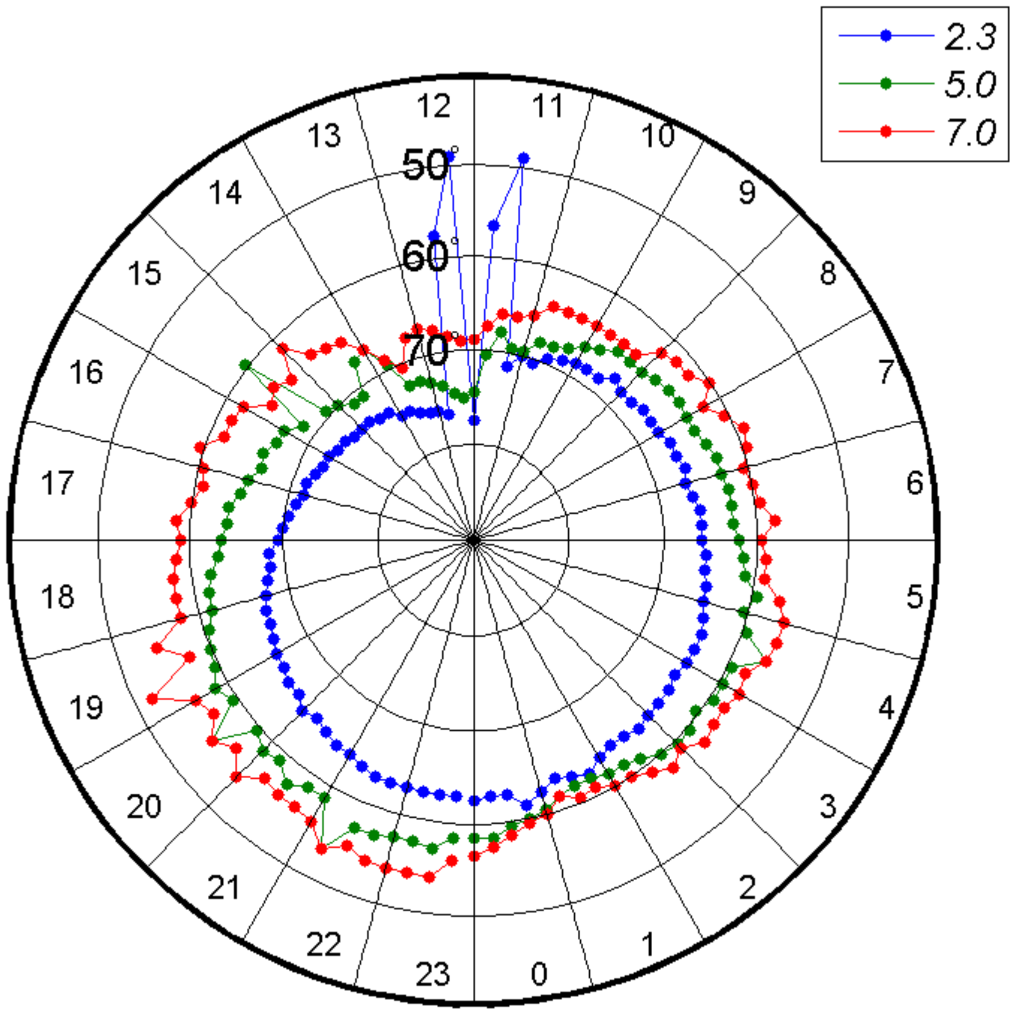
OP Boundary (Storming)





OP Boundary Morphology

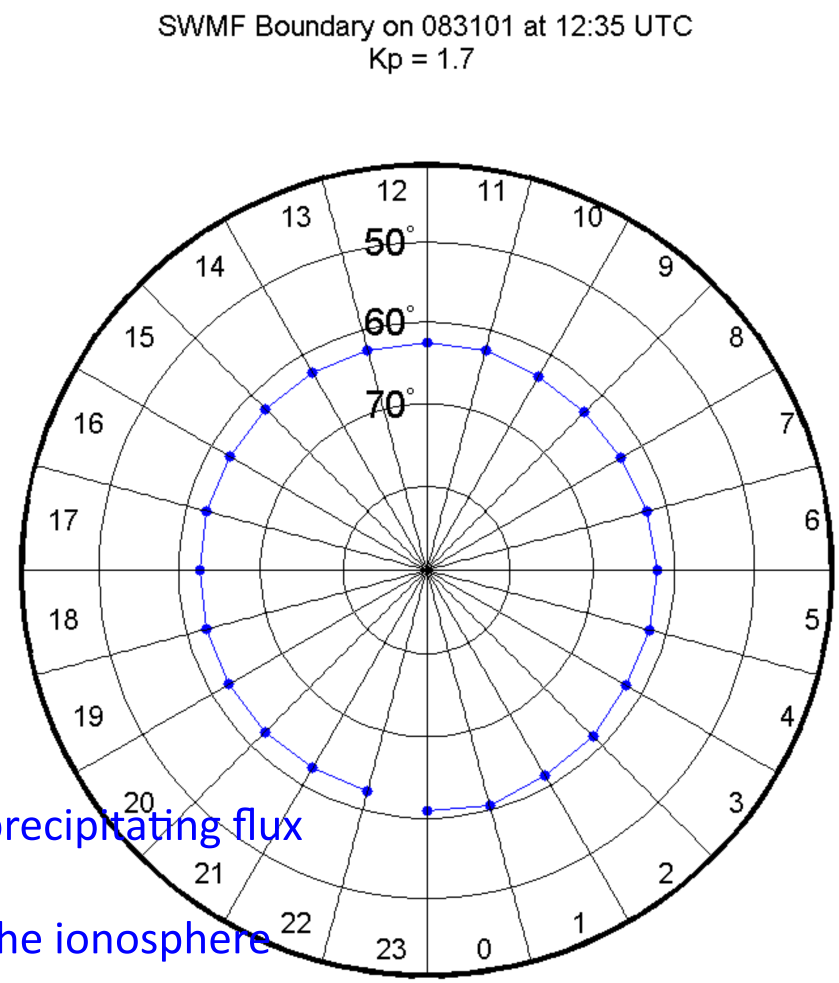
Oviation Prime Boundary on 083105 at Various Kp Values



SWMF-Fok RC

- <u>SWMF Model Boundary Plot</u>
- One point per MLT (15° spacing)
- Boundary is automatically computed using CCMC algorithm

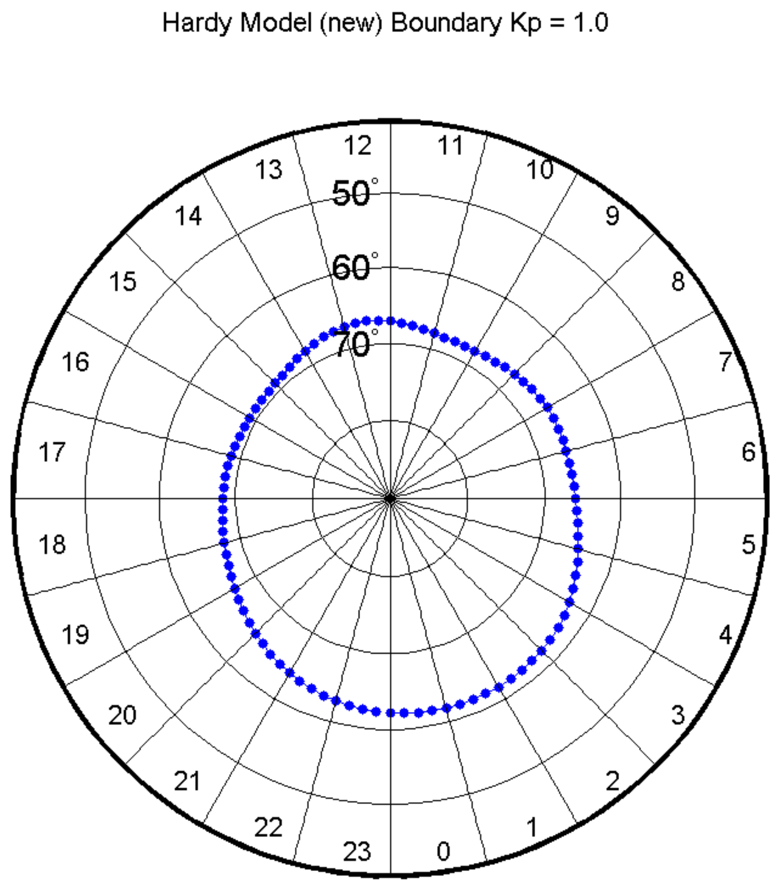
- Observe
  - <u>High symmetry</u>
  - Low Kp dependence / low variation in general



Note: from a crude method in calculating precipitating flux
Assuming strong pitch angle scattering
30% of ring current flux precipitating into the ionosphere

