



Carnegie Mellon Electricity Industry Center

Sources of disruption of the power system

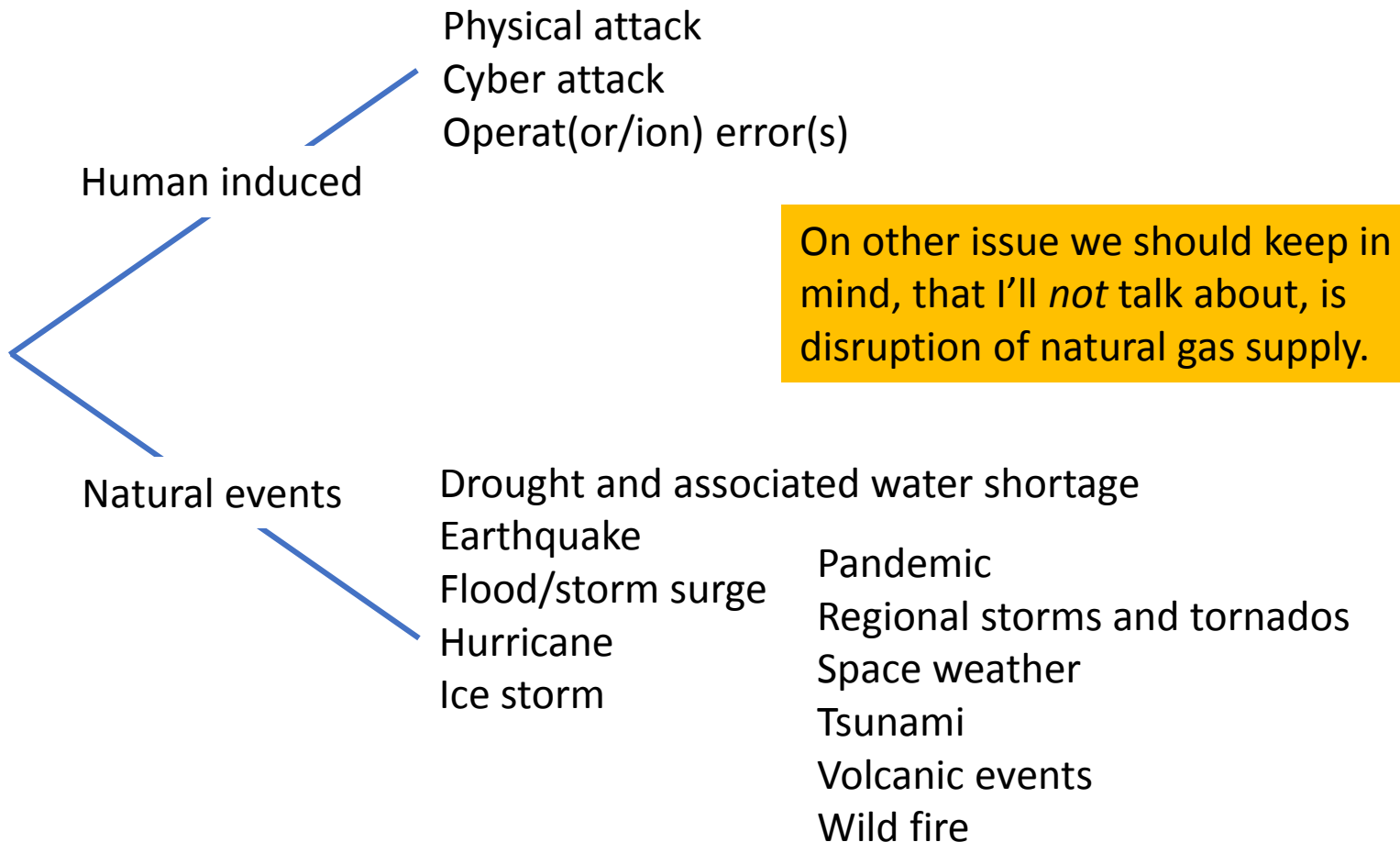
Prof. M. Granger Morgan
Department of Engineering
and Public Policy
Carnegie Mellon University
412-268-2672
granger.morgan@andrew.cmu.edu



