Hakamada-Akasofu-Fry (HAF) Kinematic Solar Wind Model
Software Version Description

UPOS-A83-07

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Version 2.2

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1 Scope

1.1 Identification

The Hakamada-Akasofu-Fry (HAF) Kinematic Solar Wind Model was developed by the Geophysical Institute of the University of Alaska (UAF) and Exploration Physics International, Inc. (EXPI). Its primary purpose is to provide quantitative forecasts of geoeffective solar wind conditions. Specifically, it provides shock propagation and temporal profiles of the solar wind speed, density, and interplanetary magnetic field (IMF) at the L1 Sun-Earth libration point using synoptic solar observations and solar event data. This information can be used to predict the time and severity of terrestrial disturbances following solar events. The HAF model also produces chronological sequences of ecliptic cross-section plots of the IMF. This is Version 2.2.

1.2 Model Overview

The HAF Model is based on a simplistic but representative picture of the origin and evolution of the solar wind. The solar wind originates from the open field regions in the corona (corresponding to x-ray coronal holes), and the highest speed streams emanate from the regions where the magnetic flux tube divergence is least (Wang *et al.*, 1990). At a distance of about two to three solar radii from the center of the Sun, the bulk flow kinetic energy of the outflowing coronal plasma dominates over the magnetic energy and the coronal magnetic field is drawn out into interplanetary space. The high conductivity of the coronal plasma allows the interplanetary magnetic field to be treated as frozen in the plasma. The foot points of the field lines are anchored to the Sun, so the rotation of the Sun establishes a spiral IMF structure out in interplanetary space, when viewed from above. Magnetic lines of opposite polarity are separated by current sheets. The passage of the Earth through a current sheet is seen as a sector-boundary crossing and is often followed by increased geomagnetic activity.

As the Sun rotates, alternately slower and faster streams flow outward along the Sun-Earth line. The frozen-field condition prevents the faster streams from passing the slower speed streams. The faster streams are decelerated and the slower streams are accelerated in the interaction process. In the HAF Model, parameterized compression algorithms account for this view of the stream-stream interaction. If the computed velocity gradients are steep enough, the algorithms allow forward and reverse shocks to be established.

Figure 1 shows a block diagram of the HAF Model. There are three main sections in this model: 1) the time-dependent boundary conditions (from the source field derived from solar magnetograms), 2) the HAF model; and 3) outputs. There are empirical algorithms in the model to represent the velocity enhancements on the inner boundary resulting from solar transient events (CMEs and flares).