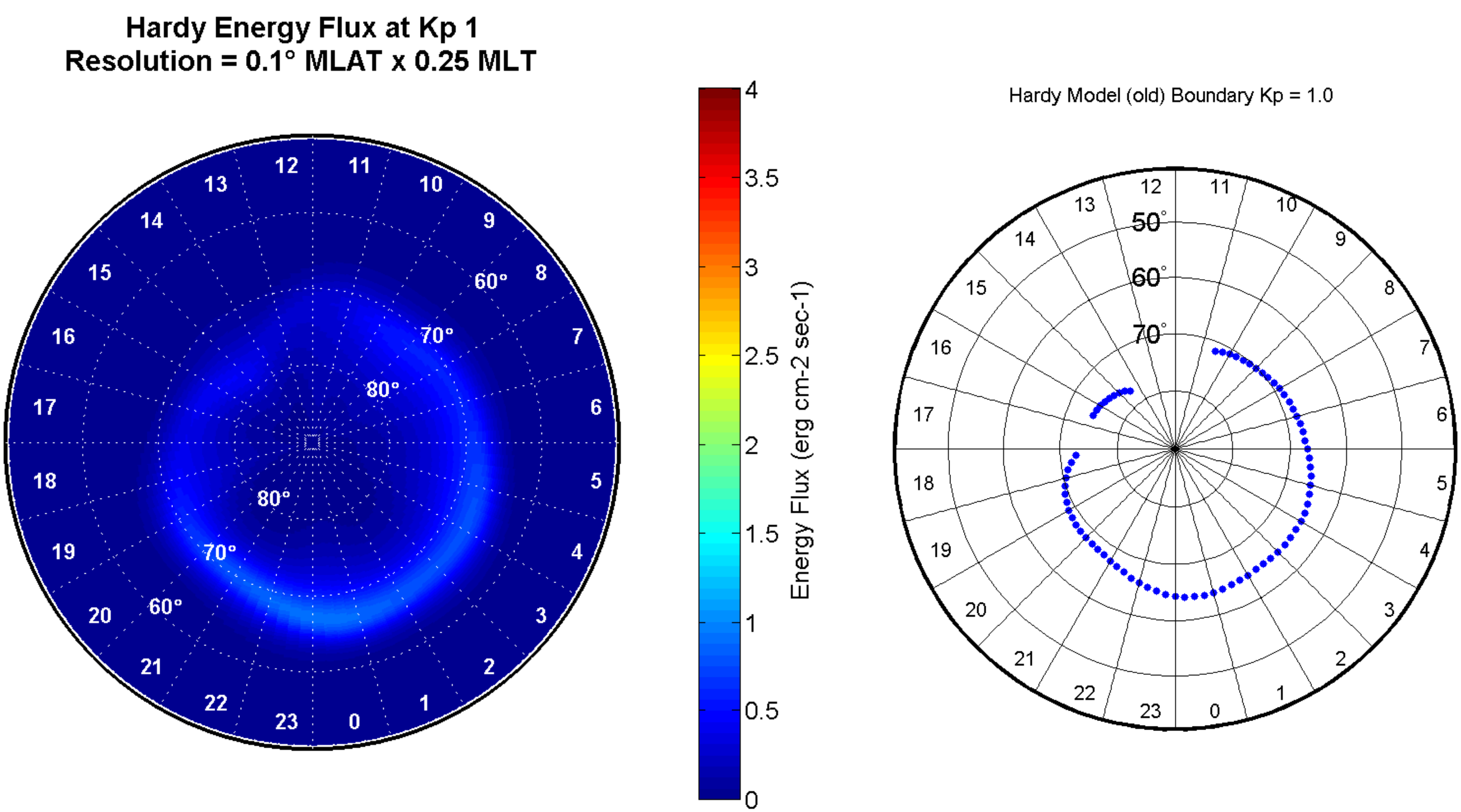
Mei-Ching: a refined method with realistic representation/calculation of precipitating flux

New Hardy (NH)

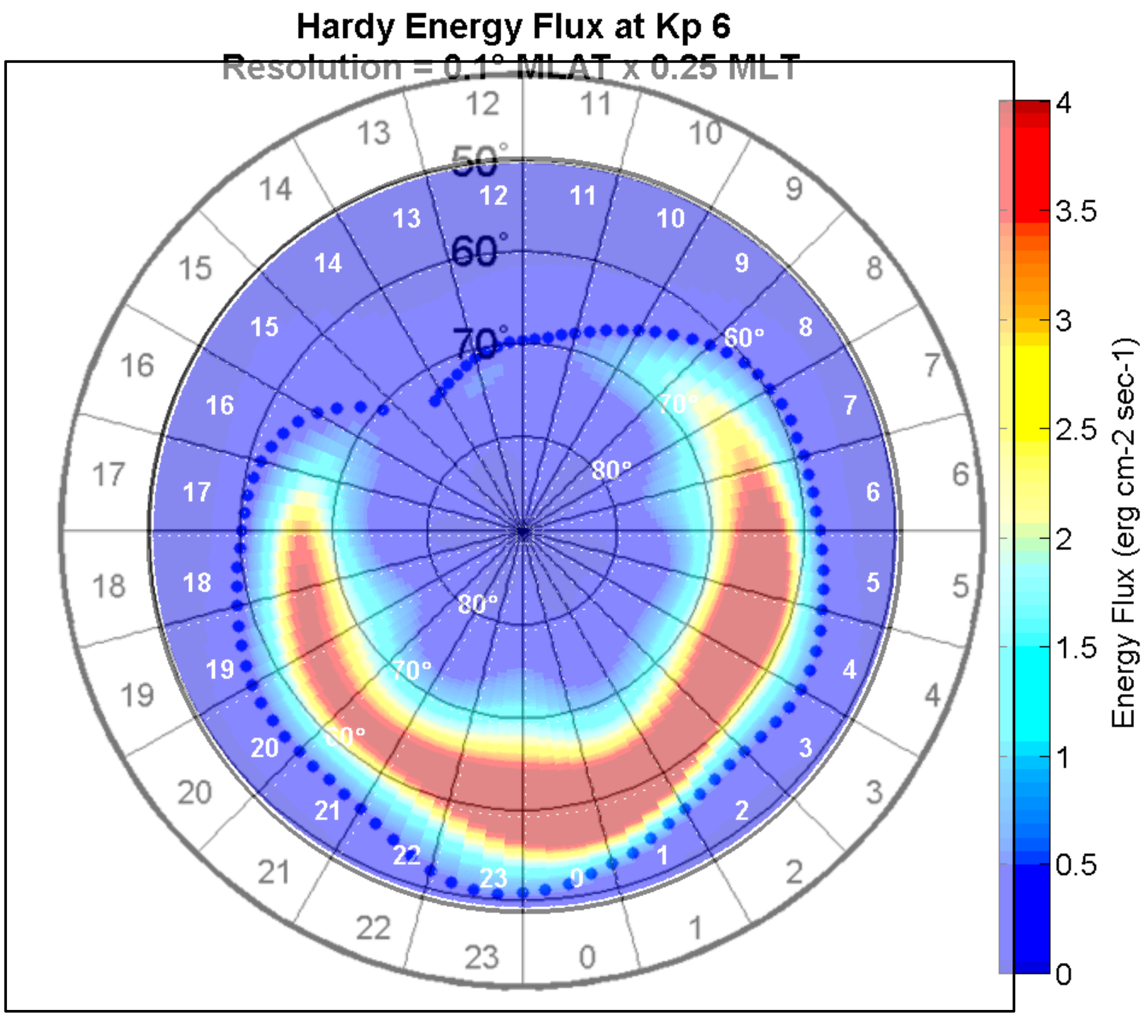


Hardy Model (new) Boundary Kp = 1.0
12
11
10
9
8
7
6
5
4
3
2
1
0
23
22
21
20
19
18
17
16
15
14
13
50°
60°
70°

