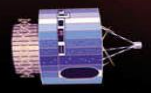
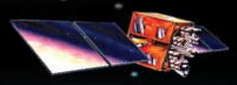
Solar-flare induced disturbances in the U.S. electric grid and their economic impact

Space Weather Week, Boulder, CO
Sarah Mitchell / Karel Schrijver
Lockheed Martin ATC





April 26, 2012

Worst Case Emphasis

- Large solar explosions are responsible for space weather that can impact technological infrastructure on and around Earth
- Media and science community alike put emphasis on “worst case scenario” of solar weather (unusual and infrequent events)

Substantial even short of extreme

- We conducted a study using public information that reveals a general correlation between large but not extreme solar flares and disturbances in the U.S. electric grid; these disturbances have an impact of $5-8 billion a year on the GDP

Getting into it

- Who we are
- A bit of background on solar weather and how it affects power grids
- Input for the study
- Putting the data together
- Review of the correlation
- Economic impact
- Further thoughts
- In conclusion…

Who we are

- Karel Schrijver
  - Lockheed Martin Senior Fellow – Physicist
  - Research includes Solar and Heliospheric Magnetic activity, as well as the activity of stars other than the Sun. In recent years, his work has focused on space-weather phenomena, in particular on the coupling of the Sun's magnetic field to interplanetary space.
  - PI for the SDO AIA instrument
- Sarah Mitchell
  - Lockheed Martin – Senior Systems Engineer
  - Program Manager for the SDO AIA instrument

CMEs and GICs

- The main cause of GICs is the interaction of the magnetic field carried within CMEs with the geomagnetic field
- With speeds of 400–2500 km/s, it takes some 1–4 d for CMEs to propagate from the Sun to the Earth (typical transit time of 2–3 d)
- The magnitude of GICs depends on:
  - Location and time of day (through the geomagnetic position relative to the Sun-Earth line) at impact
  - On the ground conductivities in a wide area around any particular site for depths from sea level down to in excess of 100 km

Correlation

- As the (combination of) parameters that best defines geo-efficiency of solar events remains elusive, we take an end-to-end view, looking for correlations in the U.S. electric grid with the source of major perturbations in the heliospheric field:

We analyze frequency patterns of power-grid disturbances prior to and following major solar flares in a superposed epoch analysis

Input Data #1

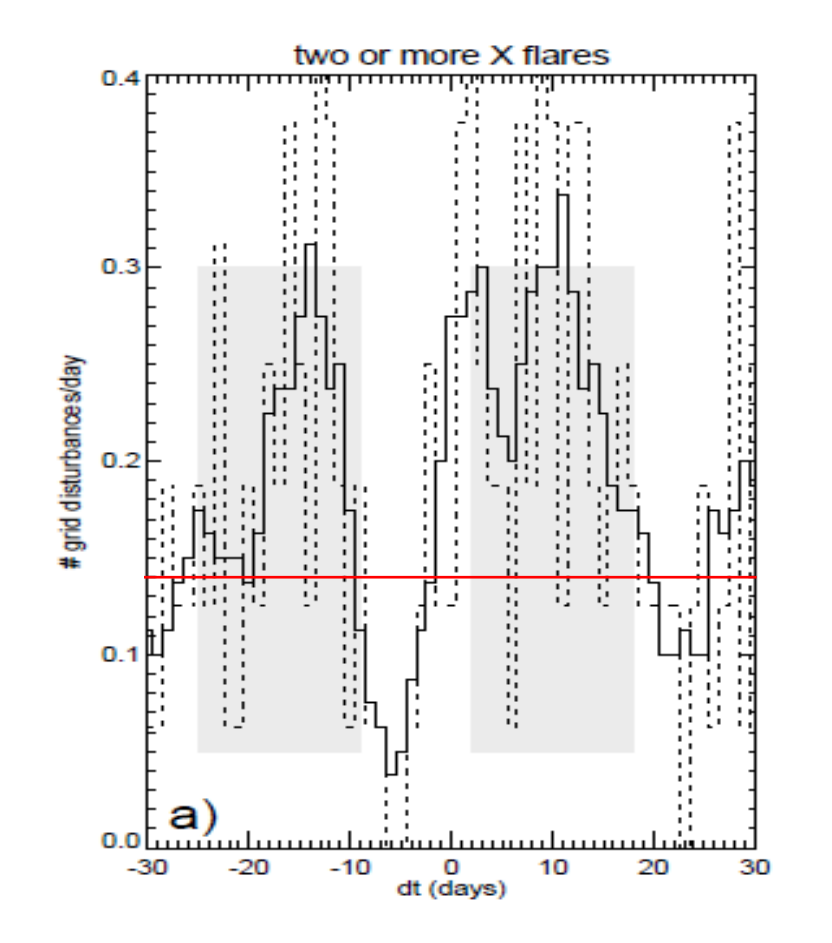
- A compilation of “system disturbances” published annually by both the North American Electric Reliability Corporation (NERC) and the Office of Electricity Delivery and Energy Reliability of the Department of Energy (DOE)
- These include “electric service interruptions, voltage reductions, acts of sabotage, unusual occurrences that can affect the reliability of the bulk electric systems, and fuel problems”
- We use the combined disturbance reports for 1216 events in the period 1992 through 2010 (*1)*

