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CORONAL HEATING AND SOLAR WIND ACCELERATION MECHANISMS

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14. ABSTRACT
The project goal is to determine whether the magnetic expansion factor plays a physical role in solar wind acceleration or whether it simply serves as a proxy that can be used to distinguish between solar wind with slow (~300 - 500 km/s) and fast (~>650 km/s) speeds. During the period of performance, a methodology has been developed, through which suitable pseudostreamers can be identified and their resulting solar wind speeds can be determined. This is done applying the existing Wang-Sheeley-Arge (WSA) model output produced with Air Force Data Assimilative Photospheric Flux Transport (ADAPT) input maps, allowing the determination of the time of arrival at the specified spacecraft of the exact parcel of solar wind that left the pseudostreamer. We have shown that the methodology outlined is useful to identify unambiguous cases where spacecrafts like ACE are magnetically connected to pseudostreamers, and it can also be used to compare the field line expansion factors with the associated terminal solar wind speed.

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1 Summary

The project goal is to determine whether the magnetic expansion factor plays a physical role in solar wind acceleration or whether it simply serves as a proxy that can be used to distinguish between solar wind with slow (~300 - 500 km/s) and fast (~>650 km/s) speeds. During the period of performance, a methodology has been developed, through which suitable pseudostreamers can be identified and their resulting solar wind speeds can be determined. This is done applying the existing Wang-Sheeley-Arge (WSA) model output produced with Air Force Data Assimilative Photospheric Flux Transport (ADAPT) input maps, allowing the determination of the time of arrival at the specified spacecraft of the exact parcel of solar wind that left the pseudostreamer. We have shown that the methodology outlined is useful to identify unambiguous cases where spacecrafts like ACE are magnetically connected to pseudostreamers, and it can also be used to compare the field line expansion factors with the associated terminal solar wind speed.

2 Introduction

2.1 The magnetic expansion factor

The magnetic expansion factor (f_s) has been a parameter used in the calculation of terminal solar wind speed (v_{sw}) in the Wang-Sheeley-Arge (WSA) coronal and solar wind model. This factor measures the rate of flux tube expansion in cross section between the photosphere out to 2.5 solar radii, and is inversely related to v_{sw} (Wang & Sheeley, 1990). Since the discovery of this inverse relationship, it has been debated whether f_s plays a causal role in determining terminal solar wind speed or merely serves as proxy. One way to investigate this is via pseudostreamers, which occur when coronal holes of the same polarity are near enough to one another to limit field line expansion. Pseudostreamers are of particular interest because despite having low f_s, spacecraft observations show that solar wind emerging from these regions have slow to intermediate speeds of 350-550 km/s (Wang et al., 2012).

2.2 Project outline

The goal of the proposed program was to develop a methodology to identify a set of pseudostreamers that are magnetically connected to spacecraft, using the Wang-Sheeley-Arge (WSA, Arge & Pizzo 2000, Arge et al., 2003a, & 2004) model output produced with Air Force Data Assimilative Photospheric Flux Transport (ADAPT, Arge et al., 2009, 2010, & 2013) input maps. This allows the determination of the time of arrival at the specified spacecraft of the exact parcel of solar wind that left the pseudostreamer. Thereafter the pseudostreamers magnetic expansion factor can be compared with the observed solar wind speed from the spacecraft. This work will help solidifying whether f_s plays a physical role in the speed of solar wind originating from regions that typically produce slow wind.

3 Methods, Assumptions, and Procedures

3.1 Pseudostreamer identification

To identify periods where spacecraft are magneticaly connected to pseudostreamers, the WSA model was used to derive 2D global maps of coronal holes and their associated solar wind speed for the past decade (Fig. 1a). The maps also indicate the location of a spacecraft at a specific time (white crosshairs), and where the spacecraft is magnetically connected to coronal hole boundaries (black lines). Figure 1a shows an example of a pseudostreamer where there are two coronal holes of the same polarity that are magnetically connected to the Advanced Composition Explorer (ACE) spacecraft.

Once a pseudostreamer is identified, the indicated spacecraft positions are used to determine when the emerging solar wind left the Sun. WSA retains all information for derived parcels of solar wind as they leave the Sun and travel outward, thereby deriving when an exact parcel will arrive at ACE. It is important that the spacecraft-observed and model-derived solar wind speed are in good agreement to ensure that the spacecraft is in fact measuring the speed of the solar wind that originated from the specific pseudostreamer. To check, WSA created plots of the model-derived and spacecraft-observed solar wind speeds can be used (Fig. 1b).