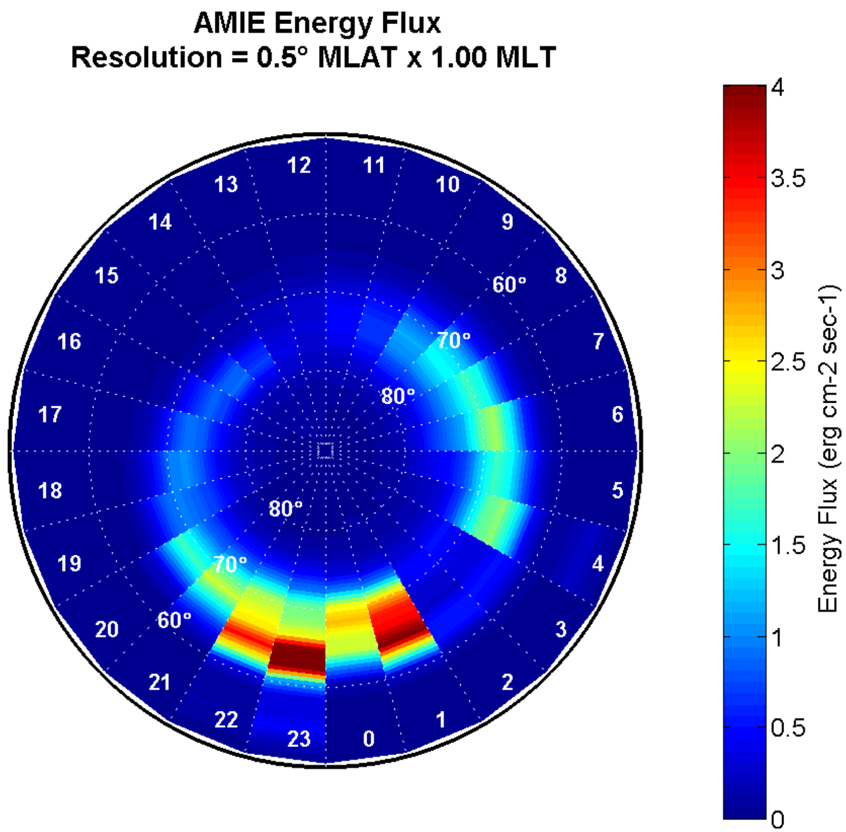
Old Hardy Kp 1

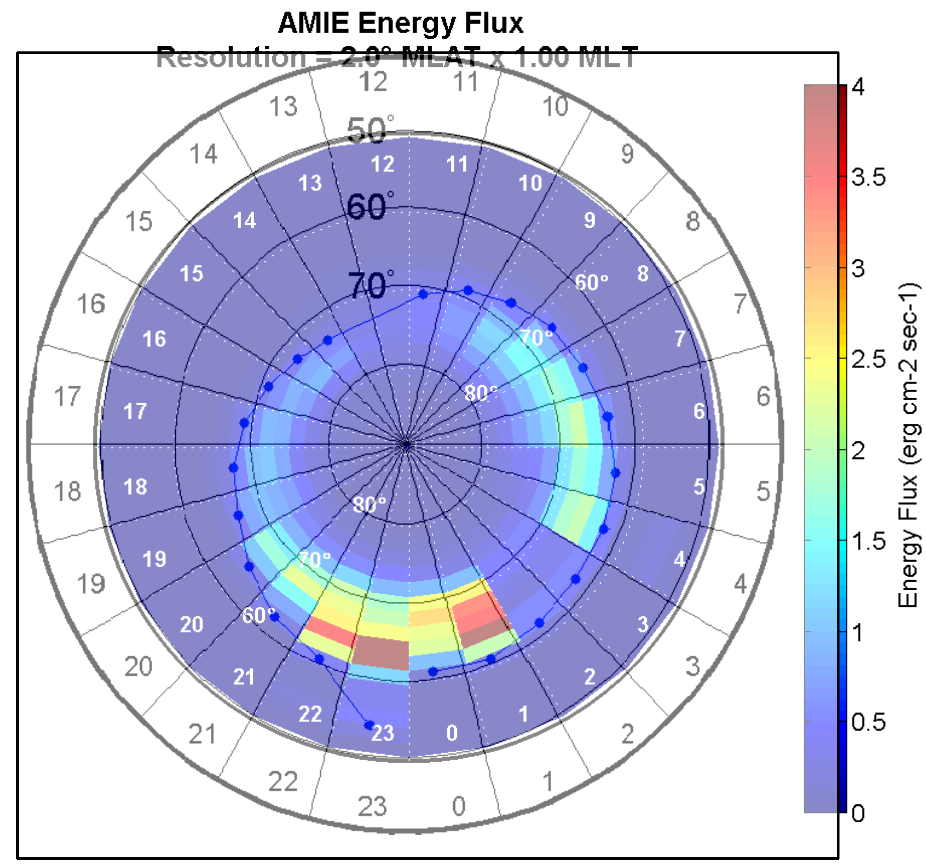


Old Hardy Kp 6



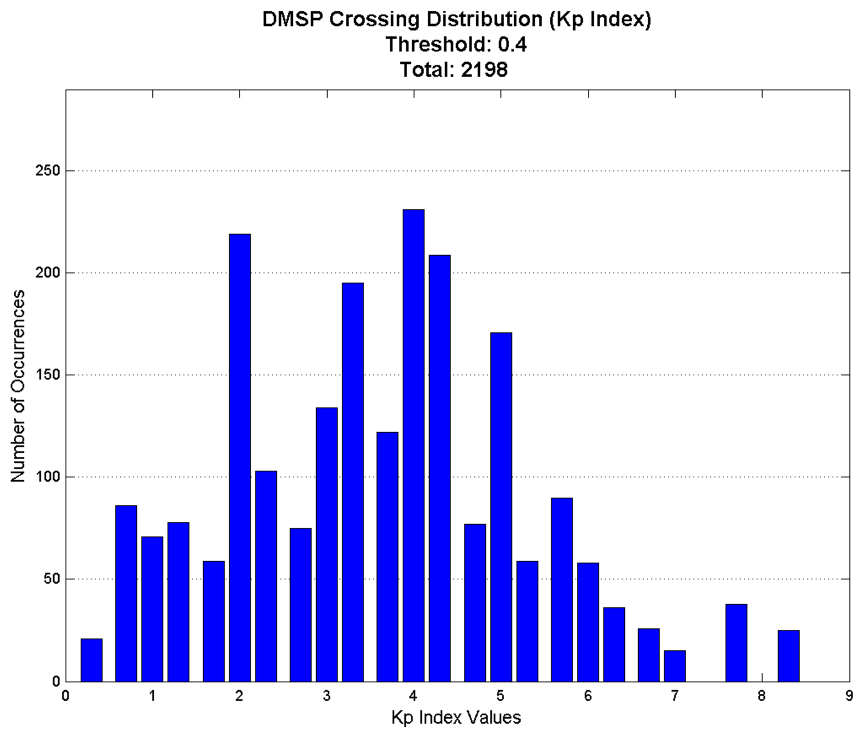
AMIE Data

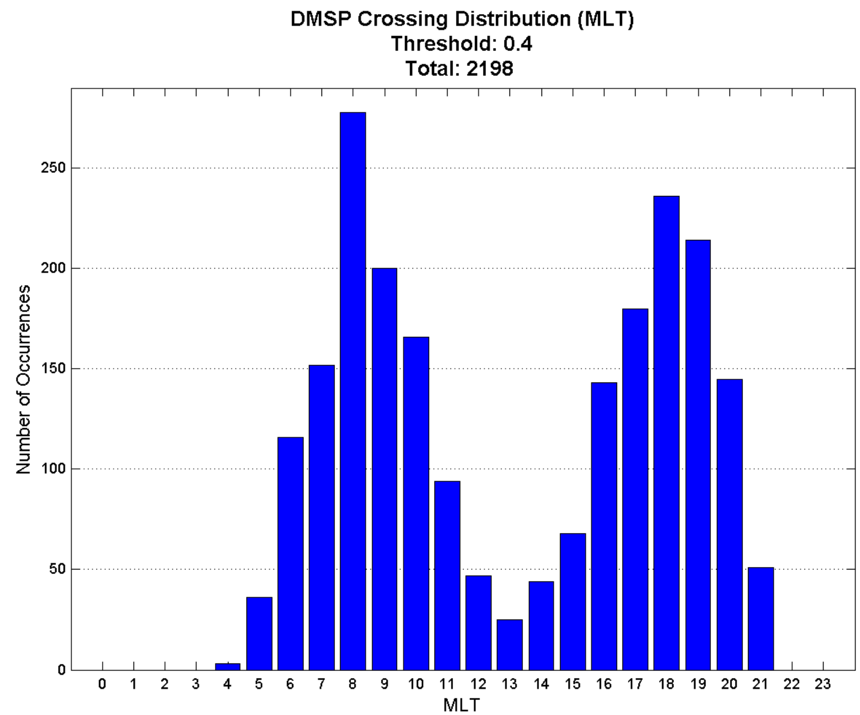




AMIE data is produced at a high cadence but with low spatial resolution. Interpolated plot is shown on the left.

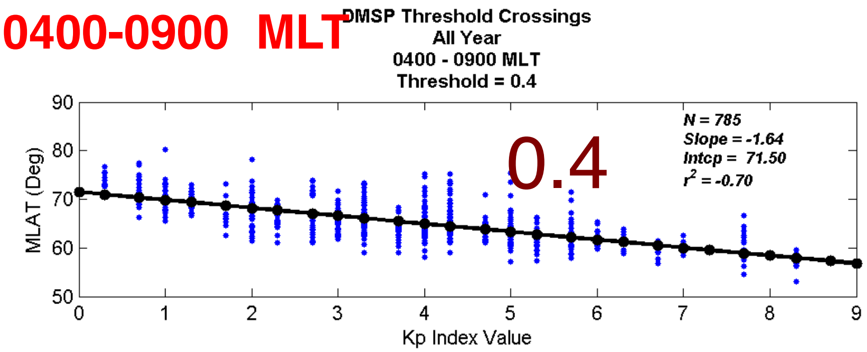
DMSP Crossings (0.4)

