Aims and Advances of the PROGRESS

PRediction Of Geospace Radiation Environment and Solar wind parameterS

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V. Krasnoselskikh, M. Balikhin

ssg.group.shef.ac.uk/progress/html

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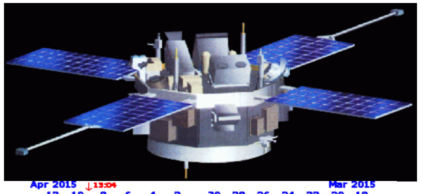
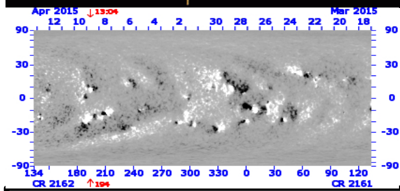
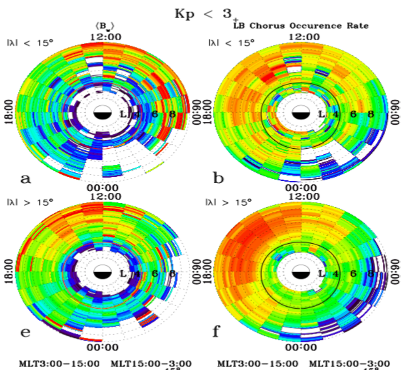
Overview





Solar wind propagation from Sun to L1 (AWSoM/SWIFT)

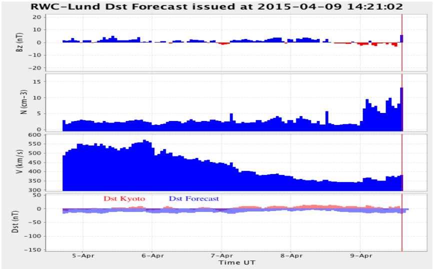
Development of new statistical models

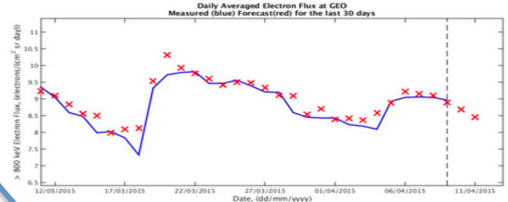


Low energy electron model (IMPTAM)

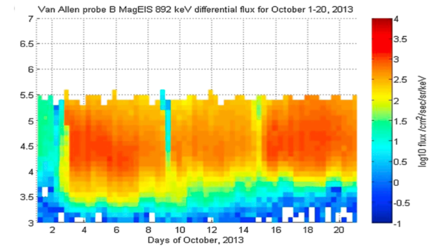
Forecast of the Evolution of Geomagnetic indices

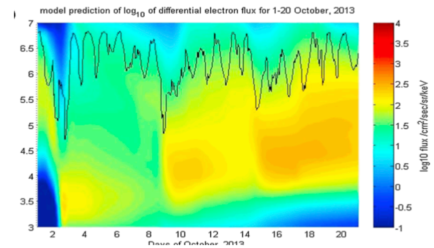
Forecast of the high energy electron environment





