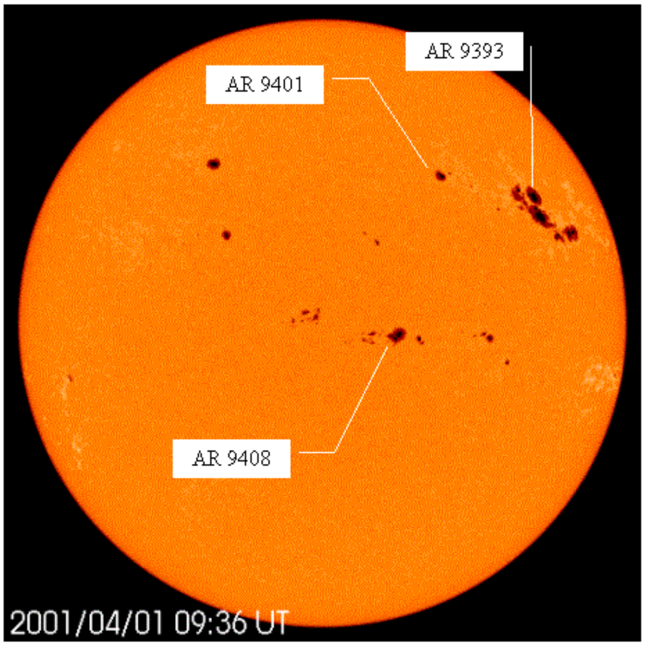

Figure 1- Region 9393 along with other nearby regions continue to produce large eruptive activity.

Solar Condition Update and Geomagnetic Activity Advisory

Large flare and CME activity is continuing to occur from Active Region 9393 along with other nearby Active Regions. Region 9393 is approaching the west limb of the Sun is becoming less connected to earth-ward directed activity (Figure 1). However the other active regions are now jointly participating in observed flare and possibly CME activity and these regions are very well-connected to direct activity earth-ward over the next several days. Solar activity has been very intense over the past few days, as a result Metatech is now issuing a *Geomagnetic Storm Advisory,* as conditions project high probabilities for large storm activity starting on April 3. On April 1 at 12 UT, a large and long-duration M-Class flare was observed, two smaller M-Class flares occurred at 19 UT and then 0 UT April 2. At 10 UT and again at 12 UT on April 2, two X-Class flares were observed (Figure 2); at 20 UT another M Class flare is in progress (not shown on plot). It is unknown at this point how well-connected from the Sun to the Earth these events will be, but the impressive chain of eruptions is likely to push considerable particle radiation earth-ward over the next 30-48 hours capable of producing a siege of long-duration and possibly intense geomagnetic storm activity.

