PRediction Of Geospace Radiation Environment and Solar wind parameterS

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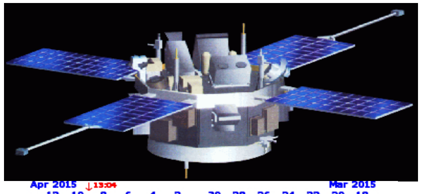
Objectives

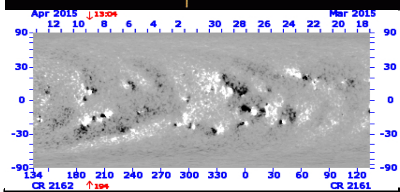
1. Develop a European numerical MHD based model that will enable the advanced forecast of solar wind parameters at L1.
2. Use system science methodologies alongside those currently available (empirical, ANN) to forecast the evolution of geomagnetic indices in response to the solar wind.
3. Construct a new set of statistical wave models to describe the plasma wave environment of the inner magnetosphere that will accurately reflect the physics of the dynamics of the radiation belts under the influence of the solar wind.

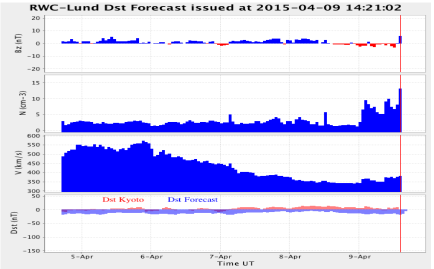
Objectives

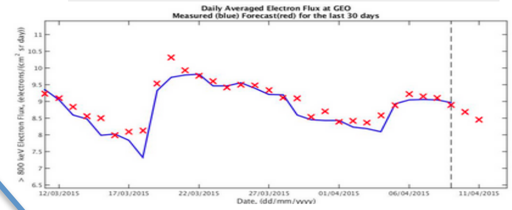
4. Incorporate forecasting capabilities into the physics based numerical model for low energy electrons IMPTAM that currently is able to provide a now-cast only.
5. Develop a novel, reliable, and accurate forecast of the radiation environment in the region of radiation belts exploiting the fusion between data based models for high energy fluxes at geostationary orbit SNB^3GEO, IMPTAM, the most advanced model for high energy electrons in the radiation belts – VERB, and state of the art data assimilation methodology.
6. To combine the prediction tools for geomagnetic indices and radiation environment within the magnetosphere with the forecast of solar wind parameters at L1 and upstream of the magnetosphere to significantly increase the advance time of the forecast.

Overview









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

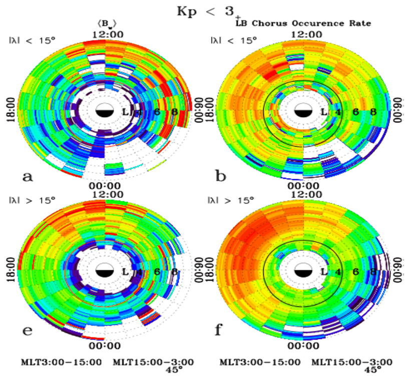
Development of new statistical models

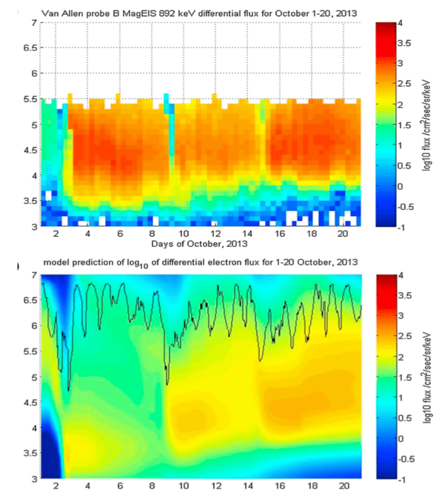
Low energy electron model

Forecast of the Evolution of Geomagnetic indices

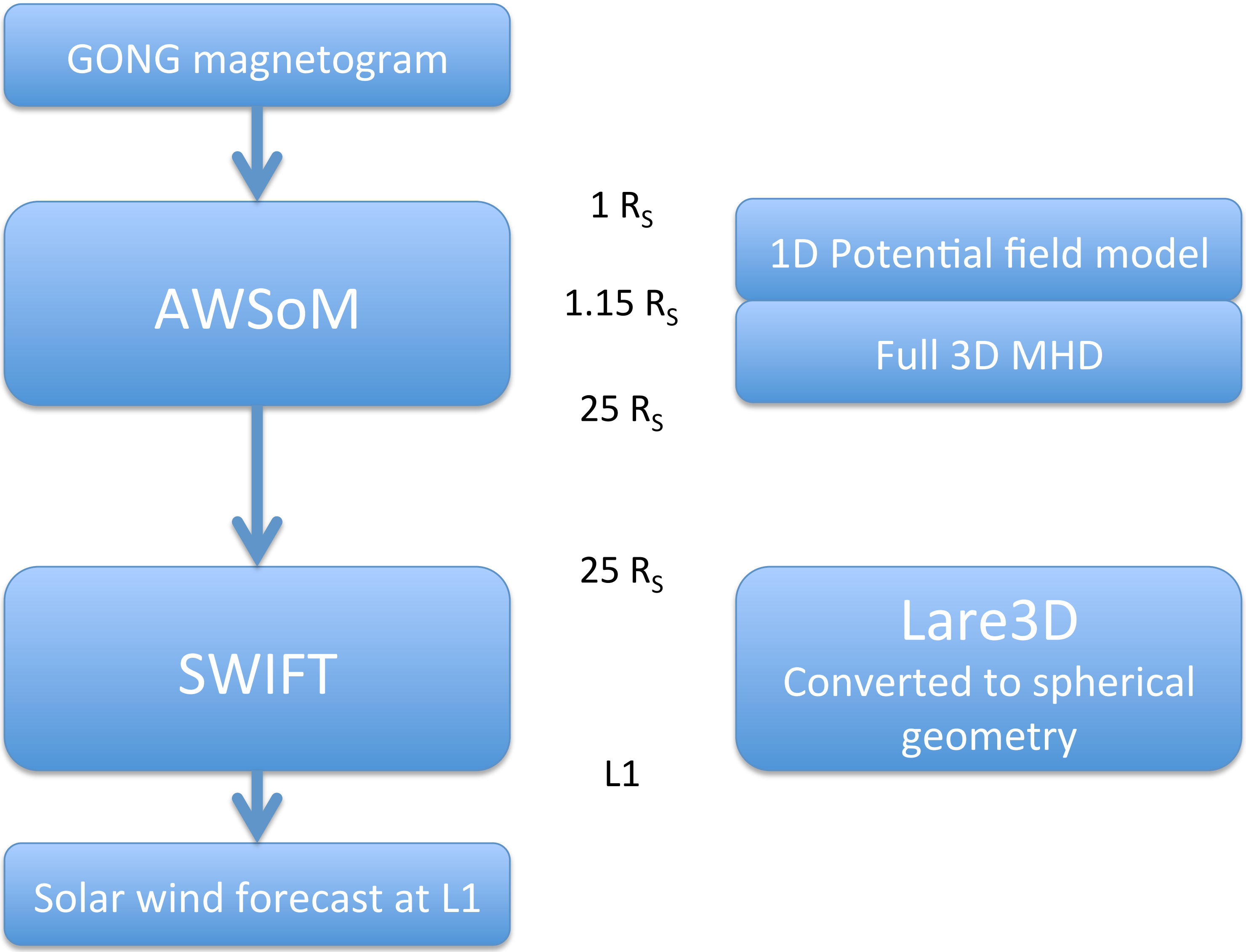
Forecast of the high energy electron environment

