When polar cap potential and reconnection rate don’t agree; understanding viscous interaction and polar cap saturation

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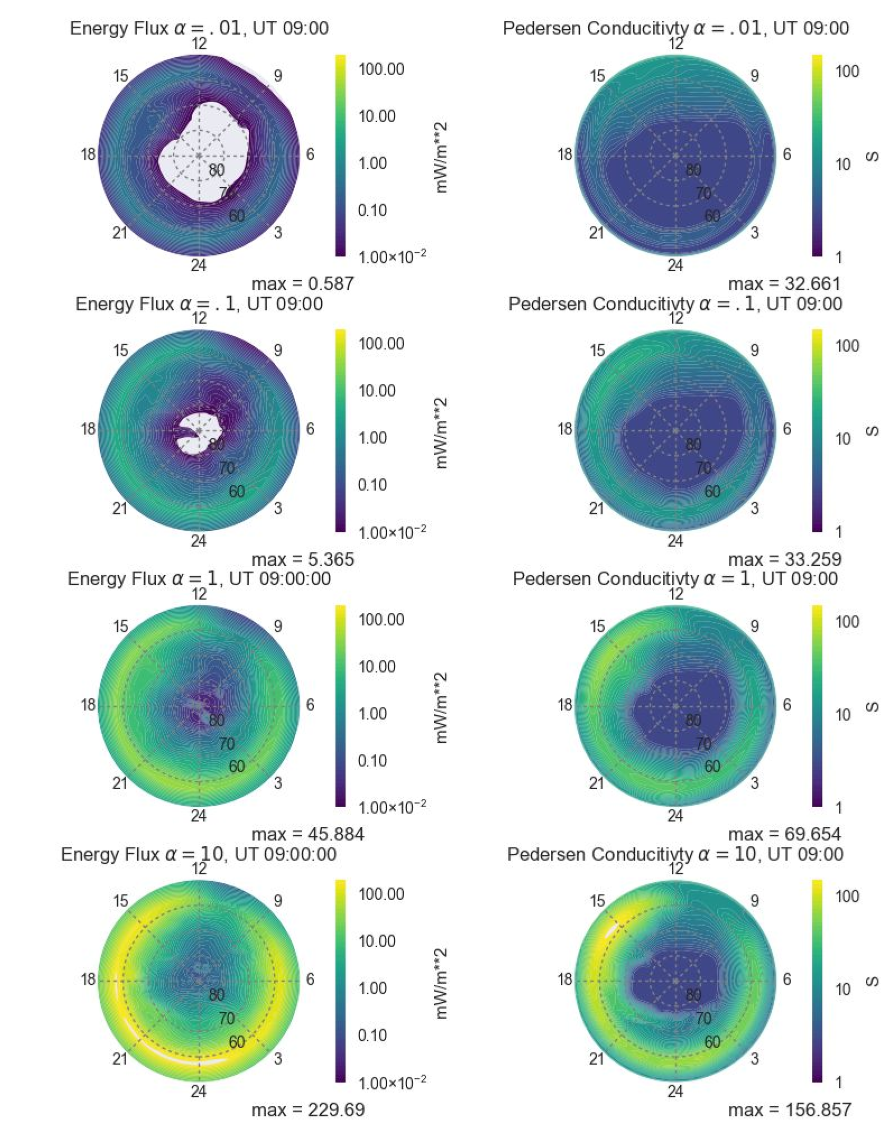

Figure 1: Shows the total energy flux of the incoming electrons on the left panels and the Pedersen conductivity on the right panels for the NH on March 17, 2013, 9:00. From top to bottom **α** = .01, .1, 1, and 10.

Using the Openggcm-CTIM-RCM model we investigate the March 17, 2013 storm. OpenGGCM is a global MHD code that we have coupled with the Rice Convection Model that does flux transport of the inner magnetosphere. We have also coupled it with the Coupled-Thermosphere-Ionosphere-Model that simulates the polar ionosphere thermosphere system.