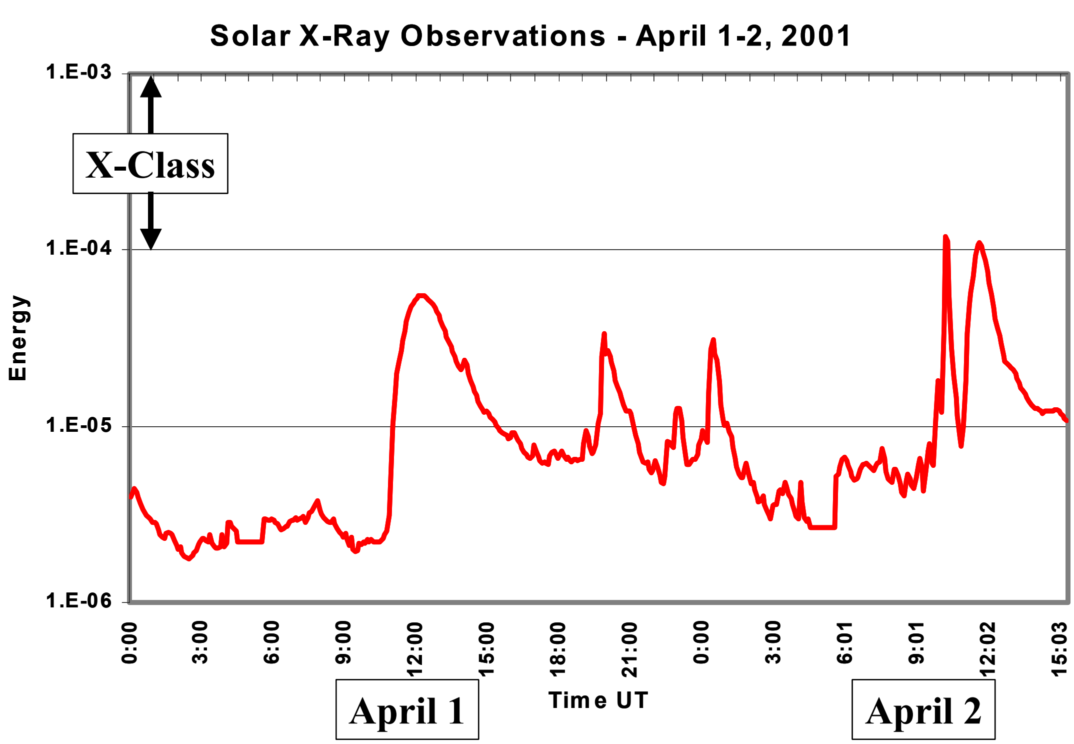

Figure 2- Flare Energies from the Sun over last 39 hours (to April 2– 15:00UT) indicate that sufficient solar energy has been erupted to trigger a possible long-duration geomagnetic storm starting April 3-4.

Further adding to the risk, several of the Active Regions positioned near the center of the Sun may produce additional large flare events over the next 24-48 hours that are also capable of prolonging and intensifying geomagnetic storm activity. In addition to the eruptive activity, a small-but-well-positioned coronal hole is now at the center of the solar disk and sending a continuous high-speed stream of particle radiation earth-ward as well. This raises the risk of enhanced solar wind conditions ultimately arriving at Earth capable of producing long-duration storm activity. The complex solar activity with many regions now actively participating makes the job of several day-ahead projections even more uncertain than usual. These observations at the Sun are only able to provide insights as to release of energy into interplanetary space at a distance of 93 million miles away from the Earth. The transit time from the Sun to the Earth can take several days. Solar wind conditions ultimately determine the intensity and duration of geomagnetic storm conditions and which regions of the Earth will experience the largest impacts.

These flare energies are not sufficient to fully forecast geomagnetic storm events, as enhancement or dissipation can occur in the 93 million mile transit to where this radiation will interact the Earth. No capability exists to acquire any further quantitative data until it arrives with the solar wind. The solar wind conditions can be quite variable given the same solar energy input, and these conditions will ultimately determine the nature of the geomagnetic storm events that unfold. At a point approximately 1 million miles upstream, a solar wind monitoring satellite will be able to detect the strength of the solar wind and provide a nominal 45 minute warning time of geomagnetic storm conditions. Our clients who are subscribers to our continuous forecast services will receive these updates each minute on solar wind condition changes and the resulting geomagnetic storm activity. The forecast service also provides region and time-specific forecast and observed disturbances over the course of the storm, including GIC-levels and impacts on the entire client power system.