Fusion of forecast tools

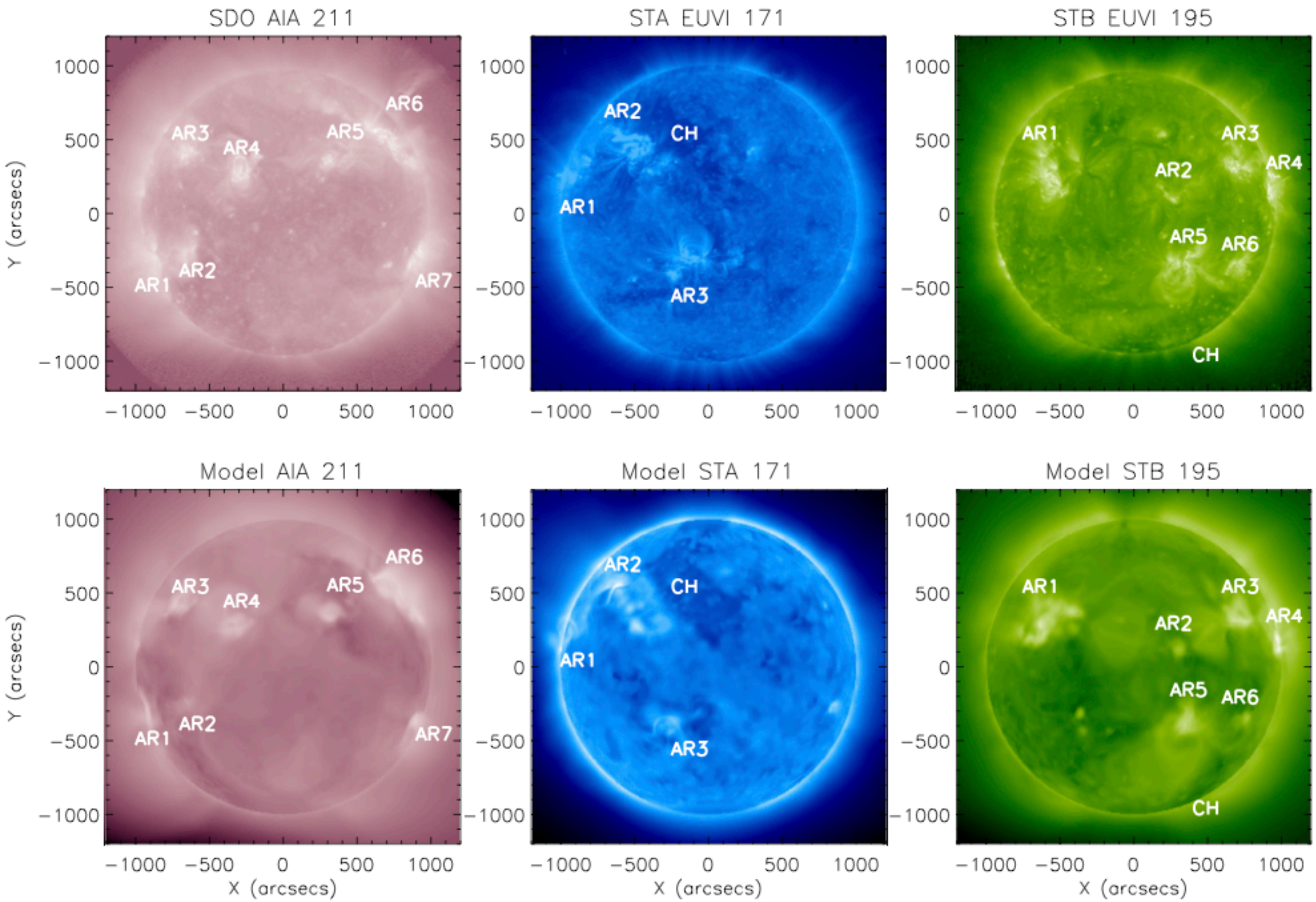




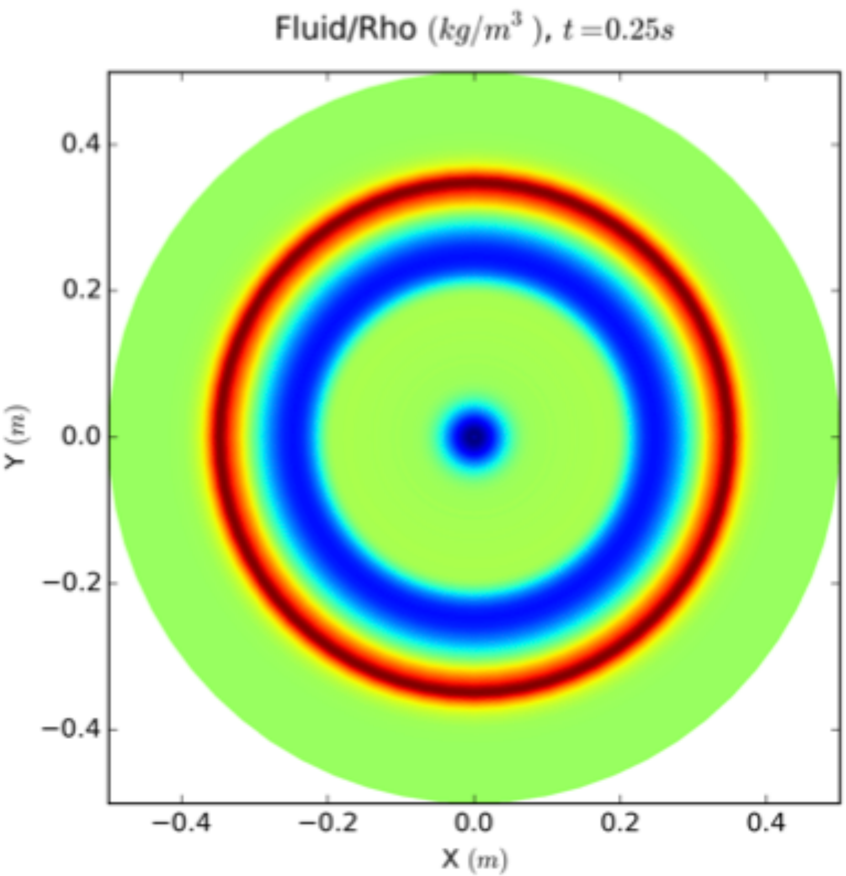
Solar wind propagation to L1

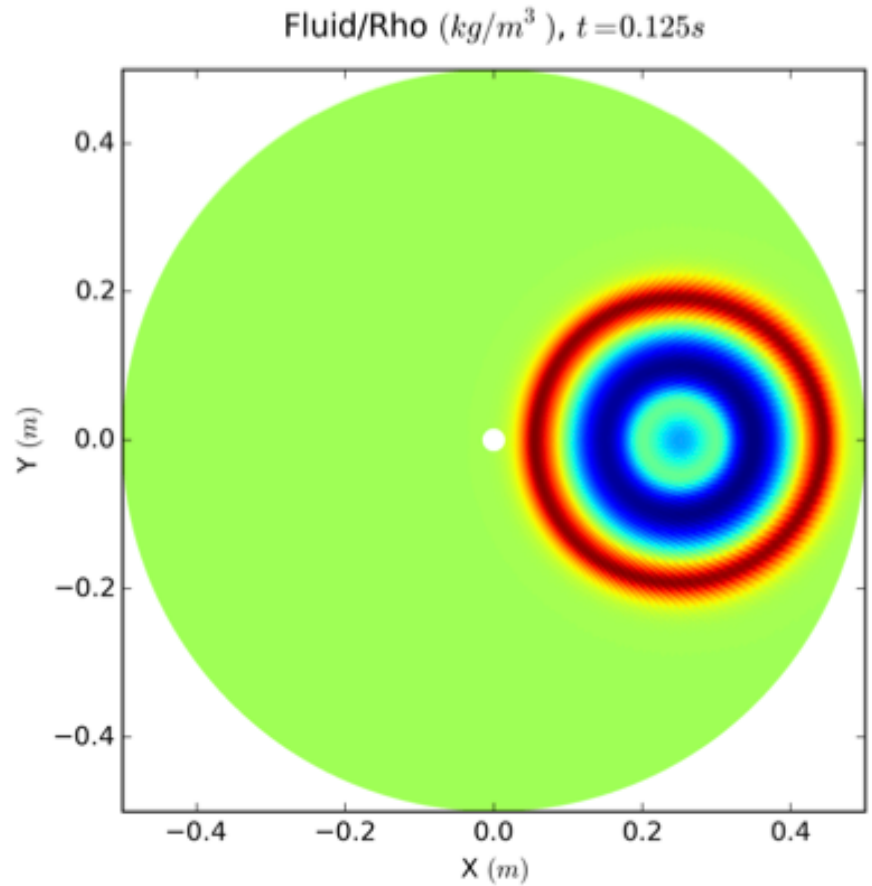