We run the simulation 4 times and the only thing that is modified is the electron precipitation into the ionosphere. We use a scaling factor **α** to multiply the energy flux into the ionosphere. We use values of **α** = .01, .1, 1, and 10. The energy flux and Pedersen conductivity are graphed in figure 1 showing the different enhancements.

Polar Cap Potential Saturation

Polar cap potential saturation is the phenomenon when CPCP stops increasing with stronger solar wind drivers. There have been many proposed mechanisms for CPCP saturation, with many still up for debate. But one thing that most theories agree on is the effect of Pedersen conductivity on CPCP saturation.

As conductivity is increased the value at which CPCP saturation occurs decreases. Figure 3 shows one of these tests for solar zenith angle dependence of CPCP from Nagatsuma [2004].

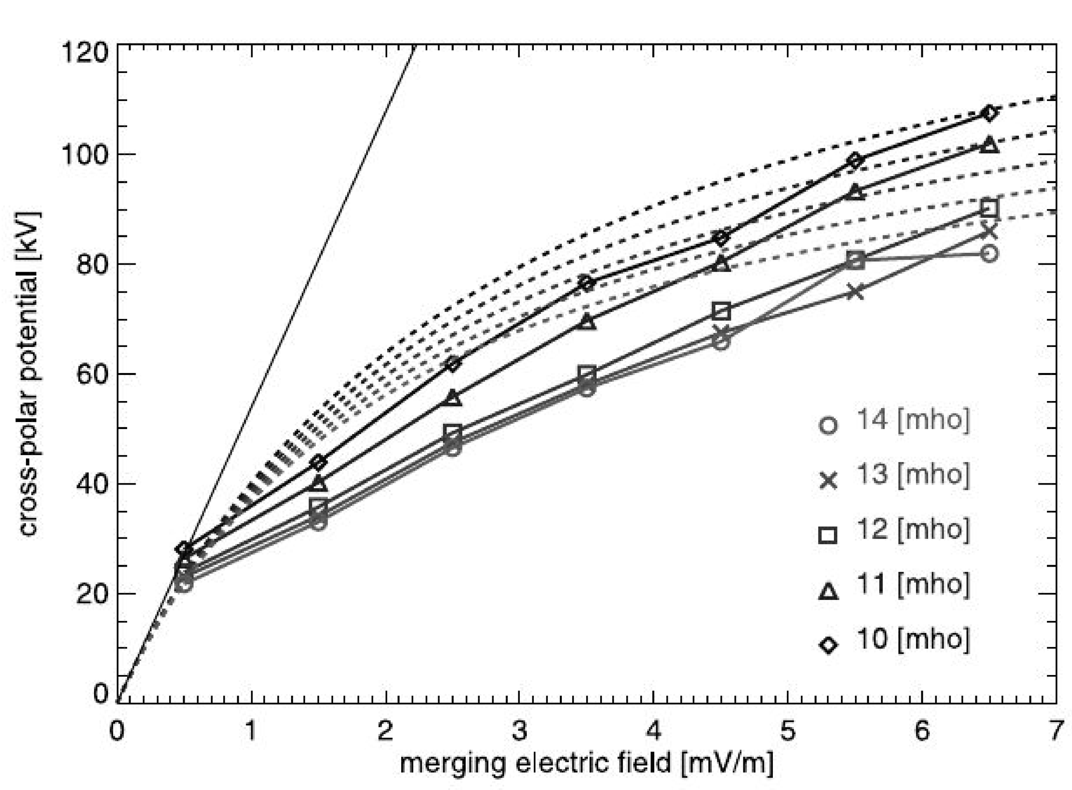

Figure 3: Shows the merging electric field compared with the CPCP for various conductivities. This figure is taken from Nagatsuma [2004] their Figure 4.

The Hesse-Forbes-Birn Method

We calculate the reconnection rate using the method (HFB) outlined by Hesse et al [2005]. This requires tracing all the field lines in a magnetic domain that could possibly intersect a reconnection region and integrating the parallel electric field along that line.

$$R = -\Xi_{\max} = \max \int_{\alpha,\beta} E_{\|} \, ds$$

The HFB method is a useful because magnetic topology does not have to be found. That is helpful for real solar wind conditions when separators are difficult to locate. In a simple constant solar wind simulation the HFB method agreed with traditional methods to within 12%.