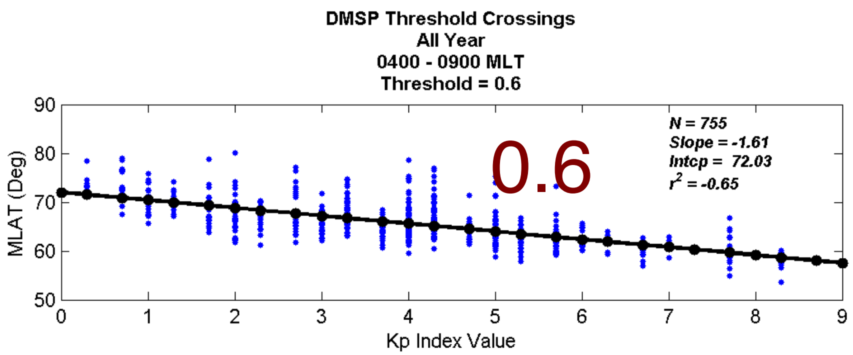


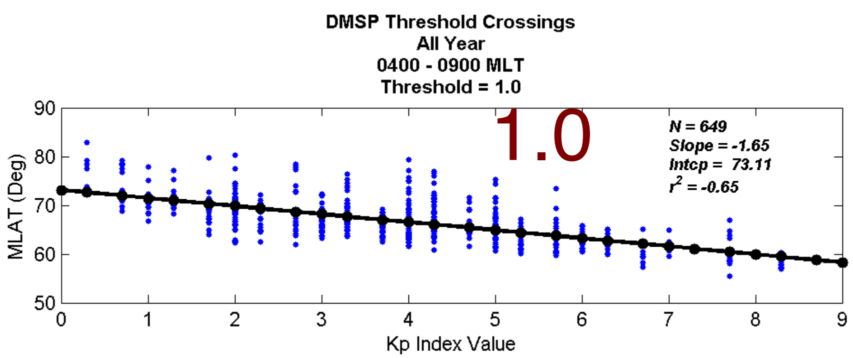


DMSP Crossing Statistics

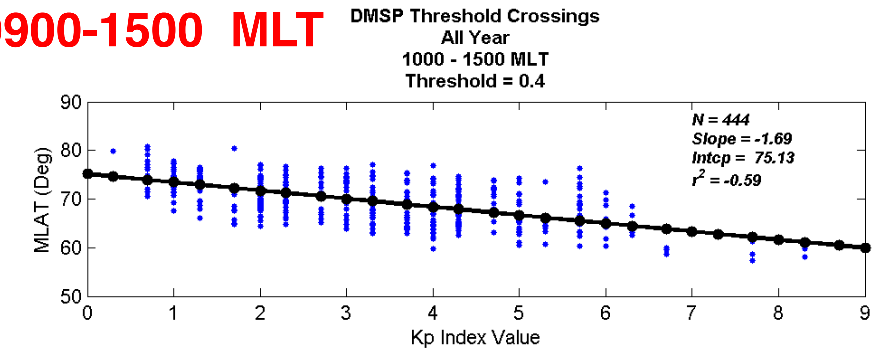
0400-0900 MLT

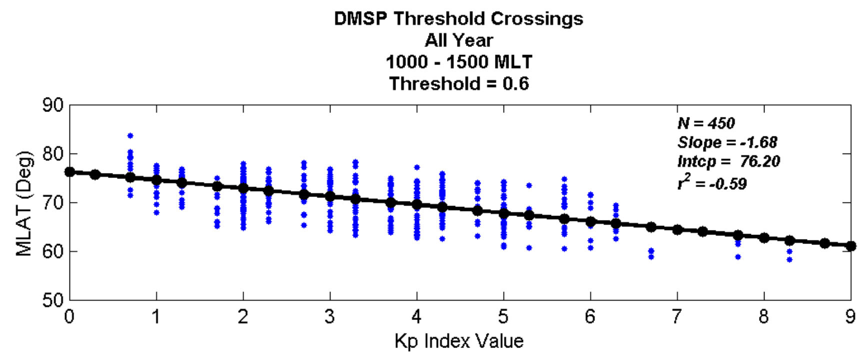


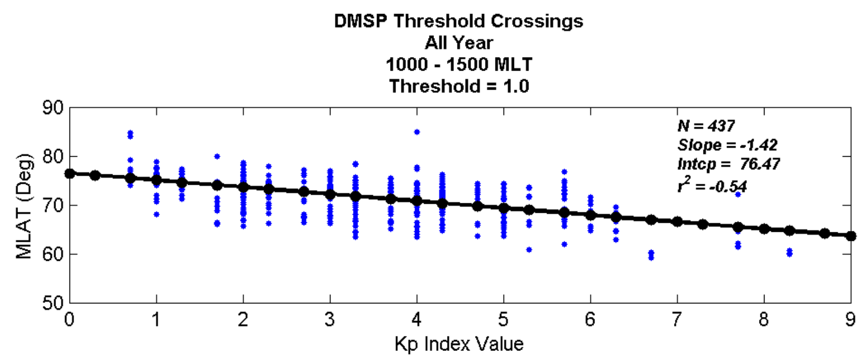




0900-1500 MLT

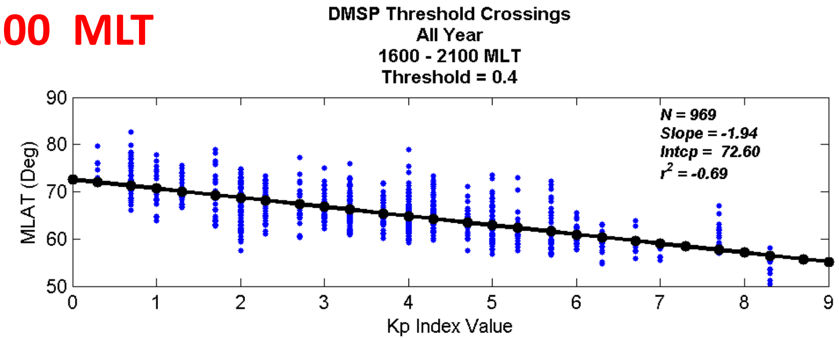


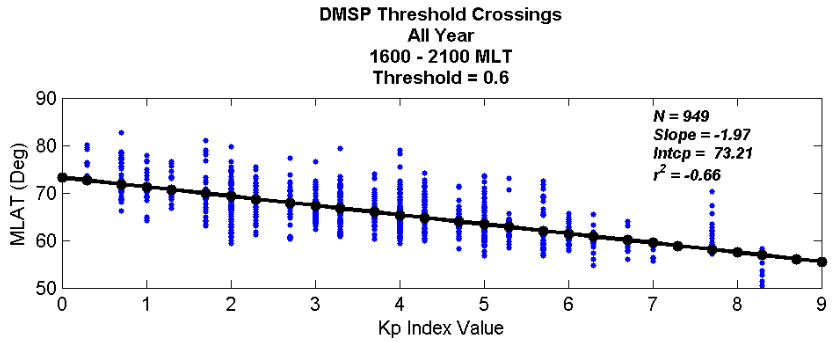


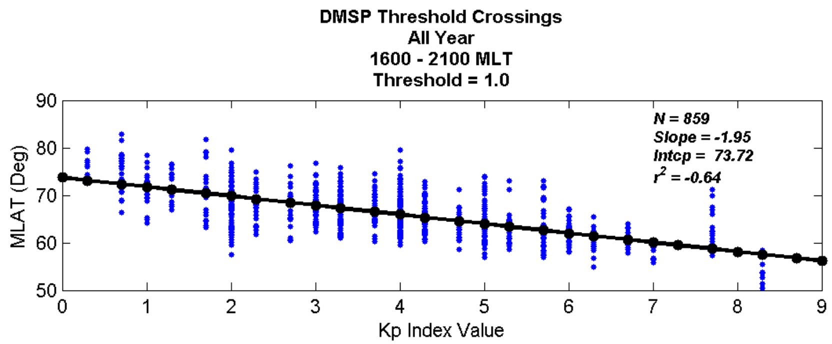


DMSP Crossing Statistics

1600-2100 MLT

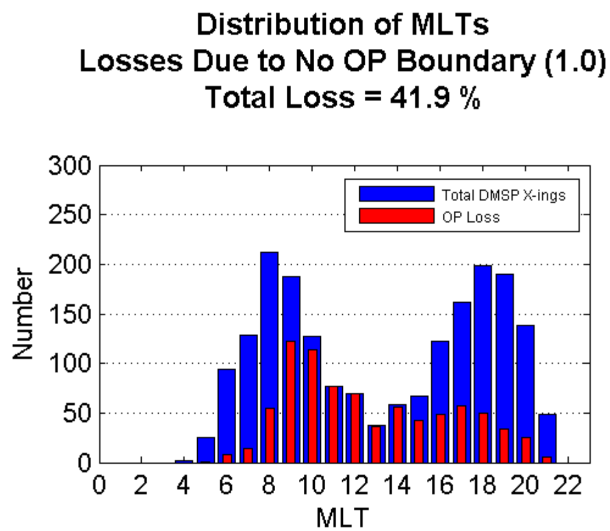


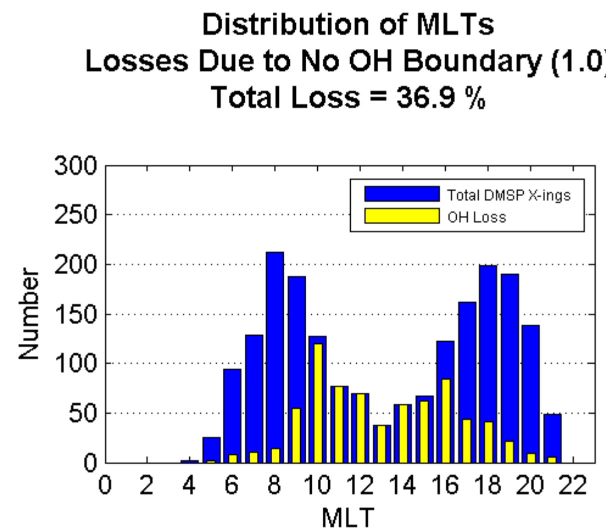


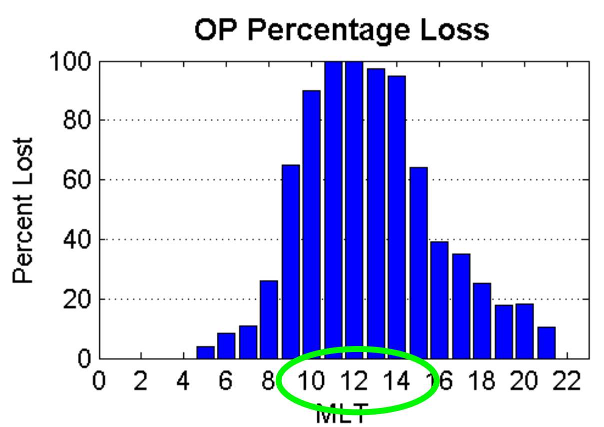


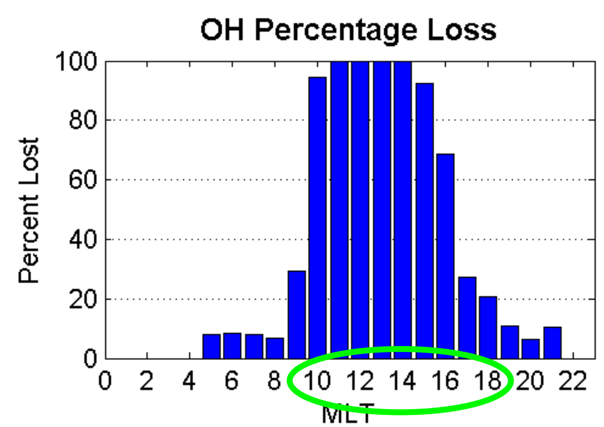
Data Losses

MLT (1.0 erg/cm^2/sec)









Analysis

- Analysis Formulas
  - Prediction Efficiency
    - 1 is perfect
    - 0 is worst
  - Skill Score
    - 1 is perfect
    - 0 is "no advantage"
    - Negative values indicate worse than reference (but not necessarily a bad result)
  - RMSE / DE / RE
  - MAE

$$PE = 1 - ARV$$

$$ARV = \frac{\sum_{i=1}^{n}(x_i - \hat{x}_i)^2}{\sum_{i=1}^{n}(x_i - \bar{x}_i)^2}$$

$x_i \longrightarrow observations\ (DMSP)$

$\hat{x}_i \longrightarrow predictions\ (model)$

$$SS = 1 - \frac{\sum_{i=1}^{n}(a_i - x_i)^2 / n}{\sum_{i=1}^{n}(b_i - x_i)^2 / n}$$

$x_i \longrightarrow observations\ (DMSP)$

$a_i \longrightarrow forecast\ (OP)$

$b_i \longrightarrow reference\ (OH)$

Prediction Efficiencies

	Season: ALL ToD: ALL Kp: ALL								
	0.4			0.6			1.0		
	N	Mean	PE	N	Mean	PE	N	Mean	PE
NH	*2198*	*2.54*	*0.26*	*2154*	*3.17*	*0.13*	*1945*	*3.95*	*-0.06*
OH	*2059*	*0.16*	*0.51*	*1724*	*-0.01*	*0.39*	*1227*	*-0.19*	*0.35*
OP	*2122*	*1.16*	*0.55*	*1772*	*0.76*	*0.55*	*1130*	*-0.09*	*0.53*