AWSoM Validation



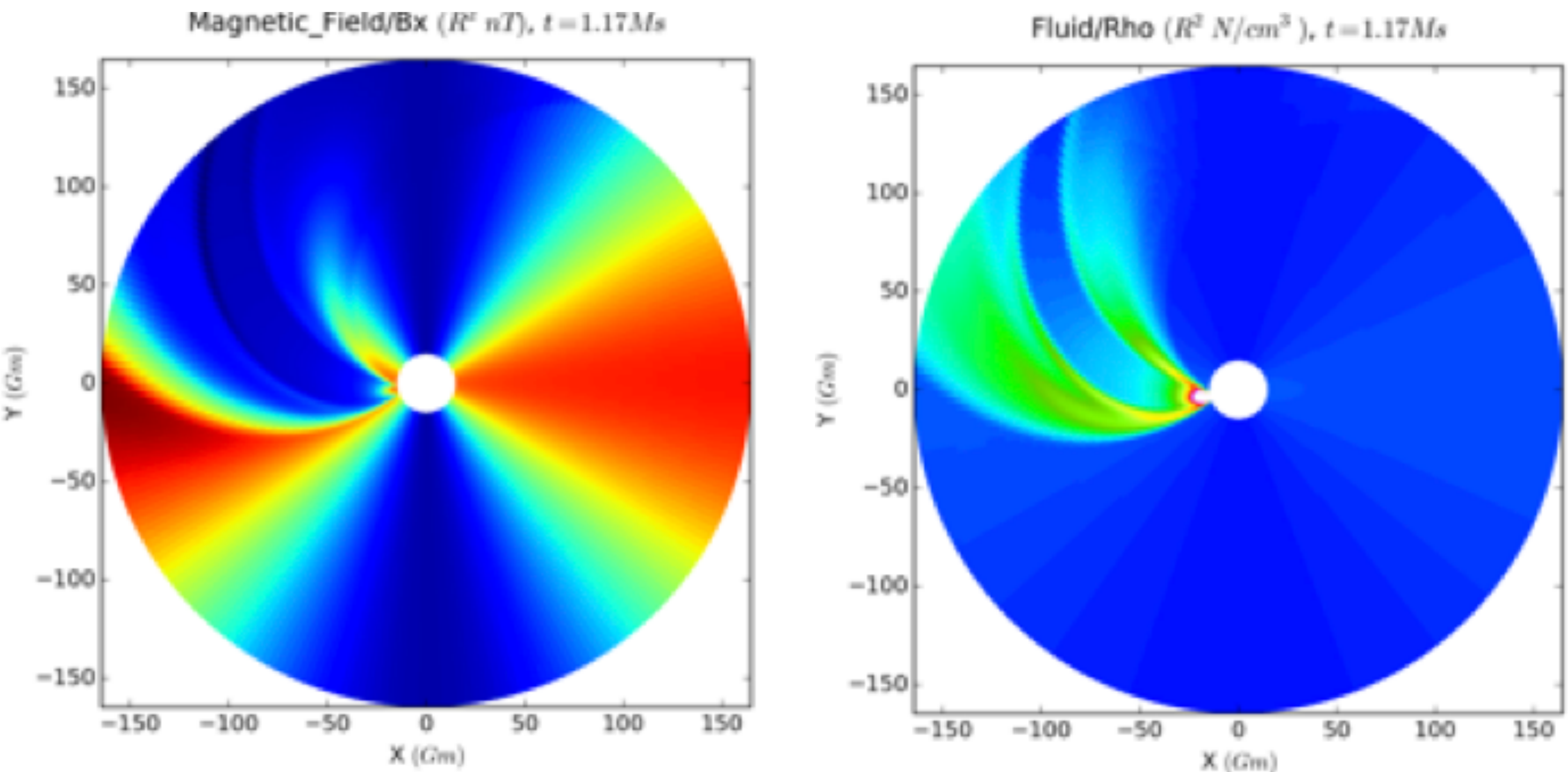
SWIFT Validation





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 – Talk by Vitaliy Yatsenko on Sunday)