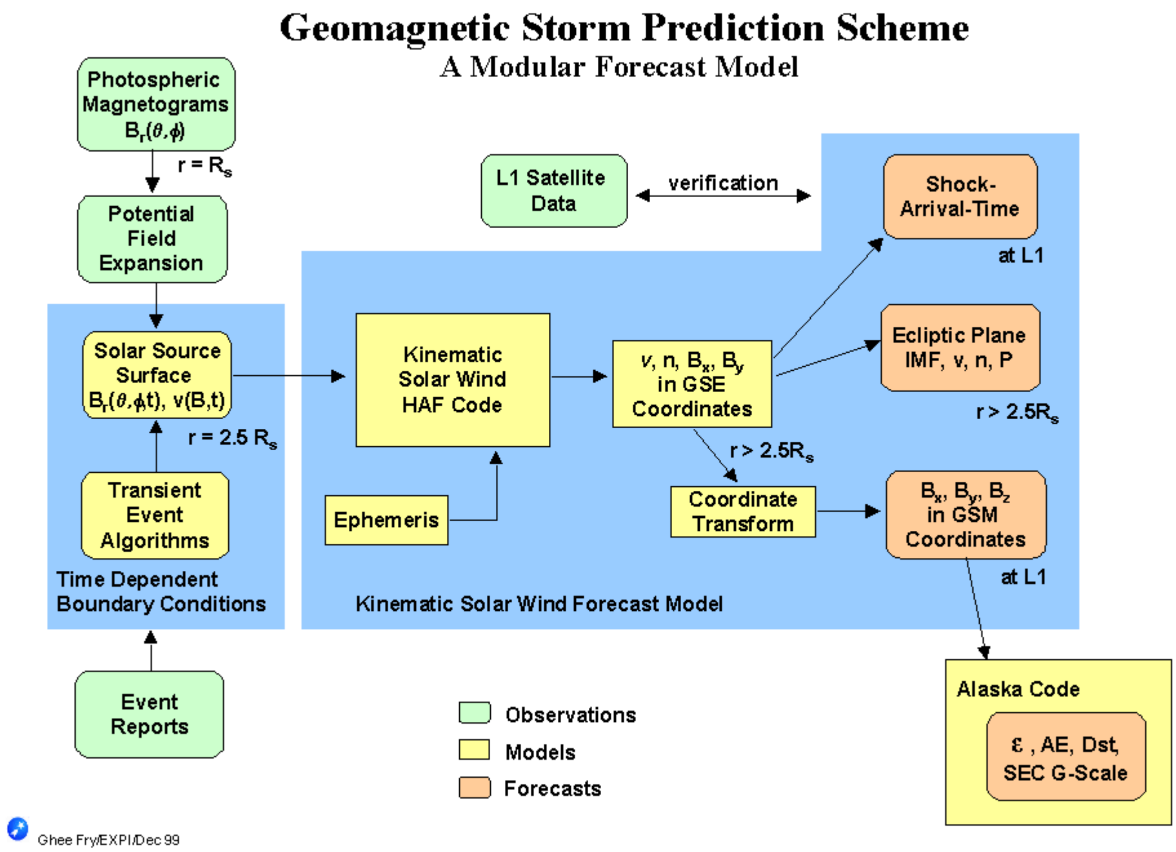

Figure 1: Block diagram showing the components of the Hakamada - Akasofu-Fry Solar Wind Model (HAF Code).

Boundary Conditions.

The HAF Code requires that the solar wind speed, magnetic field and density be set on the inner boundary of the computational domain. The inner boundary conditions that drive the HAF Code are derived from observations of the large-scale photospheric magnetic field. Synoptic maps are computed by several observatories, such as the Wilcox Solar Observatory at Stanford University (e.g., Hoeksema, 1984). These synoptic maps represent the inferred configuration of the large-scale magnetic field at the point where the bulk-flow energy dominates over the magnetic field energy.

The HAF Model ingests the synoptic maps to determine the inner-boundary magnetic field. The HAF Model then utilizes the Space Environment Center's improved Wang-Sheeley algorithm for computing source surface magnetic field and ambient velocity at the source surface (Arge and Pizzo, 2000). The velocity, v, on the model inner boundary is a function of the ratio of the magnetic flux in the photosphere and source surface along the connecting field line. Density is assumed uniform on the source surface, and is determined out in the heliosphere using mass flux conservation.

Algorithms for determining boundary values were selected to provide the closest match between the calculated and observed solar wind speeds at the Earth.

Outputs.

The HAF Code can provide solar wind speed, density, and IMF at any point in the heliosphere. For forecasting purposes, output is chosen at the L1 Sun -Earth libration point. The IMF is output in geocentri c solar equatorial (GSE) coordinates (Russell, 1971). Since the HAF Code is based upon the Parker model of solar -wind flow (no polar component to the flow), and the IMF is embedded in the flow, the IMF can have only x and y components in the GSE frame. F or comparisons with L1 data and operational predictions, the IMF is transformed into the geocentric solar magnetospheric (GSM) frame.

1.3 Document Overview

Section 1 describes the scope of the Hakamada-Akasofu-Fry (HAF) Kinematic Solar Wind Model.

Section 2 lists Referenced Documents.

Section 3 provides a detailed description of the contents of Version 2.2 of the Hakamada-Akasofu-Fry (HAF) Kinematic Solar Wind Model.

