Propagation Delay Prediction of Interplanetary Shocks and Discontinuities

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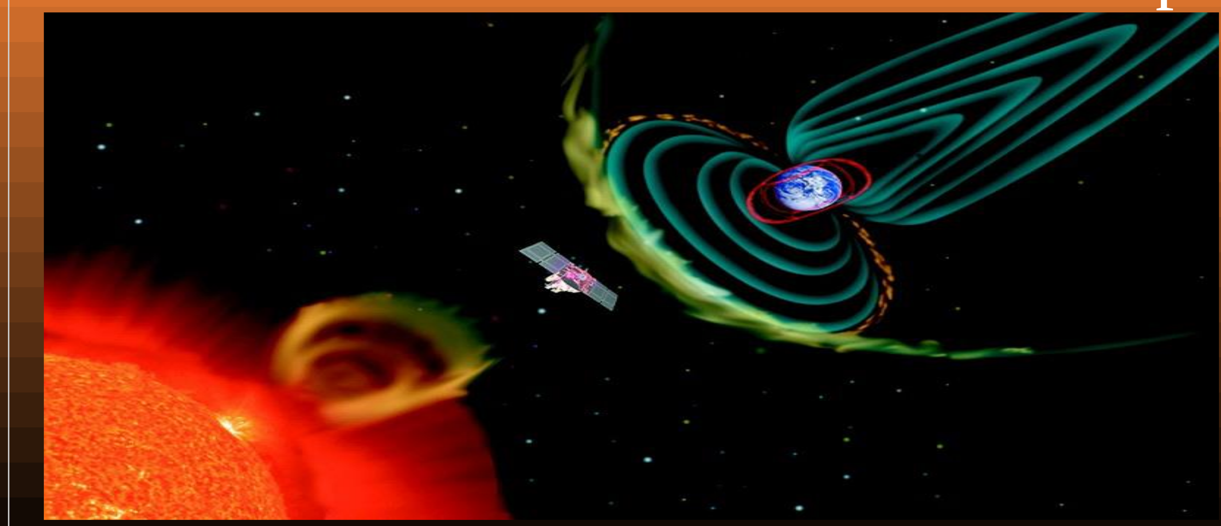
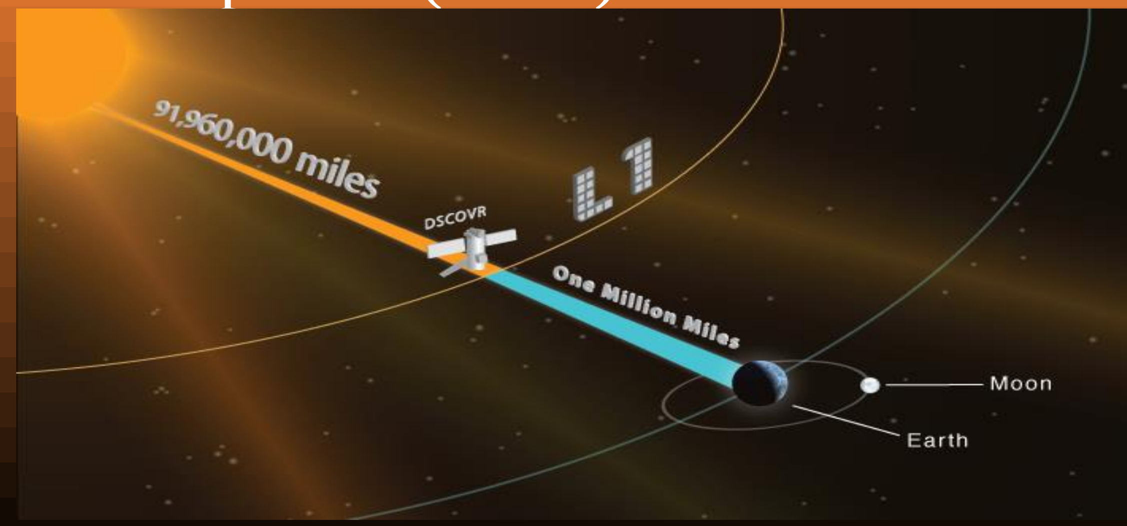
Introduction

The use of a flat-plane propagation method (referred to as convection delay) to predict arrival times of CMEs and other solar-wind discontinuities results in significant error. Consequently, finding a method to accurately calculate the normal tilt of shock phase fronts, and thus improving on propagation-delay predictions, has become a topic of interest amongst space-weather researchers. A modified minimum variance analysis method, a cross product method, and a method that combines both of these techniques (MVAB-0, CP, and MVCP, respectively), have been suggested for use in calculating such a normal. Using ACE data from 104 sudden-impulse generating shocks, we present findings from our attempts to discover correlations between three shock parameters and delay error. After a coarse optimization of parameters, we also display results from an in-depth analysis on the effectiveness of the three techniques compared to convection delay. Synthesizing insights gained from our work, we are able to propose a shock propagation-delay prediction method to be used in real-time to aid forecasters at NOAA SWPC.