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

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

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

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

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

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

Assessment of forecasts

Statistics of whole data sets (1998-2014)

	Dst	LUND	SN_1	BMR	OM	PERS
count	149016	147374	146343	147383	147383	149015
mean	-13	-19	-13	-12	4	-13
std	21	17	20	21	26	21
min	-422	-230	-437	-650	-335	-422
1%	-88	-83	-76	-93	-84	-88
50%	-9	-16	-10	-7	10	-9
99%	20	7	18	7	36	20
max	95	31	62	32	48	95

Assessment of forecasts

Assessments of whole data sets

	BIAS	MAE	RMSE	CORR	MSESS:PERS	MSESS:BMR
LUND	-6.69	10.06	12.91	0.85	-7.20	0.24
SN_1	-0.96	8.15	11.35	0.84	-5.34	0.41
BMR	0.46	9.94	14.83	0.74	-9.82	nan
OM	16.74	19.60	23.07	0.78	-25.20	-1.42
PERS	-0.00	2.75	4.51	0.98	nan	0.91

Assessments of data sets Dst < -50

	BIAS	MAE	RMSE	CORR	MSESS:PERS	MSESS:BMR
LUND	10.40	19.56	27.86	0.72	-3.79	0.64
SN_1	13.80	20.13	28.18	0.76	-3.90	0.63
BMR	8.26	33.59	46.16	0.73	-12.15	nan
OM	16.44	26.15	33.42	0.72	-5.89	0.48
PERS	1.25	7.59	12.73	0.95	nan	0.92

Assessment of forecasts

Storm forecasts

- Low pass filter data (8 hours)
- Dst < 50 nT

~ 500 storms found

Lund

-ve Dst for all data

For storms median error ~ zero

SN_1

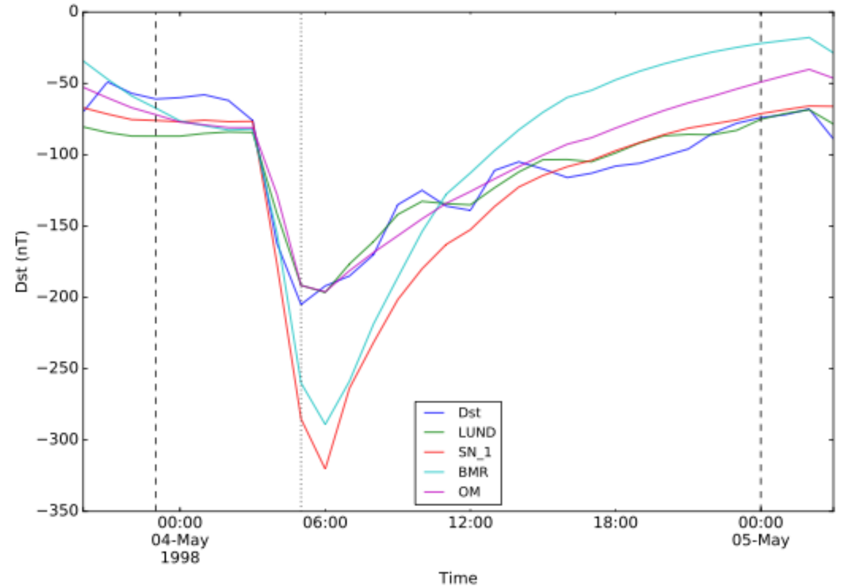
Median errors close to zero for all data

Subsets have slightly positive medians

BMR and OM

Consistent positive errors for storms

Evidence for positive bias



	n	p
LUND	273	54
SN_1	174	35
BMR	203	40
OM	123	24
PERS	0	0

Assessment of forecasts

Storm

	BIAS	MAE	RMSE	CORR	MSESS:PERS	MSESS:BMR
LUND	1.92	14.56	21.48	0.83	-2.94	0.58
SN_1	4.67	14.80	22.02	0.83	-3.14	0.56
BMR	5.15	22.48	33.32	0.79	-8.48	nan
OM	10.92	20.30	26.40	0.81	-4.95	0.37
PERS	0.77	6.62	10.82	0.96	nan	0.89

Main phase

	BIAS	MAE	RMSE	CORR	MSESS:PERS	MSESS:BMR
LUND	0.37	13.65	19.72	0.88	-1.08	0.54
SN_1	5.62	15.38	22.56	0.85	-1.72	0.40
BMR	3.69	19.71	29.12	0.83	-3.53	nan
OM	13.08	19.86	25.68	0.85	-2.52	0.22
PERS	5.84	8.38	13.68	0.96	nan	0.78

Recovery phase

	BIAS	MAE	RMSE	CORR	MSESS:PERS	MSESS:BMR
LUND	4.18	15.65	23.34	0.79	-7.86	0.60
SN_1	5.01	14.95	22.34	0.81	-7.12	0.64
BMR	6.63	25.19	36.98	0.76	-21.24	nan
OM	9.99	21.15	27.66	0.76	-11.44	0.44
PERS	-2.83	5.34	7.84	0.98	nan	0.96

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

(Talk by Balikhin on Thursday)