Input Data #2

- The catalog of solar flares compiled by NOAA
- We limited our study to large flares of GOES classes M and X
- For the period 1992-2010 there were 1897 M- and X-class flares for 1054 distinct dates

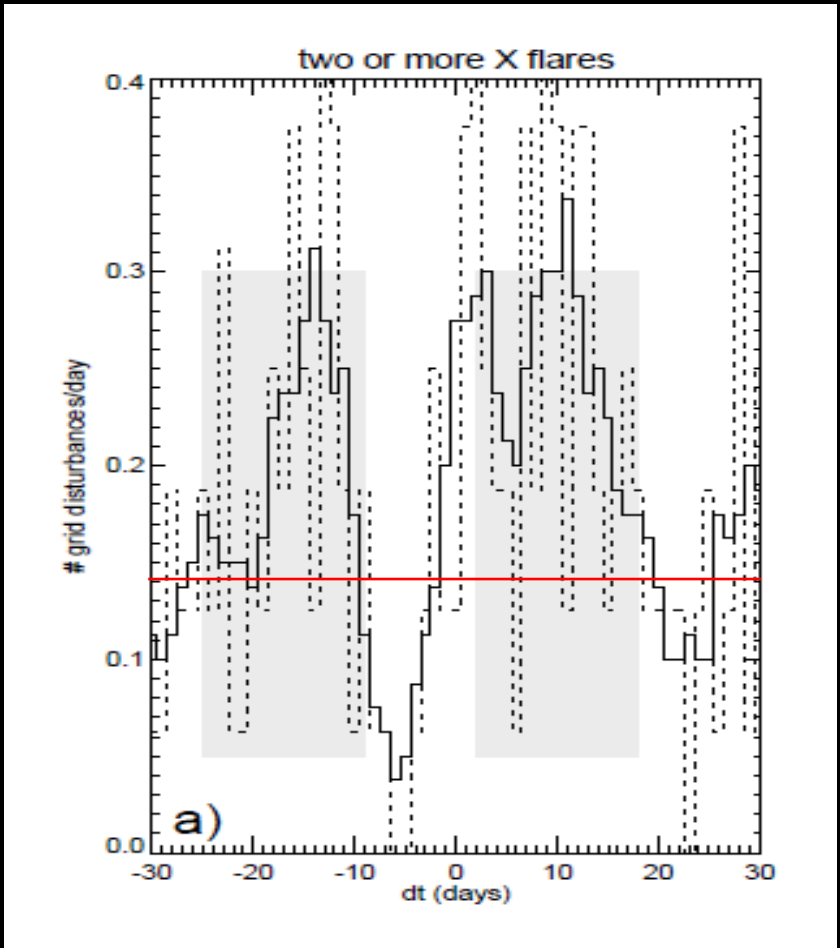
- Nearly half of all M-class flares and over 90% of X-class flares are associated with CMEs (*2)*
- Thus, most such flares affect the dynamics of the heliospheric field, and thereby can potentially couple into the geomagnetic field

