SHILLELAgh: A data-driven solar wind model for studying solar energetic particle events

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Introduction

Solarwind-Heliosperic Imaging in Latitude and Longitude by Estimating Large-scale Attributes (SHILLELAgh) **[1]** is a method for **estimating the properties of the solar wind (SW) in the equatorial plane**. OMNI and STEREO in situ solar wind data is used as input. The solar wind is assumed to propagate radially at a constant velocity and the corona is assumed to remain static. A **2D map of solar wind properties is obtained** that is well suited for use in investigations of heliospheric features that are constrained to Parker spirals (e.g., co-rotating interaction regions). In this work, **the possibility of determining the source region of solar energetic particle (SEP) events is investigated** using the model. Our method provides a convenient vehicle for assessing the directionality and hence, the geo-effectiveness of SEP events.

Methods

In situ data from OMNI [2] and the STEREO [3] spacecraft are used as input to SHILLELAgh. First, **timeseries data is back- and forward-propagated** to determine the solar wind properties along the balistic path connecting the Sun and spacecraft using,

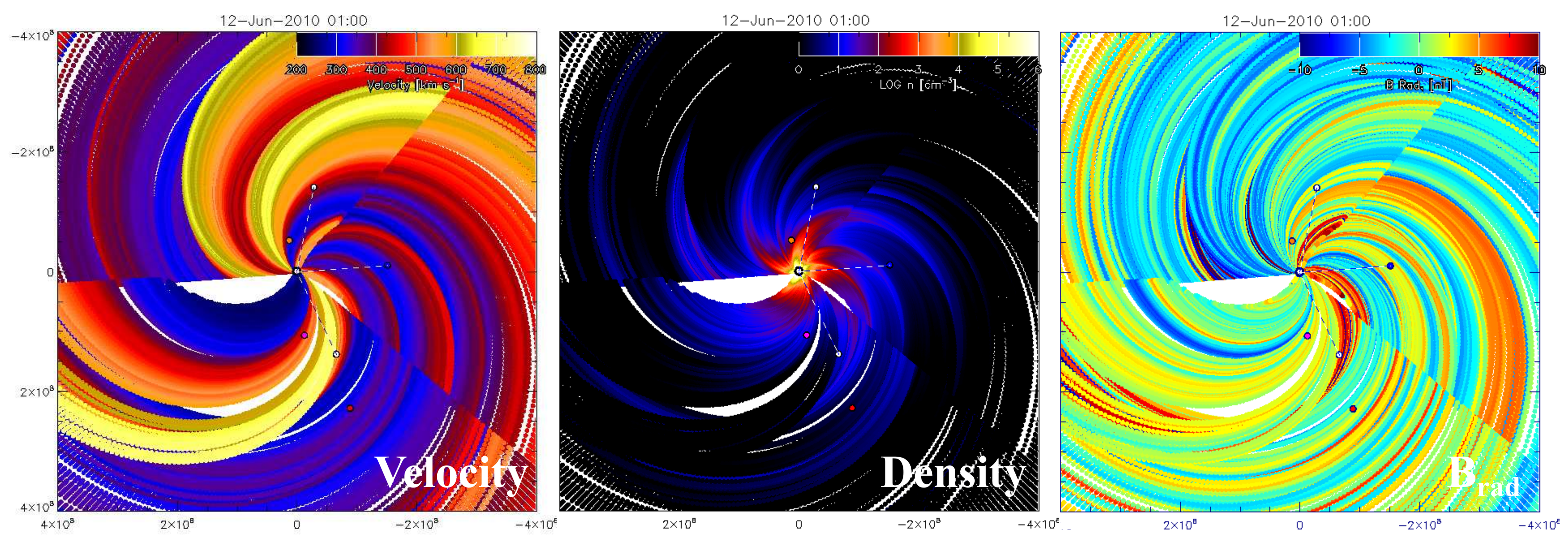
$$r_{\rm b} = r_{\rm s} + v_{\rm b}(t_0 - t_{\rm b}),$$

where r_s is the spacecraft-Sun distance, v_b is the SW velocity, t_0 is the simulation time, and t_b is the time the in situ data was recorded. This assumes a constant velocity for each solar wind particle, once released from the Sun. The solar wind properties are then **extrapolated to every location in the equatorial plane** assuming Parker spiral geometry using,

$$r_{\rm p} = r_{\rm b} - v_{\rm b}(\theta_{\rm p} - \theta_{\rm b})/\Omega_{\odot},$$

where θ_b and θ_p are the heliographic-inertial longitudes of the back propagated points and points along intersecting Parker spirals, and $\Omega_\odot$ is the solar angular rotation rate. This assumes a static corona.