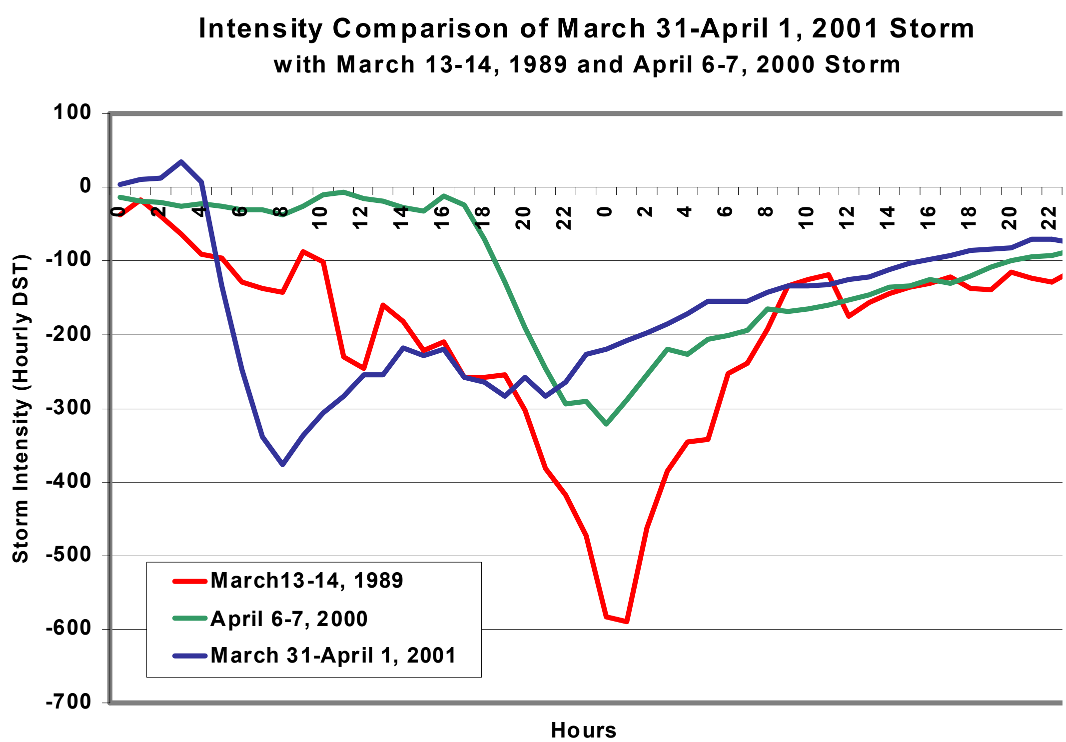

Figure 3 – A comparison of the March 31, 2001 storm indicates that this storm was (as projected) at a level of intensity between the storms in April 6-7, 2000 and the March 13-14, 1989 Superstorm. The storm built rapidly in the early hours but deteriorated over the rest of the two-day period.

Review of March 31, 2001 Geomagnetic Storm Activity

As we had advised on March 29, the storm that occurred on March 31 had an intensity (on a planetary level) that was less intense than the March 13-14, 1989 Superstorm but a bit more intense than the April 6-7, 2000 Storm. Figure 3 shows a plot comparing these three storms by measuring the DST readings near the equator. The DST reading gives a proxy for the amount of energy deposition that occurs over time into the Earth's magnetosphere. As shown, this storm started off with a rapid level of growth compared to the other storm events. However, solar wind conditions did not sustain for long-enough durations to continue building the intensity of the storm. Some aspects of the storm produced regional intensifications that had power system operational impacts. In general terms, this storm was strong, but storms can and have occurred that could be a factor of 5 to 10 times more intense. Only minor enhancements in solar wind conditions would have been necessary to create a significantly higher intensity storm scenario.

Region and Time Specific Review of Storm Activity and Impacts

The storm conditions exhibited several important phases that would have the possibility for impacts on power system operations. The times and locations of these impacts can be summarized as follows:

Sudden Storm Commencement (SSC) – 00:53 UT

At 00:23UT, the solar wind monitoring satellite detected the arrival of a large high-speed solar wind shock front. This large shock pushed in the dayside magnetosphere four or more earth radii and produced a wide spread, but short-duration geomagnetic field disturbance which was observed at approximately 00:53 UT around the world. The region of highest-intensity would have been centered over the Pacific and at low-latitudes. Figure 4 provides an illustration of the highest intensity regions that would have experienced the disturbance.

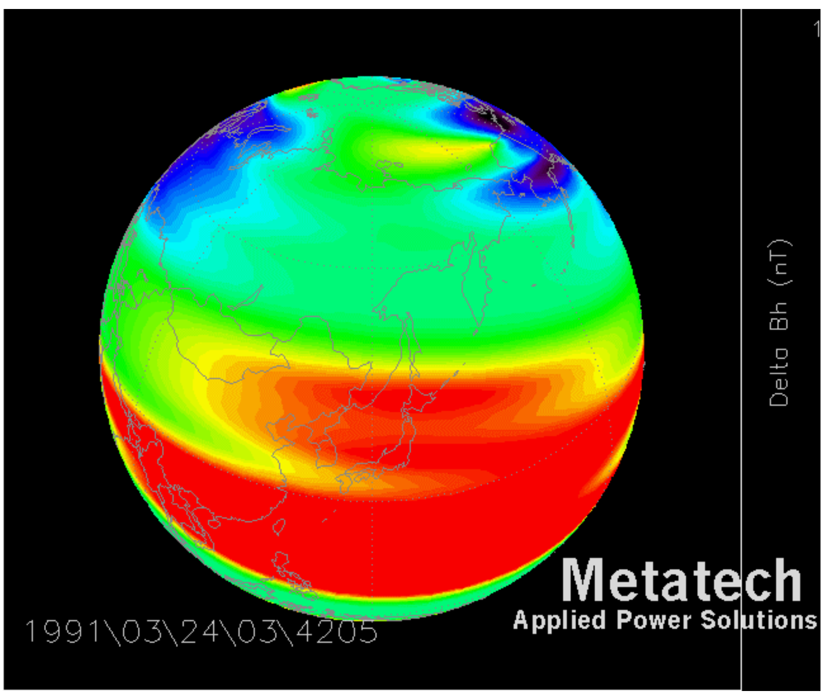

Figure 4 – Regions of highest intensity magnetic field disturbance due to SSC event at time 00:52-00:55 UT. Large GICs could result across broad regions across Japan, Korea, China, India, etc.

Even though North America and Europe where located quite distant from the highest impact regions, sizable shocks would have resulted in these regions, capable of producing large but brief GIC's. Some power system disturbances were observed in New York due to this event, as an example of the widespread footprint of these shocks.

