Multi-Spacecraft Observations of SEPs: Applications for 3D Propagation Modelling

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STEREO SWG #20
Meredith, NH
October 27 - 29, 2009
OUTLINE

- Part 1
  3D Propagation Model and First Results

- Part 2
  Future Applications to Observations with STEREO-A/B, SOHO, ACE, WIND

Activity started as part of the ISSI Team # 118 on 
Transport of Energetic Particles in the Inner Heliosphere

THE 3D PROPAGATION MODEL

Particle propagation in a 3D archimedian spiral magnetic field, Including the effects of
• pitch angle scattering,
• focusing,
• diffusion perpendicular to B
• convection and adiabatic deceleration
Presently: model assumes impulsive injection at a localized source at the Sun

Numerical Method, solving stochastic differential equations

Path of 4 MeV p with and without perpendicular diffusion

Dröge et al., 2009
More realistic:

\[ \lambda_{\text{perp}} \text{ scales with gyroradius:} \]

\[ \lambda_{\perp} = \alpha \cdot \lambda_{\parallel} \cdot \left( \frac{r}{1\text{AU}} \right)^2 \cdot \cos \psi \cdot \sqrt{1 - \mu^2} \ \text{AU} \]

\[ \lambda_{\parallel} = 0.5 \ \text{AU} / \cos^2 \psi \]

\[ \alpha = 0.01 \]
THE 3D PROPAGATION MODEL
Single Spacecraft Applications

DROPOUTS

- no velocity dispersion
- time variations correspond to large spatial gradients perpendicular to $B$, convected past the spacecraft

CUTOFFS

Mazur et al. (2000)

ACE ULEIS 1 May 2000
I. Intensity-Time Profiles

No Perp Diffusion

Perp diffusion

With corotation

Cutoff

lower limit for $\lambda_{\perp}/\lambda_{||} : < 10^{-4}$ (at 1 AU)
II. Anisotropies

Case 1: Large anisotropy
S/C inside flux tube filled with particles

Case 2: Small anisotropy
S/C entering flux tube filled with particles later
II. Multi Spacecraft Observations

(1) Use remote observations to obtain injection parameters at the Sun
   Type II, III bursts, X-rays, CME- Radio - observations, ...

(2) In-situ Observations
   Use Intensity-Time Profiles, Anisotropy-Time Profiles
   as measured on several spacecraft separated in longitude, latitude, radial distance to infer
   • Injection characteristics at the Sun
   • Propagation parameters in Interplanetary Space
APPLICATION OF 3D-PROPAGATION CODE TO OBSERVATIONS BY STEREO-A/B, ACE, WIND, SOHO

Candidate Time Periods

I. May 2007
II. Nov 2008
III. May 2009

A - B Separation: 9.2°

(http://www2.physik.uni-kiel.de/stereo/browseplots/index.php)
2008 - Nov 3/4 Events
In-Situ Observation with ACE and STEREO

Candidate Time Periods

I. May 2007
II. Nov 2008
III. May 2009

(II) Nov 3/4 2008 Event
N35W38
C1 X-ray event
Type III burst
Small CME

(Wiedenbeck et al., ICRC 2009;

Wiedenbeck et al., 2009
Event:
N35W38

Separation
Footpoint - Flare

\( \Delta \Phi \)
STEREO-B   -2°
ACE        24°
STEREO-A   45°

A - B Separation: 82°
2008 - Nov 3/4 Events
Remote Observation with SOHO and STEREO

Stereo-B

Soho

Stereo-A

Nov 4, 2008 Event
Active Region 11007
2008 - Nov 3/4 Events
Remote Observation with STEREO and WIND

WIND / WAVES

Onset times on
Nov 3, 22:45
Nov 4, 03:24

STEREO / WAVES
2008 - Nov 3/4 Events
Remote Observation with SOHO

SOHO / EIT

CMEs

Nov 3  23:30  
Speed:  ~ 370 km/s  
Width:  ~ 46°

Nov 4  03:54  
~ 732 km/s  
~ 66°
2008 - Nov 3/4 Events
In-Situ Observation with ACE and STEREO

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In-Situ Observation with ACE, WIND and STEREO

ACE / EPAM

WIND / 3DP

Type III bursts on Nov 4: 03:24
2008 - Nov 3/4 Events
In-Situ Observation with ACE, WIND and STEREO

STEREO / SEPT

STEREO / SEPT

SEPT/STEREO-B

SEPT/STEREO-A

10 min average

Day of 2008

10 min average

Day of 2008
POSSIBLE COMPLICATIONS

Flare Longitude is not Necessarily Injection Longitude

Intensity contours of 50%_{\text{max}} type III bursts

Magnetogram

Open field line maps computed with PFSS model

View from the Earth:

View from above solar North:

Klein, et al., 2008

Fast access to open field lines at large $\Delta \Phi$ due to non-radial flux tubes
2008 - Nov 3/4 Events
Event Summary

• ~40 - 300 keV electrons observed over large range of solar longitudes

• intensity (two injections)- and anisotropy-time profiles are providing constraints on pitch angle scattering, perpendicular diffusion, and location of injection

• PFSS model does not show open field lines that connect to near-equator region

• Possible resolution of this puzzle: dynamical changes in magnetic field configuration by CME

Mason, et al., 2009

Open field line maps from photosphere to 2.5 $R_S$ surface from PFSS model.

Yellow: open field lines that connect to the ecliptic
SUMMARY

May 2007 Events
Good candidates for single spacecraft analysis of intensity and anisotropy

Nov 2008 Events
Multispacecraft analysis could be promising, Ion intensity too small

May 2009 Events
Good statistics for ions and electrons, intensity and anisotropy measurements are available

Events observed at large longitudinal separation: non-radial flux tubes close to the Sun may be important