engineering and public policy

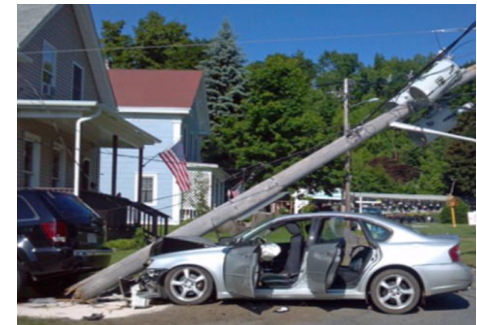
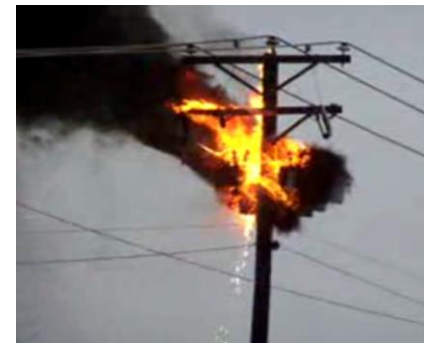
Preparing Technical Leaders to Address Policy Issues
that Involve Science and Technology.

Past and possible future sources of large disruptions



Most disruptions are brief and local

Most causes of power outages, such as lightning strikes, falling trees, squirrel electrocutions, or vehicles crashing into poles, cause little prolonged disruption to daily life. These events result in short term power outages, as evidenced by the median power outage in the United States lasting less than three hours in 2014.



IEEE Benchmark Year 2015 Results for 2014 Data. IEEE Working Group on Distribution Reliability. Available at: <http://grouper.ieee.org/groups/td/dist/sd/doc/Benchmarking-Results-2014.pdf>, Accessed February 8, 2016.

Image sources: wcvb.com; wikipedia; consumerwarningnetwork.com; lightingsafety.com; rhizome.com