Low energy electron flux forecasts

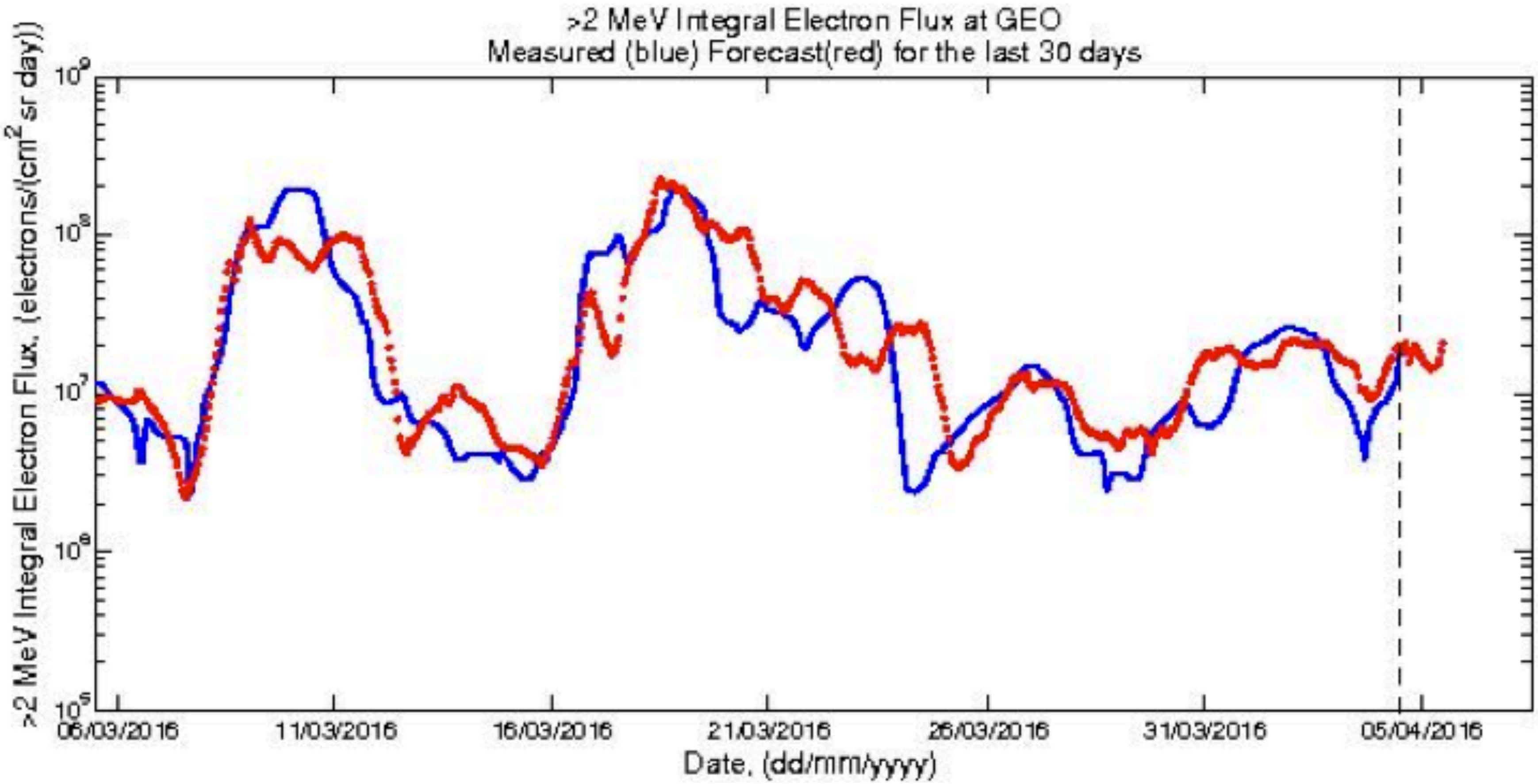
- Evolution of low energy electrons within the inner magnetosphere strongly depend upon conditions in the plasma sheet boundary layer
- THEMIS data used to generate a new empirical model for boundary conditions depending upon solar wind parameters.

High energy electron flux forecasts

- NARMAX forecasts of electron fluxes at geostationary orbit
  - Talk by H.-L. Wei later today
- NARMAX forecasts used to estimate outer boundary fluxes for VERB numerical model
- VERB model expanded to use data assimilation methods to accurately model electron fluxes in the radiation belts

