2008 GEM modeling challenge: metrics study of the Dst index in physics-based magnetosphere/ring current models and in statistical/analytic specifications.

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Abstract:

In this paper the metrics-based results of the Dst part of the 2008-2009 GEM Metrics Challenge are reported. The Metrics Challenge asked modelers to submit results for 4 geomagnetic storm events and 5 different types of observations that can be modeled by statistical/climatologic or physics-based (MHD or kinetic) models of the magnetosphere-ionosphere system.

We present the results of over 30 model settings that were run at the Community Coordinated Modeling Center (CCMC) and at the institutions of various modelers for these events. To measure the performance of each of the models against the observations we use comparisons of one-hour averaged model data with the Dst index issued by the World Data Center for Geomagnetism, Kyoto, Japan, and direct comparison of one-minute model data with the one-minute Dst index calculated by the United States Geologic Survey (USGS)

The DST index:

Measures geomagnetic activity by tracking the horizontal magnetic perturbation at mid-latitude stations around the Earth.
Negative values (DST<-50 nT) during storm times.

KYOTO-DST:
1-hour-averaged index (real-time, provisional, definitive) from the KYOTO World Data Center. Uses 4 magnetometers (HON, SJG, HER, KAK). Baseline subtraction done in the time domain. Correct baseline determined much later (years after measurement) for definitive index.

USGS near-real-time DST:
1-minute averaged data from 4 (or 3) stations provided by he United States Geologic Survey. Real-time analysis and baseline subtraction are done in the Fourier domain (allows for determination close to real-time).

Types of calculations to obtain DST:

Magnetosphere models (SWMF, OpenGGCM, LFM):

"DST" at Earth's center"

$$dB = \Sigma\, (\mathbf{J}\times\mathbf{R})_Z\, R^{-3} dV$$

with $\mathbf{R}$=(-x,-y,-z) and dV the volume element at position $\mathbf{R}$.
Magnetic perturbation at center of Earth identical to the Z component of dB in SM coordinates.

Ring Current models (and WINDMI from energy balance):

Dessler-Parker-Sckopke relation from total energy and DST*:

$$DST^* = -3.98\ 10^{-30}\ E_{RC}$$
$$DST^* = Dst/1.5 + 0.2\ (P_{dyn,sw}\,[eV])^{1/2} - 20$$

thus:

$$DST = -5.97\ 10^{-30}\ E_{RC} - 0.3\ (P_{dyn,sw}\,[eV])^{1/2} + 30$$

Events studied:

GEM 2008 modeling challenge

Event 1: Oct. 29, 06:00 to Oct. 30, 06:00, 2003
(part of the Halloween Storm)
Event 2: Dec. 14, 12:00 to Dec. 16, 00:00 2006
(AGU storm)
Event 3: Aug. 31, 00:00 to Sep. 1, 00:00, 2001

Event 4: Aug. 31, 10:00 to Sep. 1, 12:00, 2005

Timelines are online at http://ccmc.gsfc.nasa.gov
select "Metrics and Validation"
"GEM Metrics Challenge"
"Time Series Plotting Tool"
Dst is "Metrics Study 5"

Model runs for each event

Global Magnetosphere Models:

Run ID	Model Description	E 1	E 2	E 3	E 4
1_SWMF	SWMF v7.73, BATS-R-US, 2 million cells, min. res. ¼ RE	yes	yes	yes	yes
2_SWMF	SWMF v7.73, BATS-R-US, 700000 cells, min. res. ¼ RE	yes	yes	yes	yes
3_SWMF	SWMF v8.01, BATS-R-US coupled to RCM, 2 million cells, min. res ¼ RE	yes	yes	yes	yes
4_SWMF	SWMF v8.01, BATS-R-US, 3 million cells, min. res. ⅛ RE	yes	yes	yes	yes
5_SWMF	SWMF v8.01, BATS-R-US coupled to RCM, 3 million cells, min. res ⅛ RE	yes	yes	yes	yes
6_SWMF	SWMF v20090403 BATS-R-US+RCM2, 900k cells, RT on 64 procs, res. ¼ RE	yes	yes	yes	yes
7_SWMF	SWMF V. 20110215 BATSRUS+CRCM, 1.78M cells, 1/8 RE res.	yes	yes	yes	yes
8_SWMF	SWMF V20110111 BATS-R-US+RCM2, 1M cells, res. ¼ RE, InnerBc density0.2/cc RCM ions ratio NH/NO9/1	yes	yes	yes	yes
9_SWMF	SWMF.v20110131_SWPC, 1,007,616 cells with RCM2, res. ¼ RE, CCMC	yes	yes	yes	yes
1_OpenGGCM	OpenGGCM v3.1 coupled to CTIM, 3 million cells, min. res. ⅕ RE	no	yes	yes	yes
2_OpenGGCM	OpenGGCM v3.1 coupled to CTIM, 6.5 million cells, min. res. ¼ RE	no	yes	yes	yes
1_LFM-MIX	CMIT-LFM-MIX_1-0-4, LFMwith 53x48x64 cells, min. res. ⅙ RE radial	yes	yes	yes	yes
1_CMIT-LTR	CMIT-LTR_2-1-1, LFM with 53x48x64 cells, min. res. ⅙ RE radial	yes	yes	yes	yes
1_WINDMI	WINDMI 1.0 with nominal parameters, rectified solar wind driver	only IMF	yes	yes	yes
2_WINDMI	WINDMI 1.0 with nominal parameters, Siscoe solar wind driver	only IMF	yes	yes	yes
3_WINDMI	WINDMI 1.0 with nominal parameters, Newell solar wind driver	only IMF	yes	yes	yes

Ring Current Models:

Run ID	Description	E 1	E 2	E 3	E 4
1_FRC	Fok Ring current model run off 4_SWMF data	yes	yes	yes	yes
2_FRC	Fok Ring current model run off 5_SWMF data	yes	yes	yes	yes
3_FRC	Fok Ring current model run off 8_SWMF data	yes	yes	yes	yes
1_RCM	RCM, Hilmer and Voigt B, Siscoe-Hill PCPC, Tsyganenko and Mukai (2003) plasma at outer L	yes	yes	yes	yes
2_RCM	RCM, Hilmer and Voigt B, Siscoe-Hill PCPC, Borovsky 1998 plasma at outer L	yes	yes	yes	yes
3_RCM	RCM, Hilmer and Voigt B, Siscoe-Hill PCPC, MSM plasma at outer L	yes	yes	yes	yes
4_RCM	RCM, Hilmer and Voigt B, Weimer 2005 PCPC, Borovsky 1998 plasma at outer L	yes	yes	yes	yes
1_RAMSCB	RAM-SCB, stand-alone, LANL particles, Volland-Stern E, Dipole B	no	yes	yes	yes
2_RAMSCB	RAM-SCB, stand-alone, LANL particles, Weimer-2K E, Dipole B	no	yes	yes	yes
3_RAMSCB	RAM-SCB, stand-alone, LANL particles, Weimer-2K E, T89 B	no	yes	yes	yes
4_RAMSCB	RAM-SCBdriven by SWMA/BATSRUS+RIM	no	no	yes	yes
5_RAMSCB	RAM-SCBdriven by SWMA/BATSRUS+RIM+PWOM	no	no	yes	yes

Statistical / Analytical Specifications:

Run ID	Model Description	E 1	E 2	E 3	E 4
1_IRF	IRF, Impulse Response Function with 96 lags (ver. 0)	yes	yes	yes	yes
1_BFM	Burton (1975) Feldstein (1992) and Murayama (1982) (	yes	yes	yes	yes
1_RDST	Real-time Dst derivation (RDST), Space Environment Corp.	yes	yes	yes	yes
1_NARMAX	NARMAX polynomial derivation from previous DST, 1-hour OMNI solar wind, no ring current effects	no	yes	yes	yes
2_NARMAX	NARMAX polynomial derivation from previous DST, 1-hour OMNI solar wind, with ring current effects	no	yes	yes	yes
1_RiceDst	Rice Univ. neural network, Boyle (1997) solar wind driver and dynamic pressure	yes	yes	yes	yes

Summary:

A large number of models and model settings have been run in a collaborative effort.
Dst from both KYOTO (1-hour) and USGS (1-minute) have been used.

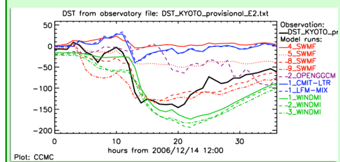
Magnetosphere models show widest range in performance and see improvement when coupled to kinetic ring current model (RCM, CRCM). Both coupled and stand-alone ring current models need improvements with particle loss (recovery phase).