SAIDI & SAIFI

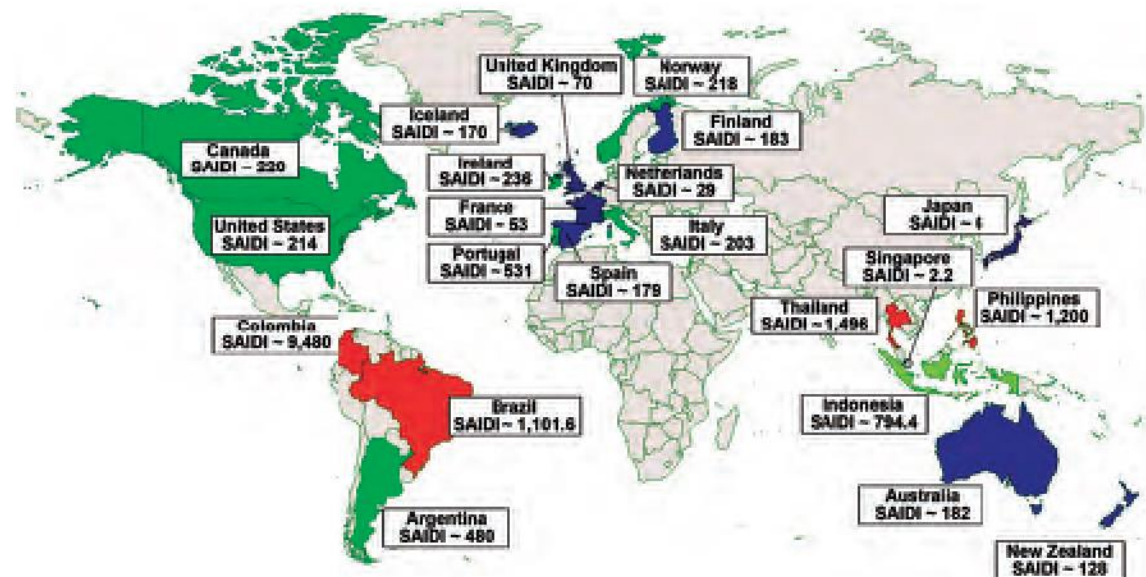
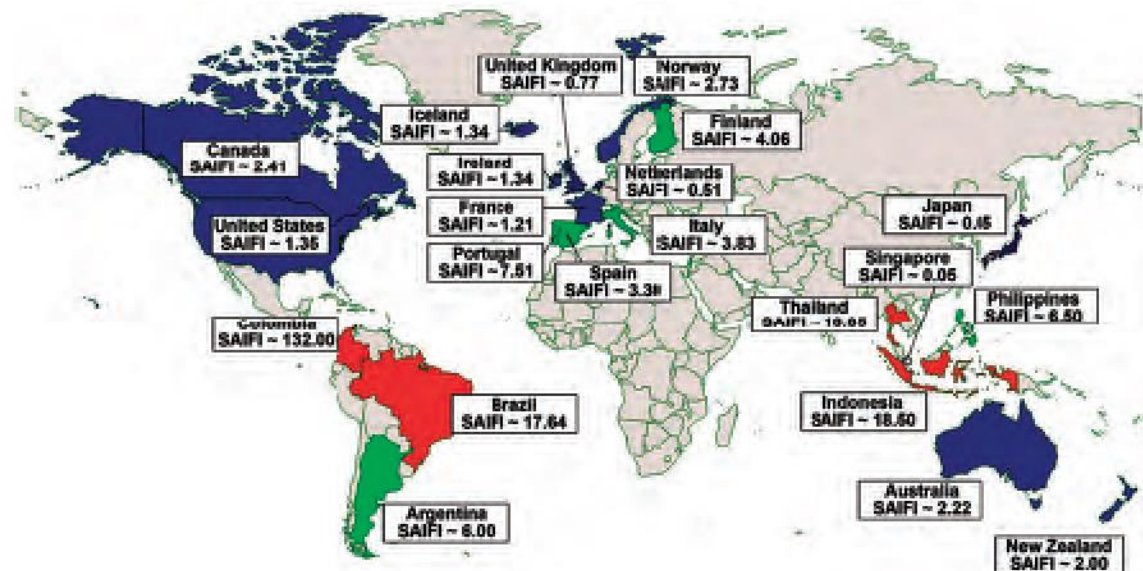