	Season: ALL ToD: Dusk Kp: Various								
	0.4			0.6			1.0		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
NH	*0.09*	*-0.14*	*0.02*	*-0.01*	*-0.24*	*0.1*	*-0.12*	*-0.41*	*0.12*
OH	*0.36*	*0.35*	*-0.04*	*0.13*	*0.4*	*0*	*-0.18*	*0.39*	*-0.14*
OP	*0.37*	*0.19*	*0.15*	*0.4*	*0.32*	*0.29*	*0.35*	*0.56*	*0.11*

	Season: ALL ToD: Dawn Kp: Various								
	0.4			0.6			1.0		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
NH	*-0.65*	*-0.27*	*-0.24*	*-1.03*	*-0.49*	*-0.13*	*-1.14*	*-0.97*	*-0.17*
OH	*0.06*	*0.05*	*-0.57*	*-0.28*	*-0.04*	*-0.84*	*-0.49*	*0.15*	*-0.68*
OP	*0.1*	*0.3*	*-0.1*	*0.2*	*0.18*	*-0.21*	*0.32*	*0.3*	*-0.46*

Cumulative Comps (0.4)

Seas	TOD	Kp	Mod	Num	Mean	Std		PE	RMSE	DE	CI1	RE	CI2	Num	SS
All Seas	All TOD	All Kp	OP	2122	1.16	2.94		0.55	3.16	1.16	0.13	1.02	0.002		
All Seas	All TOD	All Kp	OH	2059	0.16	3.12		0.51	3.12	0.16	0.13	1.00	0.002		
All Seas	All TOD	All Kp	NH	2198	2.54	3.22		0.26	4.1	2.54	0.13	1.04	0.002	2018	0.01
All Seas	All TOD	All Kp	SWMF	426	3.39	4.21		-0.03	5.4	3.39	0.4	1.06	0.006		
All Seas	All TOD	All Kp	AMIE	849	3.29	4.49		-0.24	5.56	3.29	0.3	1.05	0.005		

- OP has the best Prediction Efficiency and OH closely follows.
- OH has a regression line that closely approximates 1:1.
- The SS between OH and OP demonstrates no decisive advantage to either model.

- SWMF and AMIE do not perform well (worse than using the mean).

Cumulative Comps (0.4)

Seas	TOD	Kp	Mod	Num	Mean	Std	Num	PE	RMSE	DE	CI1	RE	CI2
All Seas	All TOD	Low Kp	OP	1319	0.97	2.96	1319	0.3	3.11	0.97	0.16	1.02	0.003
All Seas	All TOD	Low Kp	OH	1315	0.51	3.02	1315	0.31	3.06	0.51	0.16	1.01	0.003

Seas	TOD	Kp	Mod	Num	Mean	Std	Num	PE	RMSE	DE	CI1	RE	CI2
All Seas	All TOD	Mid Kp	OP	663	1.97	2.67	663	0.37	3.32	1.97	0.2	1.03	0.003
All Seas	All TOD	Mid Kp	OH	604	-0.28	3.14	604	0.34	3.15	-0.28	0.25	1	0.004

Seas	TOD	Kp	Mod	Num	Mean	Std	Num	PE	RMSE	DE	CI1	RE	CI2
All Seas	All TOD	High Kp	OP	140	-0.88	2.68	140	0.13	2.82	-0.88	0.44	0.99	0.007
All Seas	All TOD	High Kp	OH	140	-1.25	3.34	140	-0.39	3.55	-1.25	0.55	0.98	0.009

- These conclusions hold true at Low and Mid Kp values.
- At high Kp values, both models suffer.
- SWMF provides the best PE at during High Kp conditions.

Seas	TOD	Kp	Mod	Num	Mean	Std	Num	PE	RMSE	DE	CI1	RE	CI2
All Seas	All TOD	High Kp	SWMF	103	-0.36	2.43	103	0.29	2.45	-0.35	0.47	0.99	0.008
All Seas	All TOD	High Kp	OP	140	-0.88	2.68	140	0.13	2.82	-0.88	0.44	0.99	0.007
All Seas	All TOD	High Kp	NH	140	-0.72	2.94	140	0	3.01	-0.72	0.49	0.99	0.008
All Seas	All TOD	High Kp	OH	140	-1.25	3.34	140	-0.39	3.55	-1.25	0.55	0.98	0.009
All Seas	All TOD	High Kp	AMIE	115	0.81	4.1	115	-0.98	4.16	0.81	0.76	1.01	0.013

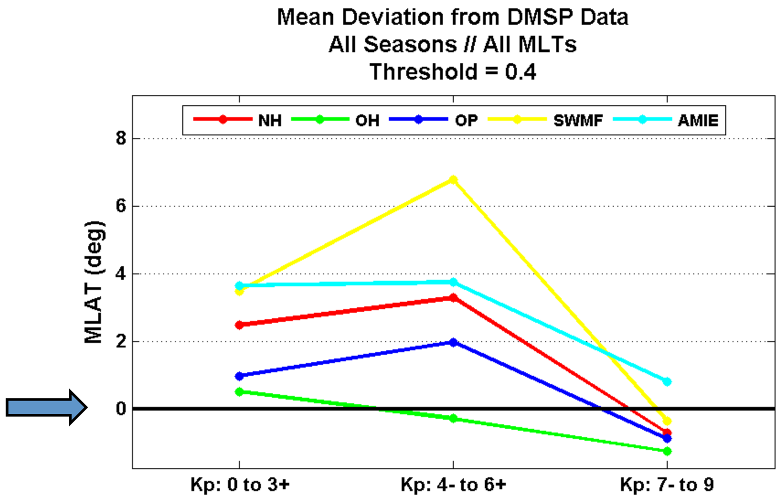
Seasonal Comps (0.4)

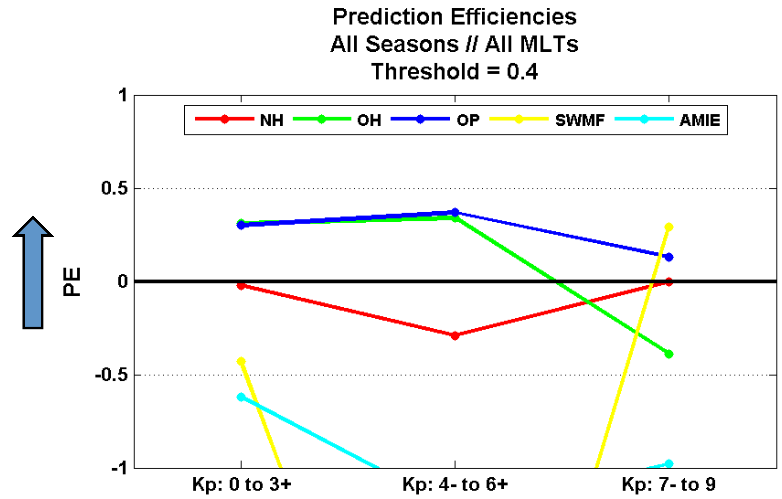
Seas	TOD	Kp	Mod	Num	Mean	Std	Num	PE	RMSE	DE	CI1	RE	CI2
WI	All TOD	All Kp	OP	478	0.74	2.82	478	0.64	2.91	0.74	0.25	1.01	0.004
WI	All TOD	All Kp	OH	460	0.46	3.01	460	0.58	3.04	0.46	0.28	1.01	0.004
WI	All TOD	All Kp	NH	498	2.76	3.16	498	0.28	4.2	2.76	0.28	1.04	0.004
WI	All TOD	All Kp	SWMF	187	2.78	3.56	187	-0.05	4.51	2.78	0.51	1.05	0.008
WI	All TOD	All Kp	AMIE	260	4.06	5.44	260	-0.79	6.78	4.06	0.66	1.07	0.011

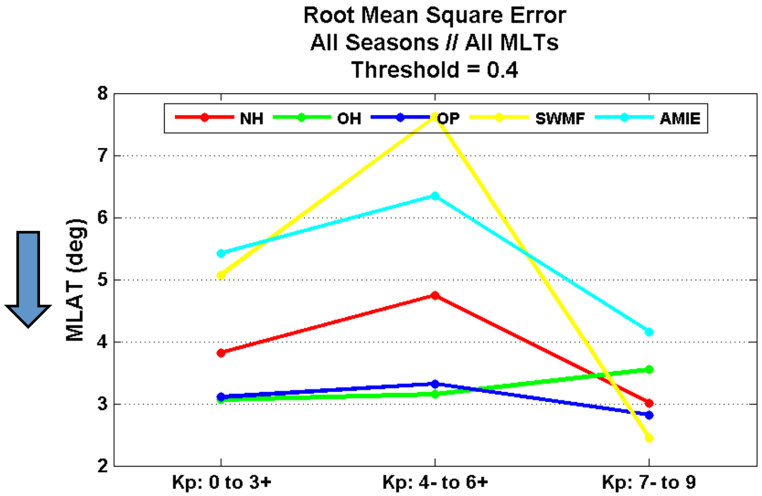
Seas	TOD	Kp	Mod	Num	Mean	Std	Num	PE	RMSE	DE	CI1	RE	CI2
SU	All TOD	All Kp	OP	663	1.34	2.9	663	0.65	3.2	1.34	0.22	1.02	0.003
SU	All TOD	All Kp	OH	623	-0.12	3.47	623	0.52	3.47	-0.12	0.27	1	0.004
SU	All TOD	All Kp	NH	687	2.55	3.76	687	0.3	4.54	2.55	0.28	1.04	0.004
SU	All TOD	All Kp	AMIE	414	2.57	3.43	414	0.24	4.28	2.57	0.33	1.04	0.005
SU	All TOD	All Kp	SWMF	164	4.15	4.7	164	-0.22	6.25	4.15	0.72	1.07	0.011

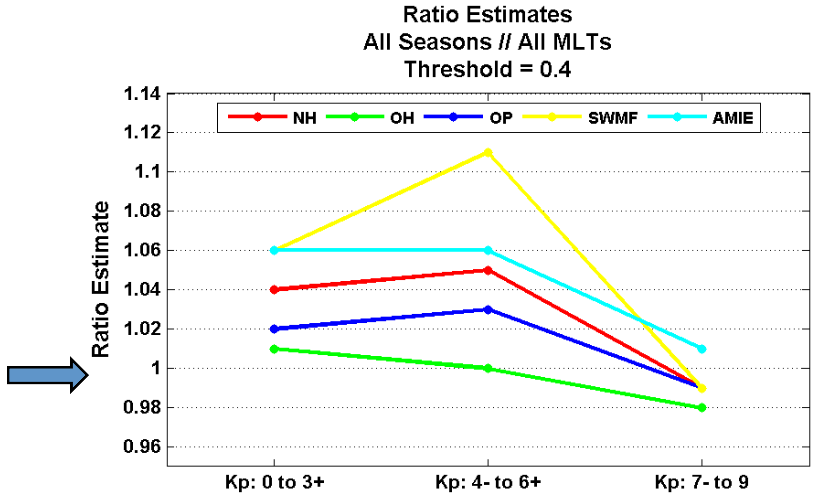
- Ovation Prime has the highest PE when seasonal dependence is investigated.