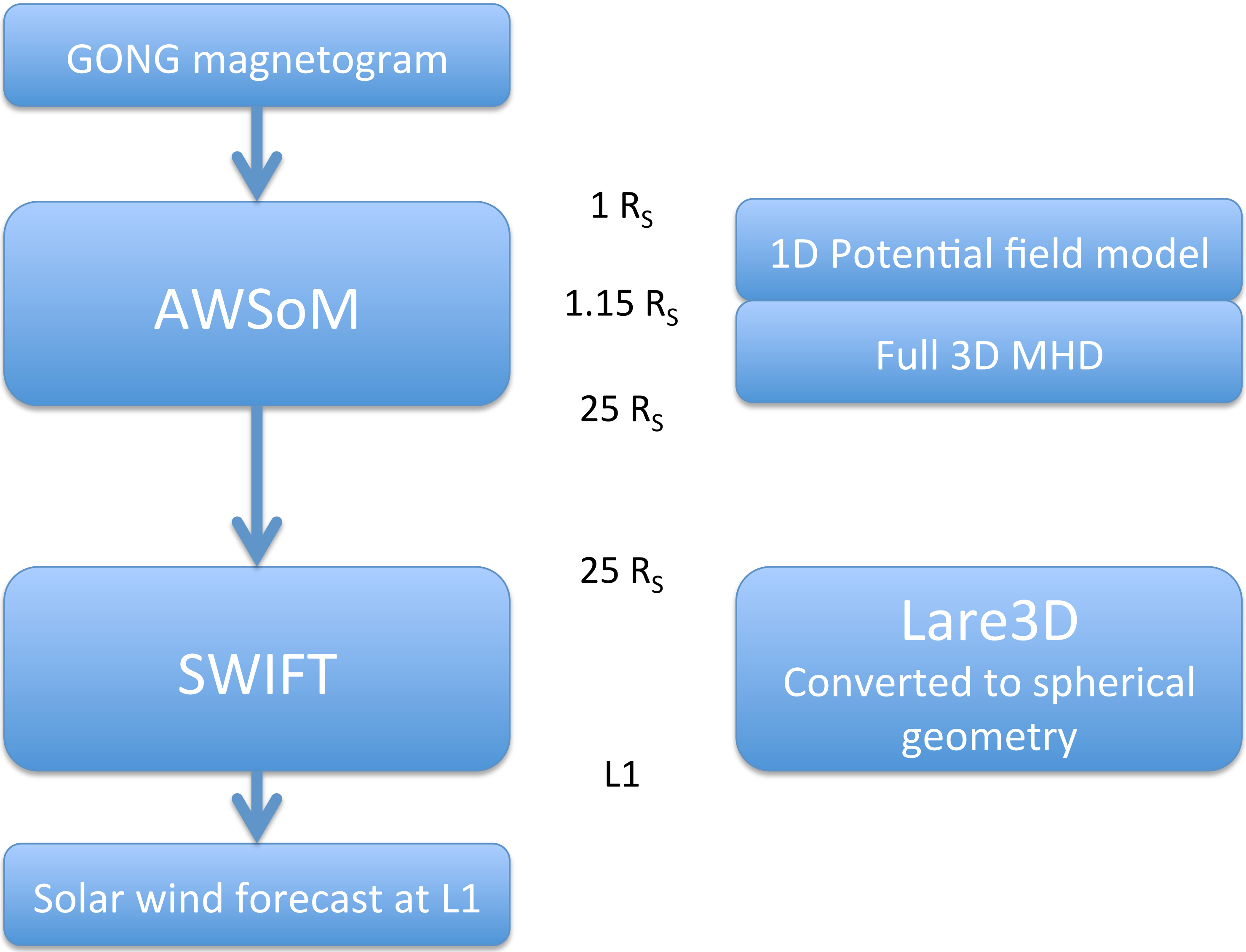
Fusion of forecast tools



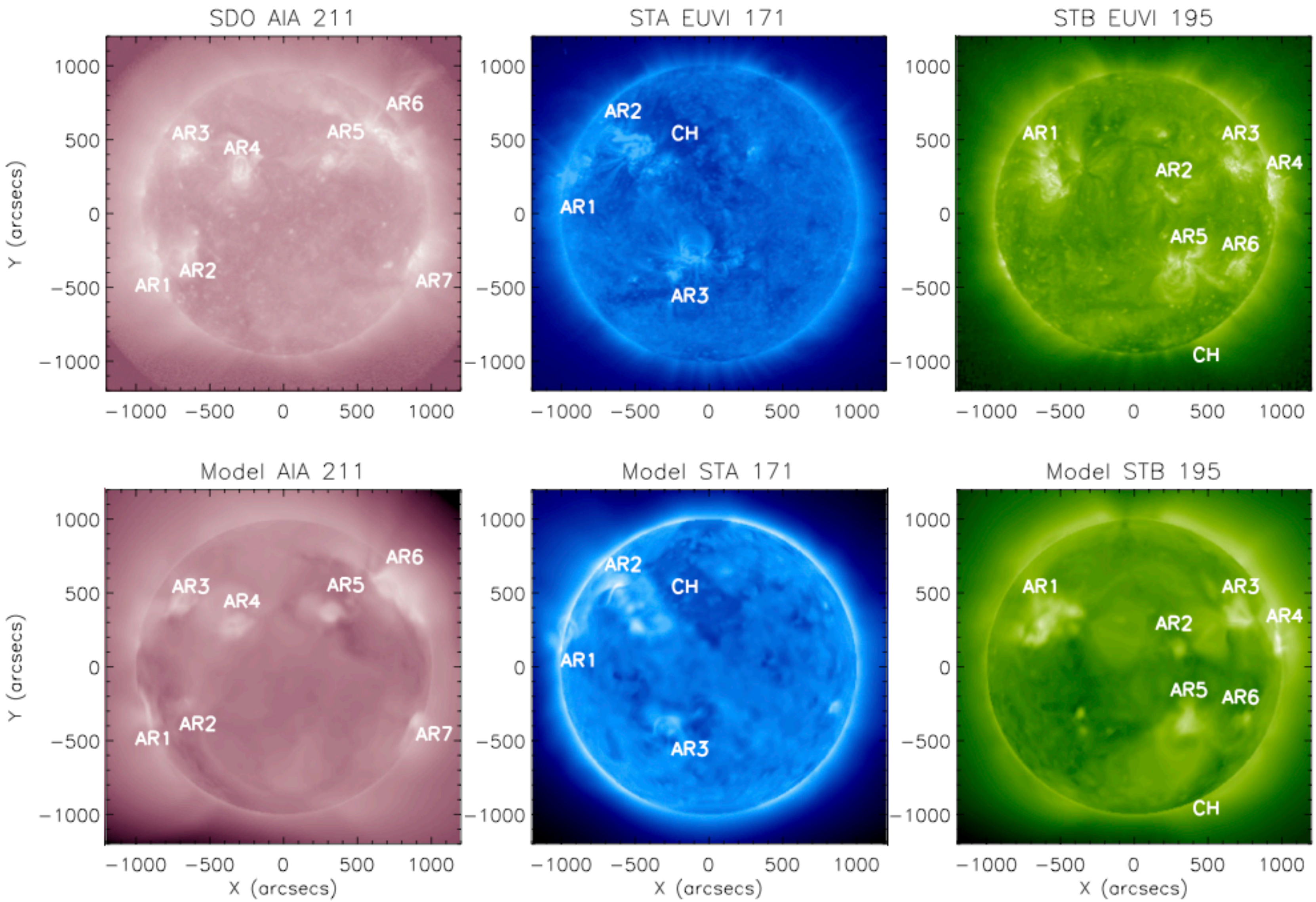


Pakhotin, Shprits Drosdov,
Balikhin VERB- NARMAX

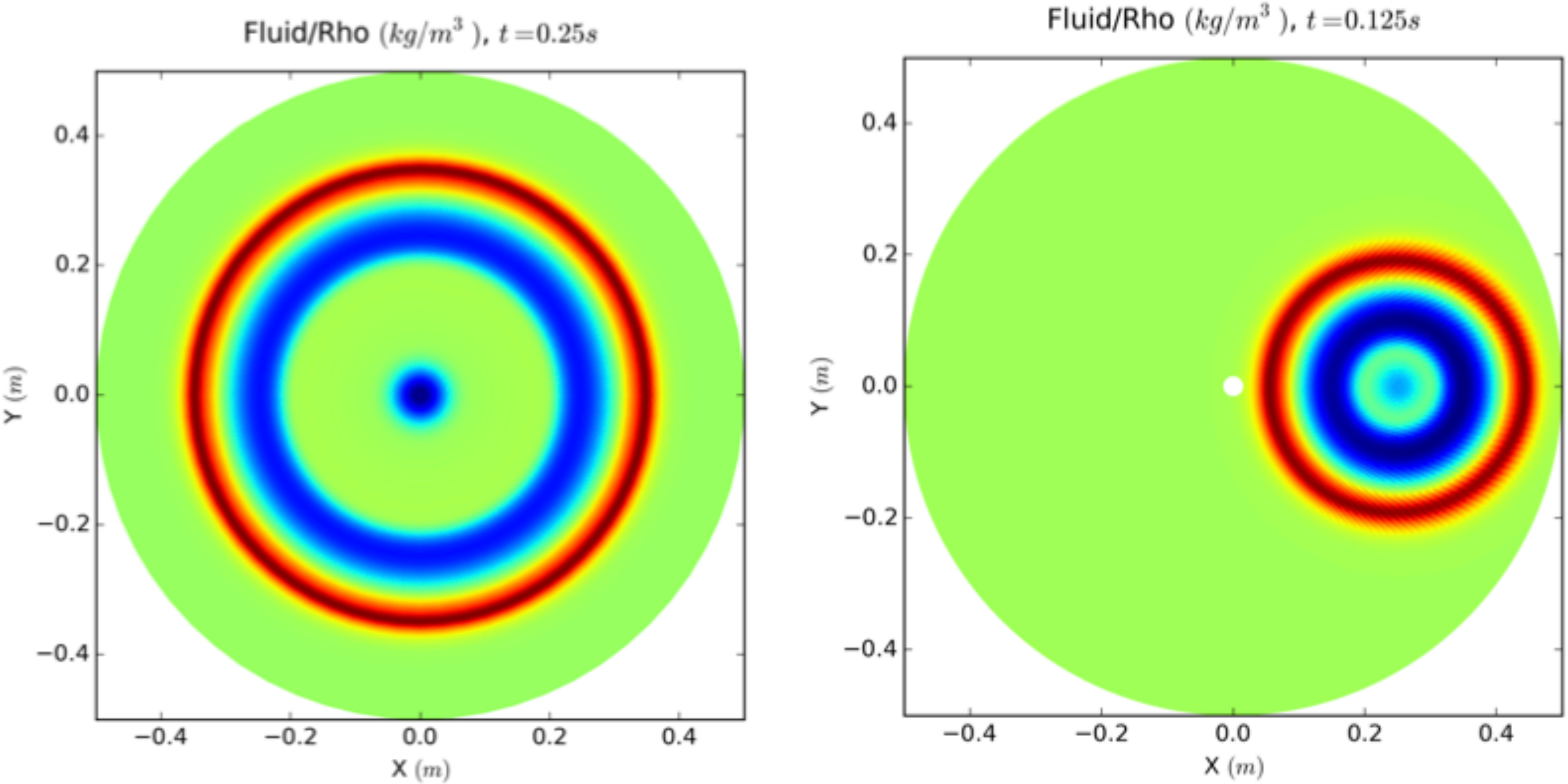
Solar wind propagation to L1



AWSoM Validation

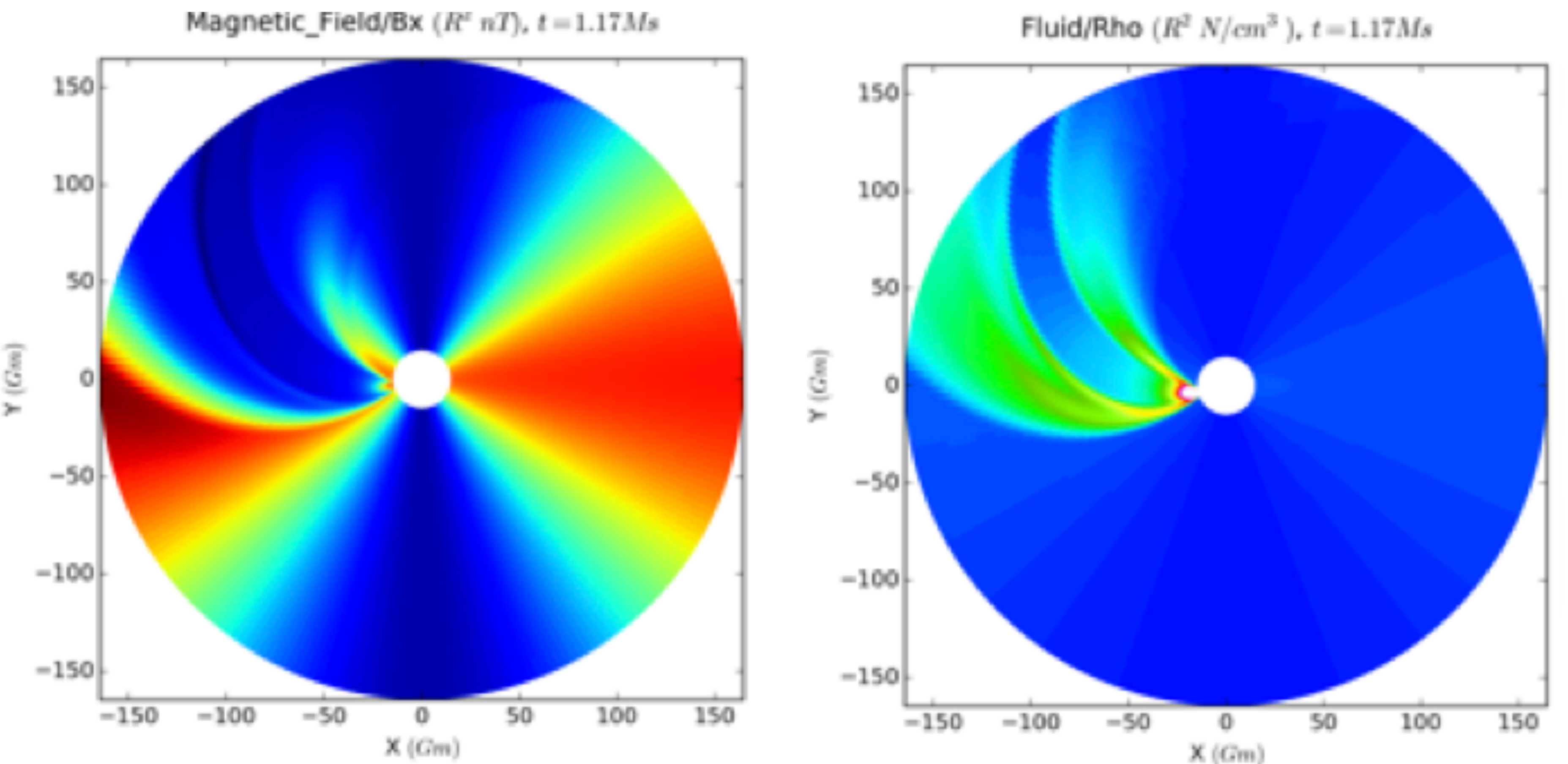


SWIFT Validation



Normalised mass density for a Gaussian pulse in spherical geometry. The pulse occur a r=0 (left) and is offset (right).

