Asymmetries in the Solar Wind from the Sun to 10 AU: Comparisons between a 3D MHD Approach and the 3D HAFv2 Kinematic Model

ASYMMETRIES IN THE SOLAR WIND FROM THE SUN TO 10 AU: COMPARISONS BETWEEN A 3D MHD APPROACH AND THE 3D HAFv2 KINEMATIC MODEL

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ABSTRACT

Comparisons were made between the 3D HAFv2 space weather forecasting kinematic model, a 3D MHD model, and in-situ observations of the solar wind. Initial comparisons of the results from the two models with observations at ACE were favorable, and we now extend this work by comparing the results from both models beyond 1 AU. The simulated time series of solar wind parameters compare well with spacecraft observations of shock arrival at widely spaced points out to 6 AU. The three-dimensional models also show similar radial and azimuthal shock configurations out to 10 AU due to the Halloween 2003 events. It appears then, that asymmetries in latitude and longitude are important to the dynamics of the heliosphere and its interaction with the interstellar medium.

1. INTRODUCTION

In Intriligator at al. 2004, 2005a, we used the space weather forecasting HAFv2 (Hakamada-Akasofu-Fry version 2) model (Fry et al., 2001, 2003; Dryer et al., 2004) of the solar wind to project simulated solar background and transient shock events, based on solar observations, out to > 80 AU in three dimensions. In Intriligator et al., 2004, we suggested that solar generated disturbances may have contributed to the dynamics of the outer heliosphere in August 2002. In Intriligator, 2005a, we compared the modeled shock arrival times and solar wind parameters with in-situ data at ACE, Ulysses, Cassini, and Voyagers for the October/November 2003 events to suggest the necessity for consideration of solar generated disturbances when examining Voyager 1 and Voyager 2 observations in the outer heliosphere. In Intriligator et al., 2005b, we compared the HAFv2 model, the 3D MHD Hybrid Heliospheric Modeling System (HHMS), and ACE observations. In the present paper, we extend this work farther out in the heliosphere to include comparisons between the two models with Ulysses observations.

2. THE MODELS

Both solar wind models incorporate a global, pre-event, inhomogeneous, background solar wind plasma and interplanetary magnetic field (IMF). Both models use the Wang-Sheeley-Arge source surface models to provide the background boundary condition - at 2.5 Rs in HAFv2 and at 0.1 AU for the HHMS. In both models transient events are superimposed on the background.

2.1 HAFv2 model

The HAFv2 model is a 3D kinematic simulation. The model includes stream/stream interactions but not interstellar pickup ions (Intriligator et al., 2004, 2005a). The HAFv2 model was successfully used in the real time space weather "Fearless Forecasts" (Dryer et al., 2004) of the Halloween 2003 events.

2.2 HHMS model

The HHMS is a Sun to Earth system of coupled models designed primarily for real-time prediction of geomagnetic activity (Detman, et al. 2004; Intriligator et al., 2005b). The HHMS gives the state of the slowly evolving background solar wind within the inner heliosphere from 45 degrees South latitude to 45 degrees North and for 365 degrees longitude, including

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stream-stream interactions and co-rotating interaction region build-up. In addition to the background solar wind, the HHMS allows for interplanetary shock initiation at 0.1 AU based on other solar observations such as solar flares, Type II radio sweeps, and/or coronagraph observations of CMEs. To begin using the HHMS for the study of shock propagation to the outer heliosphere, we focused on the October and November 2003 (Halloween) events and iteratively fine-tuned the shock inputs for agreement with the shock arrival times in the ACE data. Figures 1 and 2 in Intriligator et al., 2005b showed, respectively, the results of this tuning exercise for HAFv2 and HHMS. Figure 2 showed comparisons of HHMS simulated time series of V, n, T, entropy, and /B/ with corresponding ACE data (Intriligator, 2005b). In the present paper, the use of the HHMS is extended by tracking the simulated shocks first to 6 AU and then to 10 AU.

3. RESULTS

Figure 1 below from Intriligator et al., 2005a shows the HAFv2 model predictions for Ulysses (at 5.23 AU, 80 degrees HGI longitude, and +5.8 degrees HGI latitude) and the in-situ solar wind speed and density data for the Halloween 2003 events. The agreement between the model and the data is quite good in terms of the range of magnitudes of the speed and density and of the relative timings of the jumps. The HAFv2 model predictions of the shocks arrival times lead those observed (Lario et al.

