What Other Quantities Can Be Forecasted Using Solar Wind Speed Forecasts/Tracking & With What Accuracies?

Heather A. Elliott[1,2], Maher A. Dayeh[1,2], Raphael Attie[3,4], Michael Starkey[1], and Craig E. DeForest[5]

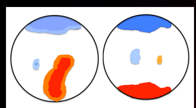
[1]Space Science, Southwest Research Institute, San Antonio, TX; [2]Physics and Astronomy Department, University of Texas at San Antonio, San Antonio, TX; [3]NASA Goddard Space Flight Center, MD; [4]George Mason University, VA; [5]Southwest Research Institute, Boulder, CO

helliott@swri.edu

Purpose: We can leverage known statistical correlations and relationships between the solar wind speed and other parameters such as the density, temperature, field strength, and SEP fluxes to forecast additional quantities using the speeds estimated from coronagraphs and heliospheric imagers like those on PUNCH.

Source Properties & Dynamic Interactions

Source Properties



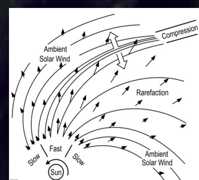
Large polar coronal holes emit very fast wind (650 to 860 km/s).

Moderately fast wind (450-650 km/s) comes from small low latitude holes and/or from edges of larger coronal holes.

Fast wind is hotter & less dense than slow wind

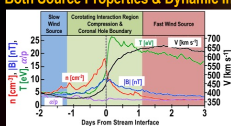
Dynamic Interactions

Dynamic interactions alter solar wind properties en route forming compressions & rarefactions which create correlations



Adapted from Pizzo, 1978

Both Source Properties & Dynamic Interactions

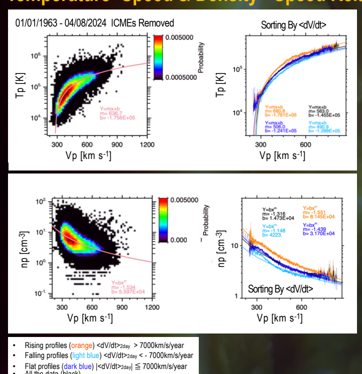


Adapted from Borovsky and Denton, 2010

Superposed epoch analysis of 27 CIR compressions.

Correlations between solar wind parameters due to source properties and dynamic interactions.

Temperature- Speed & Density - Speed Relationships



Top Left: Number of observations color-coded and binned by solar wind temperature and speed.

Top Right: Same observations sorted and binned by the steepness in the 2-day speed-time profile $<\Delta V/\Delta t>$.

We fit the results with a linear relationship to obtain the temperature formulas.

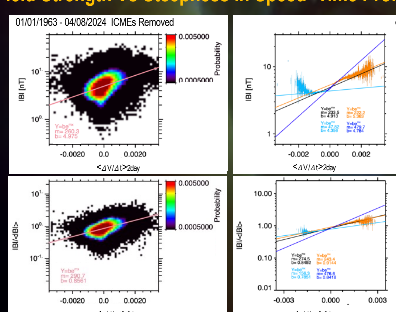
Bottom Left: Number of observations color-coded and binned by solar wind density and speed.

Bottom Right: Same observations sorted and binned by the steepness in the 2-day speed-time profile $<\Delta V/\Delta t>$.

Sorting by the steepness in the speed time profile was developed in Elliott et al. (2005, 2012).

We fit the results with a power law relationship to obtain the density formulas.

Field Strength Vs Steepness in Speed -Time Profile



Top Left: Number of observations color-coded in bins of the IMF field strength and average level of steepness in the speed-time profile for 2 day time windows ($<\Delta V/\Delta t>_{2\ day}$).

Top Right: Field strength sorted and binned by 2-day speed-time slope $<\Delta V/\Delta t>$.

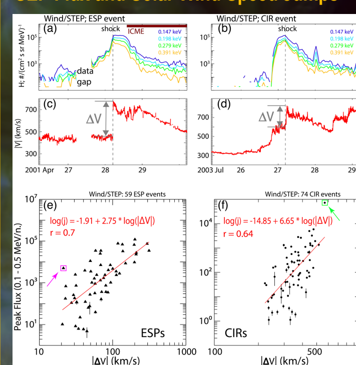
The field strength varies on long time scales. Normalizing by the average field strength from the previous solar rotation accounts for this effect.

Bottom Left: Same format is Top Left with the field strength normalized by the average field strength from the prior solar rotation.

Top Right: Same format and binning as the Top Right, but here the field is normalized by the average field strength from the prior solar rotation.