SWIFT Validation



Magnetic field Bx (left) and number density (right) over half a solar rotation basd on a mode, Parker solar wind.

Forecast of Geomagnetic Indices

- Geomagnetic activity expressed in terms of geomagnetic indices such as Dst, Kp, or AE
- Indices are used as inputs to numerical models such as VERB and IMPTAM
- Methodologies used
  - Neural nets (IRF)
  - NARMAX (U. Sheffield)
  - NARMAX + Lyapunov exponents (SRI)

Current status – a review of current online models performed as well as study of methods to assess quality

Assessment of forecasts

Models used

- BMR: Burton et al. (1975)
- OM: O'Brien & McPherron (2000)
- LUND: Lundstedt et al. (2001)
- SN_1: Boynton et al. (2011)
- PERS: Persistence Dst(t)=Dst(t-1)

Assessment

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|e_i|$$

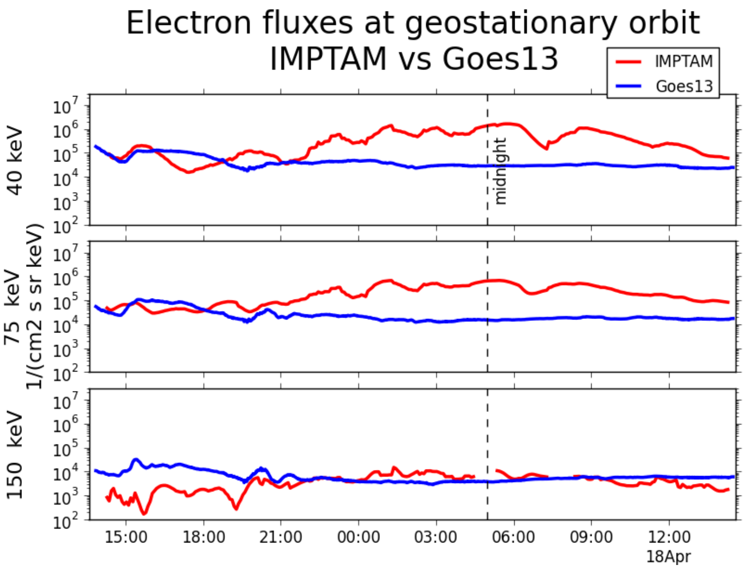
$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}e_i^2$$

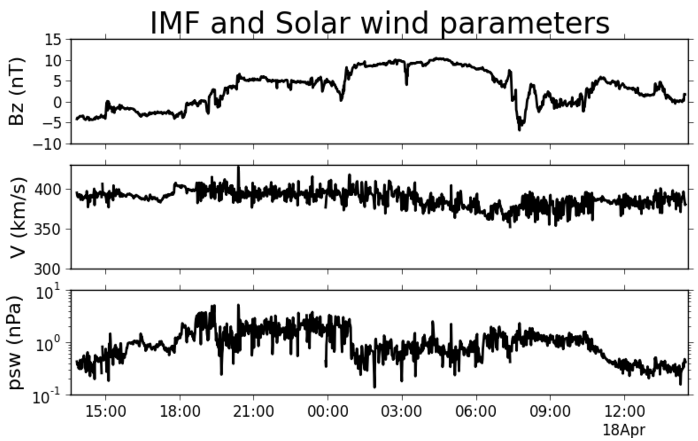
$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}e_i^2}$$

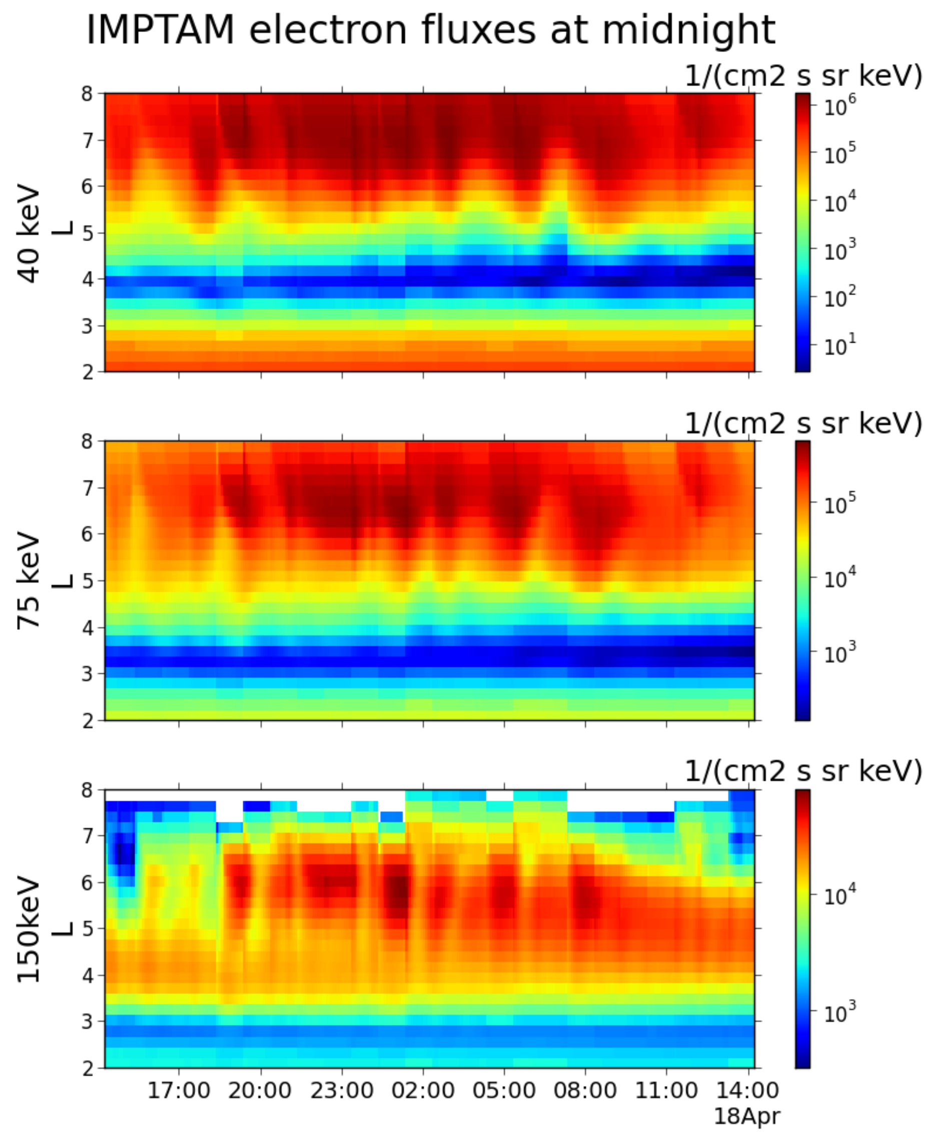
$$\mathrm{CORR} = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}}$$

$$\mathrm{MSESS} = \frac{\mathrm{MSE} - \mathrm{MSE}_{\mathrm{ref}}}{\mathrm{MSE}_{\mathrm{perfect}} - \mathrm{MSE}_{\mathrm{ref}}} = 1 - \frac{\mathrm{MSE}}{\mathrm{MSE}_{\mathrm{ref}}}$$

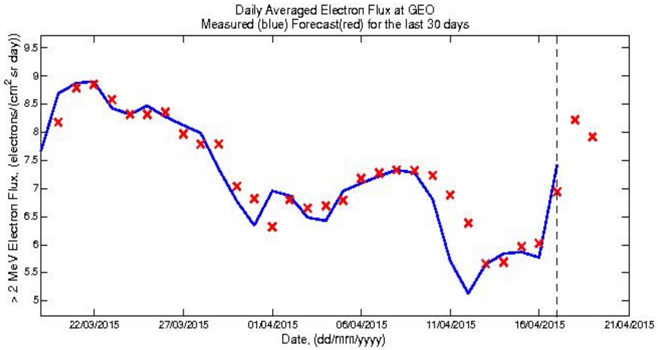
IMPTAM Low Energy Electrons
Leader -Ganushkina, FMI







