Real-Time Prediction of Geomagnetic Storms and Substorms

W. Horton, M. L. Mays,
E. Spencer, and J. Kozyra

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Real-Time Solar Wind-Magnetosphere-Ionosphere Coupling with the Optimized WINDMI

- WINDMI = low dimensional, ODE physics model that couples the solar wind to the magnetosphere-ionosphere system. Derived from projections on basic volumes of magnetospheric plasma. A basic physics model ~20 physical parameters. Fixed or dynamical Genetic Algo.

http://orion.ph.utexas.edu/~windmi

Uses three forms of Solar Wind driver:

1. (blue) Rectified solar wind electric field, a coupling
2. (red) *Siscoe et al.* (2002) dynamo voltage formula
3. (green) *Newell et al.* (2007) empirical voltage formula

http://ccmc.gsfc.nasa.gov/cgi-bin/WINDMIpred.cgi

e.g. Training phase October 3-7 2000 storm

Prediction phase April 15-24 2002 geomagnetic storm.

*Spencer, Rao, Horton, and Mays (2008), *Evaluation of Solar Wind - Magnetosphere Coupling Function during Geomagnetic Storms with the WINDMI Model*, *Journal of Geophysical Research*, doi:10.1029/2008JA0135305.

Power Flow from Solar Wind

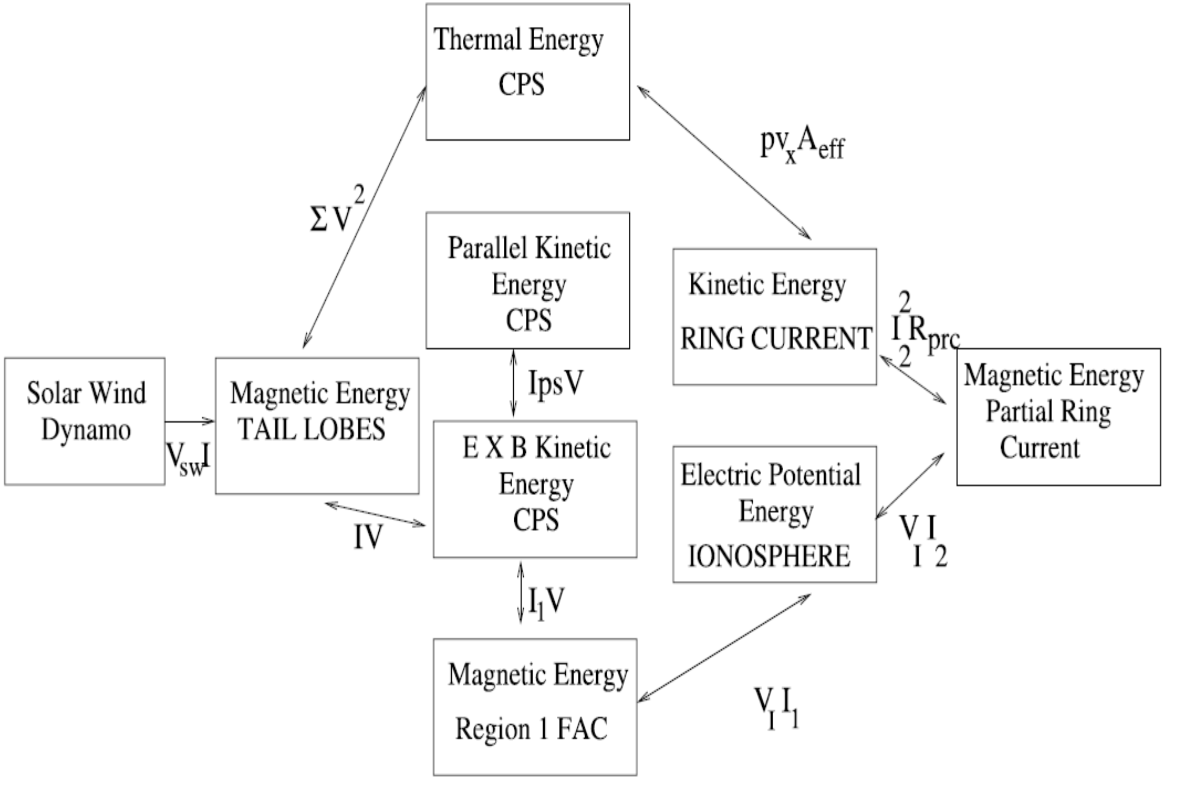


Figure 8. Energy flows in the WINDMI model. The energy transfer from the mutual inductance terms and the energy dissipation paths are not shown here. The average velocity of the particles across the Alfvén layer is given by $v_x = V/(B_{tr}L_y)$.