Parts of the plot



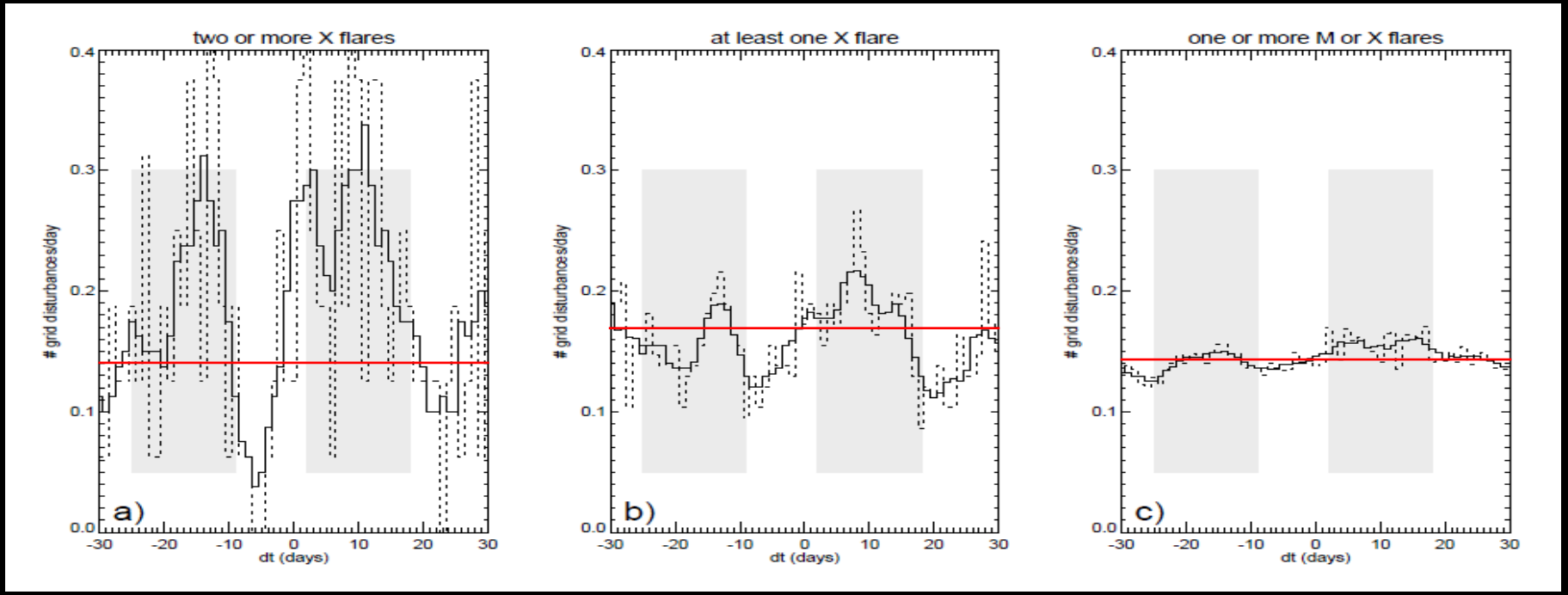
- Dotted Histogram: Daily count of grid disturbances
- Solid Histogram: 5-Day running average
- Red line: Zero line – defined as 1 day before flare occurs
- Gray boxes: The period of enhanced disturbance frequency; the leftmost boxes repeat those intervals shifted by one 27-day Bartels period which characterizes the mean bulk rotation of the heliospheric field structure

Making sense of it



- Daily frequency for grid disturbances relative to dates of two or more X flares within one day (16 cases)
- The frequency of grid disturbances, n_{dist}, following these flares is nearly doubled relative to the rate of ~ 0.14/d found one day prior to those flares