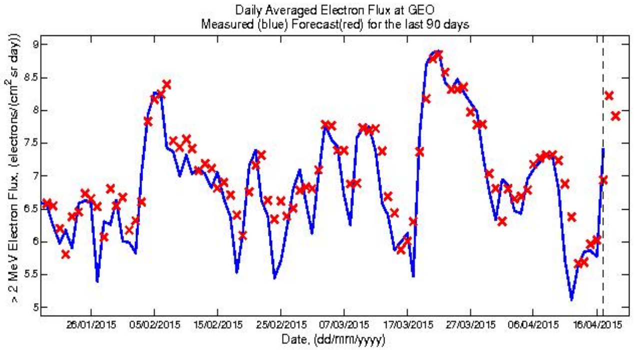
Online Forecasts – Sheffield GOES Model



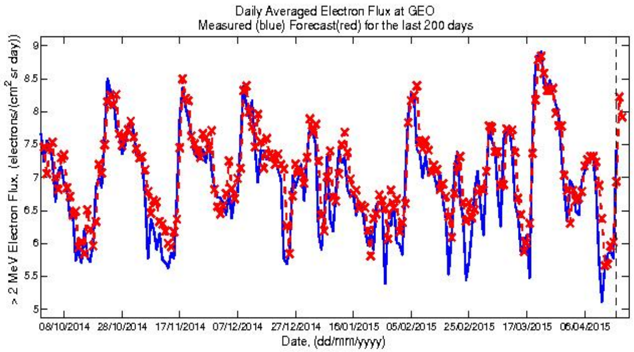
The one day ahead forecasts of the relativistic electron fluxes with energies greater than 2 MeV at GEO has been developed in Sheffield and is available in real time:

http://www.ssg.group.shef.ac.uk/USSW/2MeV_EF.html.

Past 90 days



Past 200 days



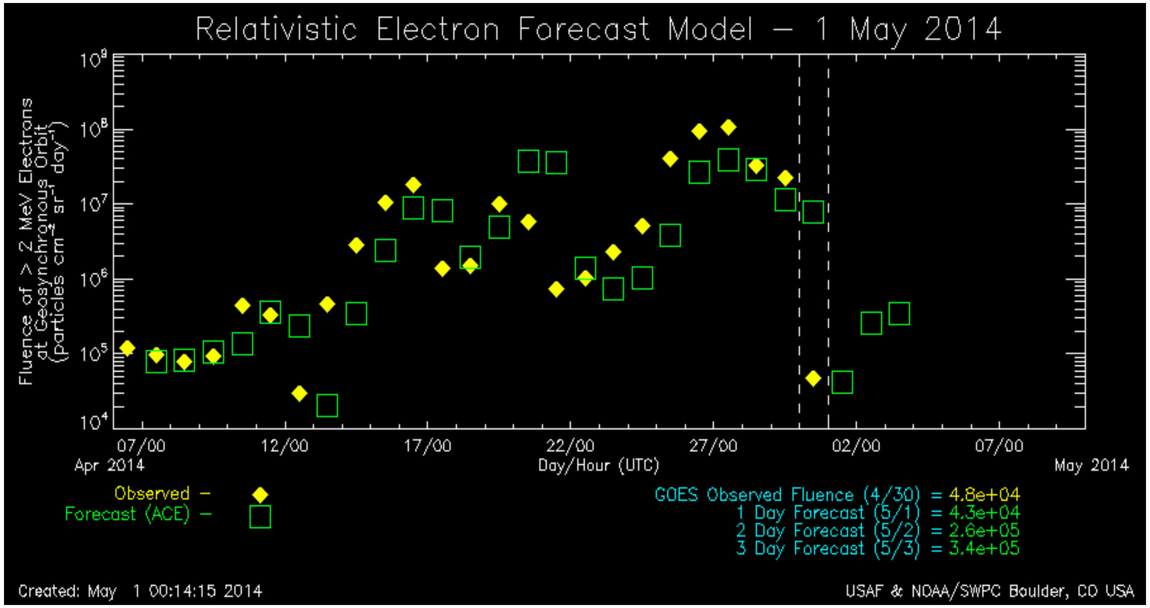
NOAA REFM Forecast

Space Weather Prediction Center 01/05/2014 21:09

NOAA / Space Weather Prediction Center

Relativistic Electron Forecast Model

Presented by the USAF and NOAA/ Space Weather Prediction Center



The impact of high-energy (relativistic) electrons on orbiting satellites can cause electric discharges across internal satellite components, which in turn leads to spacecraft upsets and/or complete satellite failures. The Relativistic Electron Forecast Model predicts the occurrence of these electrons in geosynchronous orbit.
Plots and data are updated daily at 0010 UT. Dashed vertical lines indicate the last vertical value.
When the input parameters are not available, the forecast is not shown.

REFM Verification Plot and Model Documentation

1 to 3 Day Predictions (text file) and corresponding Performance Statistics.
Predictions created using data from the ACE spacecraft.

Historical electron particle data is archived at the
National Geophysical Data Center for Solar-Terrestrial Physics.

Visually impaired users may contact SWPC for assistance.
Please credit SWPC when using these images.

Comparison of REFM and SNB^{3}GEO Forecasts (01.03.2012-03.07.2014)

Balikhin, Rodriguez,Boynton, Walker,Aryan, Sibeck, Billings (submitted to SW 2015)

$$PE = 1 - \frac{1}{N}\sum \frac{(Y(t) - Ym(t))^2}{\mathrm{var}(Y)}$$

$$C_{cor} = \frac{1}{N}\sum \frac{(Y(t) - \langle Y(t)\rangle)(Ym(t) - \langle Ym(t)\rangle)}{\sqrt{\mathrm{var}(Ym)\mathrm{var}(Y)}}$$

Comparison of REFM and SNB^3GEO Forecasts

Balikhin, Rodriguez, Boynton, Walker, Aryan, Sibeck Billings, SW 2016

Model	Prediction Efficiency Flux	Correlation Flux	Prediction Efficiency Log Flux	Correlation Log Flux
REFM	-1.31	0.73	0.70	0.85
SNB^3GEO	0.63	0.82	0.77	0.89

Comparison of REFM and SNB^{3}GEO Forecasts

Balikhin, Rodriguez, Boynton, Walker, Aryan, Sibeck Billings, SW 2016

Table 2. Contingency tables and Heidke skill scores for the REFM predictions.

Fluence ($cm^{-2}sr^{-1}day^{-1}$)	$> 10^8$		$> 10^{8.5}$		$> 10^9$	
REFM HSS	0.666		0.482		0.437	
Observation:	Yes	No	Yes	No	Yes	No
Forecast						
Yes	86	22	23	22	4	7
No	43	510	21	595	3	647

Table 3. Contingency tables and Heidke skill scores for the SNB^{3}GEO predictions.