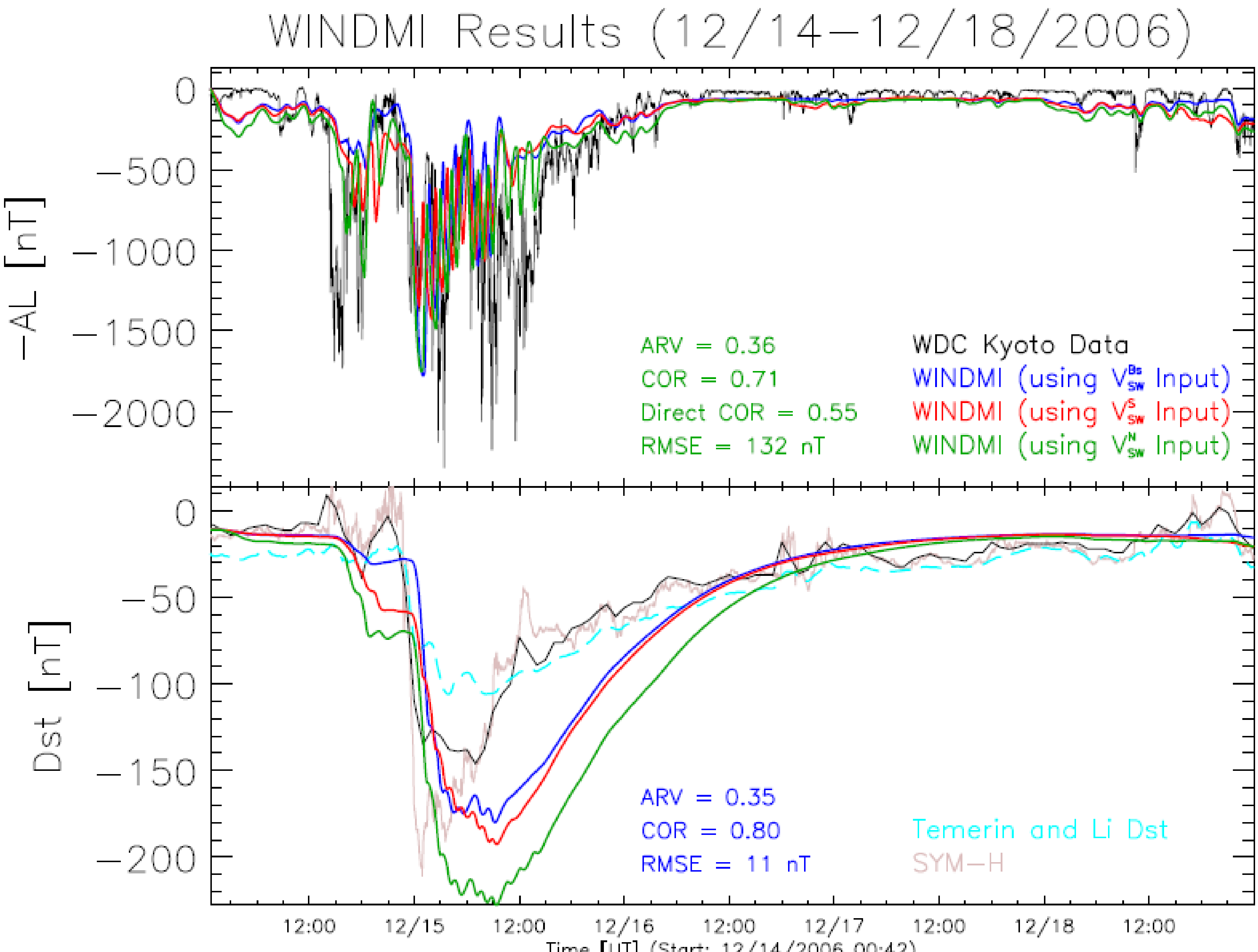
Real-Time WINDMI

• We evaluated the performance of the Real-Time WINDMI model for 22 storm/substorm event predictions from February 2006 to August 2008.

• The model predicts AL and Dst values approximately one hour before geomagnetic substorm and storm events; subsequently, every ten minutes ground based measurements compiled by WDC Kyoto are compared with model predictions: http://orion.ph.utexas.edu/~windmi/realtime/

• Real-Time WINDMI model AL and Dst predictions are validated using the average relative variance (ARV), correlation coefficient (COR), and root mean squared error (RMSE) computed from predicted- Kyoto-Data Center time series.

