# A Statistical Comparison of Global MHD Simulations and Geomagnetic Storm Indices

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**Abstract**

Space weather monitoring and predictions largely rely on ground magnetic measurements and geomagnetic indices such as the Disturbance Storm Time index (Dst or SYM-H), Auroral Electrojet Index (AL) or the Polar Cap Index (PCI) all constructed using the individual station data. The global MHD simulations such as the Space Weather Modeling Framework (SWMF) can give predictions of these indices, driven by solar wind observations obtained at L1 giving roughly one hour lead time. The accuracy of these predictions especially during geomagnetic storms is a key metric for the model performance, and critical to operational space weather forecasts. In this presentation, we perform the largest statistical study of global simulation results using a database of 140 storms with minimum Dst below -50 nT during the years from 2010 to 2020. We compare SWMF results with indices derived from the SuperMAG network, which with its denser station network provides a more accurate representation of the true level of activity in the ring current and in the auroral electrojets. We show that the SWMF generally gives good results for the SYM-H index, whereas the AL index is typically underestimated by the model with the model predicting lower than observed ionospheric activity. We also examine the Cross Polar Cap Potential (CPCP) and compare it with a model derived using the PCI (Ridley et al., 2004) as well as with results obtained from the SuperDARN network. We show that the Ridley et al. CPCP model is much closer to the SWMF values. The results are used to discuss factors governing energy dissipation in magnetosphere - ionosphere system as well as possibilities to improve on the operational space weather forecasts.

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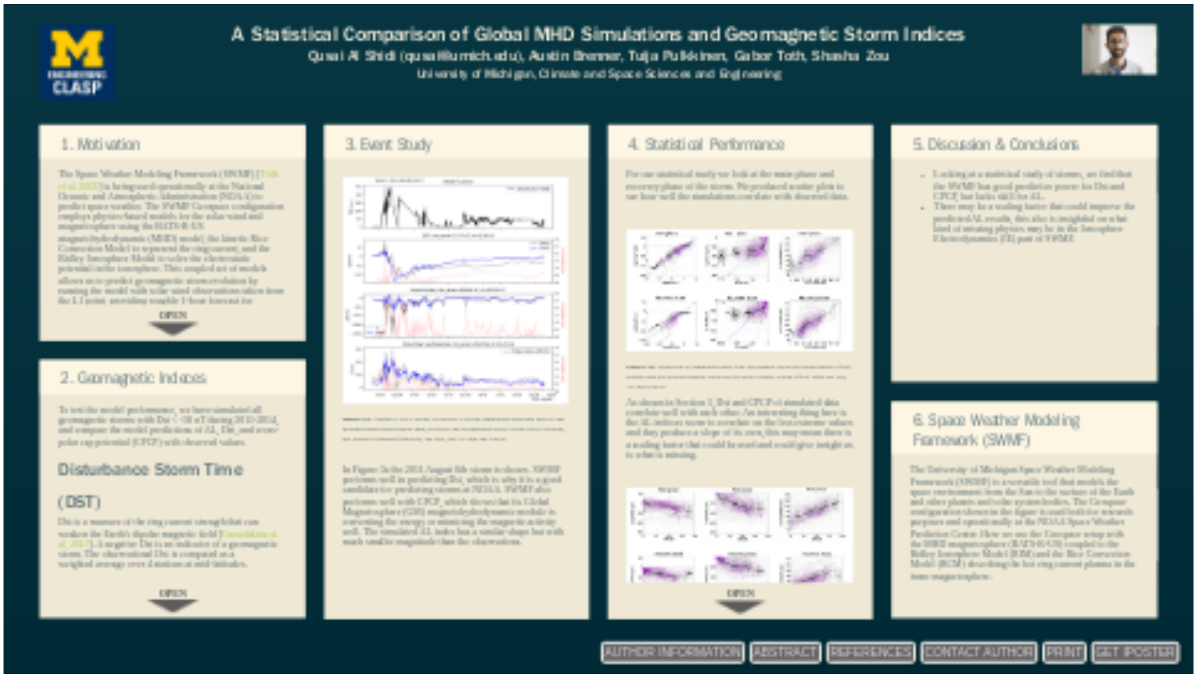