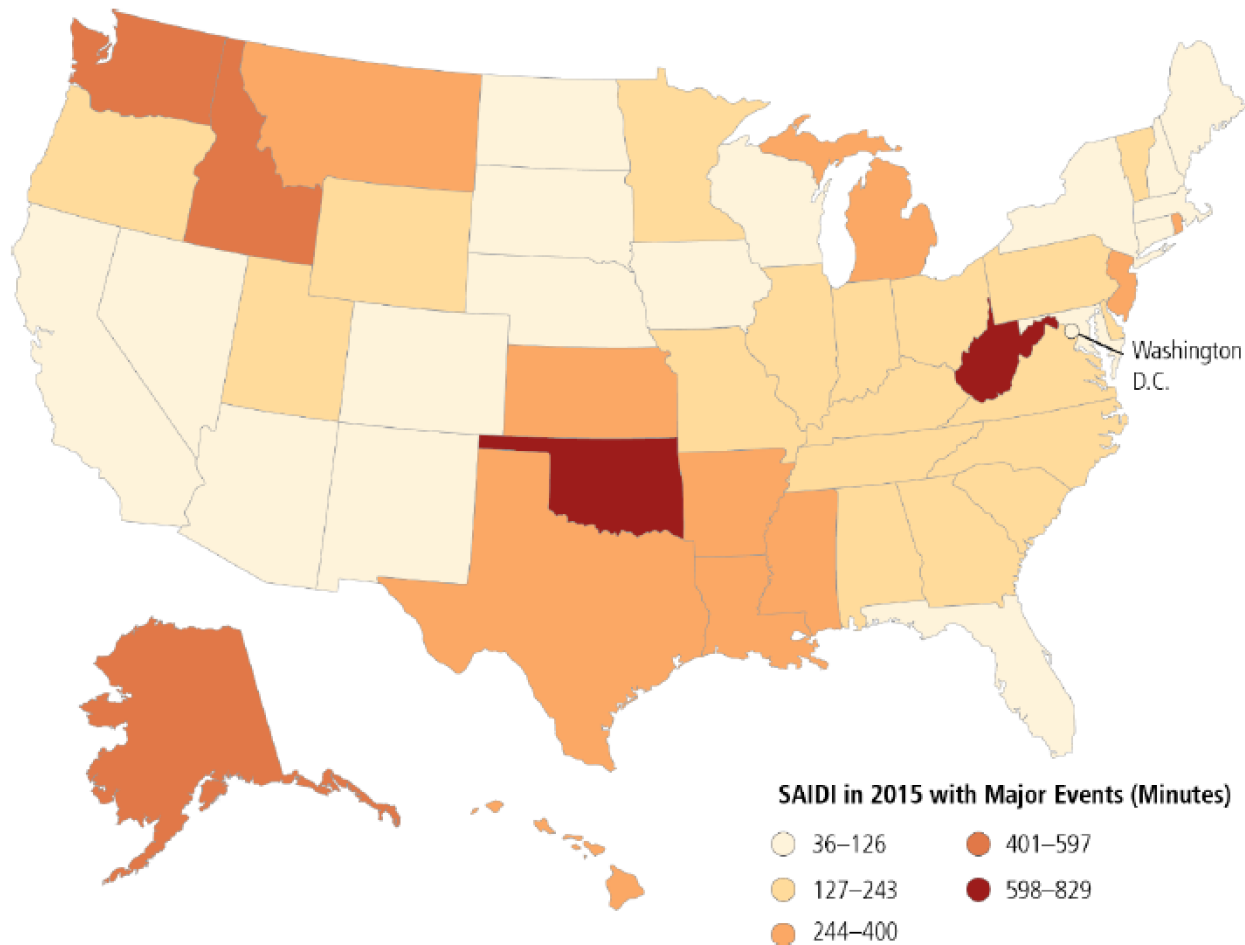
FIGURE 1.2a System Average Interruption Duration Index (SAIDI) indicators internationally for the period 1992 to 2001 (excluding only interruptions caused by major storms and hurricanes). SOURCE: EPRI (2003).



Source: EPRI and reproduced by NRC

FIGURE 1.2b System Average Interruption Frequency Index (SAIFI) indicators internationally for the period 1992 to 2001 (excluding only interruptions caused by major storms and hurricanes). SOURCE: EPRI (2003).

SAIDI by state (2015)