Mays, M. L., W. Horton, E. Spencer, and J. Kozyra (2009), Real-Time WINDMI Predictions of Geomagnetic Storm and Substorms, *Space Weather*, doi:10.1029/2008SW000459



WINDMI Results (12/14–12/18/2006)
0
−500
−1000
−1500
−2000
−AL [nT]
ARV = 0.36
COR = 0.71
Direct COR = 0.55
RMSE = 132 nT
WDC Kyoto Data
WINDMI (using V_{sw}^{Bs} Input)
WINDMI (using V_{sw}^{S} Input)
WINDMI (using V_{sw}^{N} Input)
0
−50
−100
−150
−200
Dst [nT]
ARV = 0.35
COR = 0.80
RMSE = 11 nT
Temerin and Li Dst
SYM−H
12:00
12/15
12:00
12/16
12:00
12/17
12:00
12/18
12:00
Time [UT] (Start: 12/14/2006 00:42)

Date	Data Min. Dst (nT)	Data Min. AL (nT)	Real-Time WINDMI Dst (nT)	Real-Time WINDMI Min. AL (nT)
2-8 Apr 2006[d]	-87	-1179	-26[a]/-40[b]/-45[c]	-270[a]/-341[b]/-267[c]
8-11 Apr 2006	-80	-1045	-40/-35/-47	-402/-395/-461
13-18 Apr 2006	-111	-1598	-125/-134/-122	-1123/-1000/-1017
6-9 Aug 2006	-44	-1556	-31/-42/-46	-398/-406/-465
17-23 Aug 2006	-71	-1697	-68/-56/-87	-758/-426/-811
23-26 Sep 2006[d]	-56	-1167	-20/-27/-30	-347/-307/-380
20-22 Oct 2006	-28	-822	-17/-33/-27	-224/-348/-320
9-12 Nov 2006	-51	-1622	-37/-43/-45	-709/-436/-460
29 Nov - 1 Dec 2006	-74	-1704	-49/-47/-63	-432/-370/-451
5-8 Dec 2006[d]	-48	-1175	-28/-34/-40	-386/-318/-379
14-18 Dec 2006	-146	-2349	-180/-193/-228	-1779/-1423/-1752
28-31 Jan 2007	-40	-1296	-30/-38/-38	-533/-428/-506
22-27 Mar 2007	-69	-1032	-43/-36/-66	-400/-348/-602
31 Mar - 4 Apr 2007	-63	-813	-27/-26/-37	-380/-332/-401
16-19 Apr 2007	-47	-584	-22/-38/-37	-311/-381/-385
27 Apr - 1 May 2007	-56	-942	-29/-32/-43	-399/-349/-454
21-26 May 2007	-63	-1259	-54/-48/-61	-736/-437/-699
10-13 Jul 2007	-40	-896	-27/-35/-58	-375/-350/-814
13-17 Jul 2007	-46	-891	-38/-33/-63	-410/-342/-746
25-28 Oct 2007	-51	-1047	-25/-32/-37	-364/-381/-436
19-23 Nov 2007	-71	-1552	-41/-82/-57	-654/-855/-716
7-10 Mar 2008	-72	-1332	-39/-37/-50	-937/-440/-856

Evaluating Drivers—Conclusions

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- The rectified driver was found to be the best in overall performance during both training as well as prediction phases. Often gives the best prediction of Dst.

- The Siscoe formula performed best during the training phase in re-producing the AL faithfully, and capturing multiple substorms within storms were predicted.

- Newell coupling function performed as best driver for strong –high level- AL events: was poorer for weak events.

- Conclude that multiple drivers need to be concurrently employed in space weather models to yield possible levels of geomagnetic activity and estimate of uncertainty.
- Use a pre-selection filter for low, medium and high level activity ?