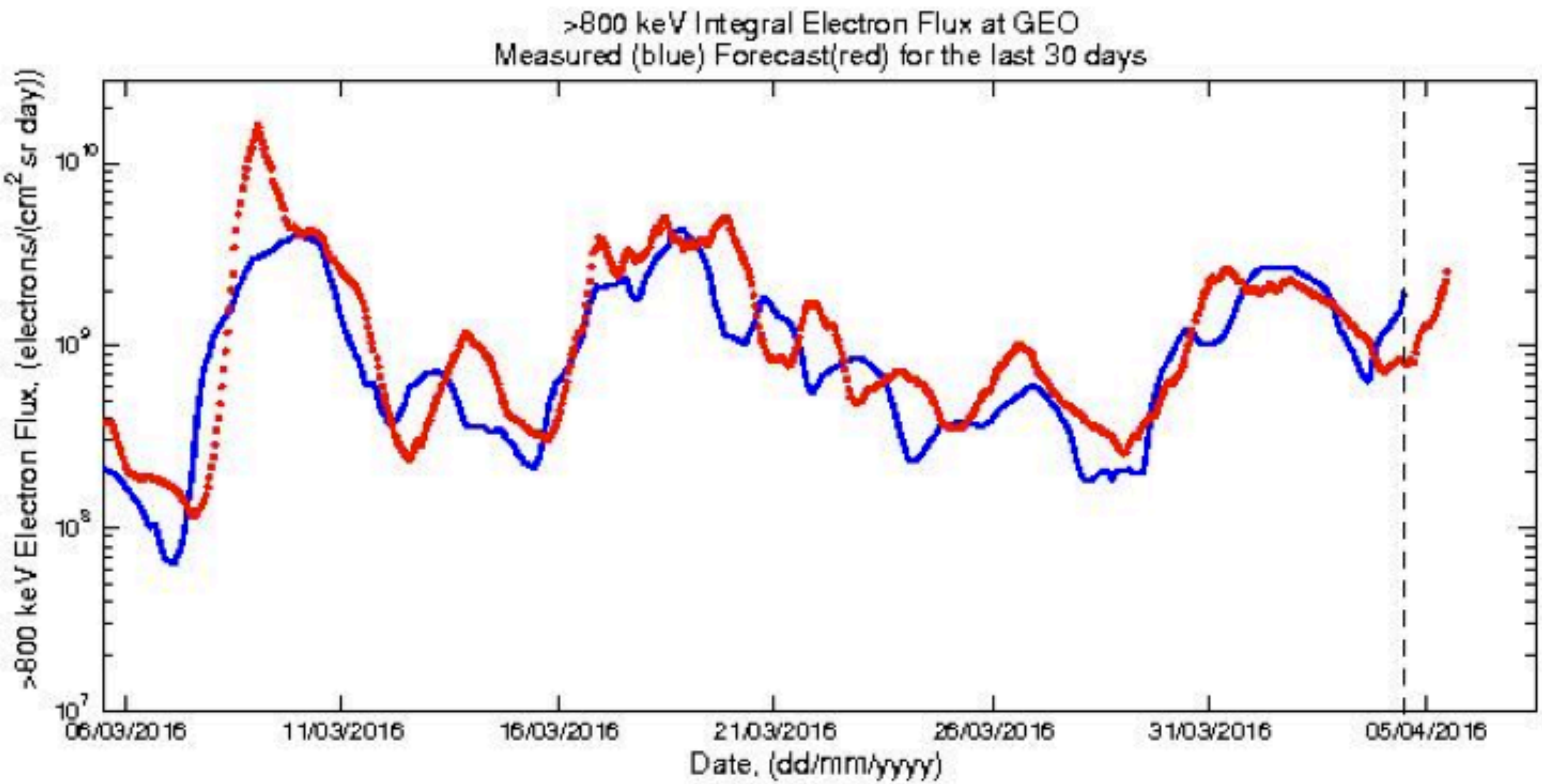
GSO electron fluxes 2 MeV

Energy 2MeV



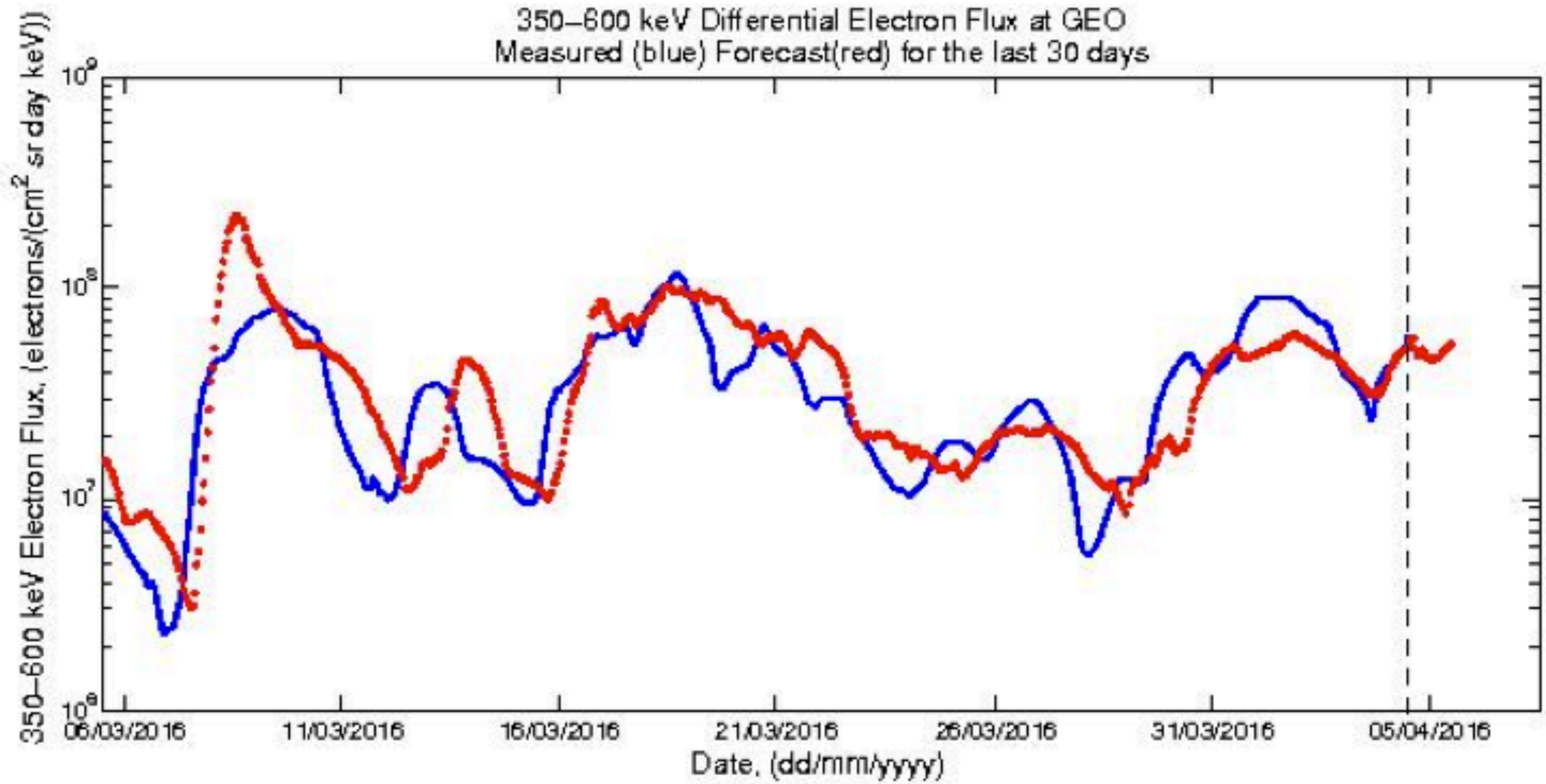
GSO electron fluxes 800 keV

Energy 800keV



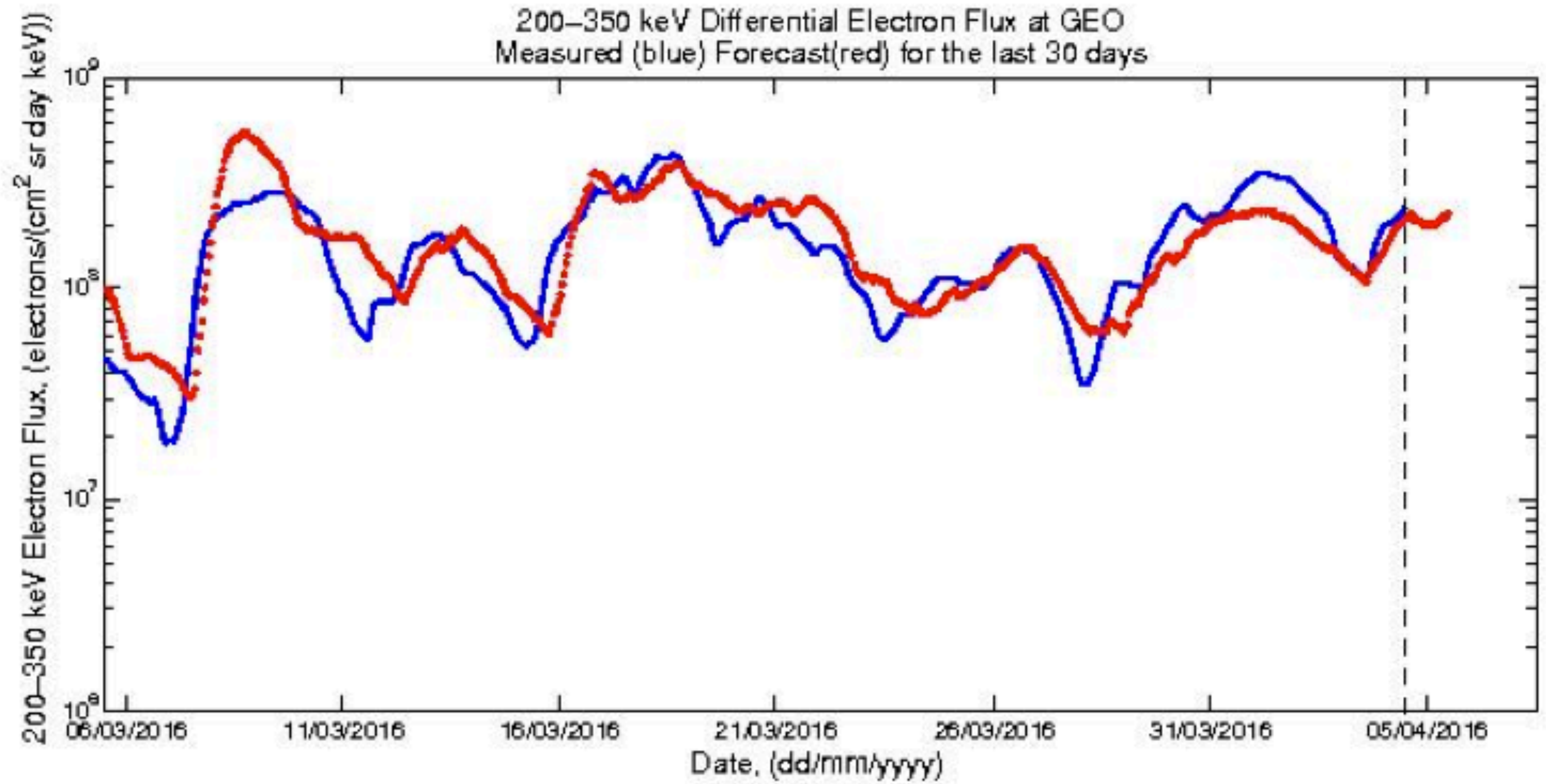
GSO electron fluxes 475 keV

Energy 475keV



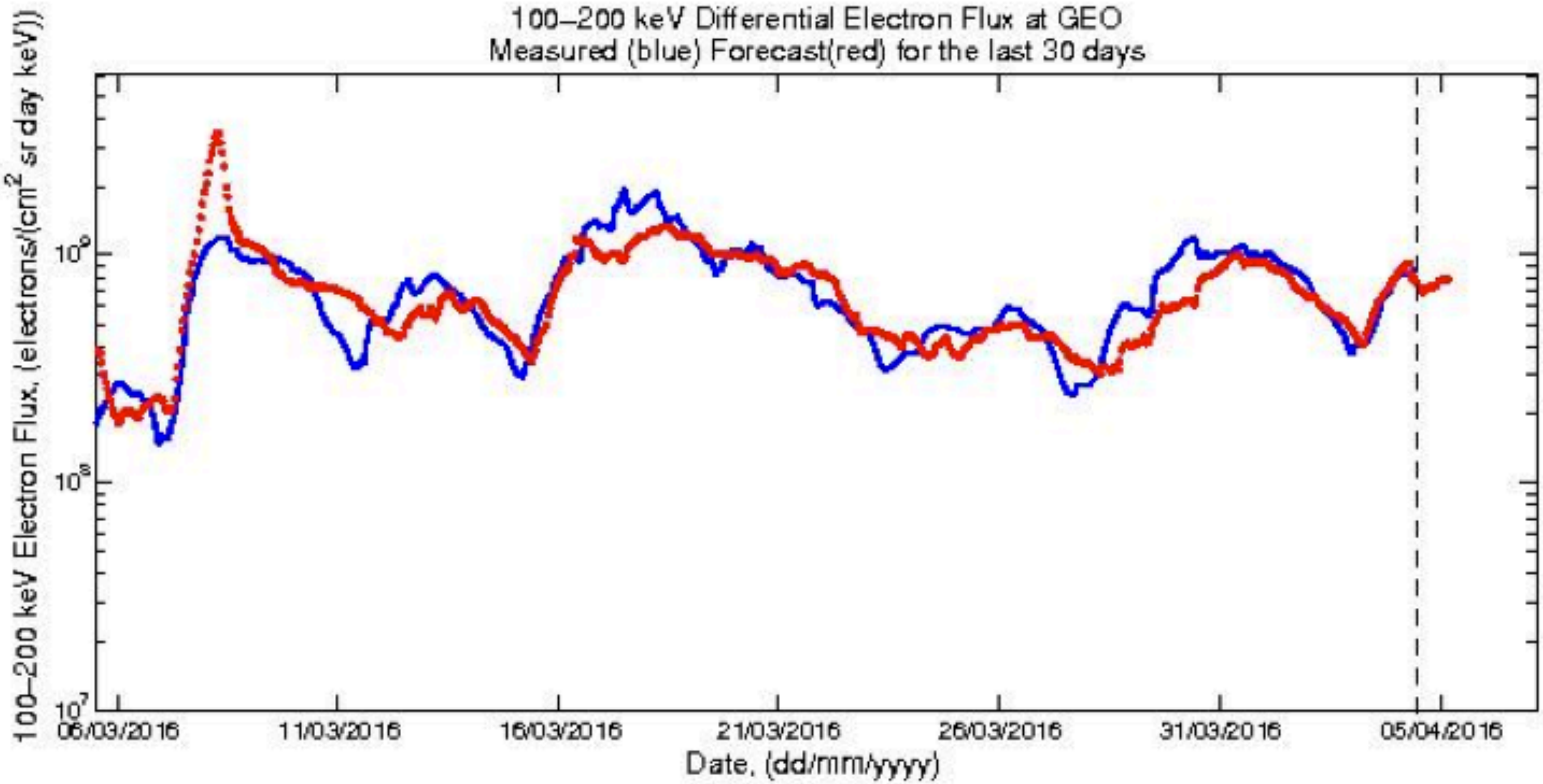
