Forbes & St. Cyr (2004, hereafter "F/SC") have provided evidence that the electricity market can be impacted by space weather. Our analysis indicated that the estimated market impact for PJM was 3.7 % or approximately $500 million dollars over the 19 month sample period. Kappenman has taken exception to this estimate and contends that we have exaggerated the magnitude of the problem that space weather poses to PJM. There are four specific issues: (1) he claims that we have ignored relevant literature; (2) he asserts that Dst is not an appropriate proxy for GICs in PJM; (3) he charges that our findings are inconsistent with the impact of the 17 September 2000 storm; and (4) he alleges that our discussion of October 2003 storms is misleading.

In our article, we have explained our methodology, multivariate regression analysis, with a particular focus on how it compares to correlation analysis. We have also explained the limitations of our analysis. We noted that "...While the Dst/price relationship was found to be robust, the precise estimate should be treated with a relatively high degree of caution given that econometric modeling is not an exact science as well as the fact that the measure of space weather may be a poor proxy for GICs" (paragraph 96). We have also noted that additional research using local magnetometer data are needed (paragraph 97). We did not claim that that our findings for PJM are representative of the impact of space weather on other power grids. On the contrary, we noted that ... "Only analysis of other power grids will tell. " (paragraph 97). Kappenman inaccurately asserts that we have indicated that our findings ... "imply much higher total costs are likely across the US and elsewhere in the world." He also inaccurately asserts that we have claimed that " ... Dst is the most suited proxy for GIC in the PJM grid..." Moreover, he inaccurately refers to our analysis as a correlation study that uses Dst as quasi-binary indicator.

1. Relevant Literature and the Magnitude of the Problem.

IEEE Reports. Kappenman cites an IEEE Working Group Report (Bomki, et. al., 1996). This article is concerned with the physical damage that GICs can inflict on the power grid equipment. We contend that the IEEE published study authored by Girgis and Ko(1992) is the more relevant study. They calculated the overheating effects of GIC currents on the performance of two large transformers. The performance of the first transformer was temporarily impacted by even relatively low levels of GICs. For example, five amps of GICs were found to reduce its allowable load by more than 25 percent (Girgis and Ko, figure 9). The second transformer they examined was a step up transformer of a more recent design. Its performance was only degraded when the GIC level exceeded 40 amps. Given that the transformers in operation on a grid represent a mix of various vintages, it would seem that the impact of space weather on the performance of the transformers of any given grid is an empirical issue.

The DOE and FERC Reports. Kappenman questions the credibility of F/SC findings by pointing out that neither the DOE or FERC studies mention space weather as a factor that contributes to transmission congestion costs. Kappenman goes on to claim that the DOE study concluded that the annual economic cost of congestion was between $157 and $444 million for PJM, California, New York, and New England. This study explicitly states that the energy model it used to generate the estimates "... does not represent transmission constraints within regions and does not account for these congestion costs in the analysis."(DOE, p. 85) Accordingly, this study says nothing about the magnitude of congestion costs within PJM, and we are therefore surprised that Kappenman would cite this study. The earlier FERC PowerPoint presentation reports that the cost of congestion during the summer months of 2000 and 2001 at 16 locations. Only one of these locations lies within the PJM control area. The study's authors do not conclude anything about total U.S. (or PJM) transmission congestion costs for the summer of 2000 or 2001. The figure of $891 million that Kappenman cites as the national estimate for the summer of 2000 apparently refers to the sum of the costs for the 16 constraints (the actual sum is $898.5 million). While the FERC study does not mention space weather as a cause of transmission congestion, it does point out that high demand is not the only culprit given that congestion also occurs during the fall and spring when demand is moderate. This is an interesting finding given the seasonal nature of geomagnetic storms (e.g., Russell and McPherron, 1973). The FERC study also includes the category of "system conditions" as a factor contributing to congestion costs but does not discuss the underlying determinants of these conditions. Based on the results reported by F/SC, we suggest that space weather be considered one of these determinants.