2 Referenced Documents

The following documents are referenced within this Version Description or are directly applicable. The scientific papers document the theoretical basis for the HAF software.

F19628-86-K0030 Development of a Numerical Scheme to Predict Geomagnetic Storms after Intense Solar Events and Geomagnetic Activity 27 Days in Advance, The Geomagnetic Storm Prediction Code and Operator's Manual, January 1991.

C.N. Arge and V. J. Pizzo, "Improvement in the Prediction of Solar Wind Conditions using Near-real-time Solar Magnetic Field Updates," *J. Geophys.Res.*, 105, 10,465-10,479, 2000.

C.D. Fry, "The Three-Dimensional Geometry of the Heliosphere: Quiet Time and Disturbed Periods," Ph.D. dissertation. University of Alaska, Fairbanks, 1985.

C.D. Fry, "The Hakamada-Akasofu-Fry Solar Wind Model Overview," 20 May 2000.

C.D. Fry, W. Sun, C.S. Deehr, M. Dryer, Z. Smith, S-I Akasofu, M. Tokumaru, M. Kojima, "Improvements to the HAF Solar Wind Model for Space Weather Predictions," in press, *JGR*, 2001.

K. Hakamada and S.-I. Akasofu, "Simulation of Three-Dimensional Solar Wind Disturbances and Resulting Geomagnetic Storms," *Space Sci. Rev., 31*, 3-70, 1982.

Y.-M. Wang and N. R. Sheeley, Jr., "Solar Wind Speed and Coronal Flux-Tube Expansion", *Astrophys. J., 355,* 726-732, 1990.

Y.-M. Wang, N. R. Sheeley, Jr., and A. G. Nash, "Latitudinal Distribution of Solar Wind Speed From Magnetic Observations of the Sun," *Nature,* *347*, 439-444, 1990.

Y.-M. Wang, N. R. Sheeley, Jr., J. L. Phillips, and B. E. Golstein, "Solar Wind Stream Interactions and the Wind Speed-Expansion Factor Relationship," *Astrophys. J., 488,* L51-L54, 1997.

3 Version Description

3.1 Inventory of Materials Released

This software system is being released on a single CD labeled *HAF Model Version 2.2.*

The documentation that supports this version is listed below and has been delivered prior to installation of the system.

- Hakamada-Akasofu-Fry (HAF) Kinematic Solar Wind Model Functional Requirements Document, UPOS-A83-03, Version 2.1, J. J. Blanchette, L. Nguyen and C. D. Fry, 28 Oct. 2004

- Hakamada-Akasofu-Fry (HAF) Kinematic Solar Wind Model Test Plan, UPOS-A83-06, Version 2.1, J. J. Blanchette and L. Nguyen, 28 Oct. 2004

- Hakamada-Akasofu-Fry (HAF) Kinematic Solar Wind Model Test Report, TBS

- Hakamada-Akasofu-Fry (HAF) Kinematic Solar Wind Model Operator's Manual, UPOS-A83-05, Version 2.2, J. J. Blanchette, L. Nguyen and C. D. Fry, 30 March, 2005

- Hakamada-Akasofu-Fry (HAF) Kinematic Solar Wind Model Support Plan, UPOS-A83-08, J. J. Blanchette, 28 Oct. 2004

- Hakamada-Akasofu-Fry (HAF) Kinematic Solar Wind Model Version Description, UPOS-A83-07, Version 2.1, J. J. Blanchette, L. Nguyen and C. D. Fry, 28 Oct. 2004

3.2 Inventory of Software Contents

Appendix B contains the complete list of directories and files being delivered as Version 2.2 of the Hakamada-Akasofu-Fry (HAF) Kinematic Solar Wind Model.

3.3 Changes Installed

3.3.1 Version 2.2

Version 2.2 contains a minor modification to the SEC source surface map retrieval scripts fusionshell.dat and fusion-sort.pl. The version 2.2 scripts can generate the appropriate HAF input files using data contained in subfolders of base observatory folders. The previous version did not allow for nested observatory data paths.