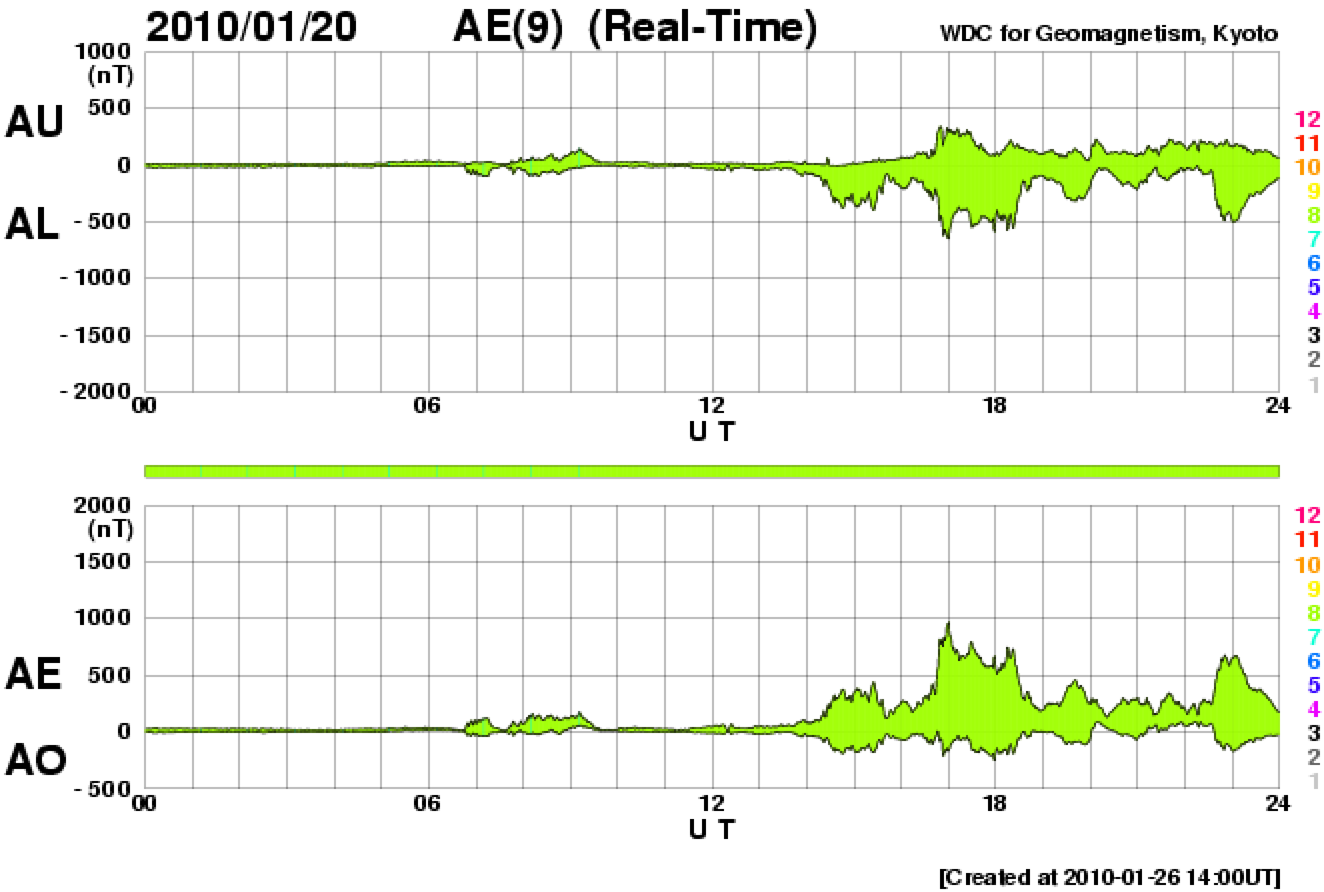
Spencer, Rao, Horton, and Mays (2008), Evaluation of Solar Wind - Magnetosphere Coupling Function during Geomagnetic Storms with the WINDMI Model, *JGR*, doi:10.1029/2008JA0135305.

Feb. 2006 - Aug. 2008 Selected Events, Mean ARV		
Input	Mean AL ARV	Mean Dst ARV
Rectified V_{sw}^{Bs}	0.38 ± 0.21	0.37 ± 0.27
Siscoe V_{sw}^{S}	0.41 ± 0.16	0.42 ± 0.23
Newell V_{sw}^{N}	0.33 ± 0.17	0.54 ± 0.39

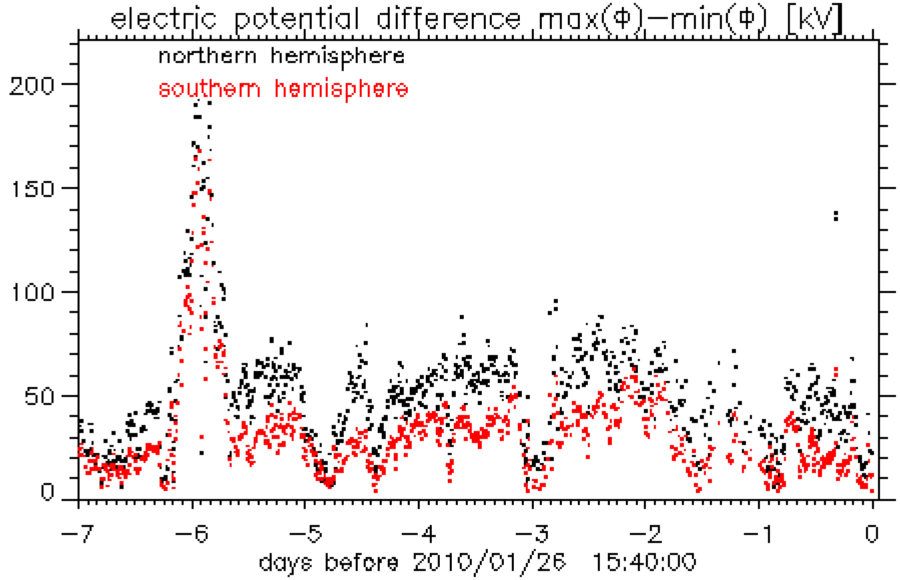
Feb. 2006 - Aug. 2008 Selected Events, Mean COR			
Input	Mean AL COR	Mean AL Direct COR	Mean Dst COR
Rectified V_{sw}^{Bs}	0.62 ± 0.13	0.40 ± 0.20	0.80 ± 0.12
Siscoe V_{sw}^{S}	0.52 ± 0.15	0.37 ± 0.18	0.77 ± 0.13
Newell V_{sw}^{N}	0.64 ± 0.12	0.42 ± 0.18	0.79 ± 0.14

