Predicting Solar Energetic Particle (SEP) Events Using SEPMOD with ENLIL

J.G. Luhmann¹, M.L. Mays², D. Odstrcil³, C.O. Lee¹, Yan Li¹, H. Bain¹, D. Larson¹, C.M.S. Cohen⁴, R.A. Mewaldt⁴, R.A. Leske⁴

1 SSL University of California, Berkeley
2 CUA/GSFC CCMC
3 GMU/GSFC CCMC
4 Caltech

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SEP events have been a highly desired space weather forecasting goal for decades.

Several concepts exist regarding their generation and transport. One of these emphasizes the shock source and the observer magnetic field connection to it as ‘key’.

(from Reames, Space Science Rev., 1999, adapted from an original version by Cane and von Rosenvinge, 1988)
Several models have now been developed to use ENLIL results for simulating the ‘global’ SEP event counterparts. STEREO and ACE SEP measurements provide excellent tests. This would be a long-desired breakthrough, e.g. for human missions.
SEPMOD was developed under CISM in mid-2000s

- A generalized* test particle code that uses the time-dependent fields and shock information from MHD heliospheric CME/ICME simulations for \textit{FORWARD MODELING} SEP event time profiles
  (* can use any MHD model results)
- **Approach:**
  
  \textit{Transport:} A field-line tracer adapted for guiding-center particle trajectories of 10-100 MeV ions of any mass and charge is now modified to include energies down to 1 MeV.

  \textit{Source:} Uses an MHD shock parameter-based ‘black box’ source description that is the same for all events. An ESP enhancement with softer spectrum is assumed to travel with the shock.
Our simulation injects SEPs onto an observer’s field line at a moving, evolving shock source. It assumes field-aligned propagation determines what is detected. The observer can be located anywhere within the heliospheric model.
While SEPMOD was being developed, parallel ENLIL developments were made to identify shocks on-the-fly.

ENLIL model outputs for SEPMOD consist of the shock details on the field lines connected to any observer.
Over the years since, ENLIL has become a regularly run forecasting and research model, e.g. based on near real-time SOHO and STEREO images (here, by the GSFC Space Weather Research Center) — continually improving.

swrc.gsfc.nasa.gov- using the WSA/ENLIL model (D. Odstrcil, N. Arge)
Independent WSA-ENLIL Model runs are made at NOAA SWPC to forecast Solar wind at Earth and STEREO locations up to a month ahead (including Earth-directed CMEs)

www.swpc.noaa.gov/wsa-enlil
One important lesson learned is that a complex heliosphere setting with multiple events is common during solar active periods (March 2012 had 29 CMEs!)

_ALSO_ model accuracy depends on including all these events…
For SEPs, we learned that shock connections from behind can matter—requiring runs to ~5 AU even for 1 AU SEP modeling. This also necessitates longer duration (~3 week) ENLIL runs.

Note can give ‘all clear’ forecasts: No strong connection=no SEPs
We have used STEREO and ACE observations to provide tests/proof of the shock-source magnetic connection concept.
Testing the shock connection/SEP onset assumption

Examples from a working Space Weather tool including SEPs

August 2010

Local velocity at multiple sites from ENLIL, including shock arrivals
Related SEP events at STEREO A/B and ACE: data and models
And these can be done routinely, whenever coronal images are available (and magnetograms for solar wind!)

July 2012
Now we have years of multipoint SEP event information to interpret.
So now we have SEP forecasting tools but have only scratched the ‘validation’ surface

e.g. EVENTS tried in 2011-2014 (retrospectively)
Note underlying importance of the accuracy of the Heliospheric models (e.g. evaluate loss of STEREO B images and also must consider uncertain future of multi-perspective imaging resources in space)…

Poor heliospheric event models mean poor SEP event models…!
Updates Since 2012-Related Projects:

Dusan Odstrcil (GMU/NASA GSFC)
LWS TR&T project to improve ENLIL for research and forecasting uses

Leila Mays (CUA/NASA GSFC)
LWS Focused Science Topic to study heliospheric shock magnetic connectivity using ENLIL

Christina Lee (SSL)
Awarded AF Young Investigator Grant to investigate coronal shock contributions

Updates since 2012-Model developments:

-multiple shocks treatments including for SEPMOD
-experiments with cone model parameters, shock locator thresholds, use of ADAPT maps, practical setups for routine ENLIL output sharing.
-experiments with numerous case studies including planetary ‘observers’
-Next: setting up for routine runs using CCMC runs-on-request pipeline