Metrics – All Models







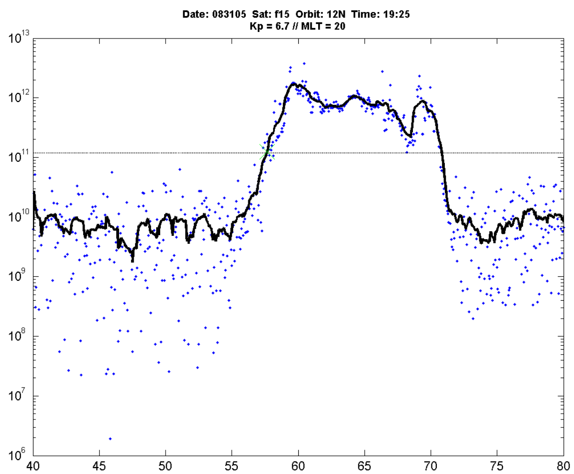


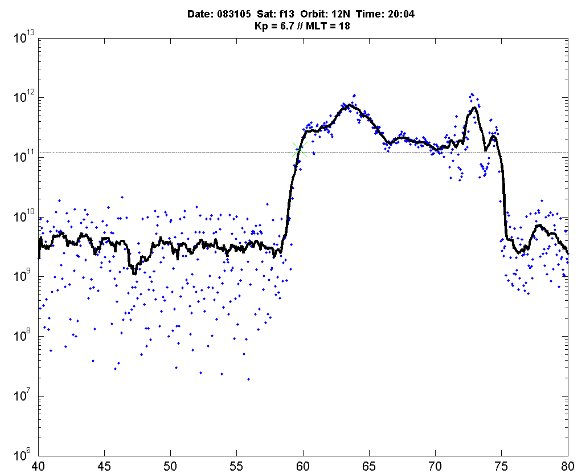
Results Summary

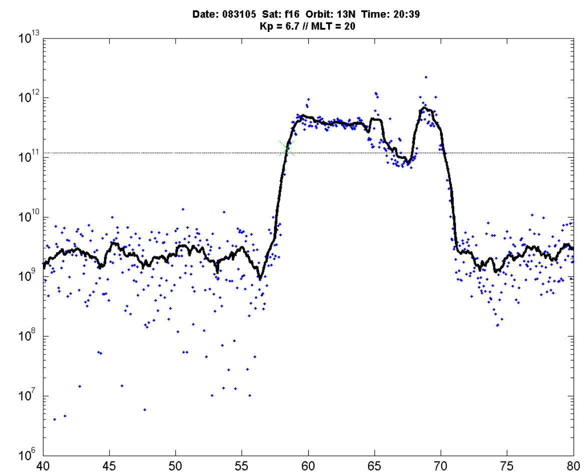
- OP has the best Prediction Efficiency and OH closely follows.
- OH has a regression line that closely approximates 1:1.
- The SS between OH and OP demonstrates no decisive advantage to either model.
- SWMF and AMIE do not perform well (worse than using the mean).
- These conclusions hold true at Low and Mid Kp values.
- At high Kp values, OH and OP suffer.

- SWMF provides the best PE at during High Kp conditions.