Feb. 2006 - Aug. 2008 Selected Events, Mean RMSE		
Input	Mean AL RMSE	Mean Dst RMSE
Rectified V_{sw}^{Bs}	123.2 ± 52.4	9.8 ± 3.4
Siscoe V_{sw}^{S}	126.1 ± 45.5	10.7 ± 4.0
Newell V_{sw}^{N}	111.5 ± 39.5	11.9 ± 6.9

Weak Substorm Captured Last Wednesday 20 Jan 2010



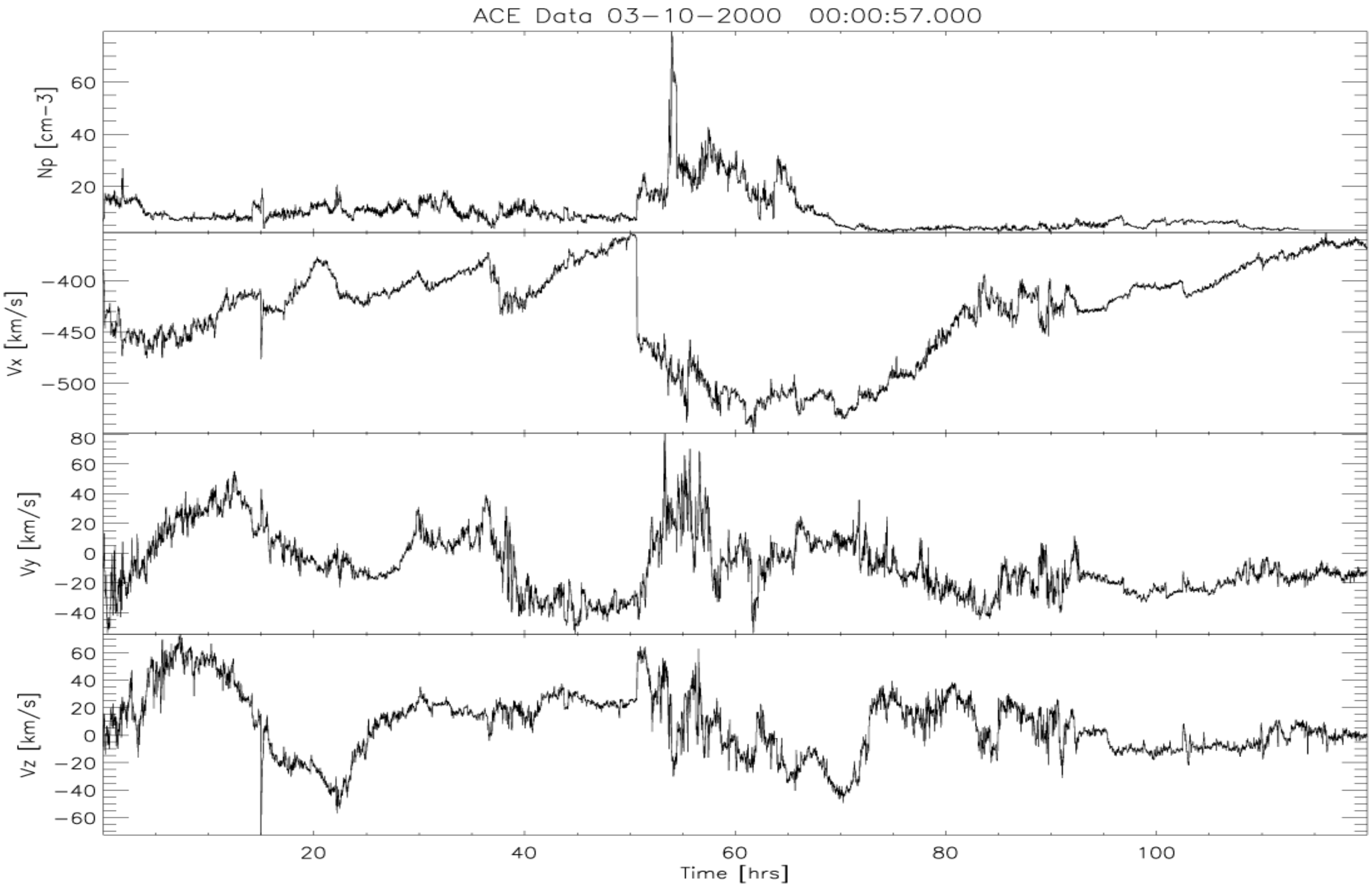
CCMC Polar Cap Voltage