Specifications based on statistical algorithms perform best in this study.

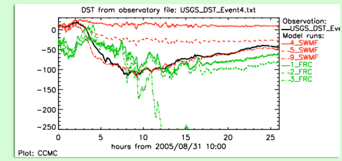
Ranking of models need to take into account multi-dimensional scores.

Sample plots

KYOTO Dst
Event 2: Magnetosphere Models



USGS Dst
Event 4: SWMF and FRC



Scores with explanations:

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Variable: DST Observation file: DST_KYOTO_provisional_E2.txt
Model_Setting   PredEff   N_region   N_finite  PredYield MinTimingError MaxTimingError Correlatio
4_SWMF          -2.129         37         37      0.242      7.000      8.000      0.630
5_SWMF          -0.096         37         36      0.367      1.000      0.000      0.836
8_SWMF           0.888         37         37      0.907      4.000      1.000      0.947
9_SWMF           0.590         37         37      0.828      3.000      1.000      0.863
2_OPENGGCM      -0.537         37         37      0.682     13.000     12.000      0.247
1_CMIT-LTR      -1.502         37         37      0.509      7.000      7.000      0.667
1_LFM-MIX       -1.541         37         37      0.534      7.000      7.000      0.696
1_WINDMI         0.429         37         36      1.035      1.000      1.000      0.895
2_WINDMI         0.089         37         36      1.124      1.000      1.000      0.908
3_WINDMI         0.050         37         36      1.052      1.000      1.000      0.911

PredEff         Prediction Efficiency metric
N_region        the number of samples in the seletcted time wintow
N_finite        the number of points that were used for comparison (ie., those that were not NaN
LogSpectDist    Log-Spectral Distance metric
nWin            the number of windows used for the spectral analysis (2-hour windows, offset by 30 minutes from the neighboring windows)
PredYield       is the ratio of the range of modeled values (max minus min) compared to the observation (max minus min)
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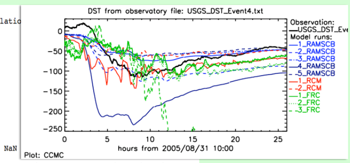
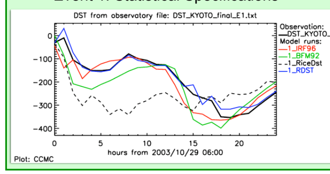
Event 4: Ring Current Models



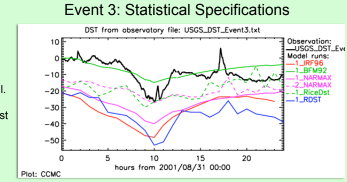
Event 1: Statistical Specifications



Statistical Specifications describe Dst well.

Event 3 is hardest to predict

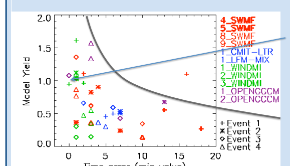
Event 3: Statistical Specifications



Model Performance in 4D Skill Score Space

1) Time Error[min(Dst)] vs. Yield

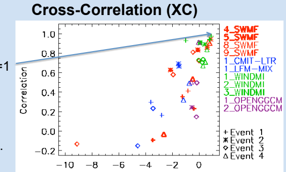
2) Prediction Efficiency (PE) vs. Cross-Correlation (XC)



Ideal combinations:

Yield=1, Error=0

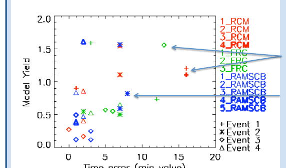
PE=1, XC=1



<u>Magnetosphere models:</u>

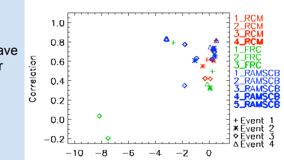
Models with high Yield tend to predict time of min(Dst) better, too.

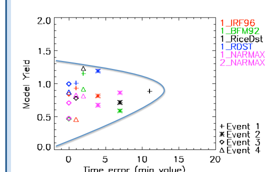
Low PE go with low XC values.



<u>Ring Current models:</u>

Several high-Yield model runs have bad timing. Many of these are for the weaker events (Events 3, 4). Some settings see early onset but not second, larger decrease of Dst.





<u>Statistical specifications:</u>

Yields between 0.5 and 1.25 and good timing, except for Event 2 (AGU storm).

Several models have zero time error but miss most of the signal (Yield<<1).