3.2 Magnetic field configurations

A new feature of WSA 4.0 is used to render the 3D magnetic field configuration for selected periods (Fig. 1c), providing confirmation that identified features have the magnetic structure of a pseudostreamer. The 3D visualization displays triads of magnetic field lines, including those directly magnetically connected to the spacecraft (white crosshairs in Fig. 1a) in addition to field lines positioned half a grid cell above and below. Finally, for confirmed pseudostreamers, the photospheric latidute and longitude are recorded, and for each field line the WSA derived expansion factor arrival time is retained, to be compared to the spacecraft-observed terminal solar wind speed.

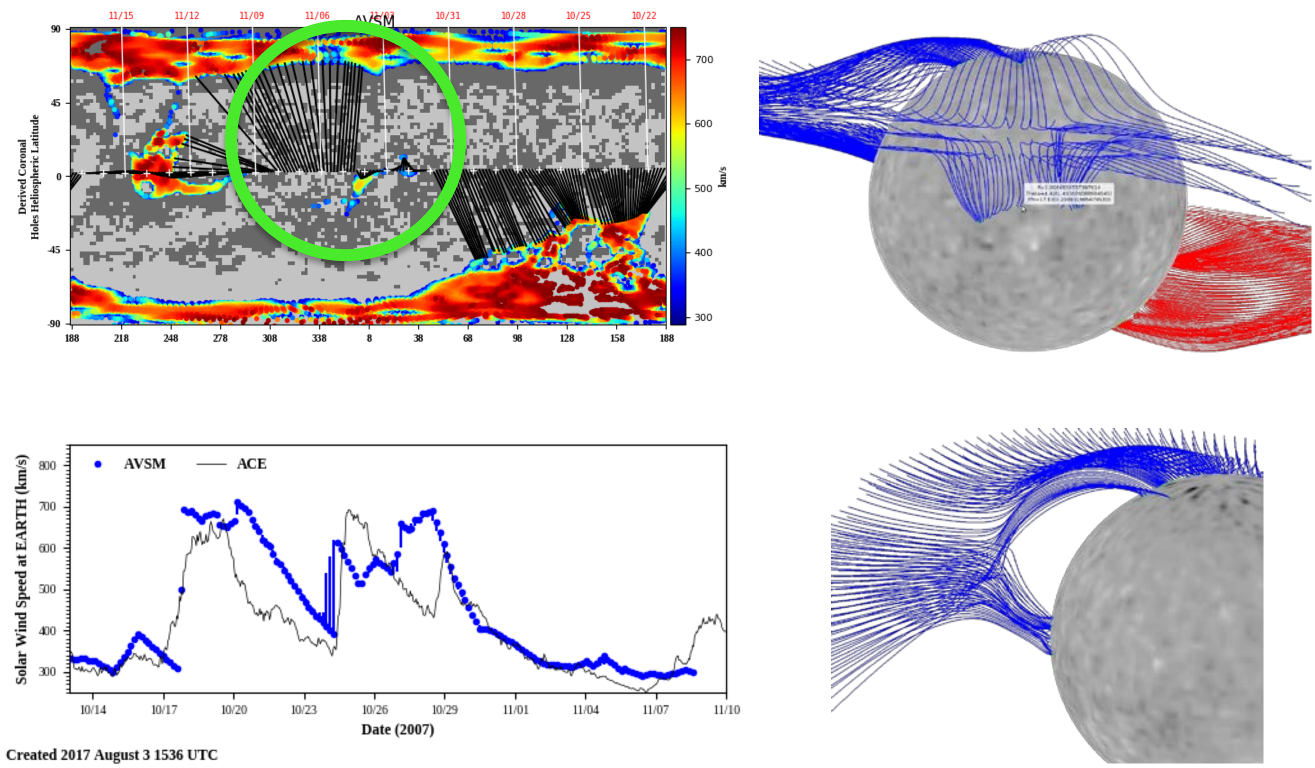

Figure 1: Illustration of the procedure of identifying a pseudostreamer. **a) (top left)** A 2D Carrington Rotation (CR) map with derived coronal holes. The green circle highlights a pseudostreamer. Light (positive) and dark (negative) gray regions indicate the photospheric magnetic field polarity, while colored regions reveal open field lines footpoints. The color-scale indicates the solar wind speed at 5 R_s as predicted by the model. White crosshairs indicate location of specified spacecraft over the rotation. The black lines identify connectivity between the outer (open) boundary located at 5.0 R_s and the source regions of the solar wind at the photosphere (1.0 R_s). **b) (bottom left)** Model-derived (blue) vs. ACE-observed (black) solar wind speed for the given CR. The model and spacecraft determined wind speeds agree well from November 3rd – 8th, which is the estimated travel time for this solar wind parcel originating at the pseudostreamer cusp (see Fig. 1a) to travel from the Sun to ACE. **c) (top right)** 3D rendered global coronal magnetic field configuration along sub-satellite points for the given CR overlaid onto the corresponding photospheric field map. Red (blue) lines represent field lines that are open and positive (negative). Field lines connected to ACE are at the center of each triad and those displayed above and below are positioned half a grid cell from the sub-satellite points. **d) (bottom right)** As in c) but with the pseudostreamer viewed from the side**.**