Resulting SW property maps are shown below for an SEP event that occurred on 12-June-2010.



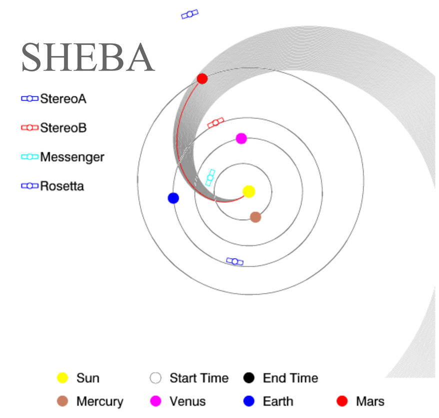
Software available:

For more info, see:

Observations

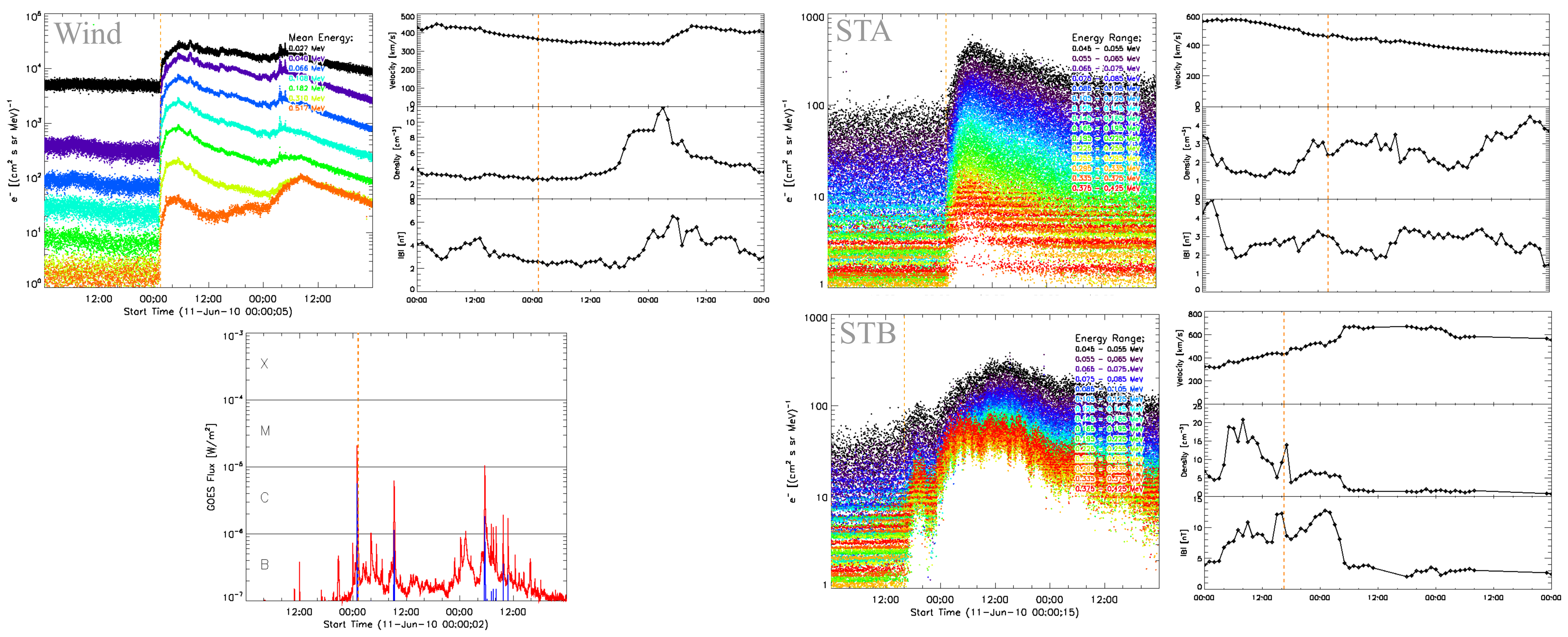
Five SEP events observed by a combination of Wind/3DP, STEREO A/SEPT, and STEREO B/SEPT are investigated here. The event times and solar-surface positions are taken to be those of the associated flares.

