SPACESTORM

Recreating the state of the radiation belts for the last 30 years

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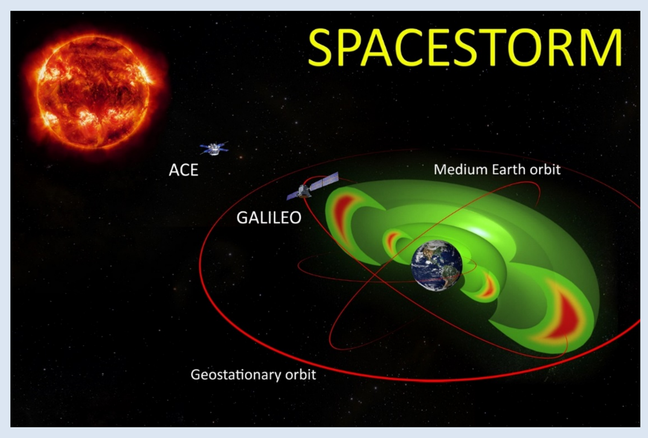
1. Introduction

Medium Earth Orbit (MEO) is becoming increasingly important

- Galileo, GPS, O3B
- Electric orbit raising
- Limited data on high-energy electrons at MEO
- No data set covers a whole solar cycle



2. The BAS Radiation Belt Model (BAS-RBM)

Physics-based model, includes:

- Transport across the radiation belts
- Interactions with electromagnetic waves
  - lower band, upper band and low-frequency chorus
  - EMIC waves
  - plasmaspheric hiss and lightning-generated whistlers
- Collisions between the electrons and the atmosphere
- Losses to the magnetopause

$$\frac{\partial f}{\partial t} = \frac{1}{g(\alpha)}\frac{\partial}{\partial \alpha}\Big|_{E,L} g(\alpha)\left(D_{\alpha\alpha}\frac{\partial f}{\partial \alpha}\Big|_{E,L} + D_{\alpha E}\frac{\partial f}{\partial E}\Big|_{\alpha,L}\right) + \frac{1}{A(E)}\frac{\partial}{\partial E}\Big|_{\alpha,L} A(E)\left(D_{EE}\frac{\partial f}{\partial E}\Big|_{\alpha,L} + D_{\alpha E}\frac{\partial f}{\partial \alpha}\Big|_{E,L}\right) + L^2\frac{\partial}{\partial L}\Big|_{\mu,J}\left(\frac{1}{L^2}D_{LL}\frac{\partial f}{\partial L}\Big|_{\mu,J}\right) - \frac{f}{\tau}$$

$$g(\alpha) = \sin 2\alpha\left(1.3802 - 0.3198\left(\sin\alpha + \sin\alpha^{1/2}\right)\right)$$

$$A(E) = (E + E_0)\left(E(E + 2E_0)\right)^{1/2}$$

3. Outer boundary condition

Need a data set that covers 30 years

- GOES > 2MeV electron flux

GOES provides:

- Integral flux
- At GEO - varying L*
- Only one energy

Model requires:

- Differential flux
- At fixed L*
- A range of energies

Need to

a) Map to fixed L* to remove diurnal variation

b) Approximate differential energy spectrum from one integral flux measurement

3a. Map to fixed L*

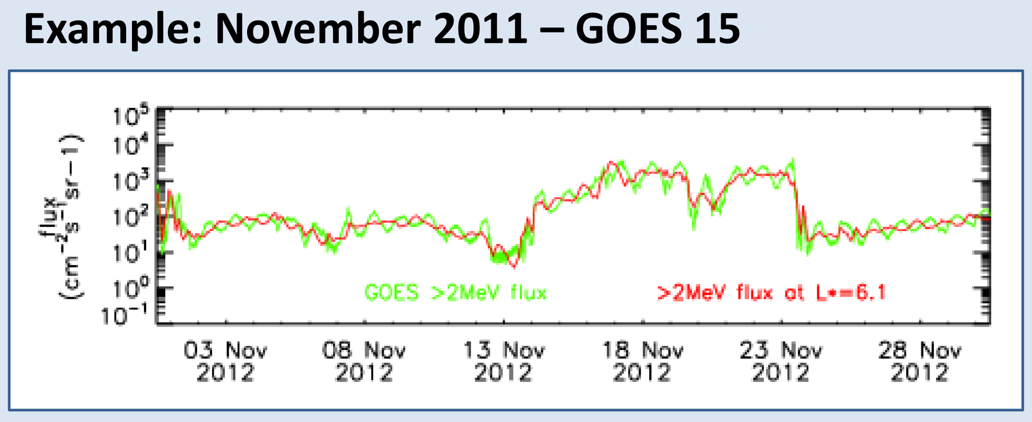
Statistical Asynchronous Regression [*O'Brien at al.,2001*]