DMSP Time Series







1925 UTC
20 MLT
f15

→

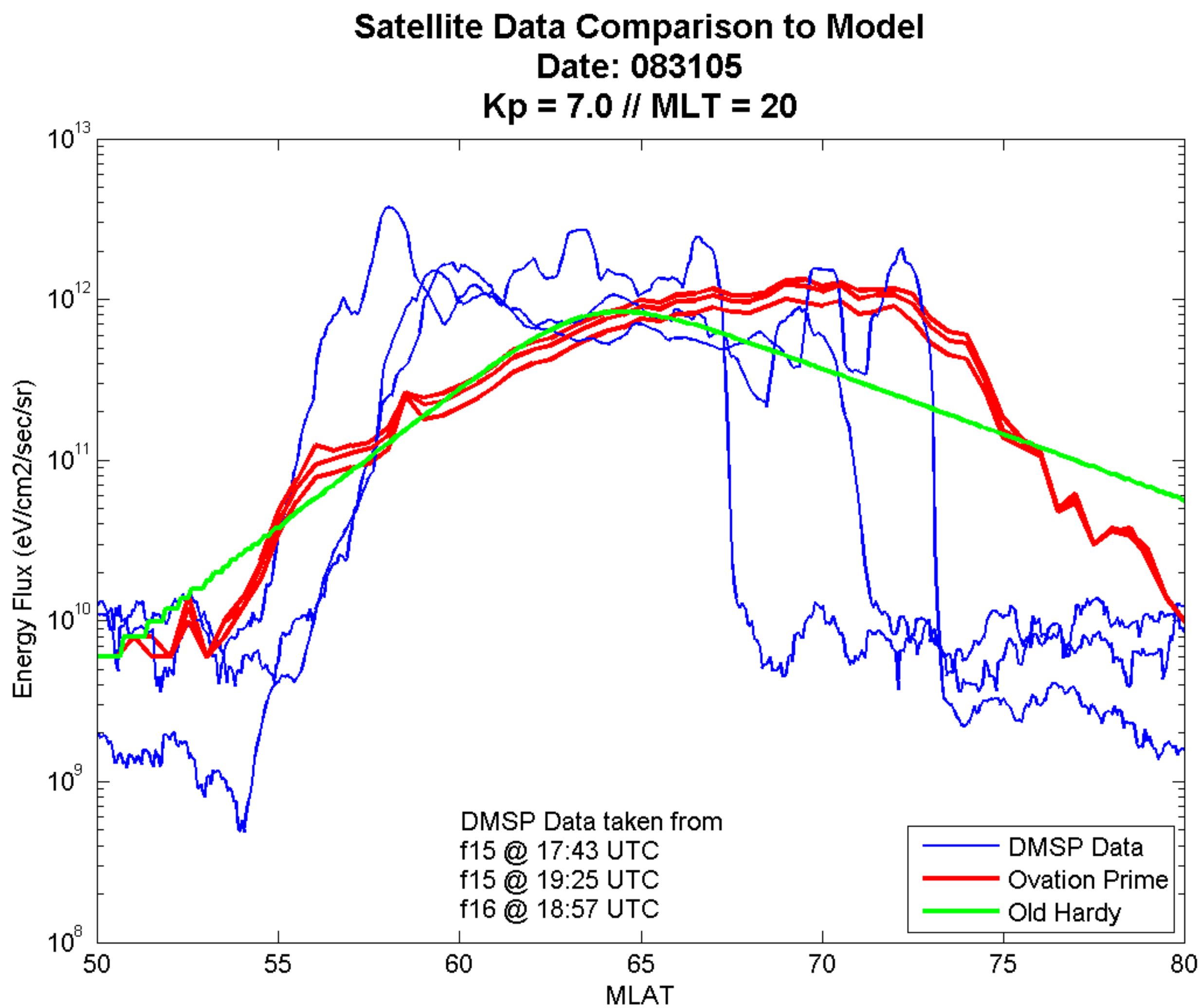
2004 UTC
18 MLT
f13

→

2039 UTC
20 MLT
f16

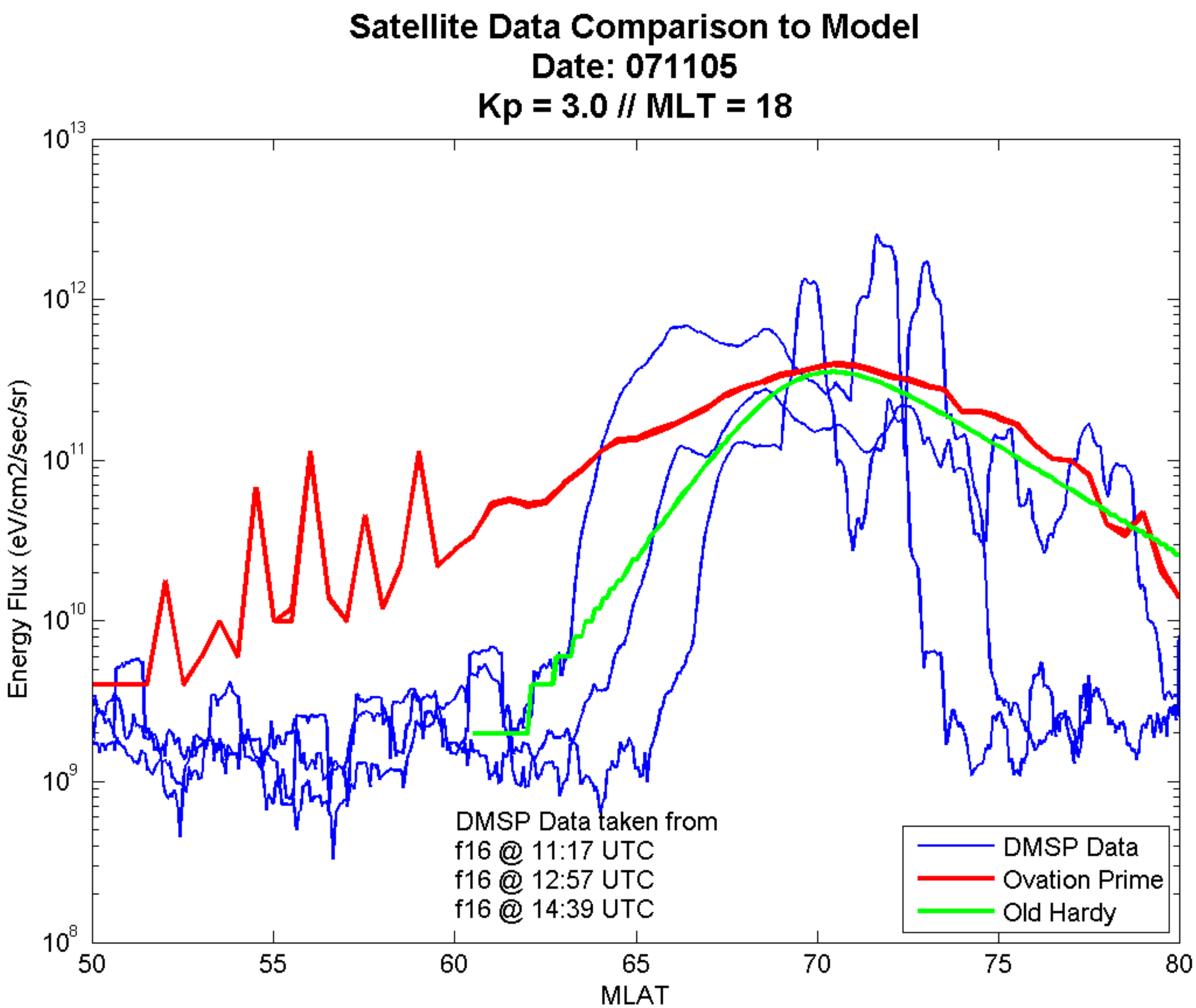
Model Performance along the satellite track

aurora with clean boundaries

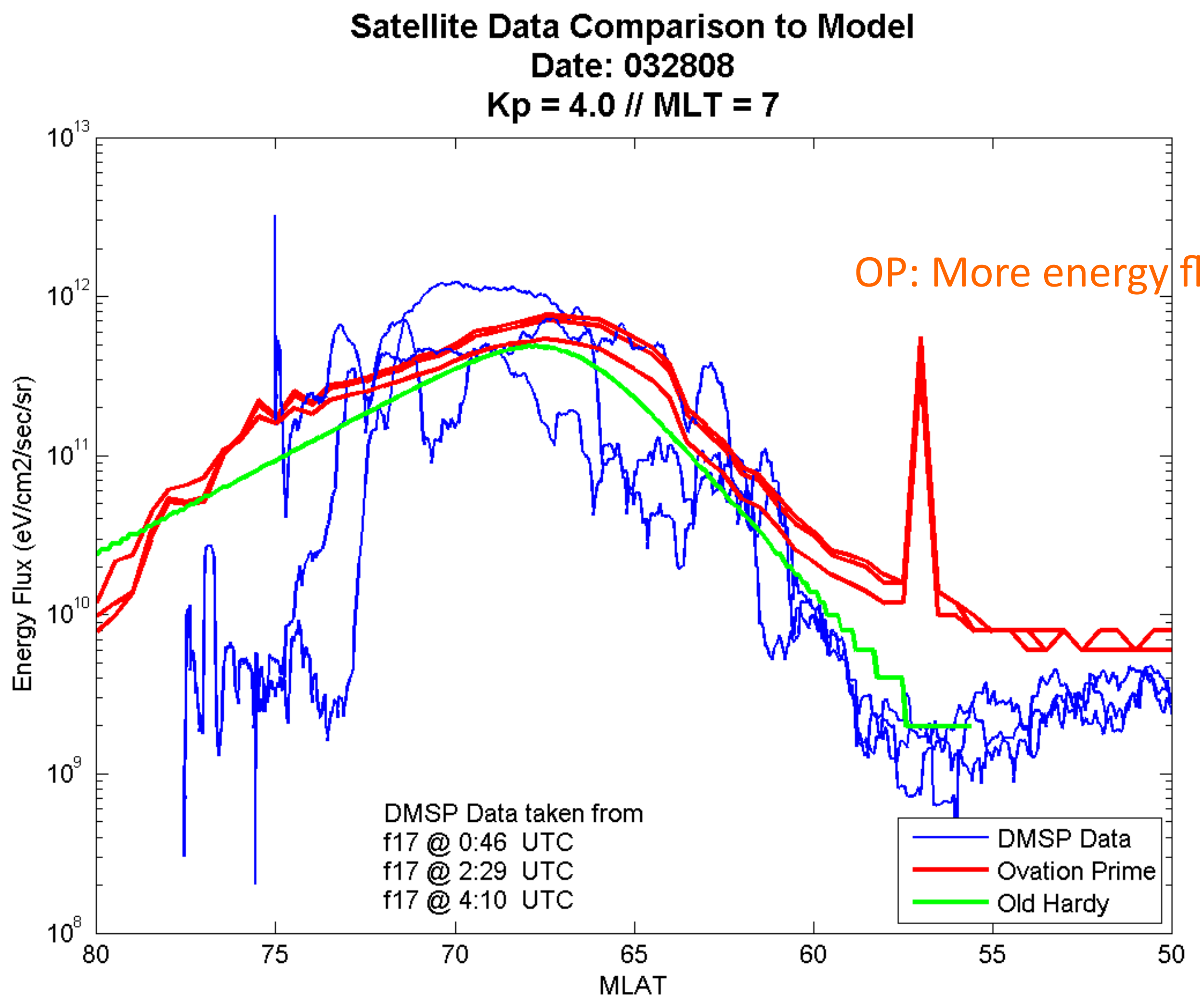


Model Performance along the satellite track

aurora with clean boundaries



Model Performance for a specific crossing



OP: More energy flux at high-lat

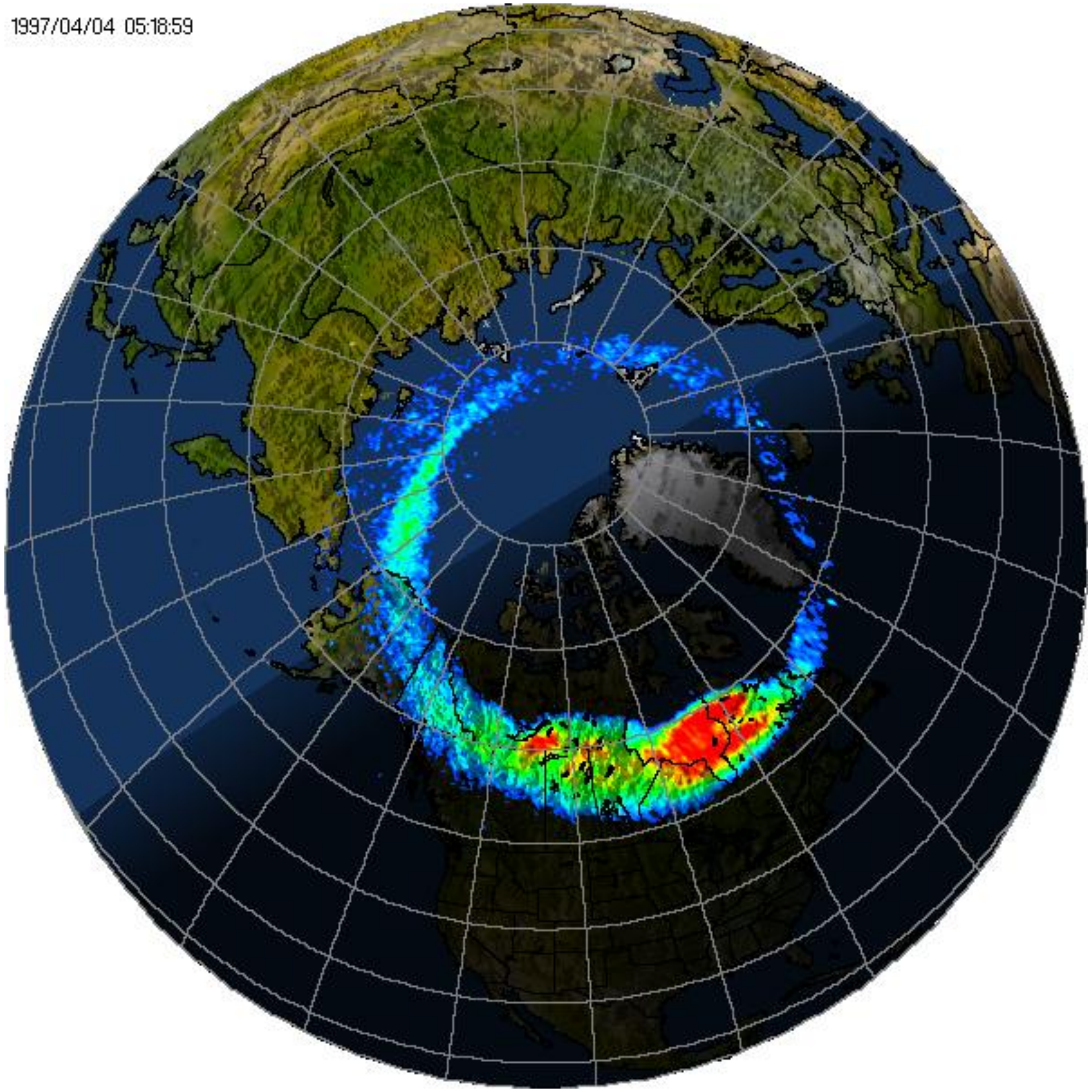
Measure of Performance future direction

- How well models do in capturing spatial features for a fixed time?
  - e.g., the MLT feature