4 Results

Figure 2a shows an example of the WSA model-derived solar wind speed (green), observed solar wind speed at ACE (red), and expansion factor (blue) for CR 2062. For each field line determined by WSA, there is an associated expansion factor and solar wind speed for the parcel of solar wind leaving the field line. For this particular pseudostreamer, the model-derived arrival time of the solar wind originating from the pseudostreamer cusp is at noon on Nov. 8th marked by the shaded gray box. The blue dots within this box thus correspond to the expansion factors of the exact field lines forming the pseudostreamer. At that time, and within +/- half a day, the WSA-derived and ACE observed solar wind speeds are in excellent agreement, providing a strong argument for that the wind observed at ACE indeed originated from the pseudostreamer. For this pseudostreamer, the observed solar wind speed dips down to around 270 km/s, and the expansion factors range between 7-21. These values correspond to very slow solar wind speeds, and relatively low to moderate expansion factors.

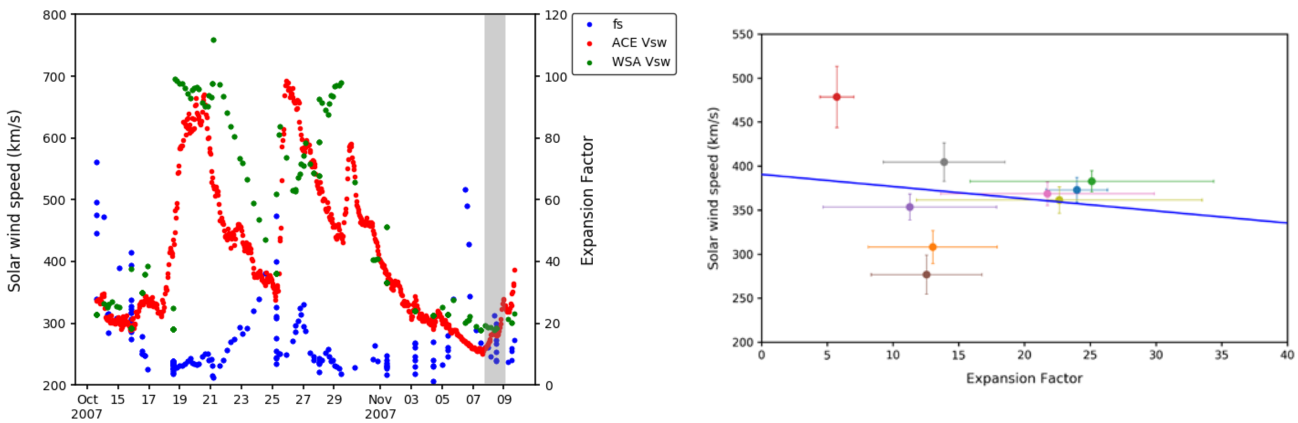

Figure 2: a) (left) Comparing the WSA-derived solar wind speed (green), ACE-observed solar wind speed (red) and magnetic expansion factor (blue) for CR 2062. The gray box indicates the terminal solar wind speed and expansion factors associated with the pseudostreamer identified in Fig. 1. **b) (right)** Average ACE-observed solar wind speed vs. average expansion factor for 9 different pseudostreamers. Horizontal error bars represent the expansion factor standard deviation for each field line forming the pseudostreamer. Vertical error bars represent the standard deviation of observed solar wind speed within +/- half a day of the pseudostreamer cusp solar wind arrival at ACE. The blue line indicates the calculated linear regression for the nine pseudostreamers.