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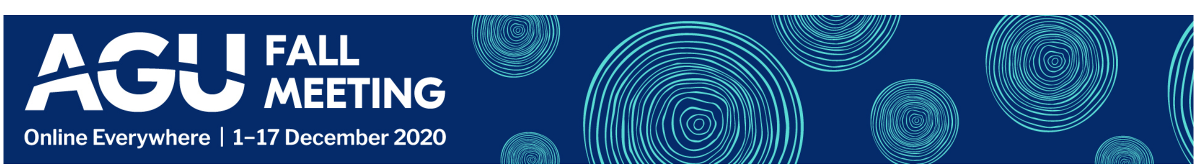

# 1. MOTIVATION

The Space Weather Modeling Framework (SWMF) [Tóth et al. 2005 (https://doi.org/10.1029/2005JA011126)] is being used operationally at the National Oceanic and Atmospheric Administration (NOAA) to predict space weather. The SWMF Geospace configuration employs physics-based models for the solar wind and magnetosphere using the BATS-R-US magnetohydrodynamic (MHD) model, the kinetic Rice Convection Model to represent the ring current, and the Ridley Ionosphere Model to solve the electrostatic potential in the ionosphere. This coupled set of models allows us to predict geomagnetic storm evolution by running the model with solar wind observations taken from the L1 point, providing roughly 1-hour forecast for geomagnetic activity indices. This is useful in forecasting geomagnetic storms before they may happen.

The accuracy of these predictions are instrumental in protecting ourselves from geomagnetic storms that could be harmful to satellites or even electrical devices on the ground. The predictions can be validated by looking at ground measurement data of the indeces that we have collected over the years. A large statistical study can verify where the models do well and why, and what may be missing.

# 2. GEOMAGNETIC INDECES

To test the model performance, we have simulated all geomagnetic storms with Dst < -50 nT during 2011-2014, and compare the model predictions of AL, Dst, and cross-polar cap potential (CPCP) with observed values.

## Disturbance Storm Time (DST)

Dst is a measure of the ring current strength that can weaken the Earth's dipolar magnetic field [Ganushkina et. al, 2017 (https://doi.org/10.1007/s11214-017-0412-2)]. A negative Dst is an indicator of a geomagnetic storm. The observational Dst is computed as a weighted average over 4 stations at mid-latitudes.

## Auroral Electrojet Indeces (AE, AL, AU)

The Auroral Electrojet (AE) index is the measure of the currents in the auroral oval [Davis and Sigiura, 1966 (https://doi.org/10.1029/JZ071i003p00785)]. AE is most useful in identifying substorms as it measures the Ionospheric currents directly. The indices are measured as the maxima (AU) and minima (AL) of 12 stations at roughly 70-degree latitude in the northern hemisphere. The simulation AL is computed similarly, as extrema along 70-degree latitude. Enhanced AL values are a measure of substorm activity, as the currents coupling the magnetotail to the ionosphere close through a westward current across the midnight sector, causing a negative deflection in the magnetic x-component.

## Cross Polar Cap Potential (CPCP)

The Cross Polar Cap Potential is the electrostatic potential across the northern pole region [Boyle et al., 1997 (https://doi.org/10.1029/96JA01742)]. As the polar cap open field lines connect to the solar wind, the polar cap potential is a measure solar wind driving intensity and energy input from the solar wind into the magnetosphere-ionosphere system.

For the CPCP observational value, we use the empirical formulation by [Ridley and Kihn, 2004 (https://doi.org/10.1029/2003GL019113)], which give the potential as function of season ($T$ = month of year * $2\pi/12$) and the polar cap index (PCI).

$$CPCP = 29.28 - 3.31 \cdot \sin(T+1.49) + 17.81 \cdot PCI$$

## Newell coupling function (dPhi/dt)

We examine the correlation of the observed and model values as well as the dependence on the model performance as function of the driver intensity given by the Newell coupling function [Newell et al., 2007 (https://doi.org/10.1029/2006JA012015)], which also can be interpreted as the reconnection efficiency at the dayside magnetopause.