3.3.2 Version 2.1

This version contains scripts to retrieve and prepare SEC source surface maps for ingestion by HAF. It also contains Fortran source code to process the source surface map data, scripts to retrieve and prepare ACE solar data for plotting purposes, and IDL plotting code.

New files:

acebuild.pl	fusion-get.pl	sourcesec.f
ace-get.pl	fusion-sort.pl	step0.f
aceshell.dat	fusionshell.dat	vdbs.pro
bcfiledoc.f	interplon.f	vdp.pro
compile_vis	mapsrc.pro	
ecimf_c.pro	startdate.pl	

3.3.3 Version 2.0

This is the initial delivery of the software system. It is labeled ‘Version 2.0’ to differentiate it from the HAF Model software that evolved before it.

3.4 Related Documents

All documents pertinent to the installation and operation of Version 2.1 of the HAF application are included in the release.

3.5 Installation Instructions

A system administrator and a database administrator need to be available to monitor the installation and the acceptance testing. Installation instructions are provided in the Hakamada-Akasofu-Fry (HAF) Kinematic Solar Wind Model Operator’s Manual and in a separate memo.

3.6 Possible Problems and Known Errors

4 Notes

APPENDIXES

A. Acronyms and Abbreviations

AFCCC	Air Force Combat Climatology Center
AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
AFSCN	Air Force Satellite Control Network
AFSPACECOM	Air Force Space Command
AFSWC	Air Force Space Weather Center
AFWA	Air Force Weather Agency
AFWIN	Air Force Weather Information Network
AF/XOW	Air Force Director of Weather
APL	Applied Physics Laboratory of Johns Hopkins University
ASCII	American Standard Code for Information Interchange
AU	Astronomical Units
AVHRR	Advanced Very High Resolution Radiometer
AVN	Aviation Model
CIR	Co-rotating Interaction Region
CME	Coronal Mass Ejection
COE	Common Operating Environment
DII	Defense Information Infrastructure
DMSP	Defense Meteorological Satellite Program
ECMWF	European Center for Medium-Range Weather Forecasts
EIT	Extreme ultraviolet Imaging Telescope on the SOHO spacecraft.
EXPI	Exploration Physics International, Inc.
FIP	Fault Isolation Procedure
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FSL	Forecast Systems Laboratory
FTP	File Transfer Protocol
GI	Geophysical Institute
GIF	Graphic Interchange Format
GMT	Generic Mapping Tools
GOES	Geostationary Operational Environmental Satellite
GOLD	Geophysical On-Line Data
GRIB	Gridded Binary
GSEQ	Geocentric Solar Equatorial Coordinates
GSM	Geocentric Solar Magnetic Coordinates
HAF	Hakamada-Akasofu-Fry
HEC	Heliocentric Ecliptic Coordinates
HEQ	Heliocentric Equatorial Coordinates
ICME	Interplanetary Coronal Mass Ejection
IDL	Interactive Data Language
IGRF	International Geomagnetic Reference Field
IMF	Interplanetary Magnetic Field

JHU	Johns Hopkins University
L1	Sun-Earth libration point
LAN	Local Area Network
LAPS	Local Analysis and Prediction System
LASCO	Large Angle and Spectrometric Coronagraph experiment on the SOHO spacecraft.
MHD	Magnetohydrodynamics
MM5	Fifth Generation Mesoscale Model
MWO	Mount Wilson Solar Observatory
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
netCDF	Network Common Data Form
NGDC	National Geophysical Data Center
NGM	Nested Grid Forecast Model
NOAA	National Oceanic and Atmospheric Administration
NOGAPS	Navy Operational Global Atmospheric Prediction System
nPa	Nano-Pascal
NSO	National Solar Observatory
nT	Nano-Tesla
NWP	Numerical Weather Prediction
OWS	Operational Weather Squadron
PACE	Polar Anglo-American Conjugate Experiment
PBL	Planetary Boundary Layer
PCA	Polar Cap Absorption
PFRR	Poker Flat Research Range
PFSS	Potential Field Source Surface
POS	Plane-of-sky
RPC	NOAA/SEC Rapid Prototyping Center
SABER	Sounding of the Atmosphere using Broadband Emission Radiometry
SAT	Shock Arrival Time
SD	Space Department of the Applied Physics Laboratory
SDP	Software Development Plan
SEC	Space Environment Center
SEE	Solar EUV Experiment
SEON	Solar Electro-optical Observing Network
SFIR	Swept Frequency Interferometric Radiometer
SFOC	Spaceflight Operations Center
SOON	Solar Observing Optical Network
SOHO	Solar and Heliospheric Observatory
SRBL	Solar Radio Burst Locator
SRS	Solar Radio Spectrograph
SSCS	Source Surface Current Sheet
STP	Solar Terrestrial Physics
SWOC	Space Weather Operations Center (Offutt)
SWXS	Space Weather Squadron
Tcl	Tool Command Language
Tk	Toolkit