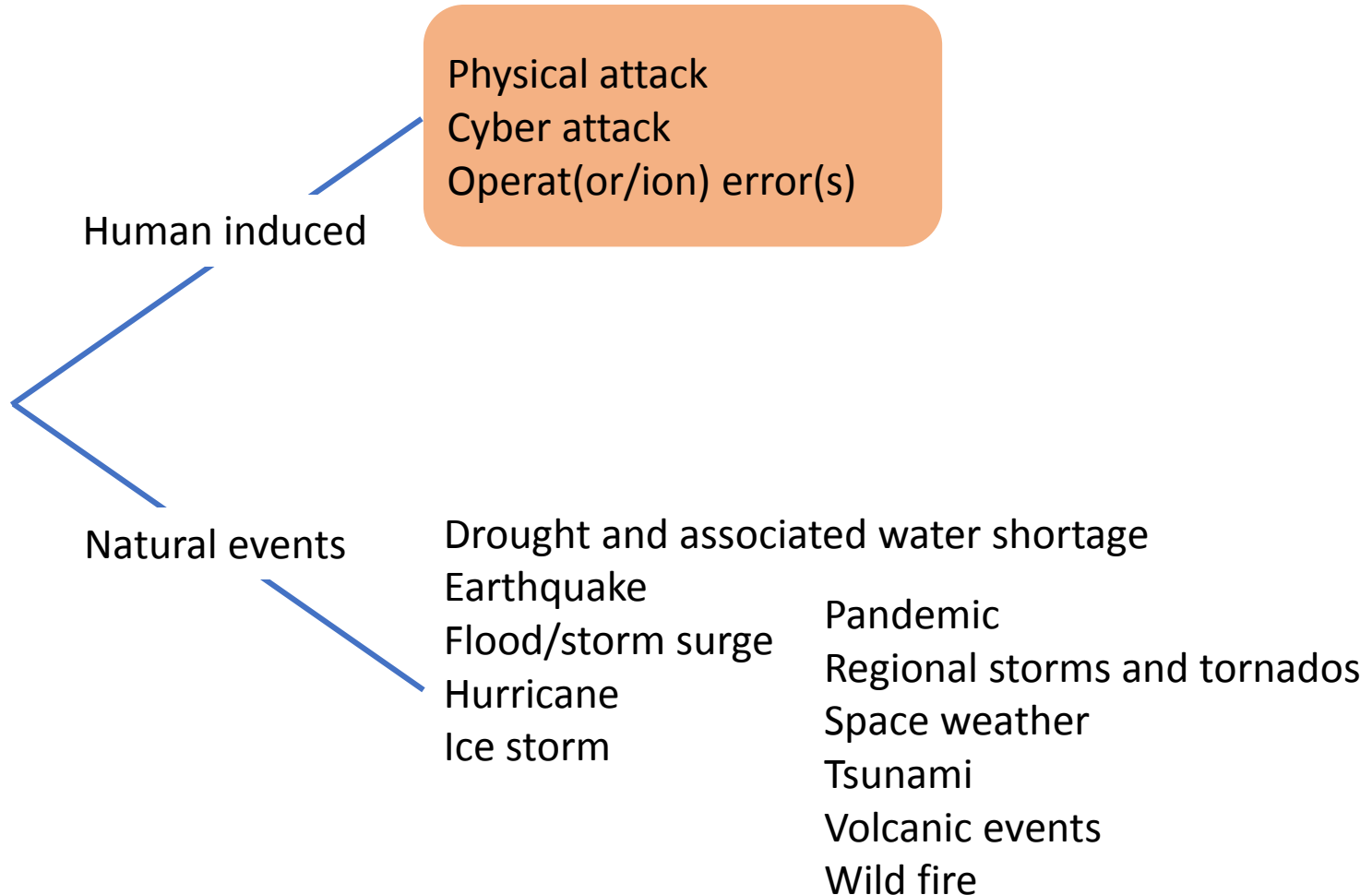
States experienced varying levels of reliability in 2015. A reliable bulk power system does not necessarily mean reliable end-user electricity service because outages often originate on local distribution systems, as reflected in the SAIDI measurements in the above map.

QER: “the average customer experiences 198 minutes of electric power unavailability per year...

The best-performing state had a SAIDI level of 85 minutes a year. In contrast, ...one state had a SAIDI statistic in 2015 of nearly 14 hours of outage for the year...