# 3. EVENT STUDY

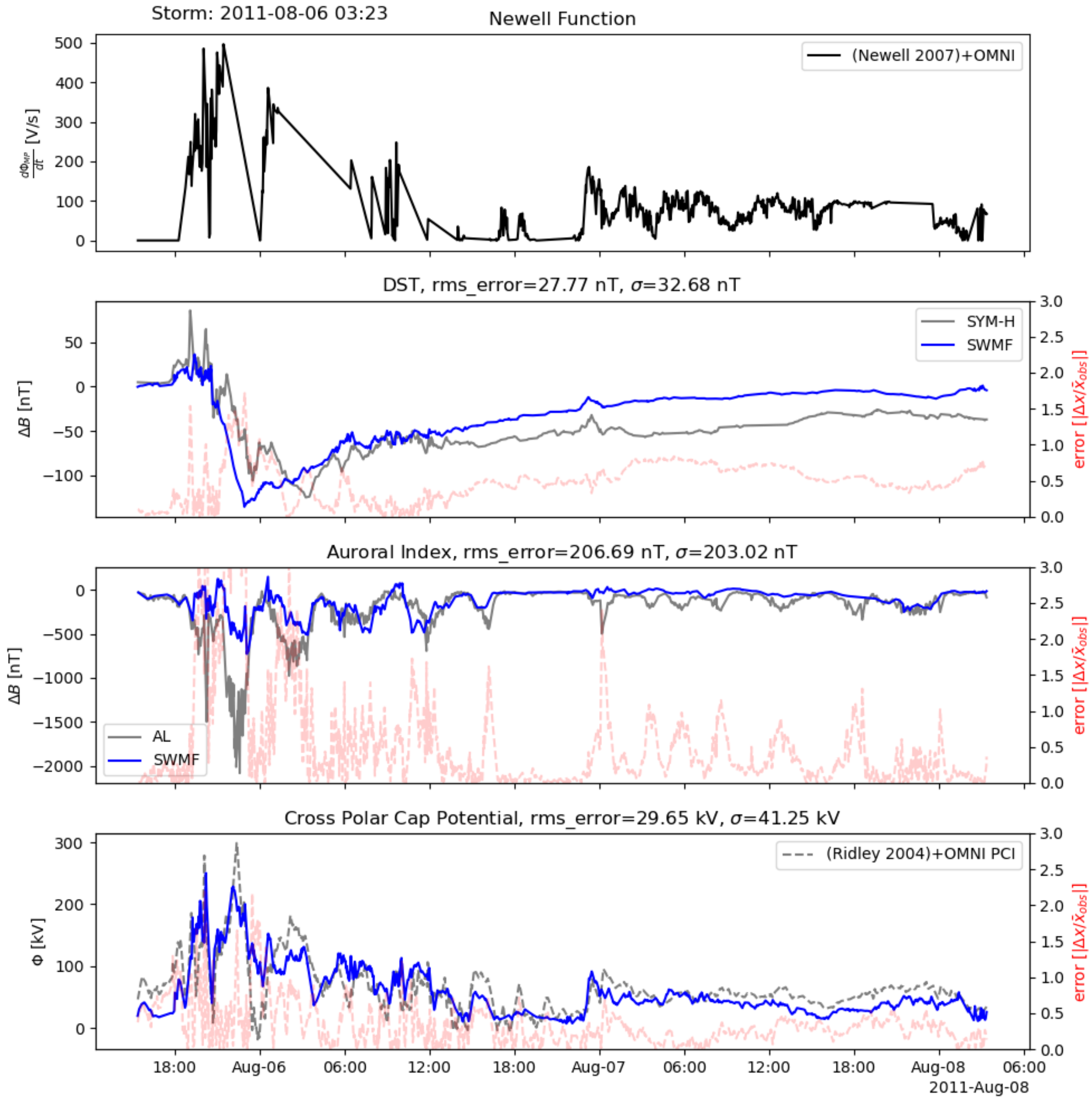


**Figure 3a.** August 6 2011 storm. In blue is SWMF simulation data and grey is the ground-based observation data, in red is the normalized error. From top to bottom, the Newell coupling function, the Dst, the AL and the CPCP.

In Figure 3a the 2011 August 6th storm is shown. SWMF performs well in predicting Dst, which is why it is a good candidate for predicting storms at NOAA. SWMF also performs well with CPCP, which shows that its Global Magnetosphere (GM) magnetohydrodynamic module is converting the energy or mimicing the magnetic activity well. The simulated AL index has a similar shape but with much smaller magnitude than the observations.