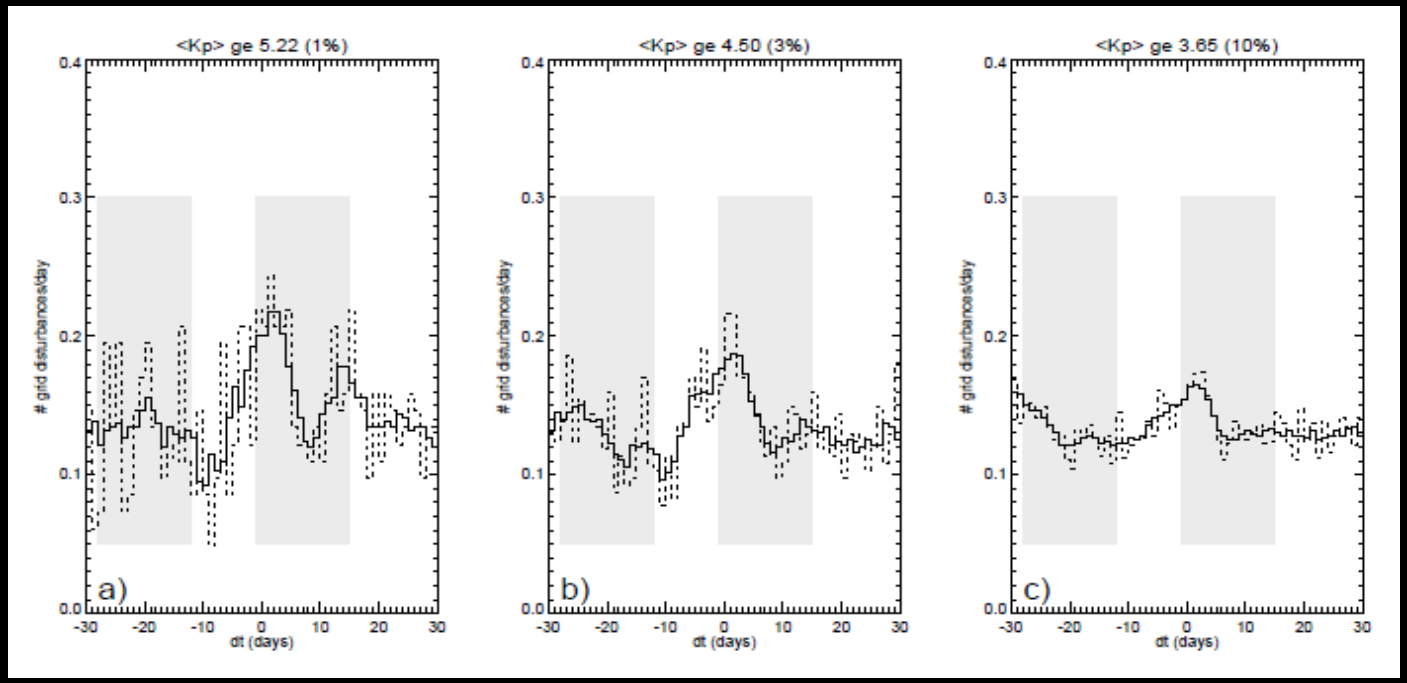
Repeating pattern



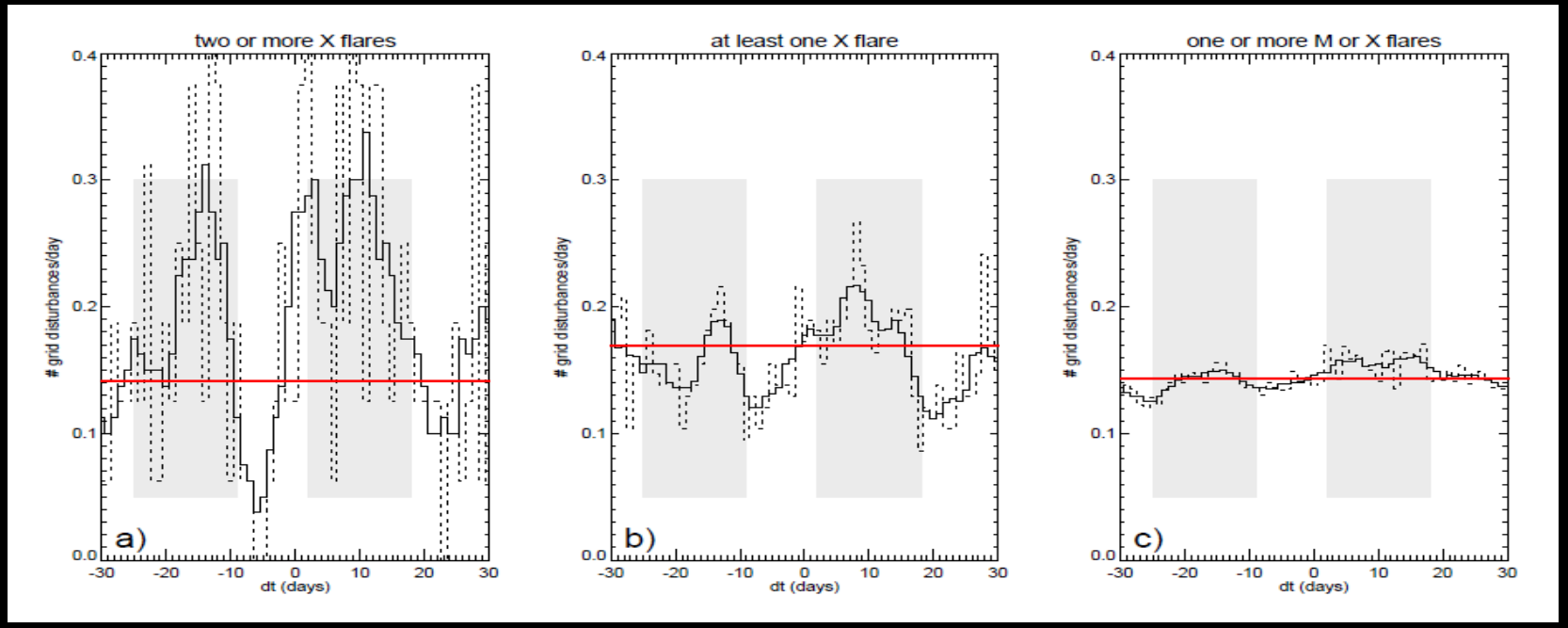
- After at least one X-class flare (116 cases), disturbances increase ~25%
- After at least one M-class flare (1897 cases), disturbances increase ~7%