Methods

1998-2013 data from Advanced Composition Explorer (ACE)





Shock detection algorithm from *Cash et al. [2014]*

Flat plane method	*Tilted plane methods*
Convection delay	**MVAB-0** + **CP** = **MVCP**

Data and Analysis

Attempts to find a correlation between parameters and delay error – Non-optimized analysis

		FREQUENCY OF ERROR IN PREDICTED ARRIVAL TIME (%)				
Hypothesis	**SHOCK PARAMETER**	**0-5 min error**	**6-11 min error**	**12-31 min error**	**Mean error (min)**	**Data Summary**
When ACE is far from the S-E line and observes a shock that is highly tilted away from the S-E line, a tilted-phase-planes method corrects for the error seen in convection delay.	ACE >40 R_E & SHOCK TILT >40^O FROM S-E LINE					Convection delay outperforms MVCP for highly-tilted/far events.
	CD	73	18	9	4	
	MVCP	55	27	18	7	
A strong shock (Mach # used as a measure of strength) will be less susceptible to tilting if it simply blasts through the solar wind, so it will travel with a relatively flat phase front plane. Thus, a tilted-phase-planes method will better predict weaker, more tilted, shocks.	MACH #					Convection delay outperforms MVCP for both strong and weak shocks.
	LOWER 50% CD	76	16	8.0	4	
	LOWER 50% MVCP	58	26	16	6	
	UPPER 50% CD	74	17	9.4	4	
	UPPER 50% MVCP	58	32	9.4	5	

The non-optimized analysis results suggest that a tilted-phase-planes method cannot predict the arrival time of a shock as accurately as a method that assumes a flat phase front plane. We recognize this as simply the outcome of one parameter permutation and acknowledge the extensive research conducted which shows the success of tilted-phase-planes methods. Therefore a coarse parameter optimization was conducted.

Parameter	Optimized Values for MVCP/MVAB-0
Data Cadence	1 minute
Limiting Angle	60
Number of Points in CP Average	3
Number of Points in MV Calculation	7
Agreement Angle	22
Minimum Eigenvalue Ratio	27
Minimum B Change Angle	1
Step Size	2
Number of Points in Shock Average	1
For Invalid Tilt Angles	Assume flat plane

Percent improvement over convection delay, pre- and post-optimization

Old SI list			New SI list		
Method	Improvement w/ Optimized Parameters (%)	Improvement w/ Original Parameters (%)	Method	Improvement w/ Optimized Parameters (%)	Improvement w/ Original Parameters (%)
MVCP	-0.4 ± 1.5	-5 ± 2	MVCP	4 ± 2	-3.5 ± 1.5
MVAB-0	0.8 ± 0.4	-9 ± 3	MVAB-0	3.1 ± 1.3	-7 ± 3
Cross Product	-10 ± 4	-9 ± 3	Cross Product	-8 ± 3	-7 ± 3

56% of MVAB-0 tilts are valid without optimization
25% of MVAB-0 tilts are valid with optimization

Conclusions

Data from the non-optimized results suggests that a tilted-phase-planes method, without optimization, accepts many tilts that are not accurate.
We therefore conclude that the optimization process not only improves the accuracy of normal calculations but weeds out those tilts which would generate inaccurate delay times.

Synthesizing our results, **we recommend either the MVAB-0 method or the MVCP method** for use with shock event forecasting because, when optimized, they both perform with more accuracy than convection delay within the error bars. An error bar analysis also reveals that neither the MVAB-0 nor the MVCP method is more accurate than the other. Although the skill score for the optimized MVCP method using the old SI list can be negative (less accurate than convection delay) within the error bars, we do not believe this is conclusive evidence to rule out this method as a viable choice; it is still shown to perform significantly higher than convection delay (improvements ranging from 2%-6%) using the new SI list.

Future Research

Knetter et al. [2004] and *Horbury et al.* [2001] show that the cross product method does quite well as a normal-calculation technique. It may be interesting to investigate the optimization of input parameters required for the cross product calculation with greater thoroughness than is conducted in this study, in an attempt to re-create or enhance the effects seen by these two research groups.
It also may be worthwhile to repeat this investigation in an attempt to better understand which features of shocks cause inaccurate delay times. Our non-optimized analysis suggests that shocks may have structures more complex than simply flat or simply tilted, which may be a partial factor in the calculations of invalid tilts.

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