The PJM Reports. Kappenman claims that PJM issued only five solar magnetic disturbance (SMD) alerts over our 19 month sample period. This does not agree with the number of SMD emergencies declared in *PJM Annual Report on Operations 2001.* This report indicates that 35 emergencies were classified as SMD in origin in 2000. In 2001, there were 60 (PJM, 2002a, p. 26). What is especially interesting is that the

number of emergencies attributed to solar magnetic disturbances was almost twice the number reported for the second most prevalent category (PJM, 2001, p. 26). Kappenman has claimed that this reported incidence is a gross overstatement. In reaction to that claim we have contacted PJM directly. An email response from a representative of PJM's Performance Compliance Department has indicated that " Historical data provided by the eSuite Emergency Messages report for Solar Magnetic Disturbance (SMD) events list occurrences of the Conservative Action Emergency Procedure, and do not represent other transmission actions that PJM may have taken in response to an SMD event. The count of events posted in the 'PJM Annual Report on Operations' is the more complete source." In any event, assuming the market price accurately reflects real-time operating conditions, then one should expect GICs to impact the market outcome to the extent that the performance of the transformers are adversely impacted regardless of whether an official emergency is declared - the laws of supply and demand can be expected to operate even when there is no formal announcement that the system is degraded.

Kappenman also objects to our estimate of the cost of space weather by noting that it exceeds the $132 million in 2000 and $271 million in 2001 of congestion costs reported in *PJM Interconnection State of the Market Report 2001.* However, these reported costs are based on the differences in the locational marginal prices, which means that they do not include the monetary impact of congestion that may occur in the "step up" transformers at the generating plants. There is no reason why these particular transformers would be immune to GICs. When their performance is degraded, less power is uplifted onto the grid than was desired. Based on the analysis of Girgis and Ko discussed above, the quantitative impact could be significant. This of course would represent a shift to the left of the supply curves in Figure 5 of F/SC. This hypothesis suggests that the locational marginal prices received by generators are higher during periods of geomagnetic activity, all other factors being held constant. This is not idle speculation on our part. We have performed a preliminary test of this hypothesis using data for PJM's Western Hub. The price at this Hub is used as a reference price by PJM in some of its congestion cost calculations (PJM, 2003, p. 106). The preliminary results indicate that this price is positively affected by space weather. One interpretation of this result is that it is not meaningful to compare the estimated cost of space weather to reported congestion costs. A large portion of reported transmission congestion costs are clearly related to terrestrial supply and demand considerations. On the other hand, reported congestion costs do not incorporate the impact that geomagnetic activity has on the reference prices used to calculate these costs.

The Bastille Day Storm. Kappenman asserts that the market impact of the 15 July 2000 storm was approximately $900,000. This ignores the econometric analysis presented by F/SC that events in the real-time market can impact subsequent prices in the day-ahead market. This estimate is as faulty as measuring the cost of a hurricane by only counting the costs incurred by uninsured homeowners. Just as insurance premiums rise after an unexpected increase in hurricane activity, day-ahead electricity prices rise following periods when real-time electricity prices exceed day-ahead prices.

2. The Use of Dst as a Proxy for GICs in PJM. Kappenman objects to F/SC's use of Dst as a proxy for GICs in PJM. This is a legitimate concern that was duly noted by F/SC. Kappenman has also indicated that he knows of no evidence of measurable GICs at K values less than K4. The research reported by Lundby et al. (1985) examined the relationship between Kp, and GIC levels on a 500 kV power line in British Columbia. Over the course of their sampling, Kp ranged from K0 to K7. The researchers successfully observed GICs in every hour of the 636 hour sample period except for 38 hours in which there was a malfunction in the equipment. A related paper by Boteler et. al. (1991) using this same data reports that when Kp was equal to one, the probability that a GIC would equal or exceed one amp was 0.177. The probability was more than 0.44 when K_p was greater than one.

3. The Large Dst Event in September 2000. Kappenman has alleged that the price did not respond as we have hypothesized to the storm on 17 September 2000. We do not agree. The real-time price one hour prior to the peak of the storm was $12.90 per MWh. As Dst declined over the next hour to -201 nT, price increased by 55 percent to $20.01 per MWh. From the regression model, the estimated cost of space weather for this hour was $9.81 per MWh. We believe that this represents a significant response given that the storm occurred on a Sunday and that there was considerable slack in the market as a result. So much so, that the real-time price had been equal to zero for several hours earlier in the day.