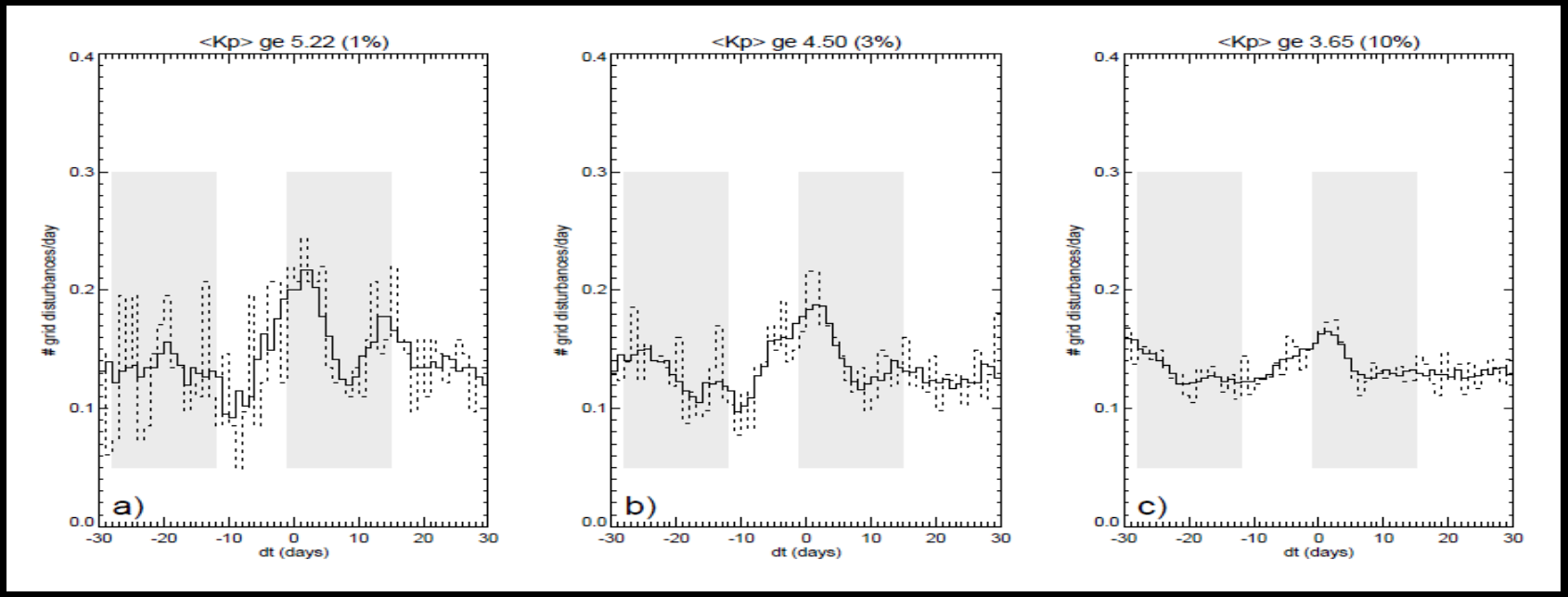
Further correlation

- Major-flare dates and dates of unusually high geomagnetic activity (Kp index) yield comparable patterns for grid disturbance frequencies in a superposed epoch analysis



Note: Gray boxes adjusted to zero time for Kp


two or more X flares
at least one X flare
one or more M or X flares
grid disturbances/day
dt (days)
a)
b)
c)


<Kp> ge 5.22 (1%)
<Kp> ge 4.50 (3%)
<Kp> ge 3.65 (10%)
grid disturbances/day
dt (days)
a)
b)
c)

Some thoughts

- We suggest that glancing blows from CMEs may reach Earth later than the 1–4 d which the leading CME front needs to pass the orbital distance of Earth
- The existence of an enhanced disturbance frequency prior to the time of major flaring reveals that, in addition to the direct effects of eruptive flares, the structure of the heliospheric field is affected by the presence of the flaring region, changing the properties of the solar wind or of its magnetic field
- This hypothesis is consistent with the existence of a period of enhanced n_{dist} about 27-d prior to the enhancement associated with major flaring, which is the Bartels period of recurring geomagnetic storms related to the rotational properties of the global solar field [*Schrijver, 2005*]

Economic impact

- A DOE report (*3, 4*) puts the costs of "power outages and power quality disturbances" to the overall economy between $25 and $180 billion annually
- A survey of the impacted sectors of industry by Electric Power Research Institute (EPRI) (*5*), for example, resulted in an annual impact of approximately $119-188 billion per year
  - The study found that businesses are affected by 3.9 electric power outages in a typical year, with almost half of these less than 3 min. in duration (which are "often not recorded in the 'official' outage statistics maintained by utilities and public utility commissions")
- If space-weather induced grid disturbances are comparable to the typical other disturbance, then our finding that ~4.0% of grid disturbances are attributable to space weather suggests that the full economic impact could be $5-8 billion per year

Some things to consider

- Only larger disturbances are reported to NERC-DOE
- Impact estimate includes costs to full production recovery, which substantially exceeds costs associated with the duration of a grid disturbance
- No outages were attributed to solar weather as a primary or contributing cause in the NERC-DOE reports in the 19 y period studied