# 4. STATISTICAL PERFORMANCE

For our statistical study we look at the main phase and recovery phase of the storm. We produced scatter plots to see how well the simulations correlate with observed data.

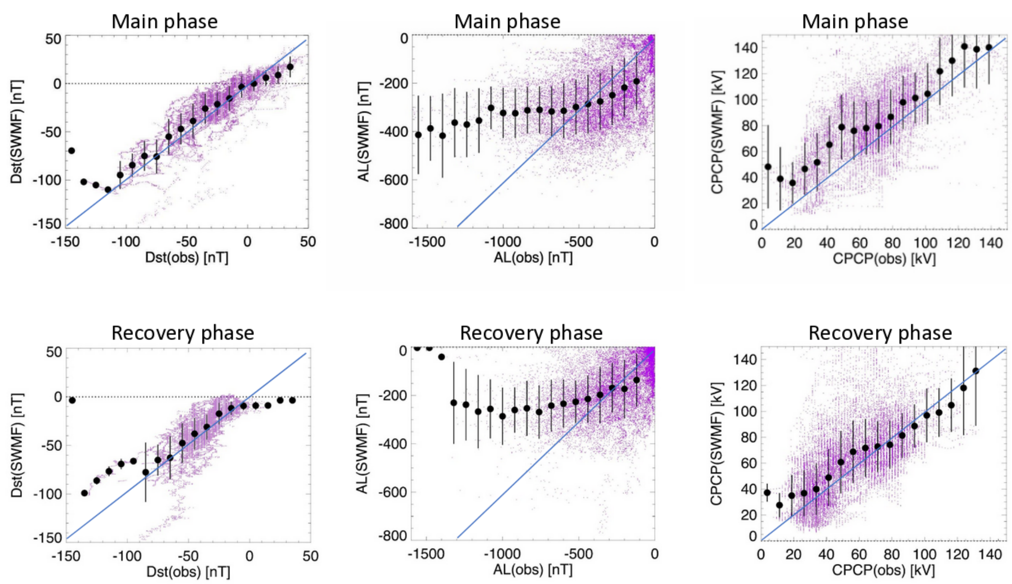


**Figure 4a.** Observed vs simulated data. The top panels show the main phase of the storms and the bottom panels show the recovery phase. From left to right are Dst, AL and CPCP.

As shown in Section 3, Dst and CPCP of simulated data correlate well with each other. An interesting thing here is the AL indeces seem to correlate on the less extreme values and they produce a slope of its own, this may mean there is a scaling factor that could be used and could give insight as to what is missing.