4. The October 2003 Storm. Given the volatile nature of real-time electricity prices and importance of terrestrial demand and supply conditions in determining these prices, we are not impressed by Kappenman's observations concerning the lack of a visually detectable relationship between space weather and the average price over any extended time period. As it turns out, the relationship between space weather and the market for electricity is more visually discernable if one looks at transmission congestion

costs. Based on our earlier analysis, we hypothesize that space weather could give rise to transmission congestion between PJM's Western and Eastern Hubs. One easily understood measure of this congestion is the absolute value of the differences between the two locational marginal prices. Figure 1 depicts the values of Dst along with both the day-ahead and real-time measures of these costs over the period 22 October – 7 November 2003. We believe that the late October spikes in congestion costs that coincide with the large declines in Dst are space weather related. One reason for this belief is that these spikes occurred during periods in which PJM had implemented SMD conservative operations. There were also similar spikes in marginal transmission congestion costs in both the New York and New England power markets at approximately the same time. For example, there were large spikes in marginal transmission congestion costs in Long Island, New York that coincided with the late October 2003 storms (Figure 2).

Conclusion. Close inspection of Kappenman's specific objections reveals that they are without merit. His reported incidence of SMD emergencies on PJM is not correct. Our preliminary empirical analysis of the real-time price in PJM's Western Hub indicates that it is not meaningful to compare the cost of space weather with reported congestion costs. Kappenman's objection to using Dst as a proxy on PJM GICs was already acknowledged in F/SC as a "less than ideal measure." His assertion that GICs are not present at low K values is not supported by the literature. Contrary to his claim, the real-time price did respond as we have hypothesized during the 17 September 2000 storm. Finally, the evidence is clear that the market for electricity was impacted by the October 2003 storms.

Kappenman has requested that we provide a table that would report on the costs of space weather for each storm that occurred over our sample period. While space constraints preclude such a table in this reply, we would be happy to present storm specific impacts in future analyses.

Kappenman claims that we have missed the point in that the market impact of space weather is simply the result of corrective measures undertaken by grid operators and/or operators of nuclear plants. For the sake of argument, suppose that Kappenman is correct and that all the market impacts are the result of corrective actions by grid operators. In our view, anyone who believes that the magnitude of these costs is not worth knowing has missed the point that prudent investments in space weather research have the potential to reduce these costs.

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Figure 1. Space Weather as Measured by Dst and Transmission Congestion Costs between PJM's Western and Eastern Hubs, 22 October – 7 November 2003.

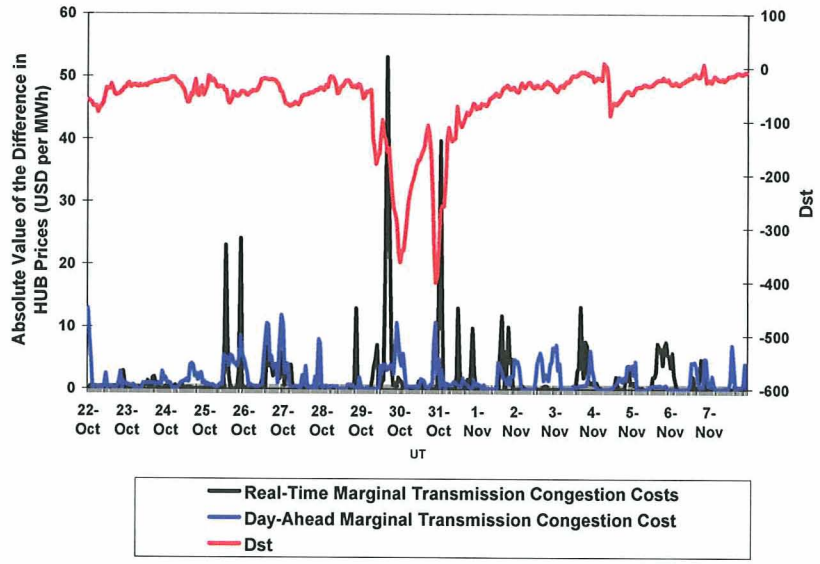

Figure 2. Space Weather as Measured by Dst and Marginal Transmission Congestion Costs in Long Island, New York, 22 October -7 November 2003.