- Determines the relationship between two time varying quantities, without the need for simultaneous measurements of both quantities
- Finds a function that maps the flux measurement at any MLT, to the flux that would be measured by the same instrument at a chosen local time.

Procedure

- Separate mappings for each GOES spacecraft
- Average GOES >2 MeV flux into 2 hour MLT bins
- Calculate MLT & Kp dependent corrections
- Calculate mappings to both dawn and dusk
  – Map flux to dawn and dusk and then average

Example: November 2011 – GOES 15

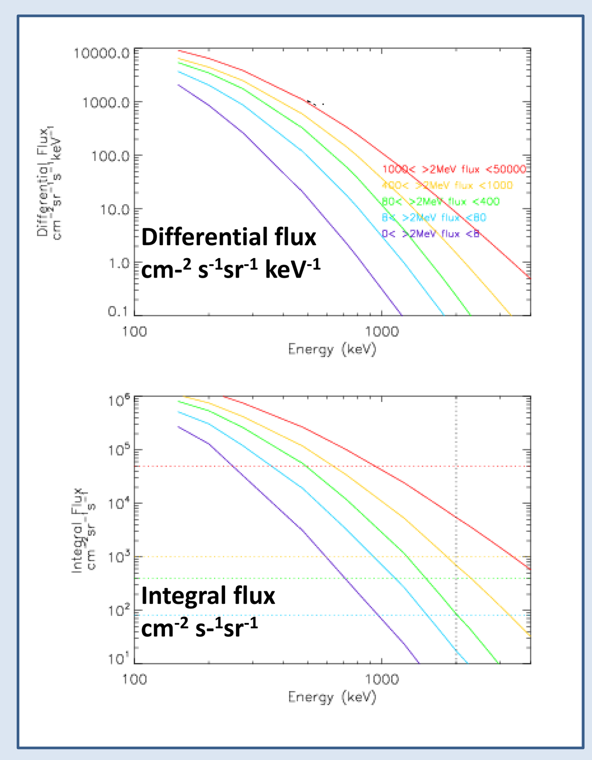


3b. Defining the spectrum

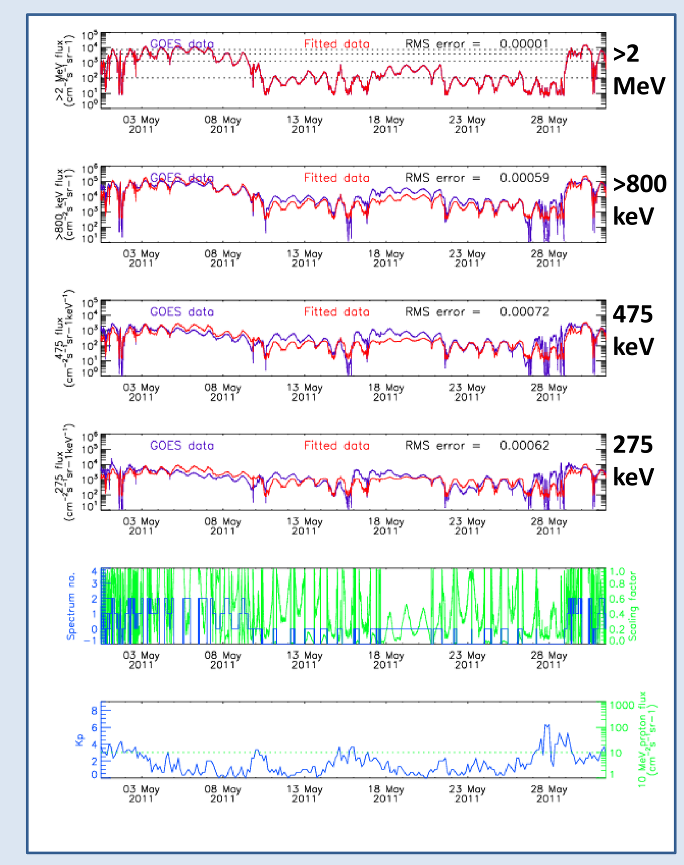
GOES provides one integral energy flux - model needs spectrum (~200 keV ≤ E ≤ ~30 MeV)