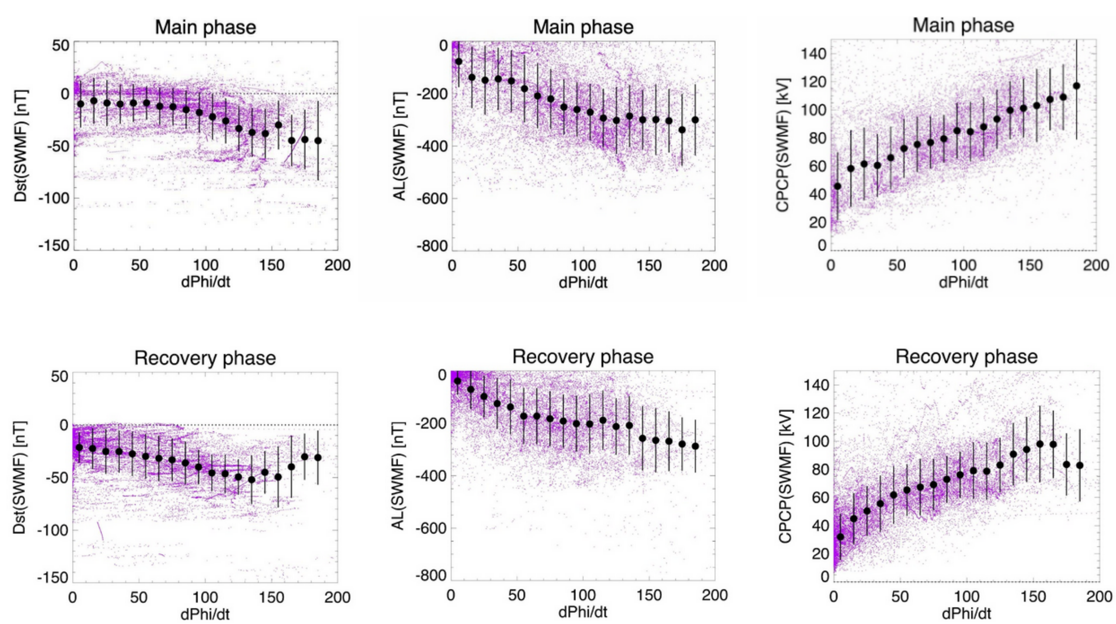


Figure 4b. Newell coupling function dependence of simulated Dst, AL and CPCP. The top panels are main phase of the storms and bottom panels are recovery phase of the storms.

The performance show no significant dependence on which phase the storms are in. This shows errors are driver independent.

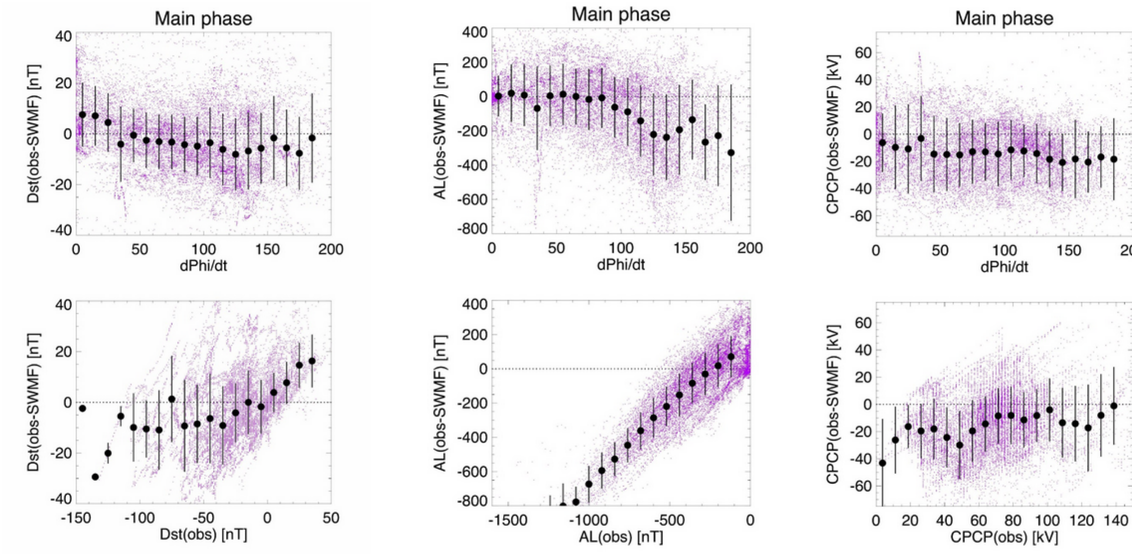


Figure 4c. Difference of simulated and observed values during main phase as a function of the Newell function (top panels) and observed values (bottom panels). The zero line is shown here to see where the values correlate best.

The DST and CPCP show good values (near zero error) for varying magnitudes of the Newell function, which shows that these are predicted well for different magnitudes of the magnetospheric activity. The AL matches well when there is low magnetospheric activity but has a larger range of off-values with increasing solar wind strength. The same can be seen when comparing the observed values with the differences, the difference of AL increases with larger observed AL.

## 5. DISCUSSION & CONCLUSIONS

- Looking at a statistical study of storms, we find that the SWMF has good predictive power for Dst and CPCP, but lacks skill for AL.
- There may be a scaling factor that could improve the predicted AL results, this also is insightful on what kind of missing physics may be in the Ionosphere Electrodynamics (IE) part of SWMF.

# 6. SPACE WEATHER MODELING FRAMEWORK (SWMF)

The University of Michigan Space Weather Modeling Framework (SWMF) is a versatile tool that models the space environment from the Sun to the surface of the Earth and other planets and solar system bodies. The Geospace configuration shown in the figure is used both for research purposes and operationally at the NOAA Space Weather Prediction Center. Here we use the Geospace setup with the MHD magnetosphere (BATS-R-US) coupled to the Ridley Ionosphere Model (RIM) and the Rice Convection Model (RCM) describing the hot ring current plasma in the inner magnetosphere.

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# ABSTRACT

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