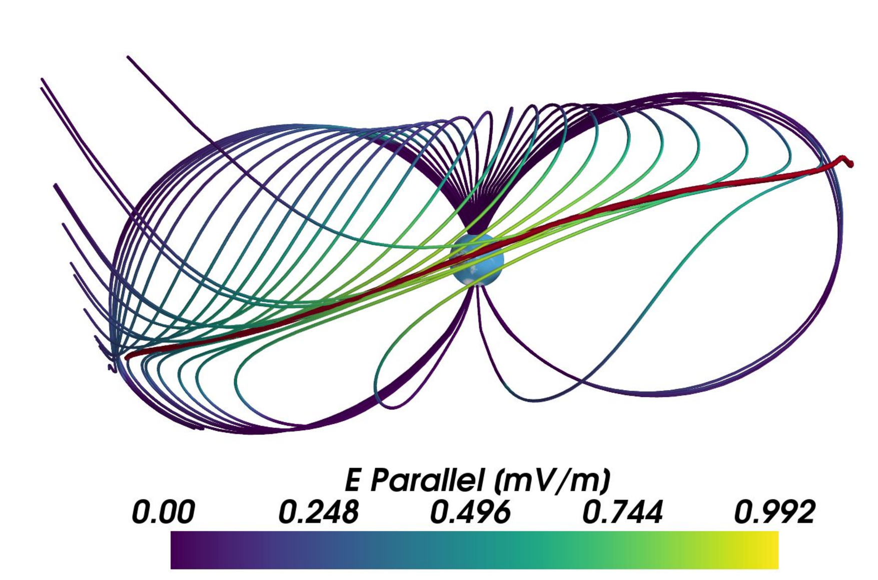

Figure 2: Shows a subset of the traced dayside magnetic field lines in a test simulation to determine the accuracy of the HFB method. E parallel is in color along the magnetic field line and the red line is the separator. Earth is shown for scale.

Viscous Interaction

Viscous interaction is a process where solar wind drags magnetosphere plasma just inside the plasma sheath. This then causes a return flow in the tail as shown in Figure 4. All of these flows of plasma are mapped along field lines into the ionosphere. This usually contains a portion of the CPCP on the order of 10-20 kV, but during extreme events can be up to 50-60.

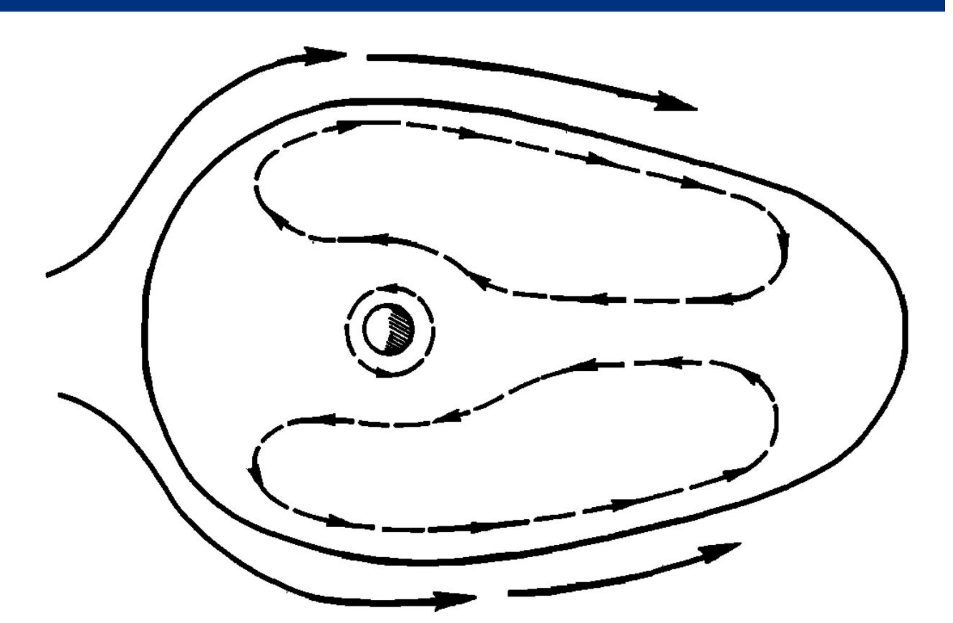

Figure 4: A cartoon of the convective flow of viscous interaction, sun is to the left and solar wind flow cause the plasma just inside the magnetosphere to circulate. This figure taken from Stern [1989].