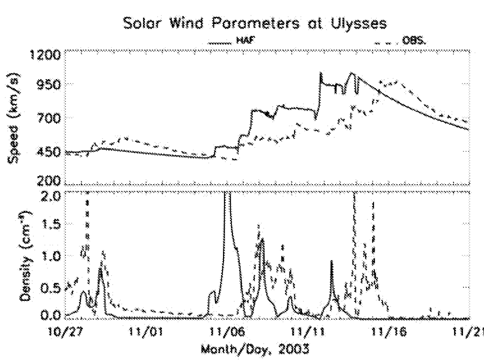


Figure 1. HAFv2 predictions and solar wind data at Ulysses for the Halloween 2003 events. The HAFv2 model at Ulysses is validated by the general agreement in speed profiles and shock arrival times with the solar wind data. No model shifting is necessary.

2005; Richardson et al., 2005). The November 6, 2003 shock is predicted to arrive on November 5; the November 7 shock is predicted to arrive on November 6, 2003; and so on. By the end of the series of stream-stream interactions, the HAFv2 model predicts the higher speeds occurring 2-3 days earlier than observed. However, the HAFv2 predicted magnitudes of the associated speed jumps are quite accurate. Thus, even though Ulysses and ACE are separated by more than 4 AU and by > 90 degrees in longitude, the HAFv2 predictions at Ulysses are accurate within a few days, and the overall envelope of the predicted speed magnitudes at Ulysses quite accurately reflects the data. In contrast, the 1D MHD results of Richardson et al., 2005 - which used 1 AU data at Earth as input to their 1D model - had to be shifted 8 days forward in time to more closely coincide with the shock arrival times at Ulysses. Despite this adjustment, their envelope of the predicted speed magnitudes did not agree well with the Ulysses data. This is not surprising, since the 3D modeling shows the large longitudinal shock asymmetry that is not taken into account in the 1D method. This again emphasizes the importance of 3D modeling.

Figure 2 shows comparisons of HHMS simulated time series of solar wind speed and IMF parameters with corresponding Ulysses observations from October 18 to December 11, 2003.

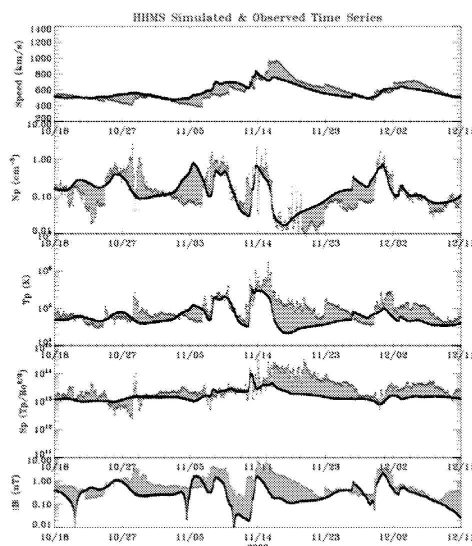


Figure 2. Comparison of HHMS simulated time series (black lines) with Ulysses 1-hour data (grey lines) for the Halloween 2003 events. The differences between the model and the data lines are filled with light grey. Starting with the top panel parameters shown are speed, density, temperature, entropy, and IMF magnitude.

Figure 3 is a helio-radius-time diagram from HHMS of specific entropy out to 10 AU along the Sun-Earth line. The multiple shock interactions in late October between 1-3 AU are in close agreement with the HAFv2 kinematic model results (Intriligator et al., 2005a).

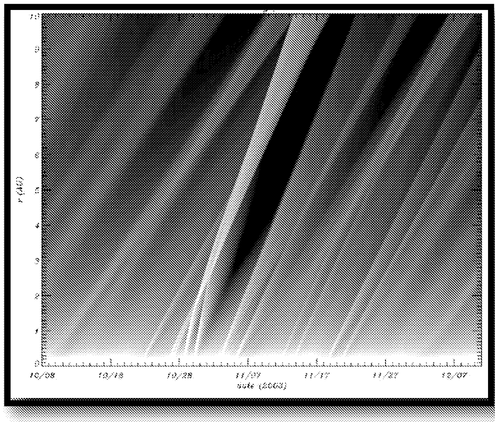


Figure 3. HHMS' specific entropy, $S = T_p / \rho^{2/3}$.

The four panels in Figure 4 show the IMF polarity before (October 12, 2003) and after (November 06, 2003) the Halloween 2003 events. The changes due to the shocks are evident in the configuration of the IMF in the ecliptic plane resulting from the Halloween events. The asymmetry of the shocks in longitudinal and radial direction are obvious and similar in both computations.