Preliminary data indicates that this particular SSC was not a particularly large event relative to events that have been previously observed. Sizes that are a factor 5 times larger can be expected to occur in the future. Other times of the SSC onset would have placed the most intense portions of the storm geographically at different regions of the planet. A SSC shock at time 12 UT would have been centered over Western Europe and Africa. Time 18 UT would have placed the disturbance over the middle of North America. These type of disturbances have caused numerous power system operational problems. They are particularly problematic due to the broad geographic exposure, and they occur mid-day locally (during system load peaks).

Electrojet Activity Storm Intensifications 02-08 UT

Beginning around time 02 UT, the solar wind magnetic field turned strongly southward beginning the growth of the main phase of the geomagnetic storm. These solar wind conditions persisted until approximately 08 UT. The coupling caused by the solar wind began a process of building unstable magnetosphere structure that produced substorms and electrojet activity at high-latitude regions and the build up of the equatorial ring-current. The electrojet activity particularly energetic from times 05-08 UT throughout North America and Western Europe. In North America, magnetic field disturbance activity was particularly intense along the US-Canada border. In Northern Minnesota magnetic field disturbances reached approximately 600 nT/min (this is a proxy for level of GIC in a region). Other observations indicate levels from 200 to 300 nT/min along the US-Canada border. For perspective, a larger storm has the potential to produce intensities up to 2000-3000 nT/min in these same regions. Similar intensity disturbances were observed at similar times across Europe, with observatories as far south as Germany recording geomagnetic field disturbances. In the southern hemisphere, activity likely extended as far north as New Zealand and southern Australia.

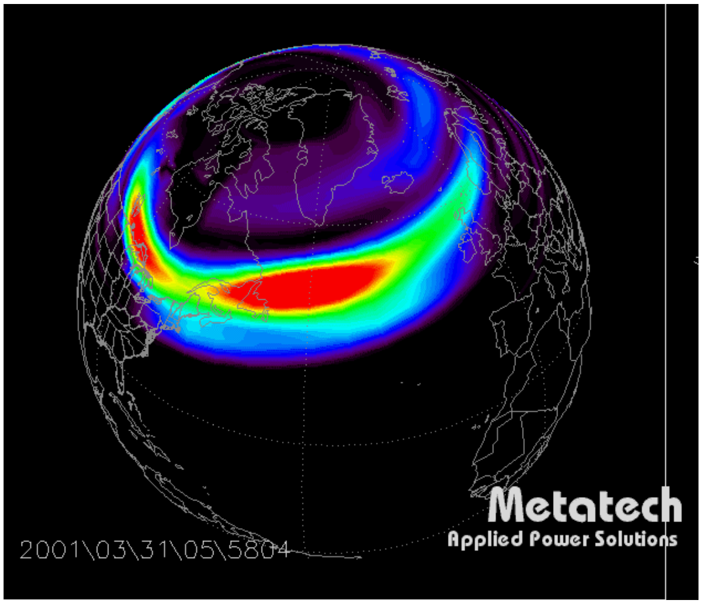

Figure 5 – Forecast Electrojet conditions 06 UT on March 31, 2001 over eastern North America and Western Europe.

At lower latitudes, the intensification of the equatorial ring-current is likely to have caused low-level GIC's but for very long-durations. This storm process would cause GIC sufficient to half-cycle saturate exposed transformers and lead to possible internal heating concerns.

Electrojet Activity Storm Intensifications 14-24 UT

At 08UT, the solar wind polarity turned sharply northward and remained this way until 14UT, at which it turned southward once again until 22 UT. This prolonged southward orientation re-started the growth phase of the geomagnetic storm. This began a process of substorm activity and development and intensification of electrojet activity over broad regions. The timing of this activity meant that regions of Europe would experience the most intense activity caused by the storm. Substantial geomagnetic field disturbances were observed over this entire time interval. Particularly large impulses were observed at around times 16 UT and 18UT from Sweden through the United Kingdom, and as far south as