In Conclusion…

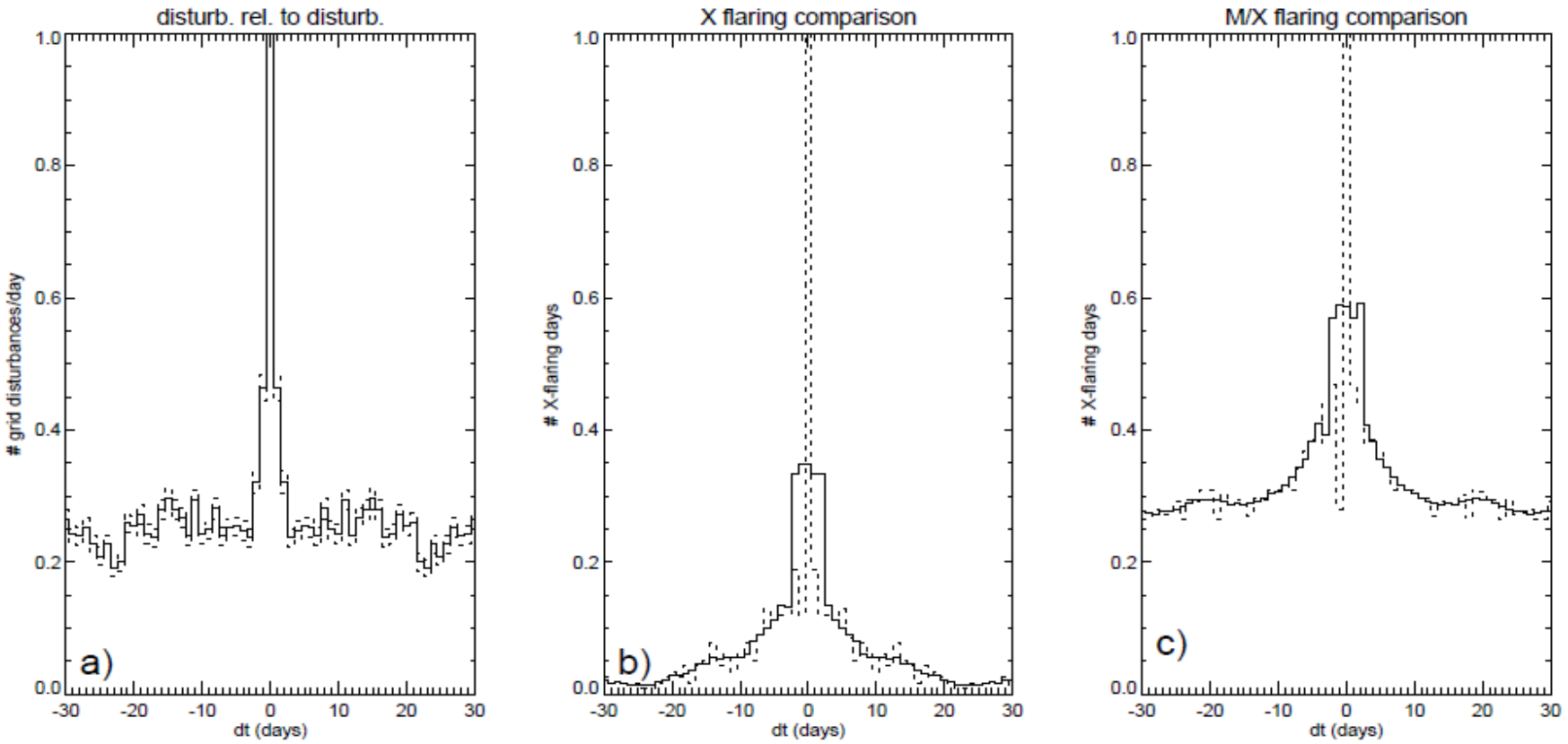
- The lack of recognition of solar flares as a cause of grid disturbances may reflect that space weather conditions can increase the susceptibility of the electric power grid to a variety of other perturbations
- These other perturbations may be identified as the cause of the disturbance, but we propose that frequently they are merely the proximate rather than the ultimate cause
- The correlation of grid disturbances with major solar flaring reveals a weakness in the US power grid not recognized to date
- The substantial economic impact of $5-8 billion per average year stemming solely from electric power grid disturbances associated with large solar flares warrants further investigation


Questions?
Thank you
for your time!