Output Quantity/ Quantity Forecasted	Input Quantity	Formula	Input Error	Output Error
SEP Peak Proton Flux for ESPs	Solar Wind Speed (V)	$F_{peak}=(9.33e{-}18)V^{7.54}$	+10%	105%
			-10%	-54.8%
SEP Peak Proton Flux for CIRs	Solar Wind Speed (V)	$F_{peak}=(9.33e{-}20)V^{7.46}$	+10%	104%
			-10%	-54.4%
SEP Peak Proton Flux for ESPs	Solar Wind Speed Jump (ΔV)	$F_{peak}=(1.23e{-}02)\Delta V^{2.75}$	+10%	30.0%
			-10%	-25.2%
SEP Peak Proton Flux for CIRs	Solar Wind Speed Jump (ΔV)	$F_{peak}=(1.41e{-}15)\Delta V^{6.65}$	+10%	88.5%
			-10%	-50.4%
Solar Wind Temperature (Scatter)	Solar Wind Speed (V)	$T=636.7V - 1.756E5$	+10%	124% to 14.8% (300 to 850 km/s)
			-10%	-124% to -14.8% (300 to 850 km/s)
Solar Wind Temperature (1-D binned)	Solar Wind Speed (V)	$T=563.0V - 1.455D5$	+10%	72.1% to 14.4% (300 to 850 km/s)
			-10%	-72.1% to -14.4% (300 to 850 km/s)
Solar Wind Density (Scatter)	Solar Wind Speed (V)	$n=(5.597e4)V^{-1.534}$	+10%	17.5%
			-10%	-13.6%
Solar Wind Density (1-D binned)	Solar Wind Speed (V)	$n=(1.473e4)V^{-1.316d}$	+10%	14.9%
			-10%	-11.8%
IMF Field Strength (Scatter)	Speed Temporal Gradient (dV/dt)	$\frac{B}{< Bpr >} = 0.8561e^{290.7<\frac{dv}{dt}>}$	+10%	-9.67% to 10.71% (300 to 850 km/s)
			-10%	10.71% to -9.67%(300 to 850 km/s)
IMF Field Strength (1-D Binned)	Speed Temporal Gradient (dV/dt)	$\frac{B}{< Bpr >} = 0.8492e^{274.5<\frac{dv}{dt}>}$	+10%	-9.16% to 10.08% (300 to 850 km/s)
			-10%	10.08% to -9.16%(300 to 850 km/s)

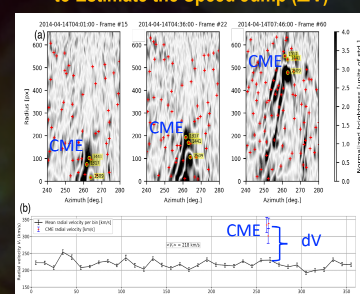
SEP Flux and Solar Wind Speed Jumps



Dayeh et al. 2025

Temporal profiles of H SEP intensities between 0.1-0.5 MeV in an ESP (a) and a CIR (b) event, along with the solar wind profiles (c,d). Scattered plots showing the correlation and the weighted fits between observed peak fluxes and the speed jump (ΔV) in 54 ESP events and 74 CIRs (e,f) (Figure 1 from Dayeh et al. 2025).

Speed Tracking the CME and Background Wind to Estimate the Speed Jump (ΔV)



Dayeh et al. 2025; balltracking by Raphael Attie

(a) Example of the tracking of plasma density structures with Magnetic Balltracking from Raphael Attie.The red crosses are at the location of the balls that track the density structures. We also show an example of the detection and tracking of a CME's leading and trailing brightness patterns tagged in yellow. The scale of the y-axis is 1px ~9.36 solar radii ~ 10170 km. (b) Mean radial velocities as a function of the azimuthal position around the sun, estimated by averaging the motion of the balls of Magnetic Balltracking over ~6.6 hr. The red cross and blue error bars show the average velocity of three density structures tracked in a CME (yellow tags in (a) (Figure 2 from Dayeh et al. 2025).

Summary and Conclusions

1. Correlations between solar wind and IMF parameters at 1 au exist owing to source properties in at the Sun and in the Corona, and the dynamic interaction that occurs en route from the Sun to Earth.
2. Reducing the errors in the solar wind speeds and densities derived from speed tracking and tomography will enable more space weather quantities to be accurately forecasted.
3. The form of empirical formulas used to forecast given quantities highly impacts the resulting forecast error of that quantity
   - The resulting error will be much higher for a forecast relationship depending on a high exponent of speed because the higher the exponent the larger the error will for the forecasted quantity.
4. We should search for empirical forecast relationships that depend on smaller exponents of PUNCH derived speeds (V), changes in speed (ΔV), and densities (n).
   - For instance the exponents are smaller for ΔV than for V then when estimating the ESP peak flux (Dayeh et al., 2025).
   - The balltracking in Dayeh et al. (2025) performed by Raphael Attie shows that the change in speed (ΔV) of the CME relative to the background wind can be estimated.