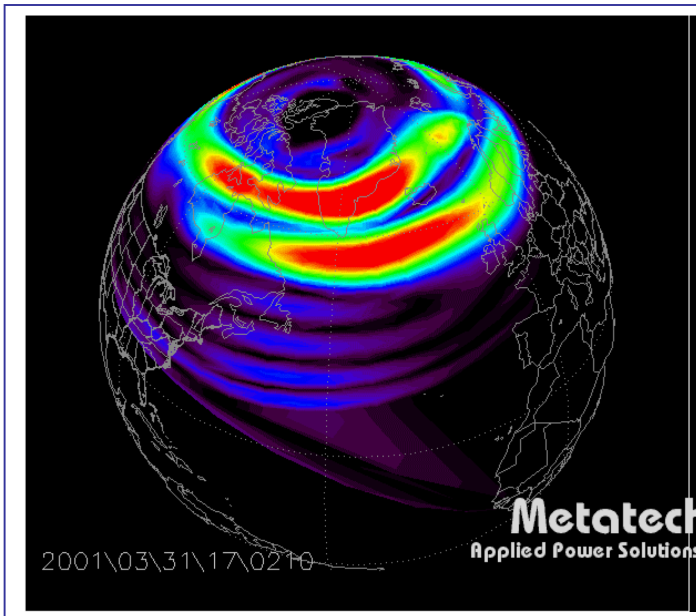

Figure 6 – Forecast Electrojet conditions 18UT on March 31, 2001 over eastern North America and Western Europe.

the northern portions of mainland Europe. Similar intensifications could have been occurring over the southern hemisphere as far north as South Africa. North America experienced lower levels of activity during these times (northern Minnesota observed 400 nT/min impulses around 23 UT).

Long-duration GICs would have again been observed at low-latitudes during this period of storm interval as well, due to continual build-up of the equatorial ring current located broadly over these regions.

At time 22UT, a second solar wind shock arrived, which would have again produced a small SSC. More importantly, its arrival heralded solar wind conditions that lead to the rapid decline of the storm, as interplanetary magnetic field strengths in the solar wind fell almost immediately to near zero.

The Problem with Indices and Real-time Monitoring

The rapid evolution of storm conditions on a planetary scale again illustrated the limitations of real-time monitoring and K Index notices and warnings to provide useful lead-time for operators of critical infrastructures that can be impacted by disturbances. A planetary level SSC shock occurred around 00:53-00:55 UT, this solar wind shock was first observed by our forecast system at 00:24 UT, a lead-time of approximately 30 minutes. This solar wind speed stayed relatively constant throughout the rest of the storm, which provided a consistent 30-minute lead-time throughout the storm of activity. NOAA did not issue their K6 warning until 00:54 UT. At 06:30 UT the largest North American substorm event occurred, starting with growth of a large west-ward electrojet over the continent beginning at 6UT, with the largest impulse in the magnetic field occurring around 6:28UT. NOAA issued both their Warning for A >50 and Observed A>50 storm alerts in the same minute at 06:24 UT.

Real-time observations of GIC would have been even more problematic due to the lag inherent in observing rapidly changing space weather disturbance conditions. GIC's can be at levels below threshold one minute and suddenly grow to very large level the next minute, too fast for any meaningful human situational awareness and intervention. Neither K Indices nor monitoring of GIC at a handful of locations provides the critical infrastructure operator with a detailed overview of the storm situation. The K indices are very vague as to which region or specific time the activity is expected, Figures 4, 5 and 6 illustrate that storms can be viewed in manner similar to the way ordinary weather is presented. This capability also allows GIC and GIC-impacts to be determined throughout the network.

Conditions Needed for a Superstorm

This storm event illustrated the potential of a moderate storm and the widespread impacts they may have upon operation of critical infrastructures. Even though this storm rated a K9 intensity at times, the more objective measure of the storm for GIC impacts comes from reviewing specific impulse intensities and locations, as discussed earlier. As mentioned, disturbance intensities could be a factor of 5 to 10 times higher at many locations than those caused by this storm. The primary solar wind conditions that determine the storm characteristics are intensity/direction of the interplanetary magnetic field and the speed of the solar wind. These variables determine the strength and location of SSC shocks and electrojet patterns. While speed was high for this storm, speeds can increase for more energetic storms by at least a factor of two. The strength of the interplanetary magnetic field could also increase by more than 50% compared to intensities observed in this storm. Another key factor was the duration of the storm, the longer the storm persists, the lower in latitude the electrojet boundaries can stretch. Electrojets extending down to the Gulf of Mexico have been observed in prior storms. Subsequent shock events can also act to intensify a storm. The secondary shock that occurred at 22UT March 31, extinguished the storm because it no longer contained intense magnetic fields. It could be just as likely that secondary shocks will have even more intense field intensities and because the magnetosphere is already highly disturbed, it has an effect somewhat like throwing kerosene on a fire and leading to a true Superstorm scenario.

Long-term climatology indicates that we have experienced on average 1 or 2 Superstorms per solar cycle (or every 11 years). It has now been 12 years last month since the last Superstorm of March 13-14, 1989.

John G. Kappenman, Metatech
218-727-2666, john@metatechcorp.com