Tix	Tk Interface Extension
UAF	University of Alaska, Fairbanks
UCAR	University Corporation for Atmospheric Research
UPOS	University Partnering for Operational Support
WDC	World Data Center
WF	Weather Flight
WMO	World Meteorological Organization
WSO	Wilcox Solar Observatory
XDR	External Data Representation

B. Inventory of Software Contents of Version 2.2

Directory .			
compile	1502	haf.par	1173
runhaf	6579		
Total of 3 files, 9254 bytes			
Directory ./bin			
ace-get.pl	6223	acebuild.pl	6312
aceshell.dat	426	fusion-get.pl	8039
fusion-sort.pl	4344	fusionshell.dat	1147
gse-get.conf	326	gse-get.pl	4532
gse-get.readme	1783	startdate.pl	3138
Total of 10 files, 36270 bytes			
Directory ./code			
asindeg.f	120	atan2deg.f	131
bcfiledoc.f	8228	bmaxmin.f	1506
calcv.f	1948	carrot.f	2168
commons.f	2981	cosdeg.f	118
cotan.f	69	cross.f	1665
ctos.f	1751	ctosve.f	3826
dot.f	1491	ecplot.f	24199
geitogsm.f	2200	geotogei.f	1744
getutc.f	2130	gseqtogei.f	2007
gseqtogsm.f	1761	hecheq.f	4756
helio.f	4783	heqhec.f	3731
iday.f	2131	interp3.f	4871
interplon.f	5759	jdymd.f	2464
ldbfld.f	4438	params.f	6393
prtparam.f	4793	r2.f	2949
rdreprec.f	14188	report.f	27446
sbdt.f	3858	sbt.f	15679
sindeg.f	117	solwind.f	31805
source1.f	14702	sourcesec.f	25436
srcfld.f	13587	srcvel.f	7649
srf.f	7307	srt.f	18998
ssindex.f	2567	step0.f	415

step1.f	716	step2.f	478
step3.f	1074	step5.f	731
stoc.f	2229	sun.f	2394
sunloc.f	3504	svrt.f	3365
tria2.f	2682	uvect.f	1673
vect.f	1544	vmaxmin.f	1562
weshere.f	5395	ymdjd.f	2430
Total of 58 files, 320642 bytes			
Directory ./data			
Total of 0 files, 0 bytes			
Directory ./data/recent			
bfield.dat	26743	earth.cmp	37
earth_0.cmp	13362	ecplot001.cmp	81801
ecplot002.cmp	81801	ecplot003.cmp	81597
ecplot004.cmp	81240	ecplot005.cmp	80424
ecplot006.cmp	80526	ecplot007.cmp	80475
ecplot008.cmp	80526	flare.cmp	118
report.dat	4112	runhaf.cmp	7315
sourceb.cmp	77993	sourcev.cmp	77993
ssi_0.cmp	5426	startime.cmp	54
velfield.dat	26743		
Total of 19 files, 888286 bytes			
Directory ./display			
compile_vis	3815	ecimf_c.pro	13860
mapsrc.pro	19451	vdbs.pro	16071
vdp.pro	17943		
Total of 5 files, 71140 bytes			
Directory ./docs			
HAF_FRD.doc	452096	HAF_FRD_CL.doc	21504
HAF_SDD.doc	613376	HAF_SVD.doc	311296
HAF_TestPlan.doc	349696	HAF_UG.doc	517120
HAF_install.doc	36352	HAF_supplan.doc	142848
Total of 8 files, 2444288 bytes			
Directory ./product_test			
haf.test12	1007	haf.test13	1007
haf.test14	1007	haf.test15	1007
haf.test16	1007	haf.test21	1008
haf.test22	871	haf.test23	893
haf.test24	893	haf.test25	871
haf.test26	871	run_product_test	13156
run_product_test.cmp	113013		
Total of 13 files, 136611 bytes			
Directory ./product_test/data			
Total of 0 files, 0 bytes			
Directory ./product_test/data/test12			
report.dat	9618		
Total of 1 files, 9618 bytes			