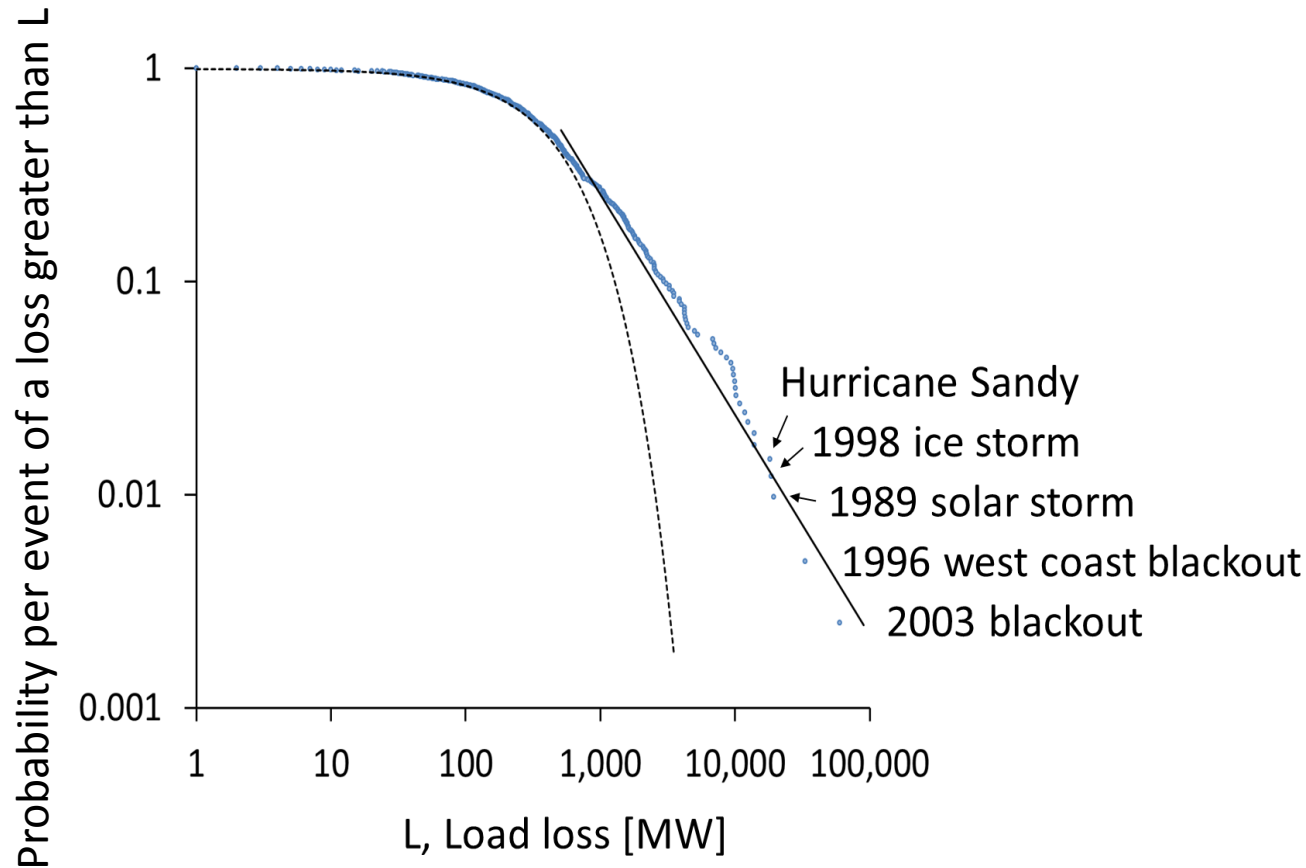
Even this state level of aggregation masks some outliers in the data. There were several utilities with a SAIDI index below 1 minute of outage for the year.”

Past and possible future sources of large disruptions



Large disruptions are more common than one might think

The relative frequency of outages in the U.S. bulk power system over the period from 1984 to 2015. The dashed line fits an exponential distribution to the more frequent events with load loss below 500 MW. Note that large outage events do not fit this line and are much more common than one might expect from an extrapolation of the frequency of smaller events. Data are from the North American Electric Reliability Corporation and the Energy Information Administration Electric Power Monthly.