Downloaded this moring from CCMC
Horton with Rastatter this morning

GEM Storm with Interplanetary Shock

Horton,Spencer,Doxas,Kozyra, GRL 2005



Storm OCT 2000, Training Phase

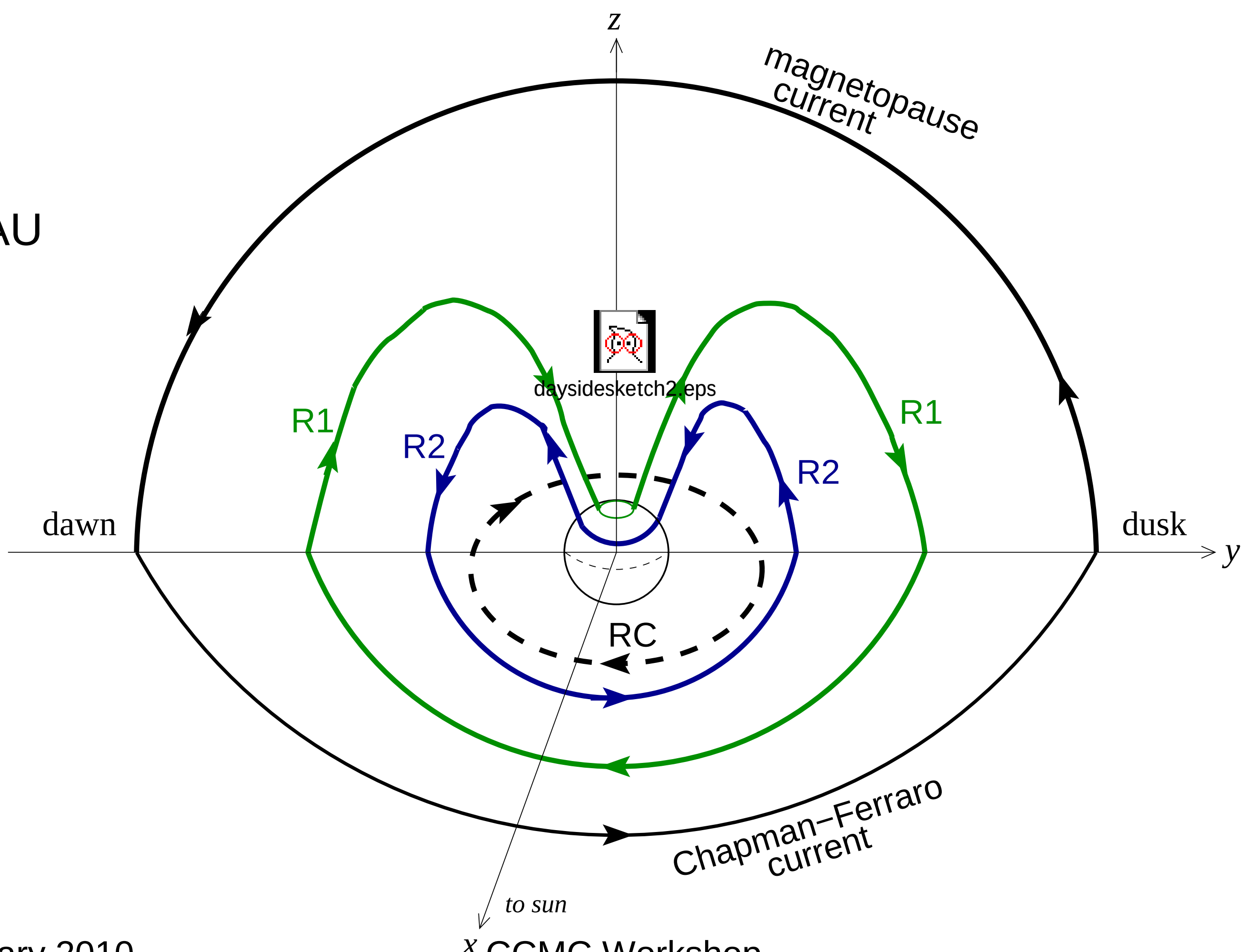
Input	AL ARV	DST ARV	AL COR
Rectified	0.57	0.28	0.67
Siscoe	0.46	0.19	0.74
Newell	0.51	0.2	0.73