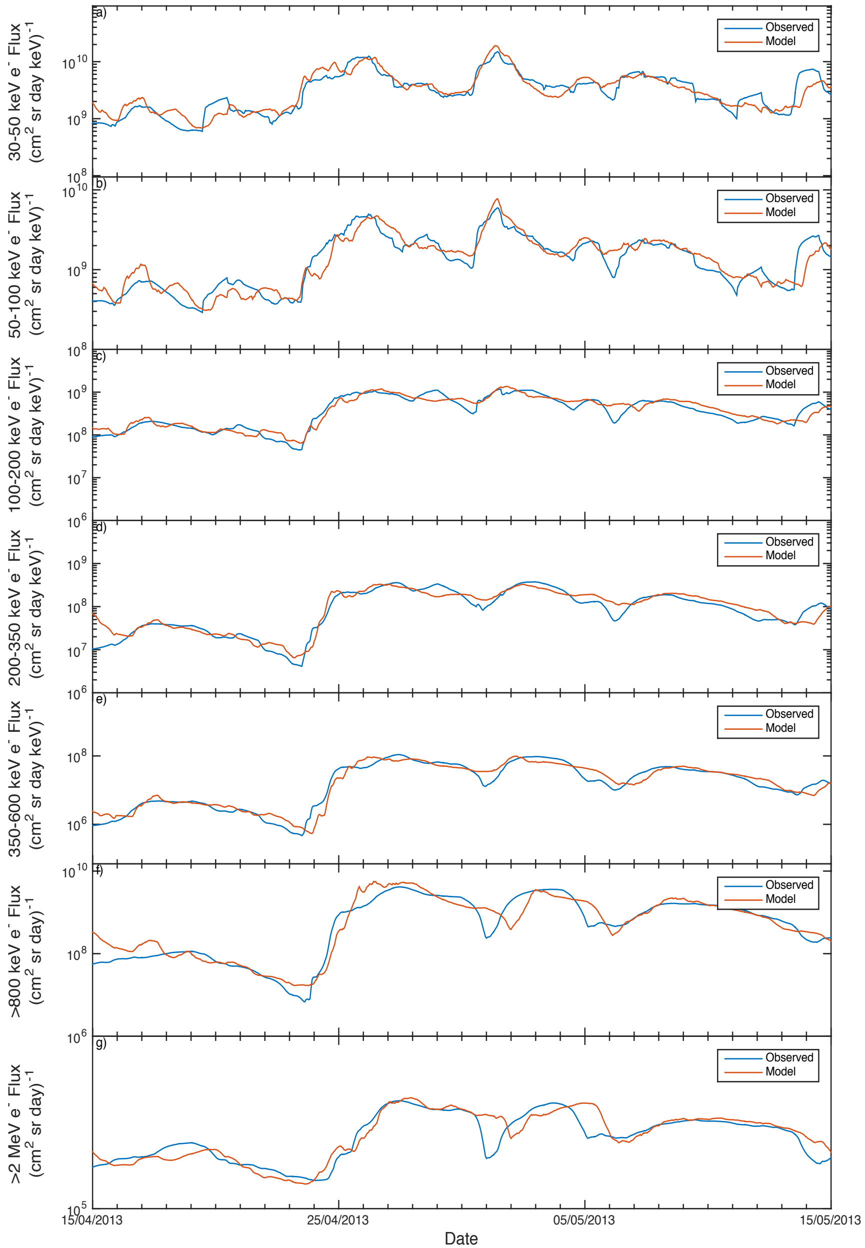
Fluence ($cm^{-2}sr^{-1}day^{-1}$)	$> 10^8$		$> 10^{8.5}$		$> 10^9$	
SNB^{3}GEO HSS	0.738		0.634		0.612	
Observation:	Yes	No	Yes	No	Yes	No
Forecast						
Yes	106	33	31	19	4	2
No	23	499	13	598	3	652

$$S = \frac{2(xw - yz)}{y^2 + z^2 + 2xw + (y+z)(x+w)}$$

Extending SNB^{3}GEO to lower energies

Model	Forecast Time (hours)	PE (%)	CC (%)	Period
40-50 keV	10	66.9	82.0	01.03.2013-28.02.2015
50-100 keV	12	69.2	83.5	01.03.2013-28.02.2015
100-200 keV	16	73.2	85.6	01.03.2013-28.02.2015
200-350 keV	24	71.6	84.9	01.03.2013-28.02.2015
350-300 keV	24	73.6	85.9	01.03.2013-28.02.2015
> 800 keV	24	72.1	85.1	01.01.2011-28.02.2015
> 2MeV	24	82.3	90.9	01.0.12011-28.02.2015

Extending SNB^{3}GEO to lower energies



Statistical Wave Models

- Interaction between waves and particles in the radiation belts modeled using sets of diffusion tensors for each wave mode.
- Current statistical models of wave amplitudes neglect solar wind measurements and geomagnetic evolution
- Analysis of VAP data has resulted in a new set of models
- NARMAX ERR analysis used to investigate relationship between wave amplitude, solar wind variations and evolution of geomagnetic indices

PROGRESS: wave models

- Statistical Wave models and physics of wave particle

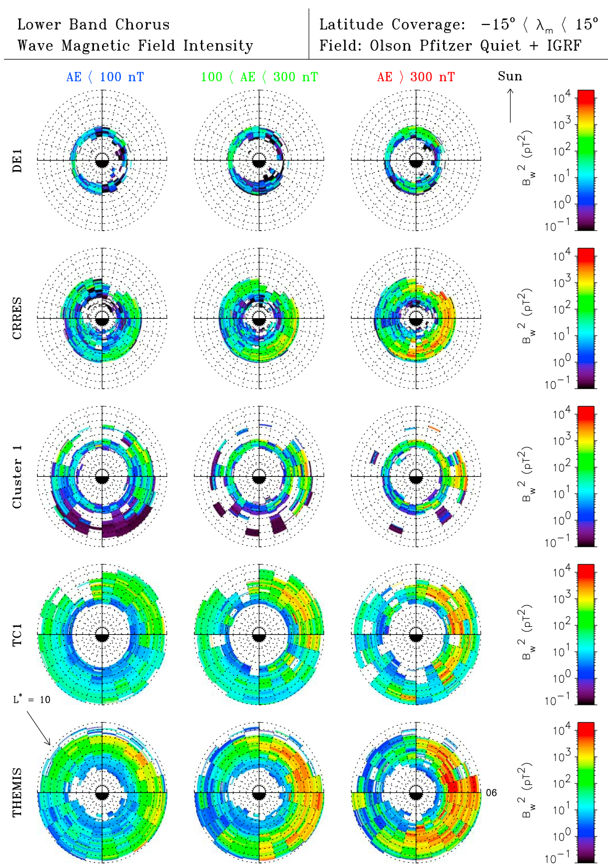
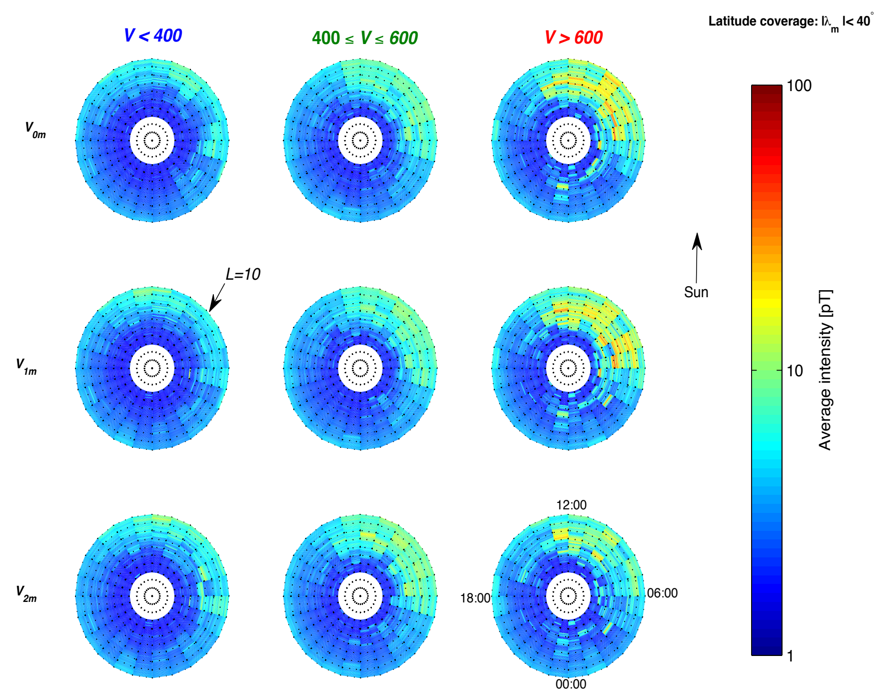
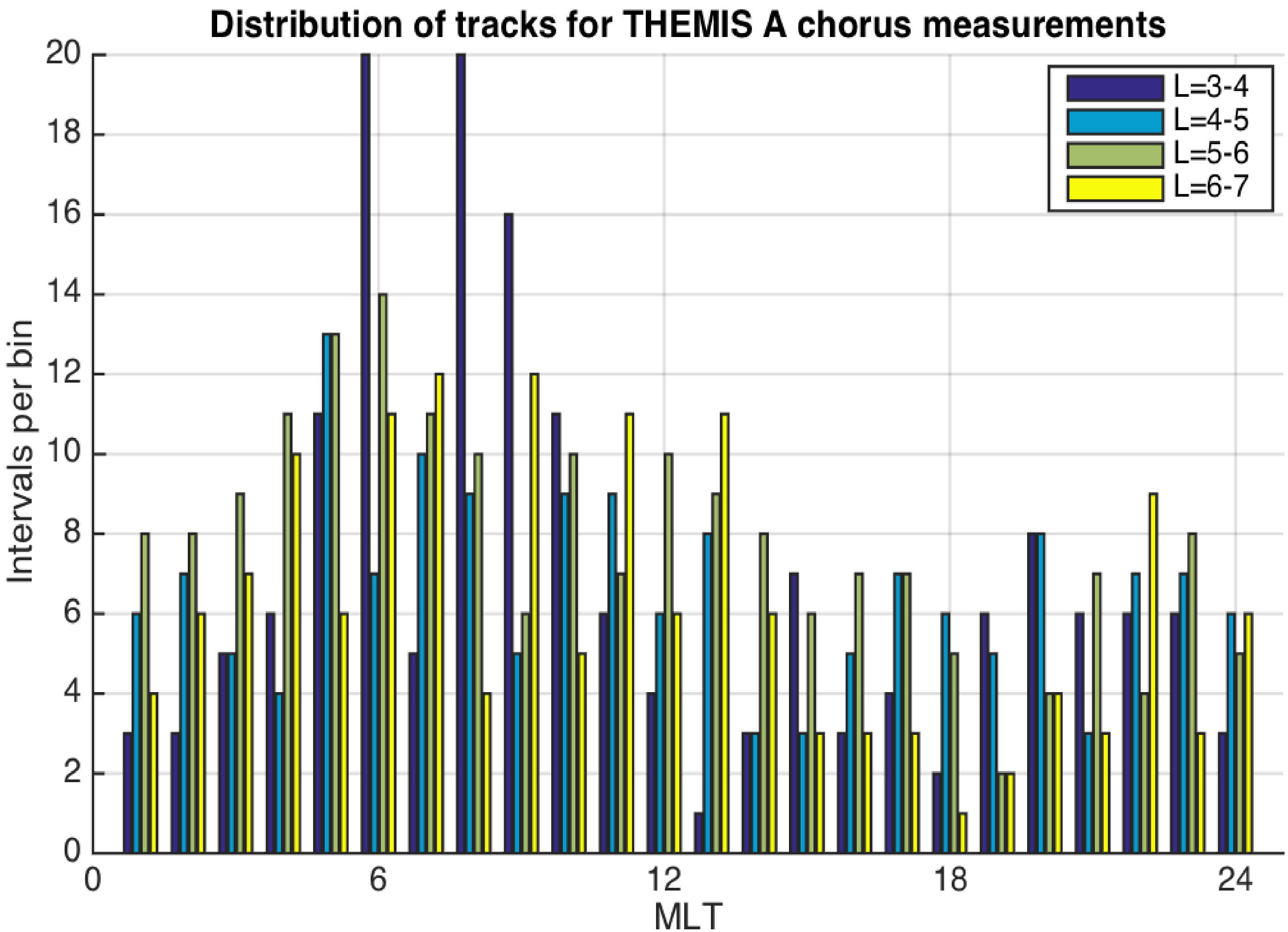