Directory ./product_test/data/test14			
bfield.dat	26728	earth.par	37
earth_0.dat	10698	ecplot001.dat	99294
flare.par	118	report.dat	9618
sourceb.par	77993	sourcev.par	77993
ssi_0.dat	2042	startime.par	14
velfield.dat	26728		
Total of 11 files, 331263 bytes			
Directory ./product_test/data/test15			
bfield.dat	26743	earth_0.cmp	153
report.dat	9618	ssi_0.cmp	71
velfield.dat	26743		
Total of 5 files, 63328 bytes			
Directory ./product_test/data/test16			
bfield.dat	26728	report.dat	9618
startime.par	54	velfield.dat	26728
Total of 4 files, 63128 bytes			
Directory ./product_test/data/test21			
bfield.dat	26728	earth_0.cmp	10698
ecplot001.cmp	99294	ecplot002.cmp	99345
ecplot003.cmp	99447	ecplot004.cmp	99600
ecplot005.cmp	99855	ecplot006.cmp	100110
ecplot007.cmp	100110	ecplot008.cmp	100110
ecplot009.cmp	100110	report.dat	9618
ssi_0.cmp	4346	velfield.dat	26728
Total of 14 files, 976099 bytes			
Directory ./product_test/data/test22			
Total of 0 files, 0 bytes			
Directory ./product_test/data/test23			
bfield.cmp	26763	cr2020_120_1mwo.dat	148439
report.dat	701	sourcefilelist.txt	21
velfield.cmp	26763		
Total of 5 files, 202687 bytes			
Directory ./product_test/data/test24			
200408_ace_mag_1h.txt	64858	200408_ace_swepam_1h.txt	55184
200409_ace_mag_1h.txt	32952	200409_ace_swepam_1h.txt	28101
bfield.dat	26763	earth_0.cmp	21354
earth_q.cmp	21354	report.dat.event	701
report.dat.quiet	262	ssi_0.cmp	8666
vdbs_cmp.ps	95955	vdp_cmp.ps	75966
velfield.dat	26763		
Total of 13 files, 458879 bytes			

Directory ./product_test/data/test25			
ecimf_001_cmp.gif	20638	ecimf_002_cmp.gif	20718
ecimf_003_cmp.gif	20754	ecimf_004_cmp.gif	20761
ecimf_005_cmp.gif	20668	ecimf_006_cmp.gif	20692
ecimf_007_cmp.gif	20692	ecimf_008_cmp.gif	20652
ecplot001.dat	101028	ecplot002.dat	100620
ecplot003.dat	100569	ecplot004.dat	100518
ecplot005.dat	99906	ecplot006.dat	99294
ecplot007.dat	99192	ecplot008.dat	98886
Total of 16 files, 965588 bytes			
Directory ./product_test/data/test26			
b_001_cmp.gif	26684	earth.par	37
flare.par	175	report.dat	701
vel_001_cmp.gif	35336		
Total of 5 files, 62933 bytes			