correlation in MLT binned by activity level or for a specific time

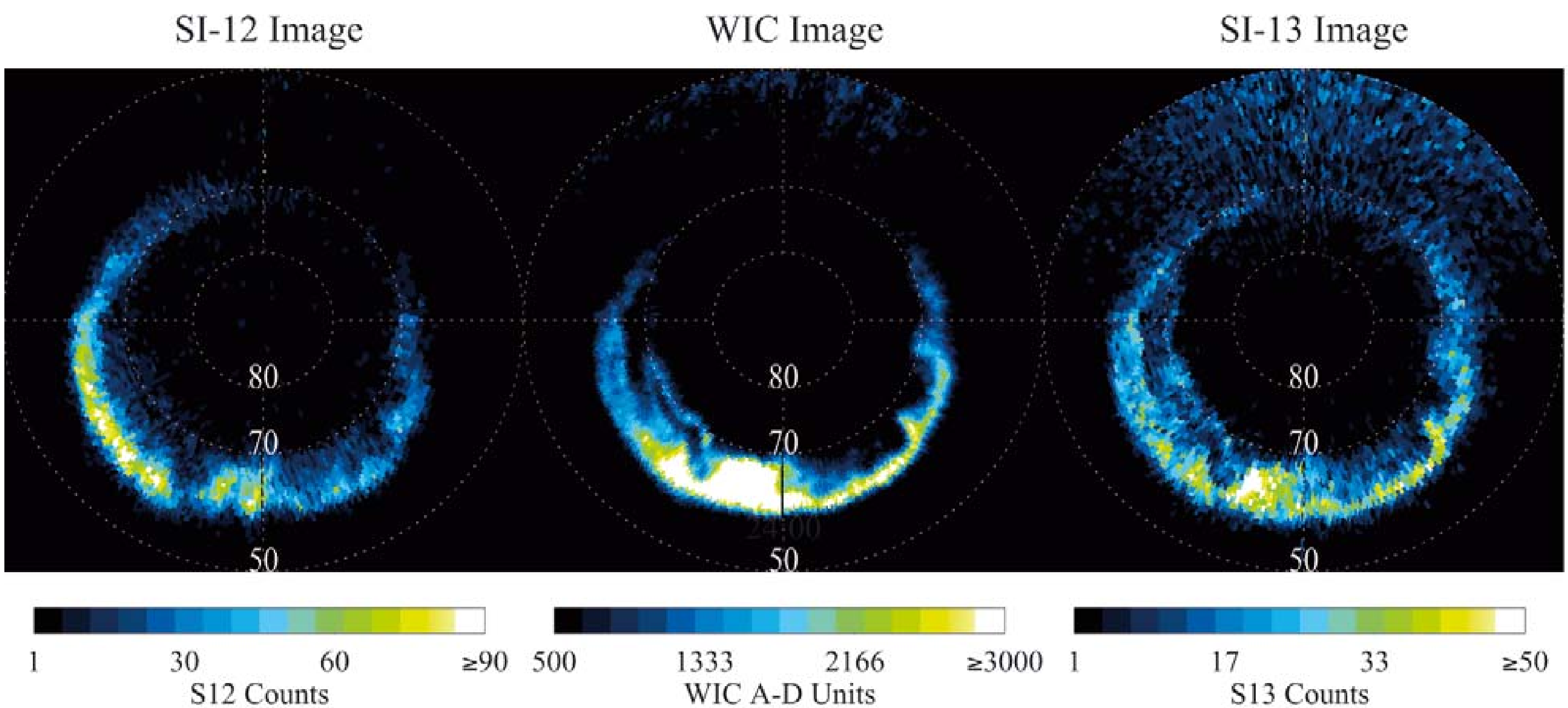
standard deviation of the boundary offset

Observations: auroral imaging

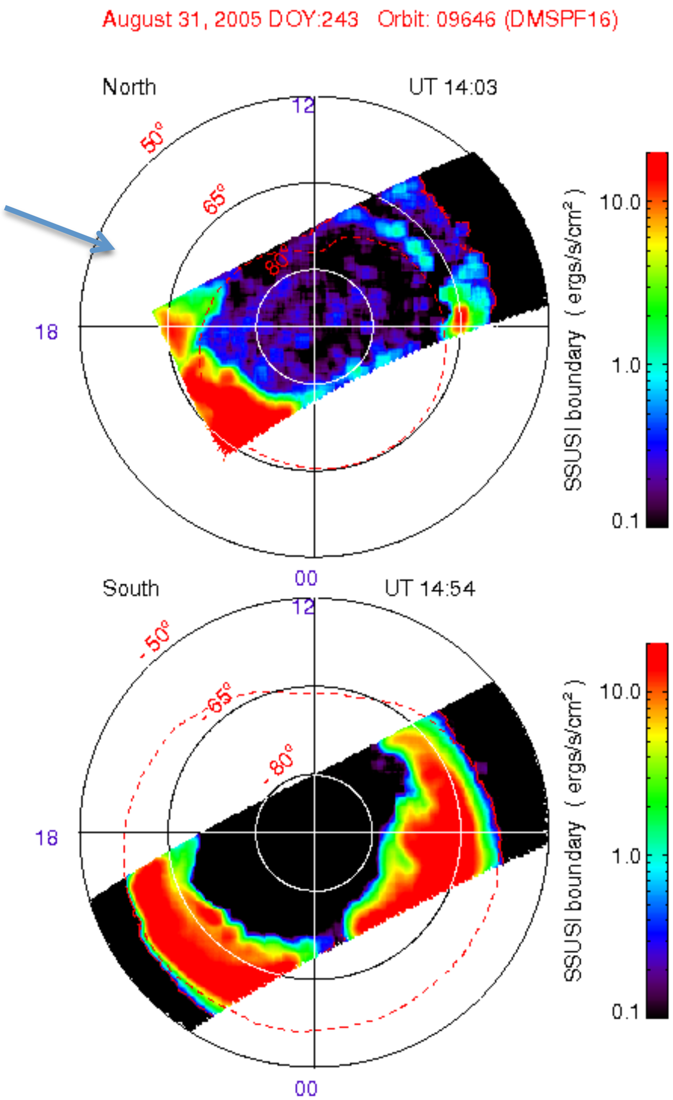


Polar UVI

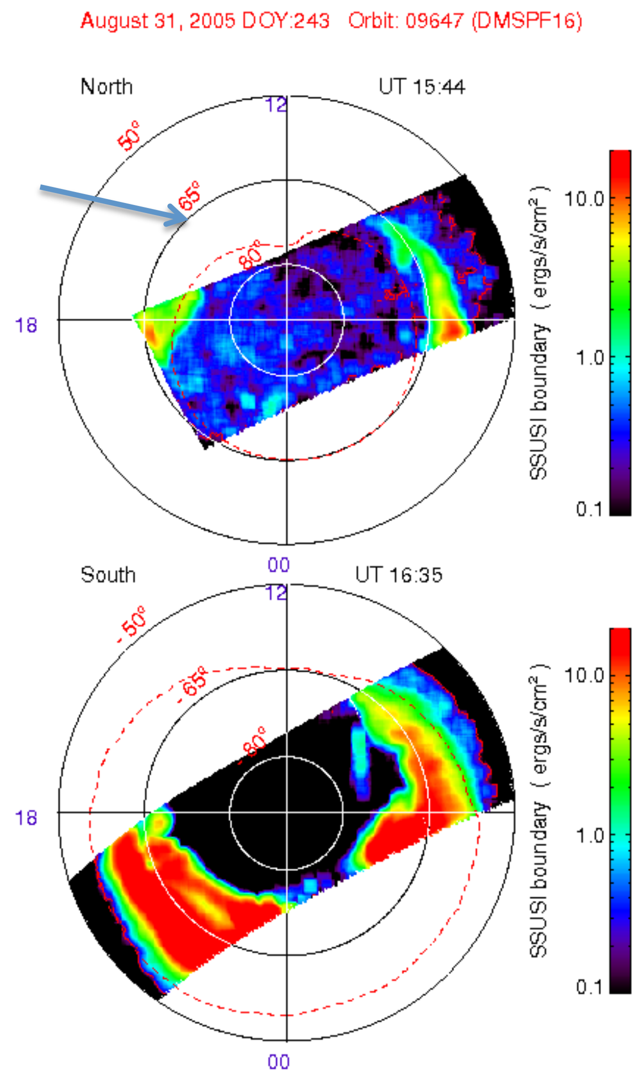
IMAGE/FUV


SI-12 Image
WIC Image
SI-13 Image
80
70
50
24:00
1
30
60
≥90
S12 Counts
500
1333
2166
≥3000
WIC A-D Units
1
17
33
≥50
S13 Counts

DMSP/SUSSI



August 31, 2005 DOY:243 Orbit: 09646 (DMSPF16)
North
UT 14:03
12
18
00
50°
65°
80°
SSUSI boundary (ergs/s/cm²)
10.0
1.0
0.1
South
UT 14:54
12
18
00
- 50°
- 65°
- 80°
SSUSI boundary (ergs/s/cm²)
10.0
1.0
0.1



August 31, 2005 DOY:243 Orbit: 09647 (DMSPF16)
North
UT 15:44
12
18
00
50°
65°
80°
SSUSI boundary (ergs/s/cm²)
10.0
1.0
0.1
South
UT 16:35
12
18
00
- 50°
- 65°
- 80°
SSUSI boundary (ergs/s/cm²)
10.0
1.0
0.1

Validation using constant energy flux

For obtaining the equatorward boundary

A: 0.4 ergs/cm^2/s
B: 0.6 ergs/cm^2/s
C: 1.0 ergs/cm^2/s

- DMSP particle flux
- DMSP SSUSI: threshold 0.4 ergs/cm^2/s
- Ovation Prime: threshold 0.4 ergs/cm^2/s
- SWMF+Fok RC
- Weimer

1erg=10.^(-7) joule
1 eV=1.6*10.^(-19) joule
Threshold 0.4 ergs/cm^2/s =2.5*10^11 eV/cm^2/s

DMSP unit: eV/cm^2/s/sr
Limit= 8.0*10^10 eV/cm^2/s/sr