Use GOES 15 MAGED to define spectra for use with all GOES spacecraft

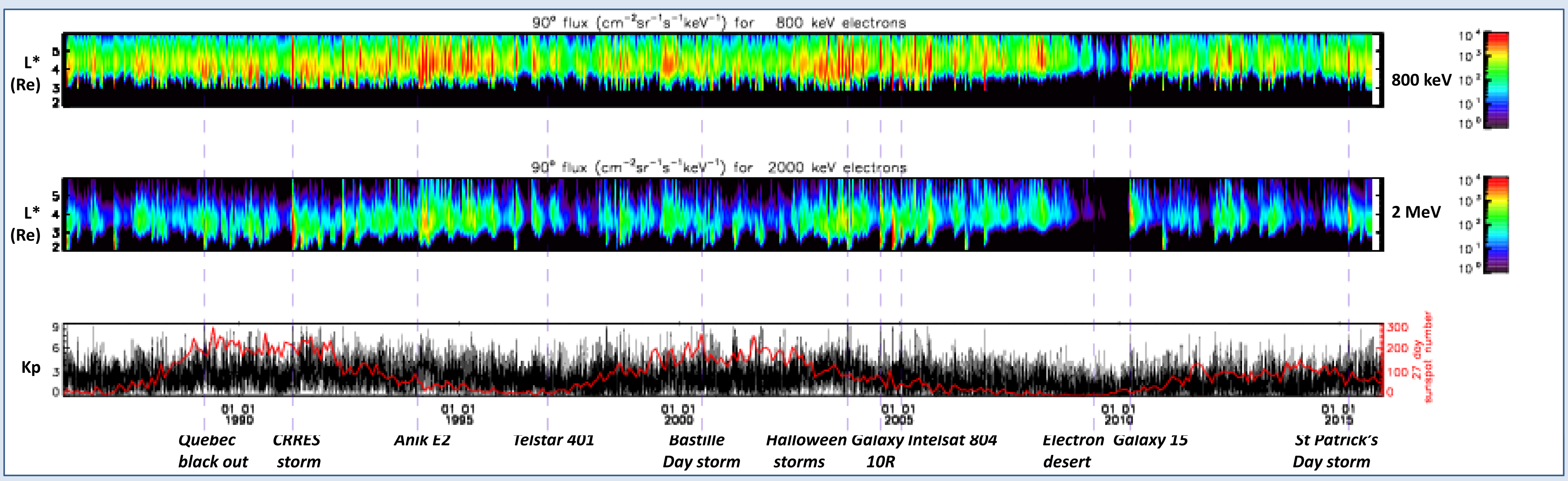
- Differential flux at 150, 275 and 475 keV from MAGED
- Estimate differential flux from >800keV and >2MeV flux: $J(1265\ keV) = \frac{I(800) - I(2000)}{1200}$
- Bin flux by level of >2 MeV flux
  – Spectrum shape depends on activity
- Fit kappa distribution to phase-space density
- Get differential and integral flux spectra



Spectra used on outer boundary



Comparison of fitted spectra and data May 2011



4. Evaluation using GIOVE-B data

Galileo In-Orbit Validation Element-B (GIOVE-B)

~4 years of data (May 2008 – July 2012)

Standard Radiation Environment Monitor (SREM), [*Evans et al.*,2008].