To date the above methodology has been used to identify nine cases where ACE traversed through a pseudostreamer. Figure 2b shows the average observed solar wind speed at ACE versus the average WSA-derived expansion factor for these nine pseudostreamers. The horizontal error bars represent the standard deviation for the expansion factor of each field line forming the pseudostreamer, and the vertical ones represent the standard deviation of observed solar wind speed within +/- half a day of the pseudostreamer cusp solar wind arrival at ACE.

While the analysis is still ongoing, the initial results are consistent with prior studies (Riley et al., 2015, Riley & Luhmann 2012, Wang et al., 2012 etc.) in that for pseudostreamers, the solar wind speed at 1 AU is slow, about 500 km/s or less, and the expansion factors are low to moderate, ranging from 5 – 25 on average. The inverse relationship derived between the wind speed and the expansion factor (Fig. 2b) further agrees with the original Wang & Sheeley prescription. However, at this point our results are statistically insignificant due to our small sample size, noted by a weak Pearson correlation coefficient of -0.17.

5 Progress and Future Work

This program was proposed as a part of a UNM graduate student thesis project, and the student, Ms. Wallace, has at this point completed all her course work and is now working full time on her thesis project. Ms. Wallace has performed all the work described in this report under the advisement of PI Pihlstrom. The initial proposal contained the planned work for a 3-year program, and the AFRL grant has covered 2 of those years, allowing for the bulk of the methodology to be worked out and tested. A paper of the first results of this work with the student as the first author is currently in progress, in which the AFRL grant will be acknowledged.

As shown, the methodology outlined has been proven useful to identify unambiguous cases where spacecrafts like ACE are magnetically connected to pseudostreamers, and it can also be used to compare the field line expansion factors with the associated terminal solar wind speed. The ultimate goal is to determine whether the magnetic expansion factor plays a physical role in solar wind acceleration or whether it serves as a proxy that can be used to distinguish between solar wind with slow (~300 - 500 km/s) and fast (~>650 km/s) speeds.

Future work includes extending the sample size to approximately 30 cases to provide more reliable statistics, by incorporating additional spacecraft (e.g., STEREO-A & B). Once a large sample set is attained the plan is to investigate magnetic characteristics as a function of the height of the point where the field lines merge, separation distance between the two coronal holes, etc. Other possible extensions include looking at the ion composition of the solar wind when pseudostreamers occur, to determine if ion composition is dependent on solar wind speed or expansion factor (using a statistical analysis). Periods where multiple spacecraft are magnetically connected the same pseudostreamer can also be investigated. Lastly, the role of f_s in modulating the fast solar wind will be explored, by conducting a similar analysis for cases where spacecrafts are deep within coronal holes.

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Appendix

Papers in preparation:

1) Wallace, S., et al., 2018, in prep: Does the magnetic expansion factor play a role in solar wind acceleration?

Presentations at conferences:

1) Wallace, S., et al., 2016, *Does the magnetic expansion factor play a role in solar wind acceleration?*, poster presentation at the Solar Heliospheric and Interplanetary Environment (SHINE) conference, Santa Fe, NM, July 2016
2) Wallace, S., et al., 2017, *Does the magnetic expansion factor play a role in solar wind acceleration?,* poster presentation at the Solar Heliospheric and Interplanetary Environment (SHINE) conference, St. Sauveur, Quebec, Canada, July 2017
3) Wallace, S., et al., 2017, *Does the magnetic expansion factor play a role in solar wind acceleration?*, poster presentation at the American Astronomical Society (AAS) Solar Physics Division (SPD) meeting, Portland, OR, August 2017
4) Wallace, S., et al., 2016, *Does the magnetic expansion factor play a role in solar wind acceleration?,* oral presentation at the American Geophysical Union (AGU) conference, New Orleans, LA, December 2017

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