Storm APR 2002, Prediction Phase

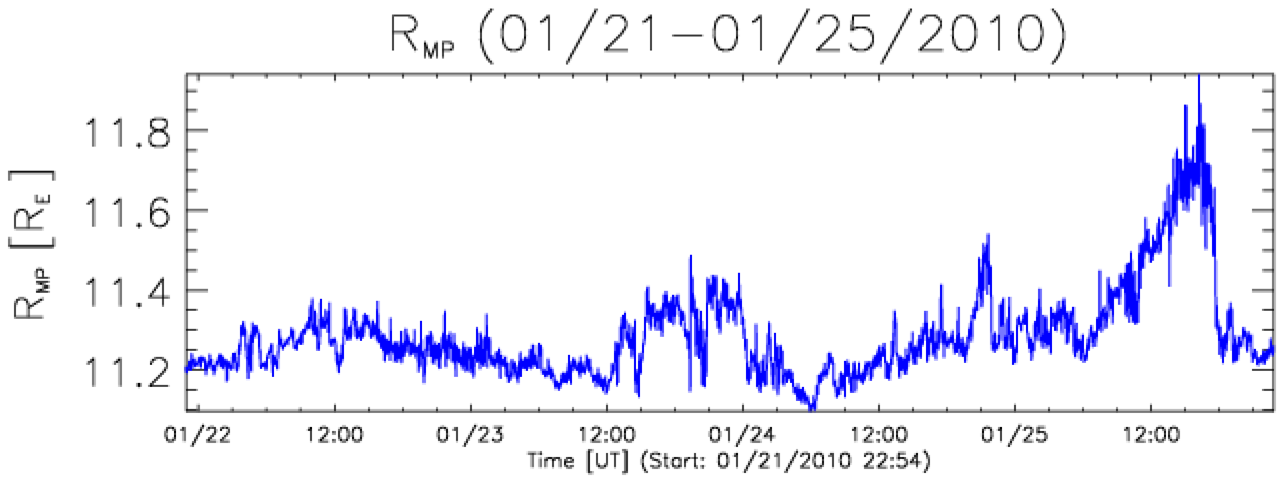
Input	AL ARV	DST ARV	AL COR	Dir. AL COR
Rectified	0.63	0.23	0.72	0.62
Siscoe	1.2	0.39	0.47	0.55
Newell	0.8	0.21	0.59	0.68

Future Addition to RT WINDMI

Gives AU index



Magnetopause Position from F=ma



Currently shown running on UT server and used to
Estimate driving of low and ultra-frequency wave power

Electronic Database: Feb. 2006 – Present

- 4 years operation with an email alert system currently set to thresholds of 50 nT and -400 nT for the predicted Dst and AL respectively.
- Performance evaluated with (1) Average Relative Variance (ARV), (2) Correlation coefficient (COR), and (3) Root Mean Squared Error (RMSE) subsequent comparison forecast with Quicklook Kyoto Data.
- Newell input function yielded the best model AL predictions followed by the Rectified, then Siscoe input functions for 2006-2008.*

  Except: 20 Jan 2010 substorm the Siscoe driver better than Newell driver.

- AL predictions correlate at least one standard deviation better with the data than a direct correlation between the input coupling functions and the AL index.
- Rectified input has the best mean Dst ARV by a difference of 13% and 37% from the mean Dst ARV of the Siscoe and Newell inputs respectively.
- Currently running-off line dayside model: bow shock, C-F and AU system.

** Mays, Horton, Spencer, and Kozyra (2008), Real-Time WINDMI Predictions of Geomagnetic Storm and Substorms, Space Weather, 2009.*