TC1 channel E >2 MeV

TC3 channel E >800 keV.

Use response functions to convert model output to SREM count rates

Giove-B response functions not available - use Rosetta response functions

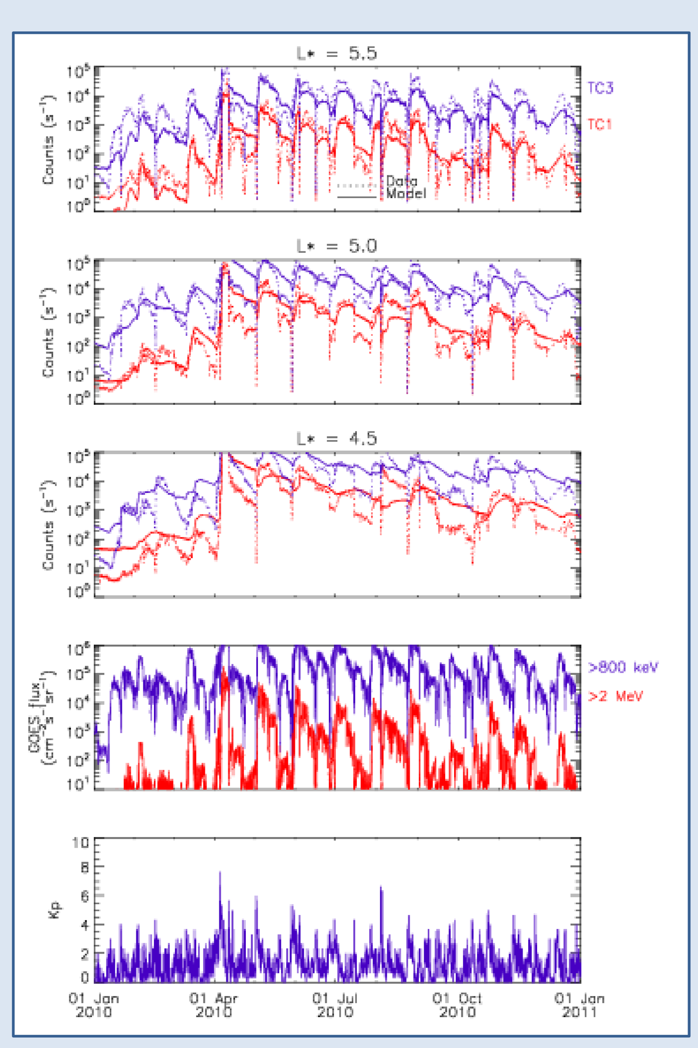
Evaluate simulation using skill scores

$$SS = 1 - \frac{\sum_1^N (X_i - Y_i)^2}{\sum_1^N (X_i - \overline{X})^2}$$

Year	TC1 at L*=5
2008	0.72
2009	0.83
2010	0.74
2011	0.58
2012	0.71

L*	TC1 in 2010
4.5	0.67
5	0.74
5.5	0.71

Skill scores



Comparison of model and GIOVE-B data

5. Conclusions

- Simulated the radiation belts between L* = 2 - 6 for the last 30 years
  – New method of deriving boundary conditions from GOES data
  – First long term simulation of the radiation belts (we think!)
- Considerable long and short-term variation throughout the belts
  – Solar cycle variations are clearly visible
  – Fast solar wind streams in the declining phase produce more intense fluxes throughout the belts
  – Low fluxes at start of solar cycle
- Results compared with the count rates from SREM on the GIOVE-B
  – Annual skill score usually exceeds 0.5, often exceeds 0.7.
- Flux spectrum along a Galileo-type orbit for 30 years will be available on the SPACESTORM website by end March 2017
  – Resource for satellite designers, operators and insurers

British Antarctic Survey

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Acknowledgement

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement 606716 (SPACESTORM)