Figure 2. Equatorial wave intensity of lower band chorus as a function of L^*, MLT and geomagnetic activity for each of the five satellites.



PROGRESS: wave models



THEMIS A 2010

PROGRESS: wave models

MLT	L-shell	
	4<L<5	5<L<7
04-08	1162	1018
08-12	952	894
12-16	888	970
16-22	1150	665
22-04	994	1118

Estimated number of LBC events in chosen bins

PROGRESS: wave models

L-shell 4-5 and MLT 22-04

LBC wave at L = 4-5 and MLT = 22-04			
Linear		Quadratic Nonlinear	
Control Parameter	ERR(%)	Control Parameter	ERR(%)
AE(t-1)	11.52	AE(t-1)p(t-2)	13.70
V(t-10)	8.45	n(t-2)V(t-6)	4.52
Dst(t-4)	1.54	AE(t-1)V(t-10)	2.50
n(t-2)	1.16	Dst(t-1)AE(t-3)	1.71
p(t-2)	0.92	AE(t-1)AE(t-1)	1.51
$\sum$ERR	23.58	$\sum$ERR	23.93

WP4: Task 4.3PROGRESS: wave models

L-shell 4-5 and MLT 04-08

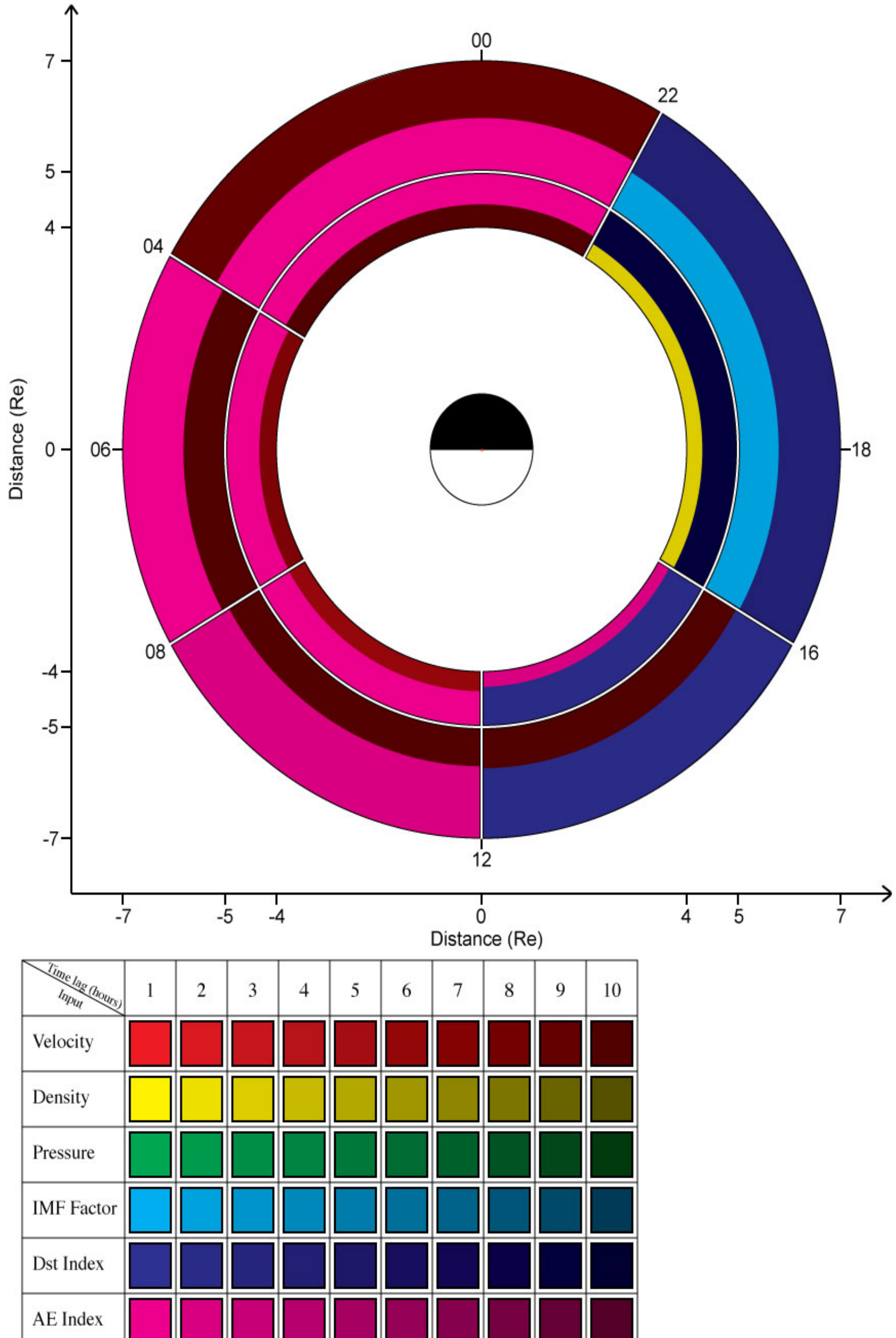
LBC wave at L = 4-5 and MLT = 04-08			
Linear		Quadratic Nonlinear	
Control Parameter	ERR(%)	Control Parameter	ERR(%)
AE(t-1)	21.75	AE(t-1)AE(t-1)	23.46
V(t-7)	11.38	AE(t-1)p(t-1)	4.62
Dst(t-7)	2.08	V(t-7)	3.09
$B_T \sin^6(\theta/2)$(t-10)	0.91	n(t-1)	2.60
V(t-5)	0.41	AE(t-1)	1.95
$\sum$ERR	36.53	$\sum$ERR	35.72