Event List				SHEBA Input	
Event	Flare t_{onset} (UT)	Flare Class	Flare HG Pos.	SW Speed [km s^{-1}]	Impact Pred.
20100612	01	M2	N23W43	325±50	Mars
20100807	18	M1	N11E34	410±50	Mercury
20100814	10	C4	N14W54	430±50	Earth
20100818	06	C4	N14W105	370±50	None
20120517	02	M5	N11W76	365±50	Earth/ Mars



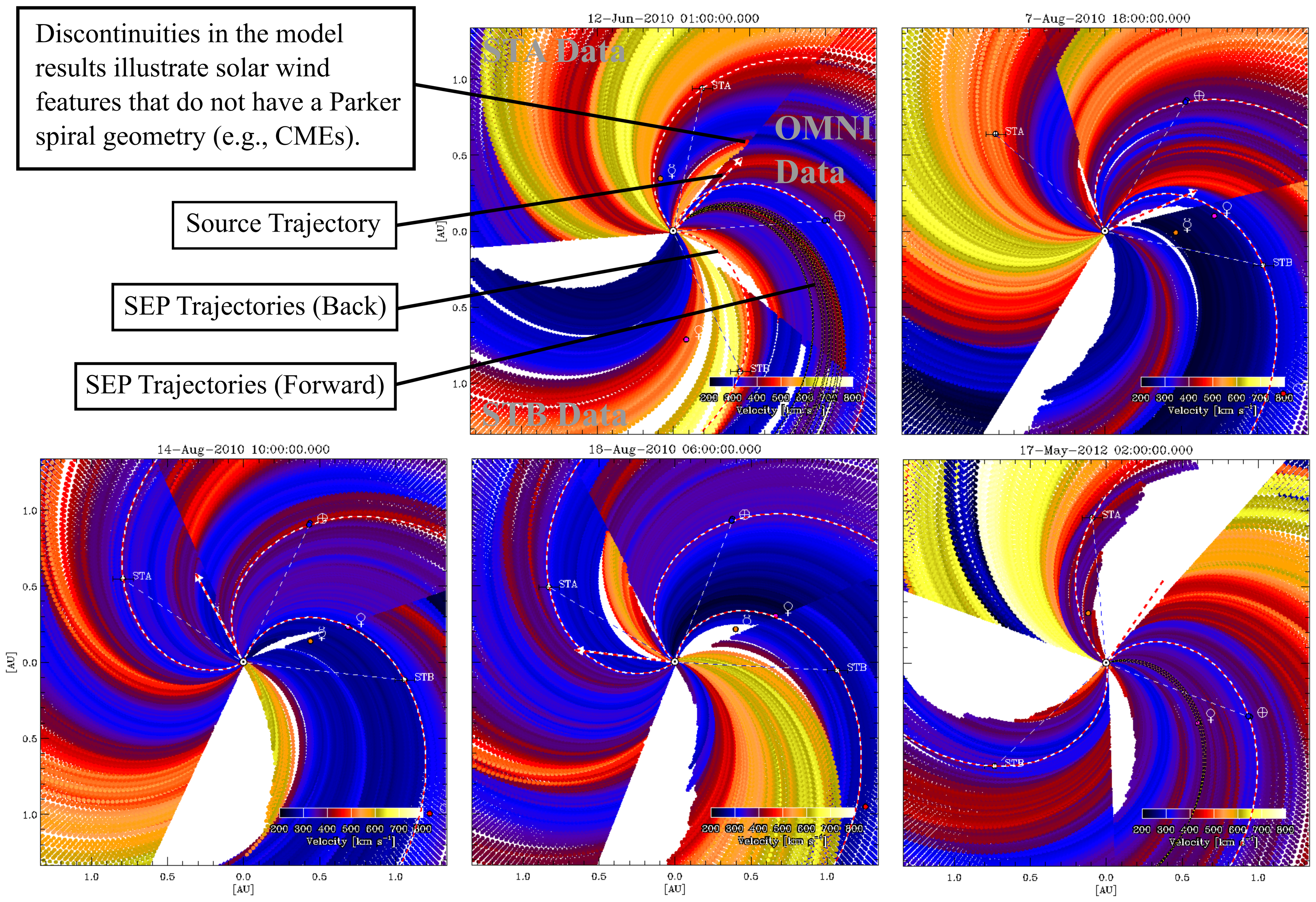
The Solar–Heliospheric Event Ballistic Algorithm (SHEBA) [5] is the **event propagation model used within the Heliophysics Integrated Observatory** (HELIO; see: http://helio-vo.eu) [6]. The model uses ballistic propagation with a user defined time, position on the Sun, and solar wind speed range as input. **A list of planets that were impacted by the event is returned**. The results of running SHEBA on this event list are shown in the table above.