The End

http://orion.ph.utexas.edu/~windmi

or google search windmi

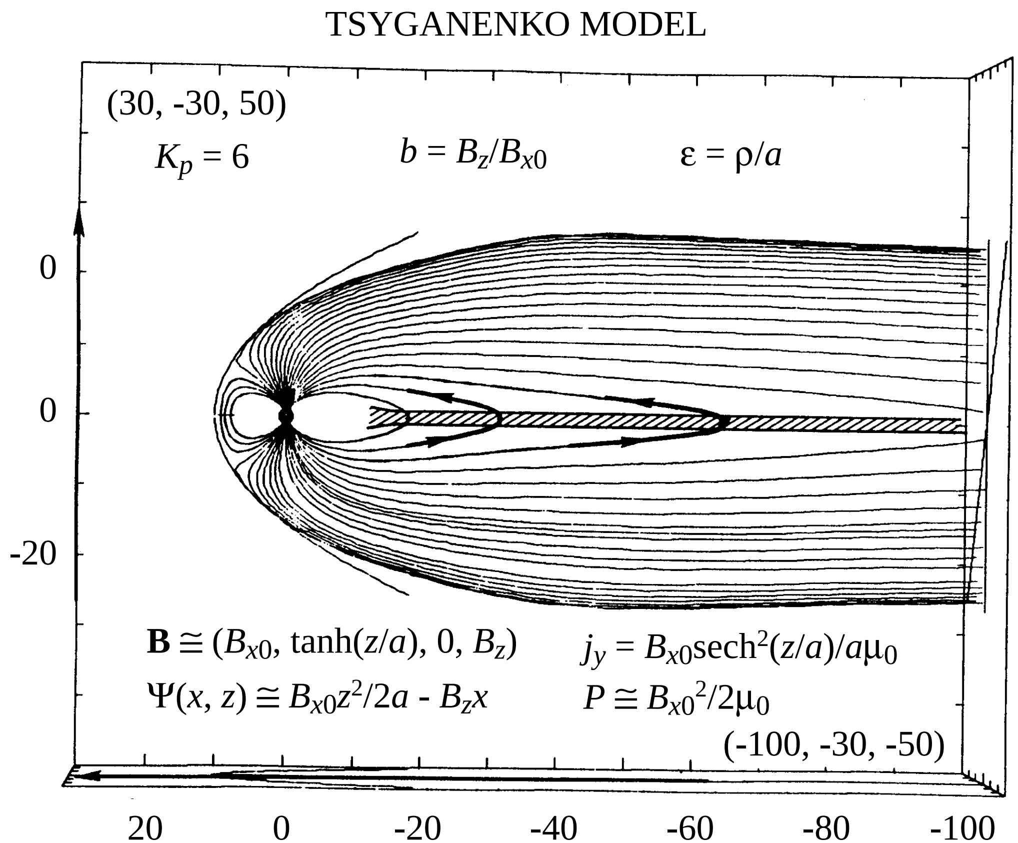
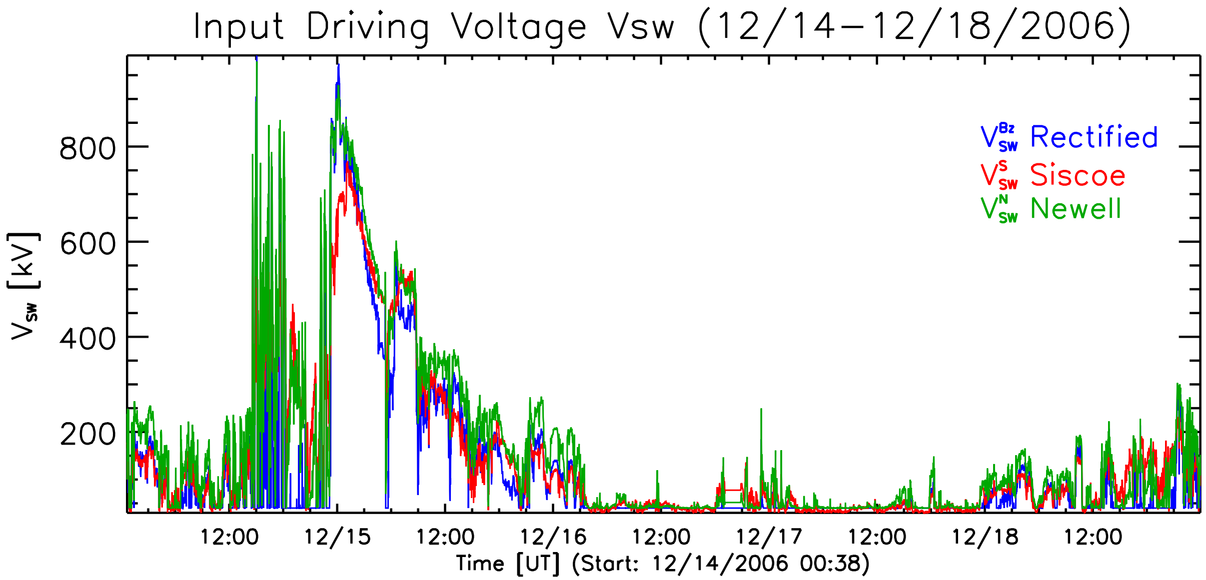


Figure from Horton-Ichikawa, *Chaos & Structures..*, 1997

Dst indices. The input to the model is the solar wind driving voltage $V_{\rm sw}$. The equations for the state vector $X = (I, V, p, K_{||}, I_1, V_I, I_2, W_{\rm RC})$ in the WINDMI model are given by:

$$
\begin{aligned}
L\frac{dI}{dt} &= V_{\rm sw}(t) - V + M\frac{dI_1}{dt} && (1)\\
C\frac{dV}{dt} &= I - I_1 - I_{\rm ps} - \Sigma V && (2)\\
\frac{3}{2}\frac{dp}{dt} &= \frac{\Sigma V^2}{\Omega_{\rm cps}} - u_0 p K_{\parallel}^{1/2}\Theta(u) - \frac{pVA_{\rm eff}}{\Omega_{\rm cps}B_{\rm tr}L_y} - \frac{3p}{2\tau_E} && (3)\\
\frac{dK_{\parallel}}{dt} &= I_{ps}V - \frac{K_{\parallel}}{\tau_{\parallel}} && (4)\\
L_I\frac{dI_1}{dt} &= V - V_I + M\frac{dI}{dt} && (5)\\
C_I\frac{dV_I}{dt} &= I_1 - I_2 - \Sigma_I V_I && (6)\\
L_2\frac{dI_2}{dt} &= V_I - (R_{\rm prc} + R_{A2})I_2 && (7)\\
\frac{dW_{\rm rc}}{dt} &= R_{\rm prc}I_2^2 + \frac{pVA_{\rm eff}}{B_{\rm tr}L_y} - \frac{W_{\rm rc}}{\tau_{\rm rc}} && (8)
\end{aligned}
$$

The 18 physical parameters of WINDMI are approximated analytically or from data and are the nominal values of these parameters. The parameters can also be



Input Driving Voltage Vsw (12/14–12/18/2006)
800
600
400
200
Vsw [kV]
Rectified
Siscoe
Newell
12:00
12/15
12:00
12/16
12:00
12/17
12:00
12/18
12:00
Time [UT] (Start: 12/14/2006 00:38)

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