PROGRESS: wave models

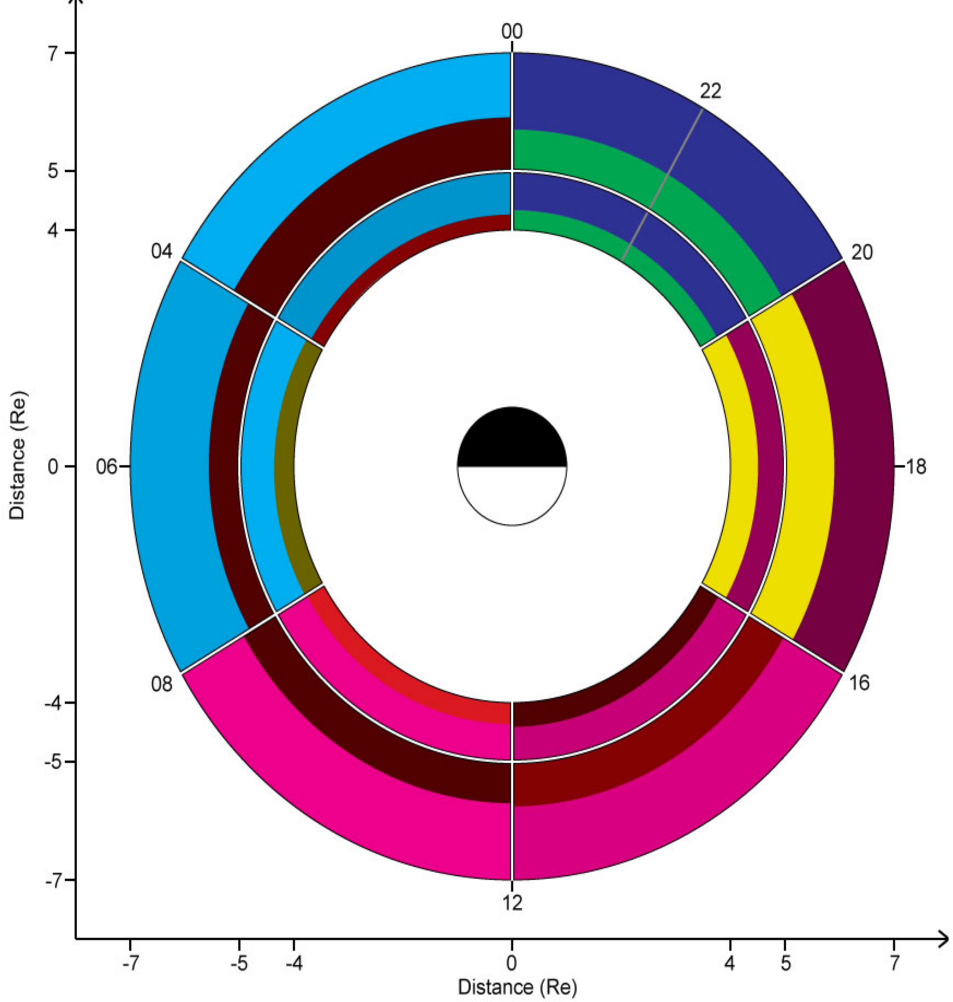
L-shell 4-5 and MLT 16-22

LBC wave at L = 4-5 and MLT = 16-22			
Linear		Quadratic Nonlinear	
Control Parameter	ERR(%)	Control Parameter	ERR(%)
Dst(t-9)	3.77	Dst(t-9)V(t-3)	4.10
n(t-3)	1.53	n(t-3)	1.54
AE(t-7)	0.77	$B_T \sin^6(\theta/2)$(t-5)n(t-10)	1.09
$B_T \sin^6(\theta/2)$(t-5)	0.62	AE(t-7)V(t-3)	0.78
p(t-1)	0.39	Dst(t-1)$B_T \sin^6(\theta/2)$(t-9)	0.75
$\sum$ERR	7.07	$\sum$ERR	8.26

PROGRESS: wave models LB Chorus

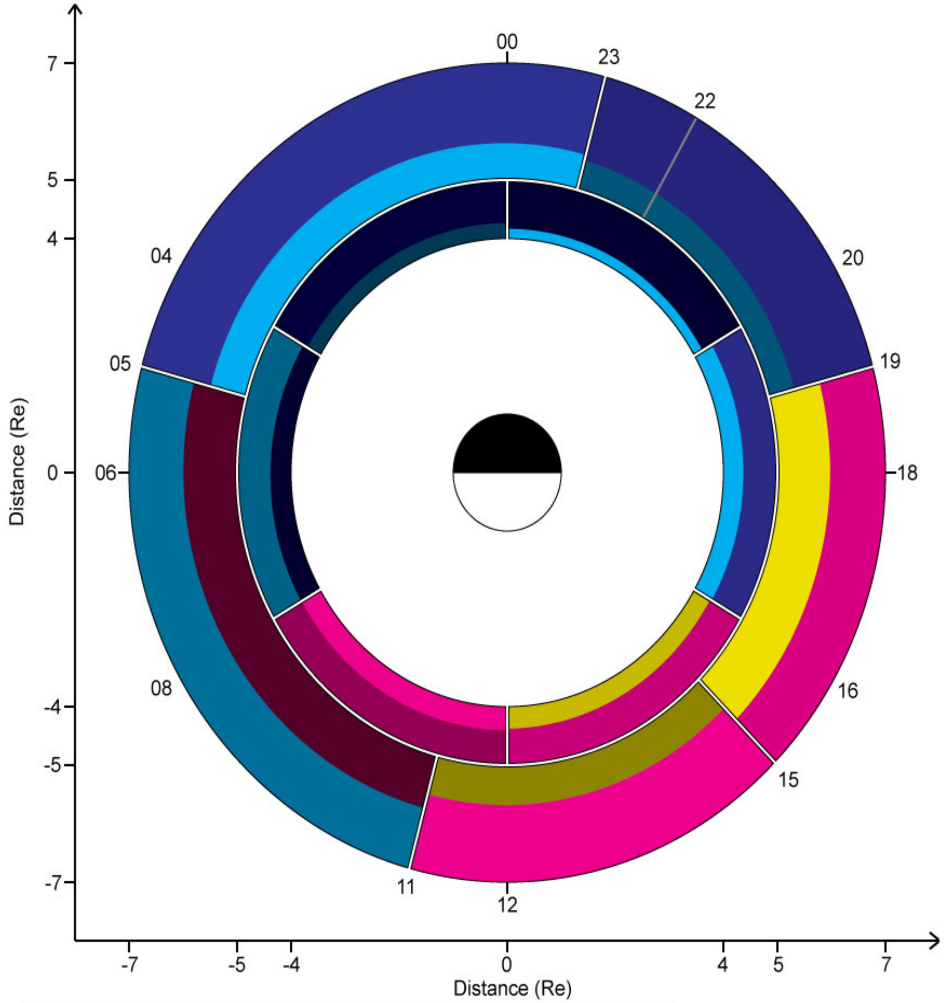


PROGRESS: wave models Hiss



Time lag (hours) / Input	1	2	3	4	5	6	7	8	9	10
Velocity										
Density										
Pressure										
IMF Factor										
Dst Index										
AE Index										

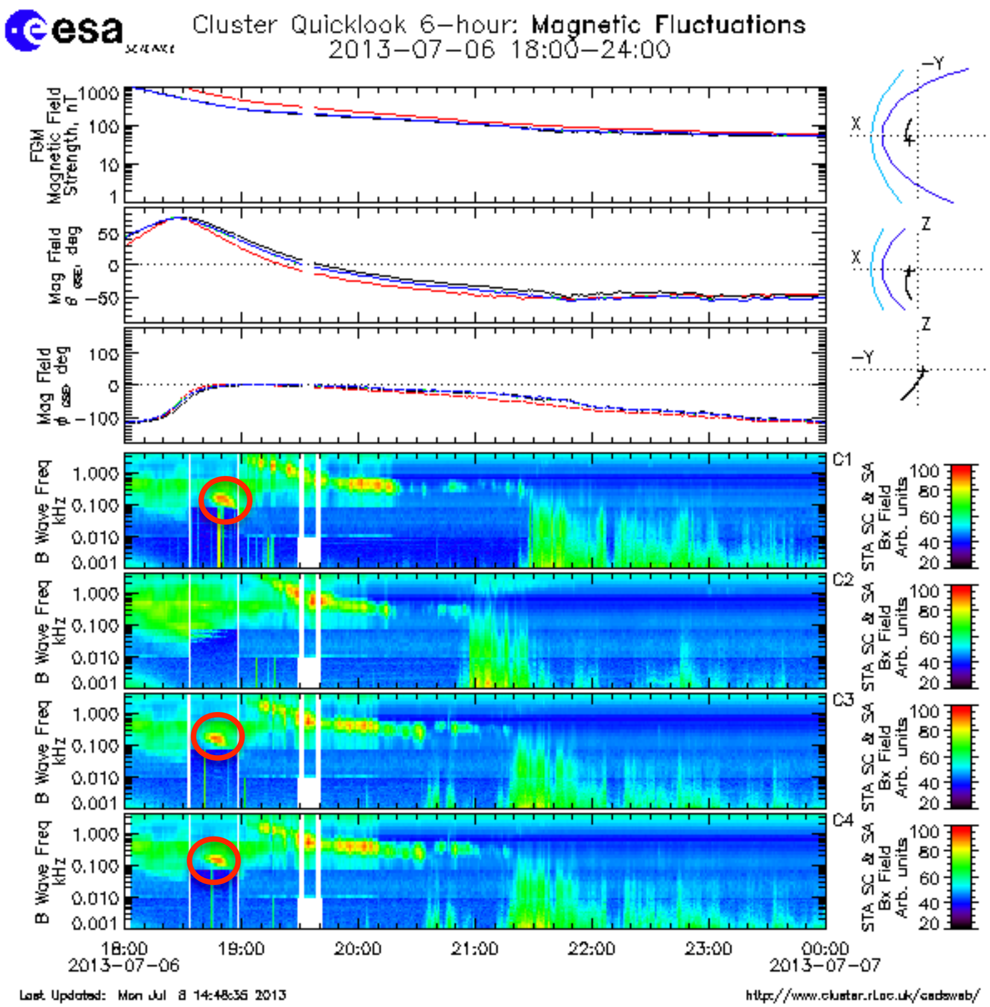
PROGRESS: wave models EMW



Time lag (hours) / Input	1	2	3	4	5	6	7	8	9	10
Velocity										
Density										
Pressure										
IMF Factor										
Dst Index										
AE Index										