GSO electron fluxes 275 keV

Energy 275keV



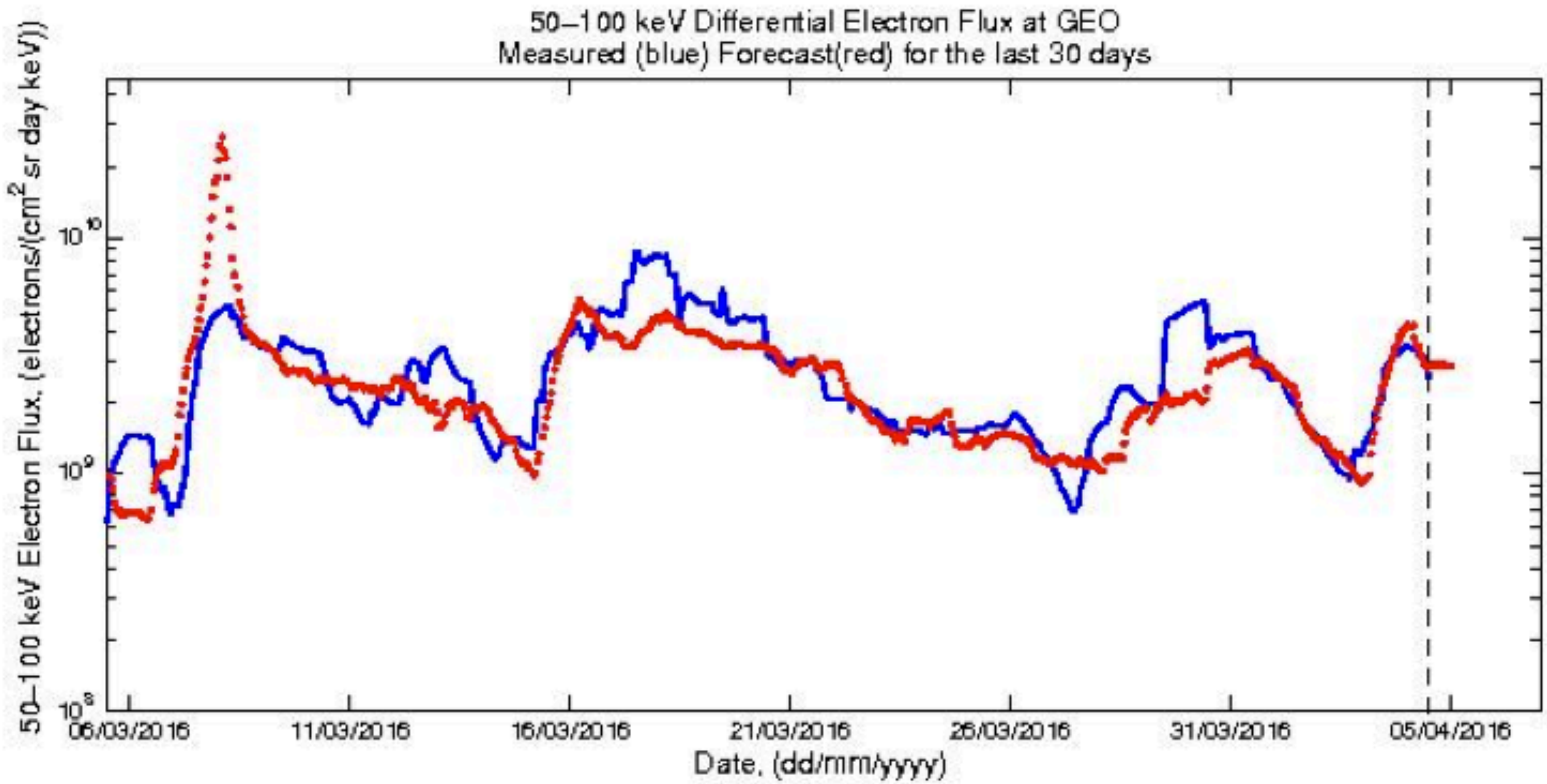
GSO electron fluxes 150 keV

Energy 150keV



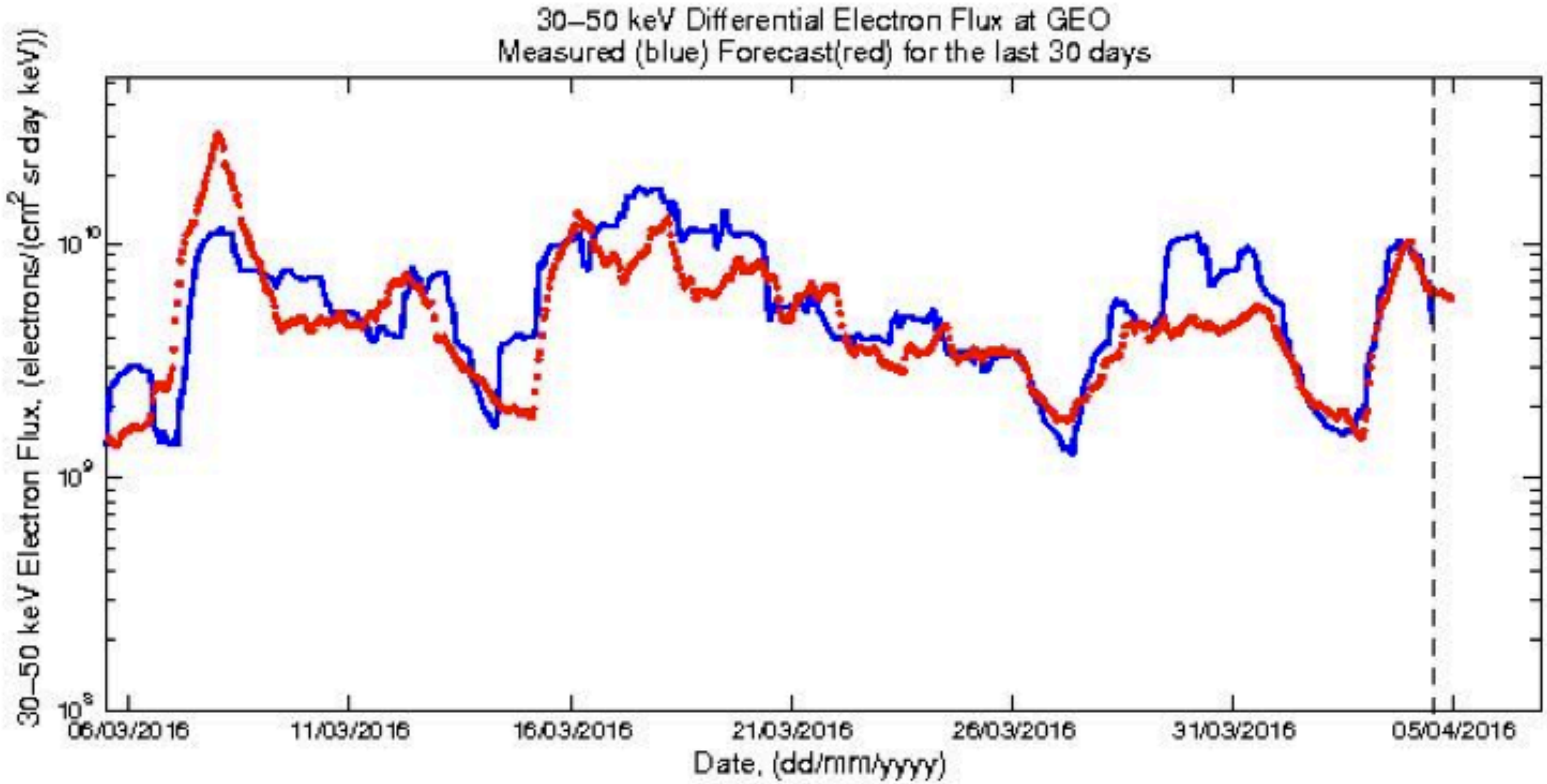
GSO electron fluxes 75 keV

Energy 75keV



GSO electron fluxes 40 keV

Energy 40keV



Summary

PROGRESS is a Horizon 2020 funded space weather project.

Main goals are to provide accurate and timely forecasts of

- Solar wind parameters at L1
- The evolution of geomagnetic indices
- The particle environment in the inner magnetosphere

Real time forecasts of interest to

- Scientists modeling these processes
- Satellite operators