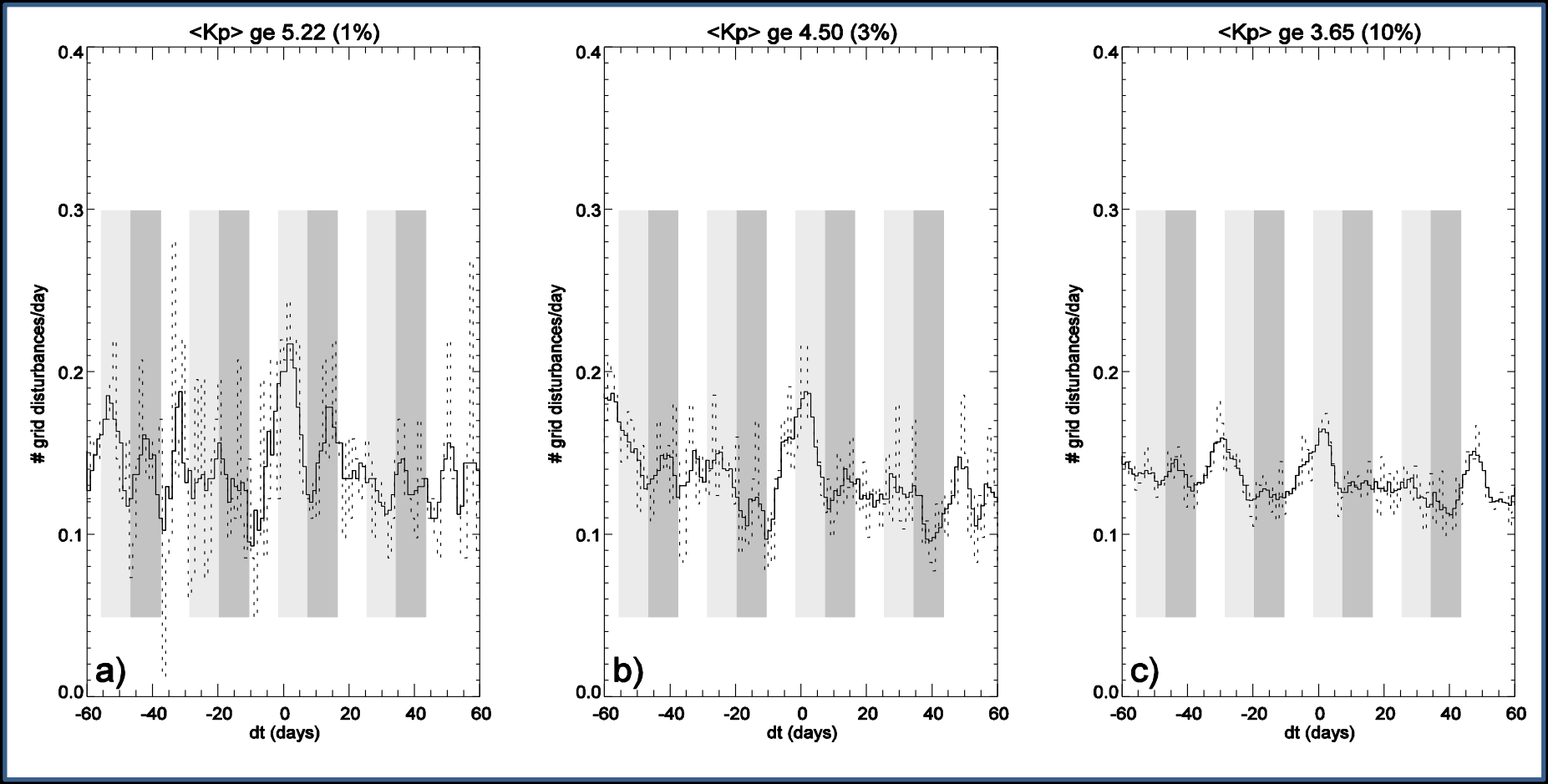
References

1. http://www.nerc.com and http://energy.gov/oe/office-electricity-delivery-and-energy-reliability
2. C. J. Schrijver, *Advances in Space Research* ***43, 739 (2009).***
3. US Dep. of Energy, *Grid 2030: A national vision for electricity's second 100 years (DOE: Office of electric transmission and distribution,Washington,* DC, 2003).
4. D. Lineweber, S. McNulty, *The cost of power disturbances to industrial and digital economy companies (PRIMEN, Madison, WI, 2001).*
5. Electric Power Research Institute, *Electricity sector framework for the future. Vol. I. Achieving a 21st Century transformation (EPRI, Palo Alto, CA, 2003).*