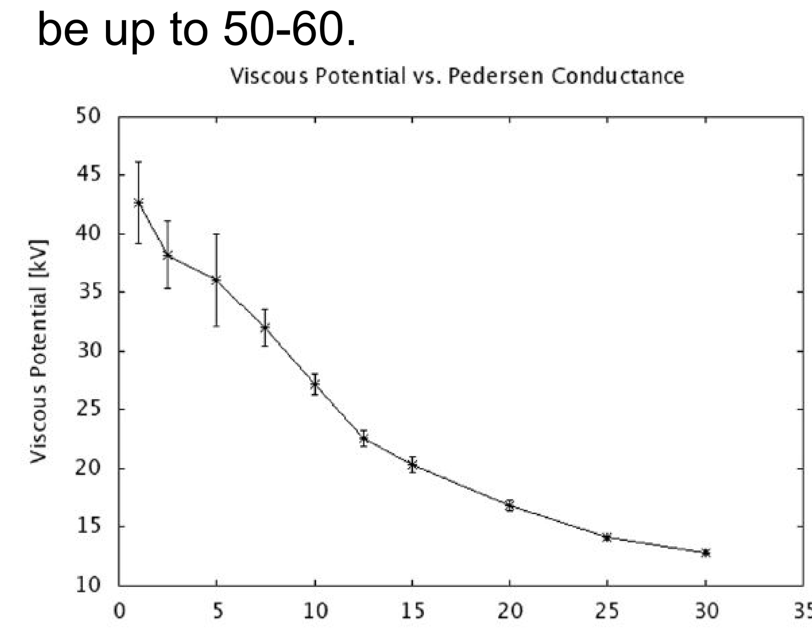

Figure 5: A graph of the pedersen conductivity dependence of viscous potential. Taken from Bruntz et al [2012]

Bruntz et al [2012] did simulations with another MHD model, LFM, looking at the conductivity dependence of viscous interaction for normal solar wind conditions and found that as ionospheric conductivity increases the effect of the viscous interaction decrease, as shown in Figure 5. When the solar wind conditions are stronger the viscous potential increases.

OpenGGCM-CTIM-RCM Results of CPCP and R

Figure 6 shows the results of our four simulations during the storm period of March 17, 2013. The CPCP and R are graphed for both hemispheres and for each scaling factor alpha and averaged over the whole simulation. Figure 7 shows the time evolution of the CPCP and R for both hemispheres. There are a few trends immediately evident. The CPCP decreases with increasing precipitation. This occurs for both hemispheres and it is fairly symmetric. The R NH appears to have a solid decrease (19%) in the reconnection rate as the precipitation is increased, but the relationship is not as clear in the R SH, when looking at the average global reconnection the total range changes only over 6%. This relation would require further testing to show its validity.

The other trend that is evident is that CPCP and R do not always agree. For lower precipitation cases the CPCP is higher than the R, while for higher precipitation CPCP is lower.There are probably two effects going on here. Bruntz et. al [2012] showed that viscous interaction increases with decreasing ionospheric conductivity.