Here, we expand on SHEBA by comparing the flare source times and locations to the SEP onset times and locations at each spacecraft. The 20100612 event is examined in detail. The SEP onset times, flare onset, and solar wind properties are shown below.



Results

Using the observed source locations, **each of the events are forward propagated** at the time of SEP onset using the back propagated solar wind velocities (see color bar). This method is similar that used in [7]. Parker spirals within 5^0 of the source longitude (dashed red arrow) are plotted (dashed yellow curves). This indicates the predicted SEP trajectories assuming a flare source. The red dashed curves show **the back-propagated SEP trajectories** assuming the SW velocity measured in situ at each SEP onset time.



The table below summarises the observed properties of each event and our comparison between the forward- ('Source HG Lon.') and back-propagated ('Predicted HG Lon.') SEP trajectories. Observed 'shallow' events have a very slow rise.

Event	SC	t_{onset}(UT)	Observed	SW Vel. [km s^{-1}]	Source HG Lon.	Predicted HG Lon.
20100612	Wind	01:03	Y	365	W43	W67
20100612	STA	01:55	Y,Noisey	455	W43	W126
20100612	STB	16:51	Y,Noisey, Shallow	438	W43	E11
20100807	Wind	19:05	Y	396	E34	W62
20100807	STA	–	N	–	E34	–
20100807	STB	18:58	Y	337	E34	E7
20100814	Wind	10:14	Y	427	W54	W58
20100814	STA	10:23	Y,Noisey	376	W54	W144
20100814	STB	10:14	Y	333	W54	W8
20100818	Wind	06:11	Y	355	W105	W69
20100818	STA	05:58	Y	362	W105	W147
20100818	STB	07:02	Y	317	W105	W12
20120517	Wind	01:55	Y	366	W76	W67
20120517	STA	06:04	Y,Shallow	626	W76	W154
20120517	STB	02:33	Y,Noisey	439	W76	E60

Discussion

Images produced by SHILLELAgh allow a quick assessment of the large-scale SW environment during an event.

We have tested the possibility of **determining SEP event source locations using observed SW properties, SEP onset times, and spacecraft locations**. While it is assumed that the SEP acceleration is restricted to the associated flare source location the above table shows that **most of the time events are observed by all three spacecraft**. Thus, the particle acceleration mechanism must be distributed over a large region of space. This is consistent with a CME shock acceleration mechanism [8].

Future work will include analysis of SEP fluency time-series to glean information about the potential CME source location and propagation speed and direction.

References

1. Bloomfield et al., 2013 (A&A; in review)
2. King & Papitashvili, 2005 (JGRA)
3. Luhmann et al., 2008 (SSR)
4. Chen, 1996 (JGR)
5. Pérez-Suárez et al., 2012 (Sol. Phys.)
6. Bentley et al., 2011 (ASR)
7. Nitta et al., 2006 (ApJ)
8. Reames, 1999 (SSR)

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