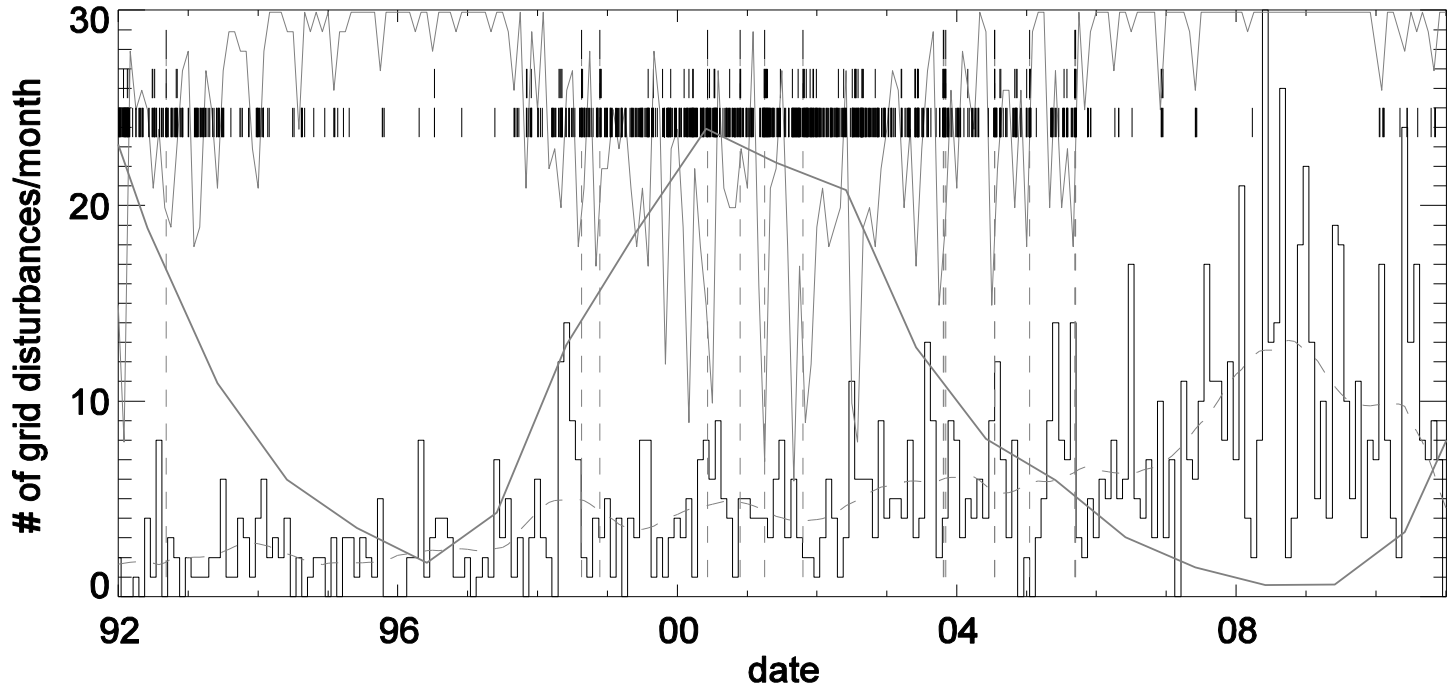
Further statistical analysis



Wider date range for Kp / Disturbances Correlation



A different look



- **Solid Histogram:** Monthly frequency of grid disturbances
- **Dashed Line:** 12-month running average of grid disturbances
- **Black Bars at Top of Plot:** Dates with (a) one of more M- or X-class flares, (b) one or more X-class flares, or (c) two or more X-class flares
- **Inverted Gray Line:** Monthly count of M and X class flares -- dashed lines downward from largest peaks
- **Solid Curved Line**: Yearly sunspot number (scaled down by a factor of five)

The calm before the storm…

- The ‘‘calm before the storm’’ in CIR/magnetosphere interactions: Occurrence statistics, solar wind statistics, and magnetospheric preconditioning

  -- Joseph E. Borovsky, and John T. Steinberg, June 2006

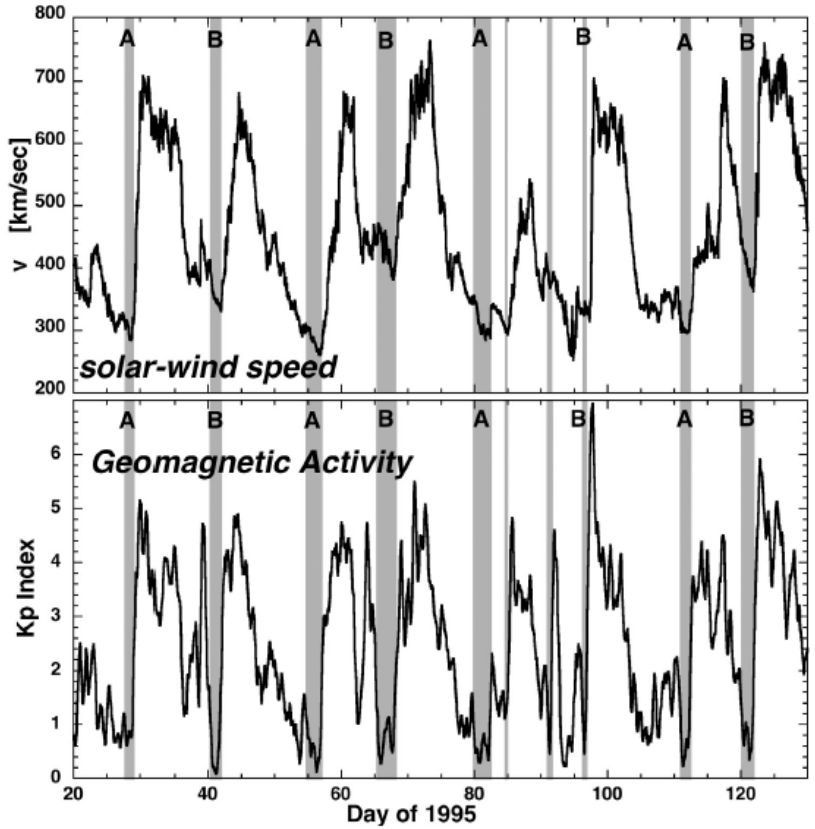


Figure 2. For 110 days in 1995, (top) the solar wind speed as measured by Wind upstream of the Earth and (bottom) the level of geomagnetic activity as measured by a running 12-hour average of the Kp index are plotted. Intervals when geomagnetic activity is very calm are marked in gray. The calm intervals recur on 27-day intervals: one set of recurrent calms are marked with an “A” and the other set with a “B.”