Terrorism

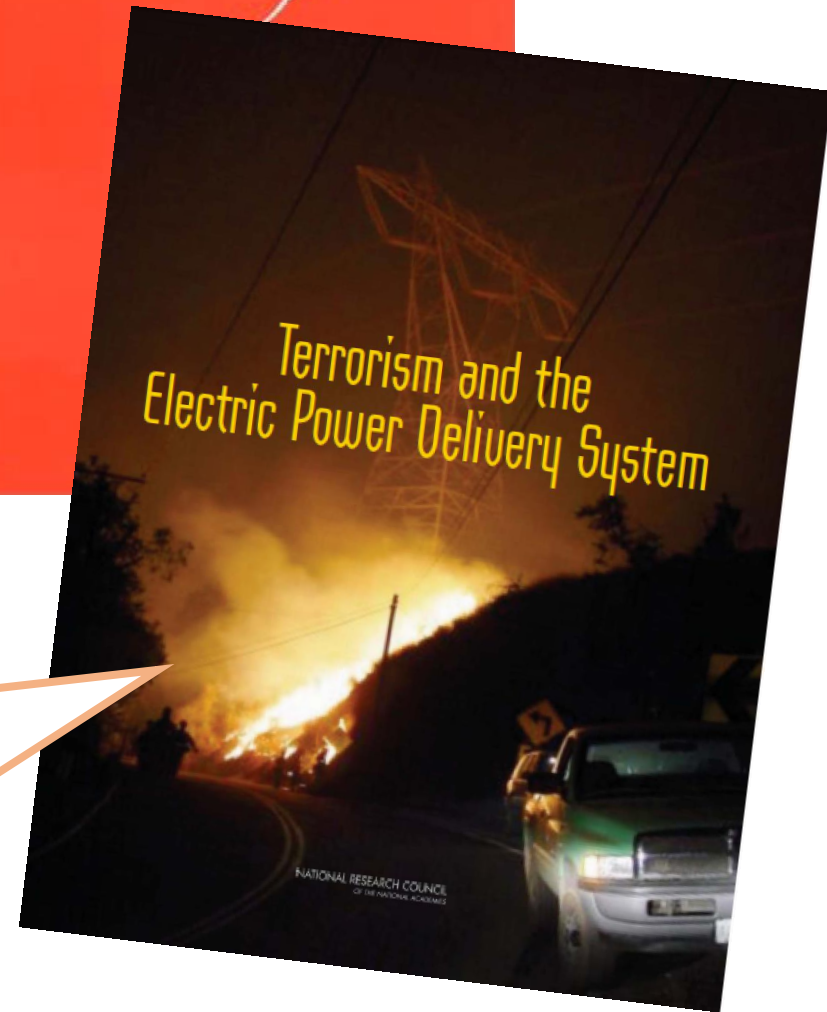
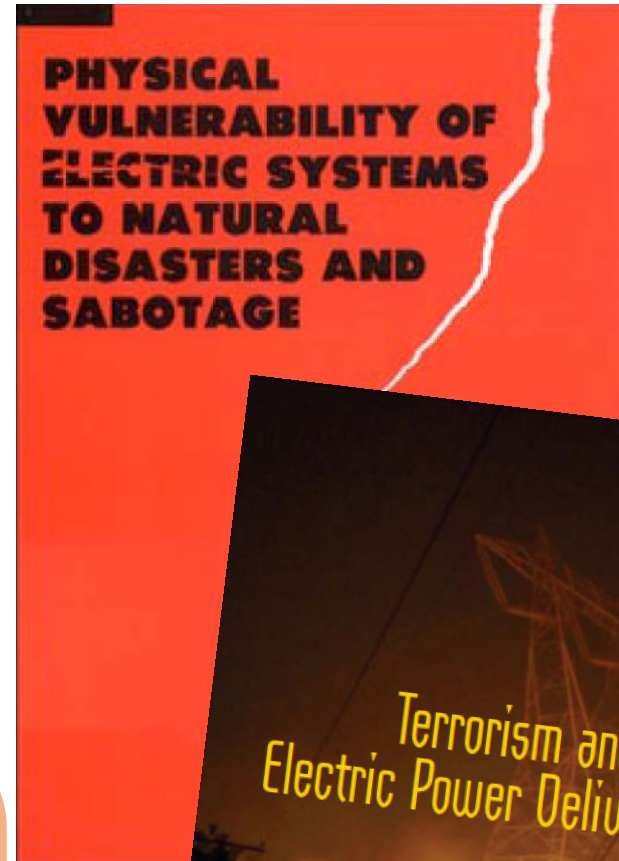
So far the U.S. have been lucky. With the exception of small isolated events there have not been physical attacks on the U.S. power system. However, both a 1990 OTA report and a 2012 report by the National Academies warn that a large coordinated attack could be devastating.

A terrorist attack on the power system would lack the dramatic impact of the attacks in New York, Madrid, or London. It would not immediately kill many people or make for spectacular television footage of bloody destruction. But if it were carried out in a carefully planned way, by people who knew what they were doing, it could deny large regions of the country access to bulk system power for weeks or even months. An event of this magnitude and duration could lead to turmoil, widespread public fear, and an image of helplessness that would play directly into the hands of the terrorists. If such large extended outages were to occur during times of extreme weather, they could also result in hundreds or even thousands of deaths due to heat stress or extended exposure to extreme cold.