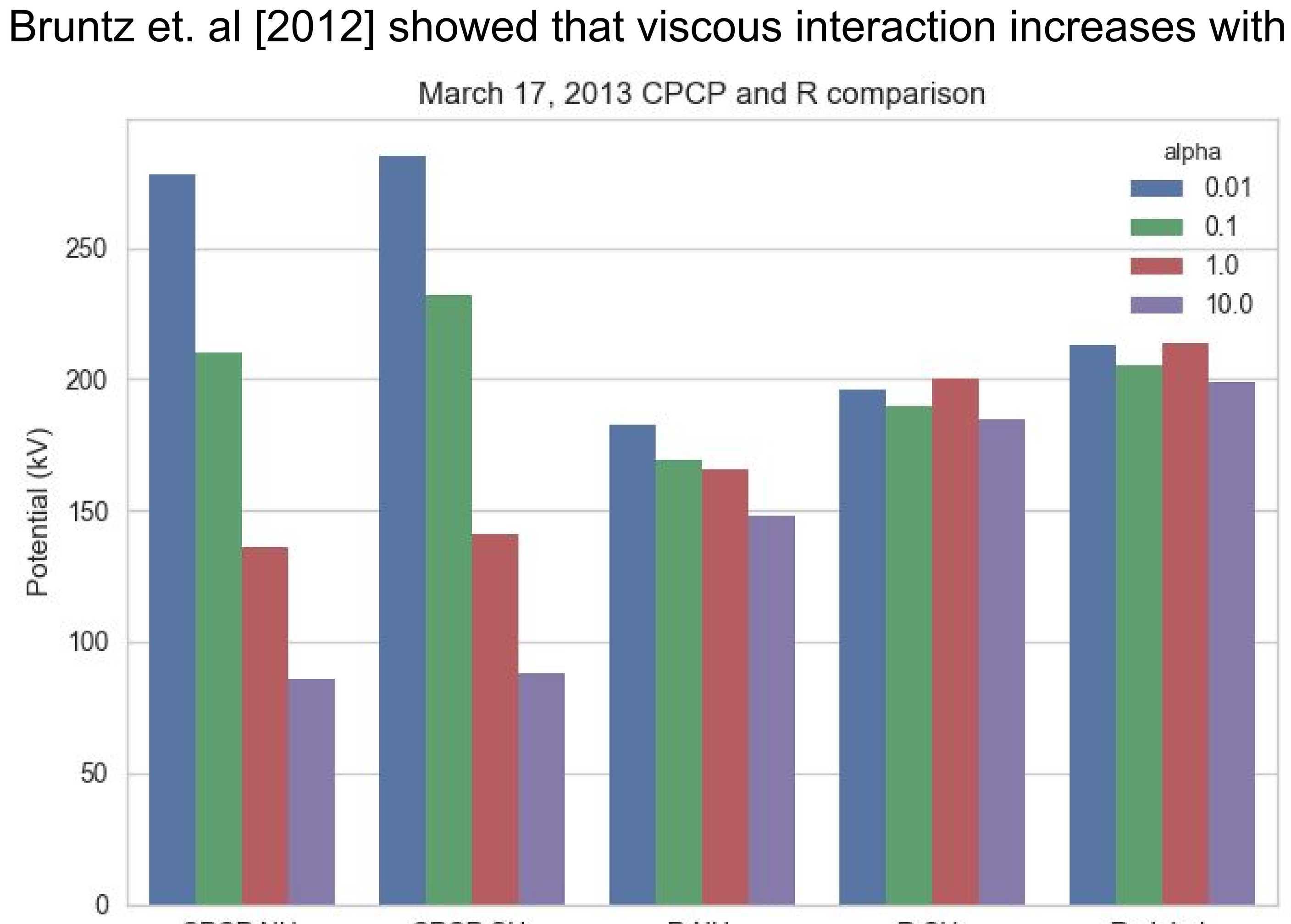

Figure 6: Shows the results of our four simulations with scaling factors of precipitation, alpha. CPCP and R are graphed for each hemisphere and R global as an average over the whole simulations time.

The possible ranges for these specific solar wind conditions could range from 20-100 kV dependant on the conductivity. For CPCP less than R the conductivity is so high because of precipitation that the polar cap is saturated at a lower potential than the reconnection potential.

Thus we find that CPCP is higher than R for low ionospheric conductivity and CPCP is lower than R for high ionospheric conductivity.