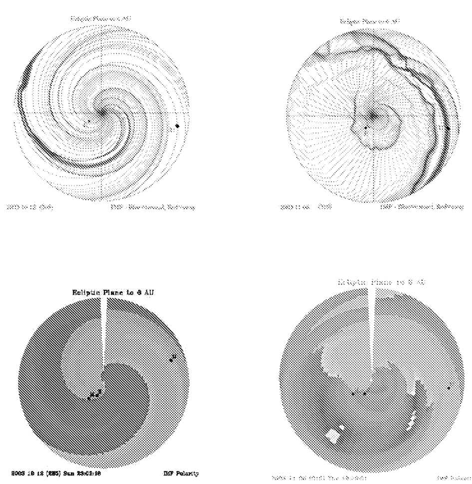


Figure 4. IMF ecliptic plane comparisons from the Sun to 6 AU before (left panels) and after (right panels) the Halloween 2003 events. Top panels: HAFv2 model. Bottom panels: HHMS simulation.

Figure 5 shows HHMS latitude comparison out to 6 AU of the IMF polarity before (upper panel) and after (lower panel) the Halloween 2003 events. The overall latitudinal asymmetries change as a function of time and heliocentric distance. Figure 6 is similar to Figure 5 and shows the latitude comparisons of the solar wind speed before (upper panel) and after (lower panel) the Halloween events. The change in the latitude variations of the speed before and after the Halloween events are quite striking. The slow solar wind speeds associated with the low latitude streamer belt are present before the

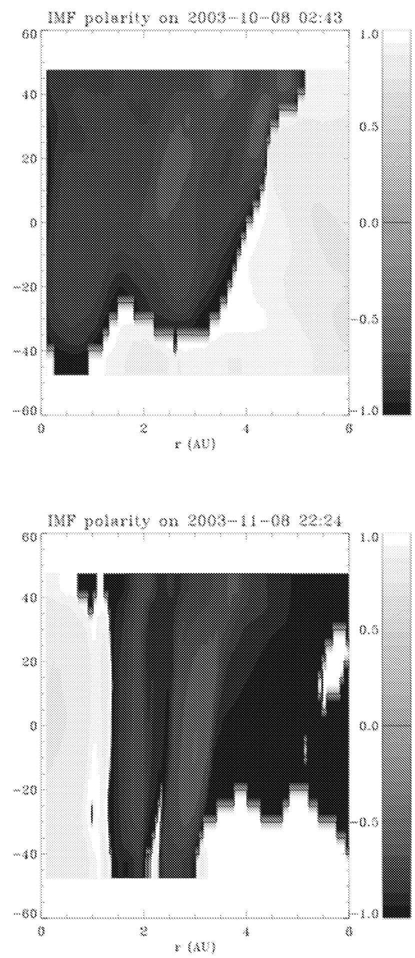
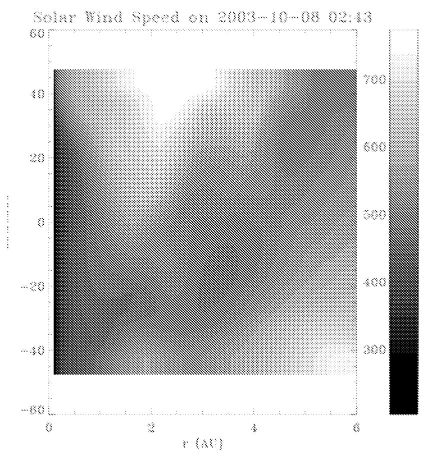


Figure 5. HHMS latitude variations (+/- 45 deg) in IMF polarity from the Sun to 6 AU in the Sun-Earth meridional plane before (upper panel) and after (lower panel) the Halloween 2003 events.

events with the higher speeds associated with high latitude coronal holes intruding toward the lower latitudes. After the events there are elevated solar wind speeds at low latitudes beyond ~ 2 AU propagating to greater heliocentric distances.



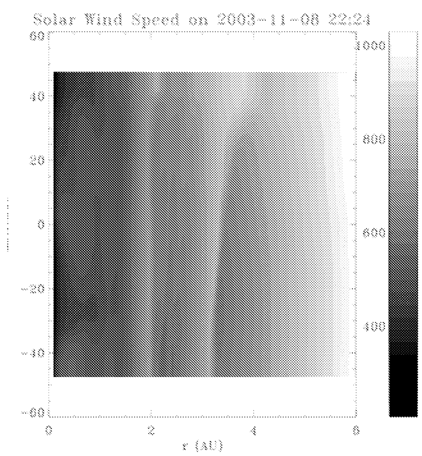


Figure 6. Same as Figure 5 but for solar wind speed.

4. SUMMARY

This work presents further comparisons of the HAFv2 3D kinematic model with the 3D MHD HHMS model. The changing and asymmetric distribution of shocked solar wind is well represented by both models. The IMF structure simulated by the HAFv2 and HHMS models is consistent both with the time series observations and between the simulations. The asymmetric propagation of solar events affects the dynamics of the outer heliosphere.

5. ACKNOWLEDGMENTS

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