EMW Spectral Observations

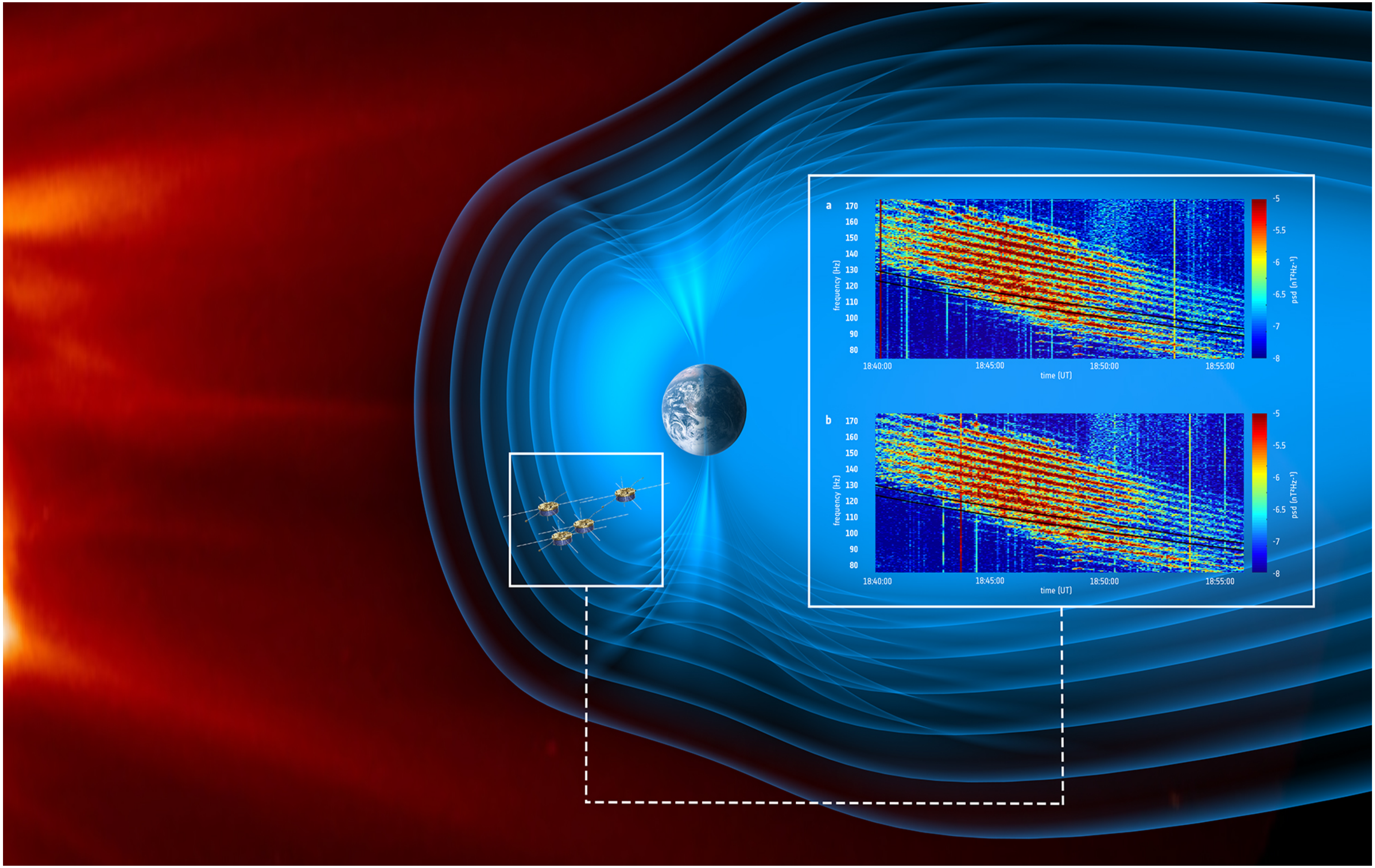
Most studies of the amplitudes of magnetosonic waves assume a continuous spectrum and hence the validity of the quasi-linear theory



The figure shows an overview of the STAFF spectrum analyser observations on July 6th, 2013. Occurrences of Equatorial magnetosonic waves are indicated by the red circles.

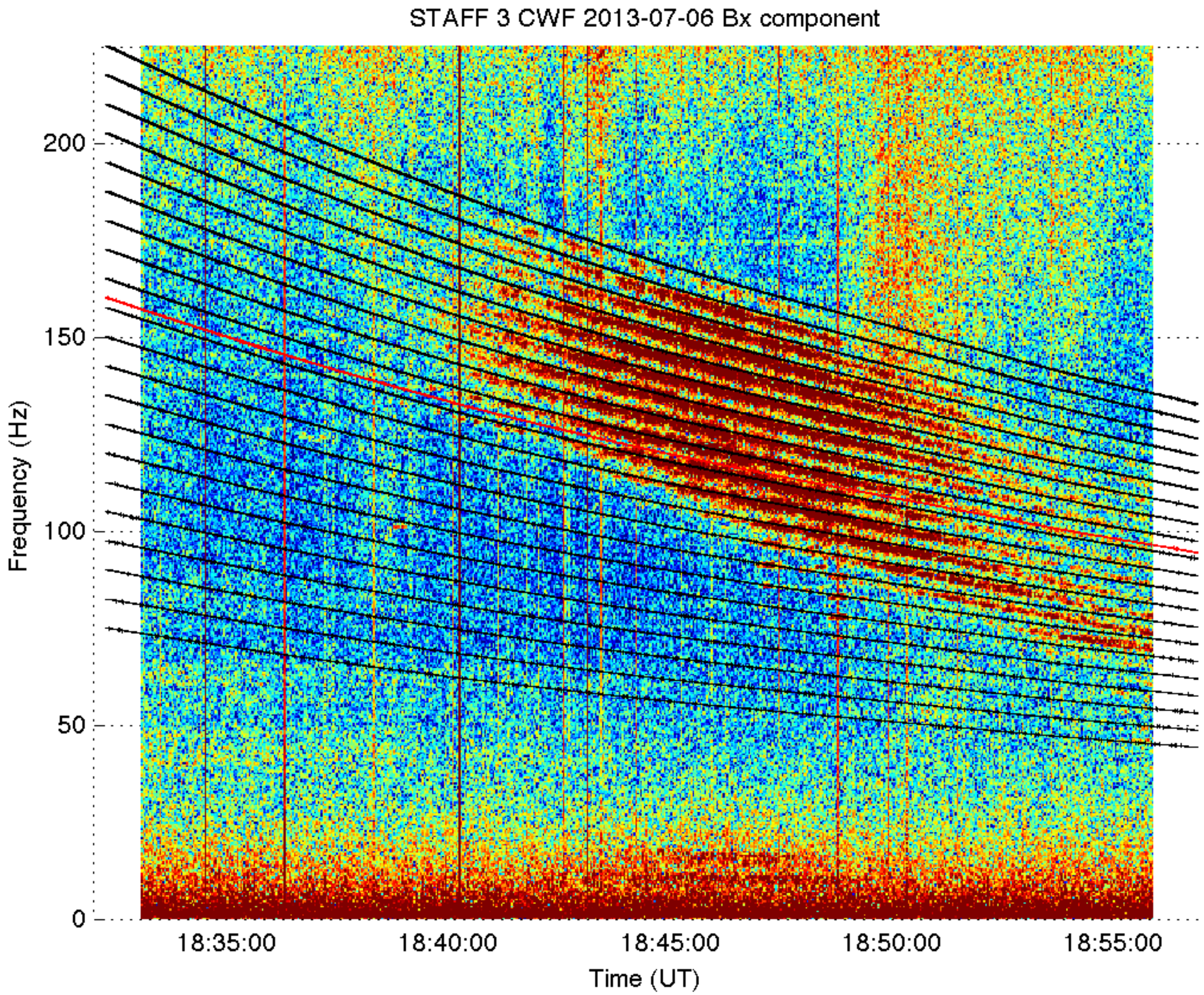
The waves appear continuous in frequency space. Thus, quasi-linear theory is used to estimate their effects on electron acceleration and loss processes.

Balikhin, Shprits, Walker et al., Nature Comm, 2015



The University Of Sheffield

Balikhin, Shprits, Walker et al., Nature Comm, 2015



Conclusion:

PROGRESS project is developing according to the proposed schedule