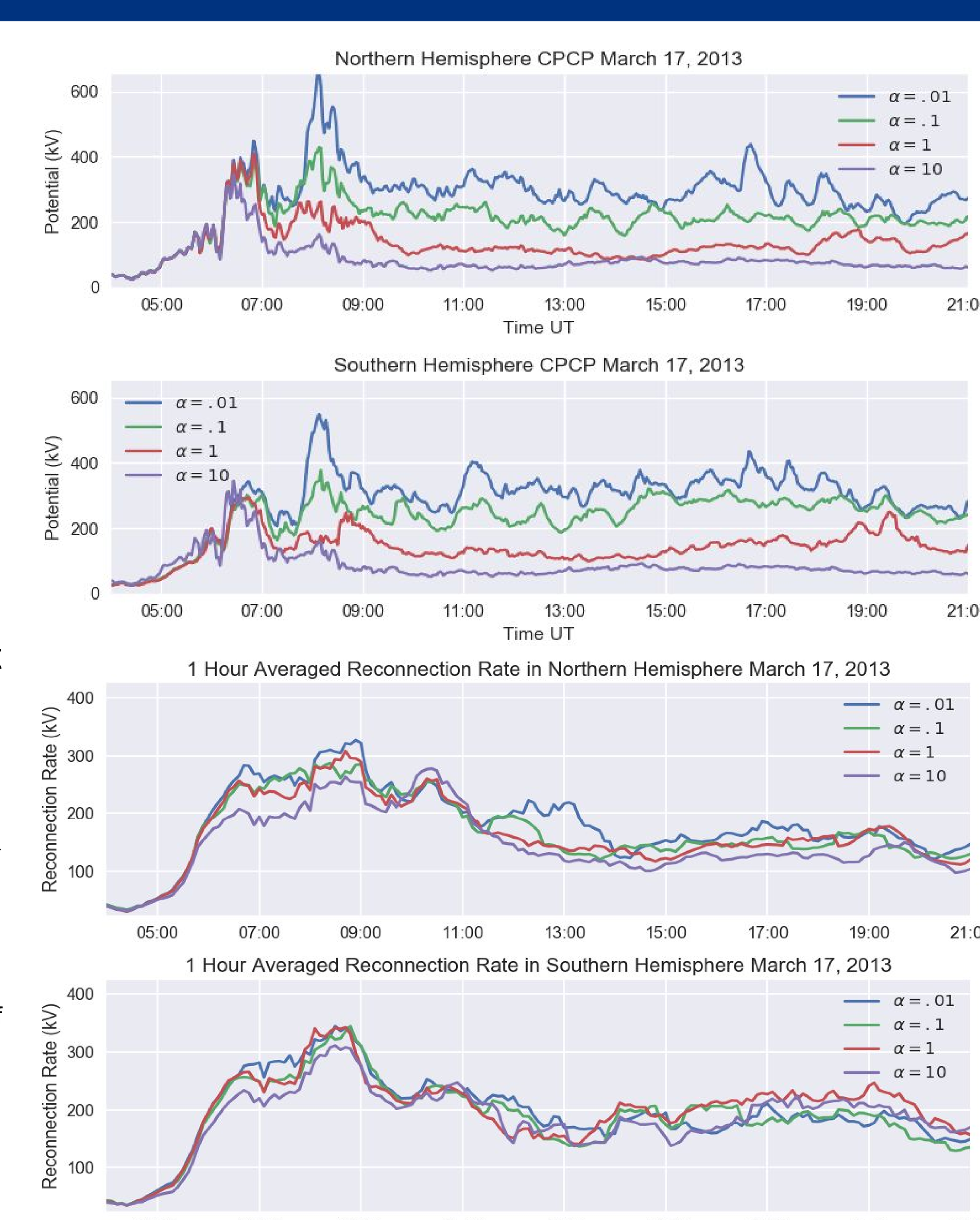

Figure 7: Shows the time evolution of our four simulations with scaling factors of precipitation, alpha. CPCP for NH and SH are the top two panels, and R for NH and SN are graphed in the bottom two panels. The CME hit at 6:00 UT march 17, 2013.

References

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