**PHYSICAL
VULNERABILITY OF
ELECTRIC SYSTEMS
TO NATURAL
DISASTERS AND
SABOTAGE**

*Terrorism and the
Electric Power Delivery System*

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

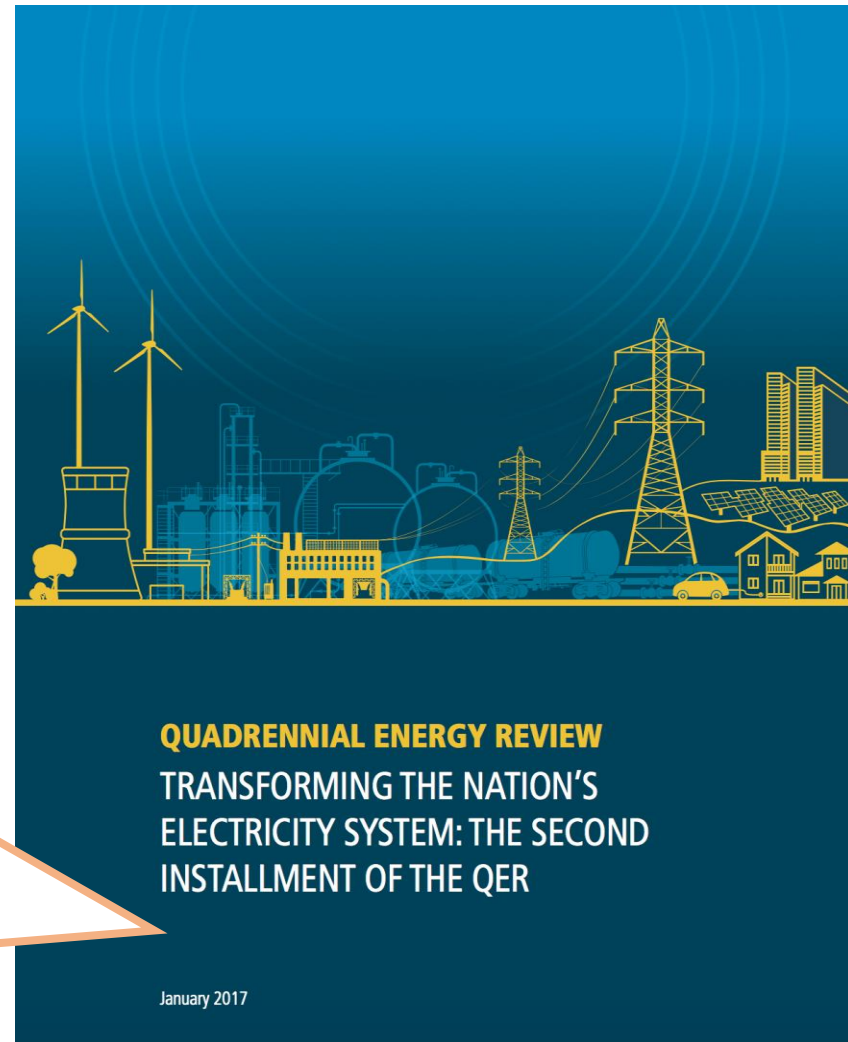


Cyber Attack

While it is much harder to cause wide physical damage or an outage of very long duration, cyber attacks could also be very disruptive (especially if it were conducted repeatedly).

Disentangling the power system from infected cyber controls poses large challenges.

The current cybersecurity landscape is characterized by rapidly evolving threats and vulnerabilities, juxtaposed against the slower-moving deployment of defense measures. Mitigation and response to cyber threats are hampered by inadequate information-sharing processes between government and industry, the lack of security-specific technological and workforce resources, and challenges associated with multi-jurisdictional threats and consequences. System planning must evolve to meet the need for rapid response to system disturbances.



Operat(or/tions) error(s)

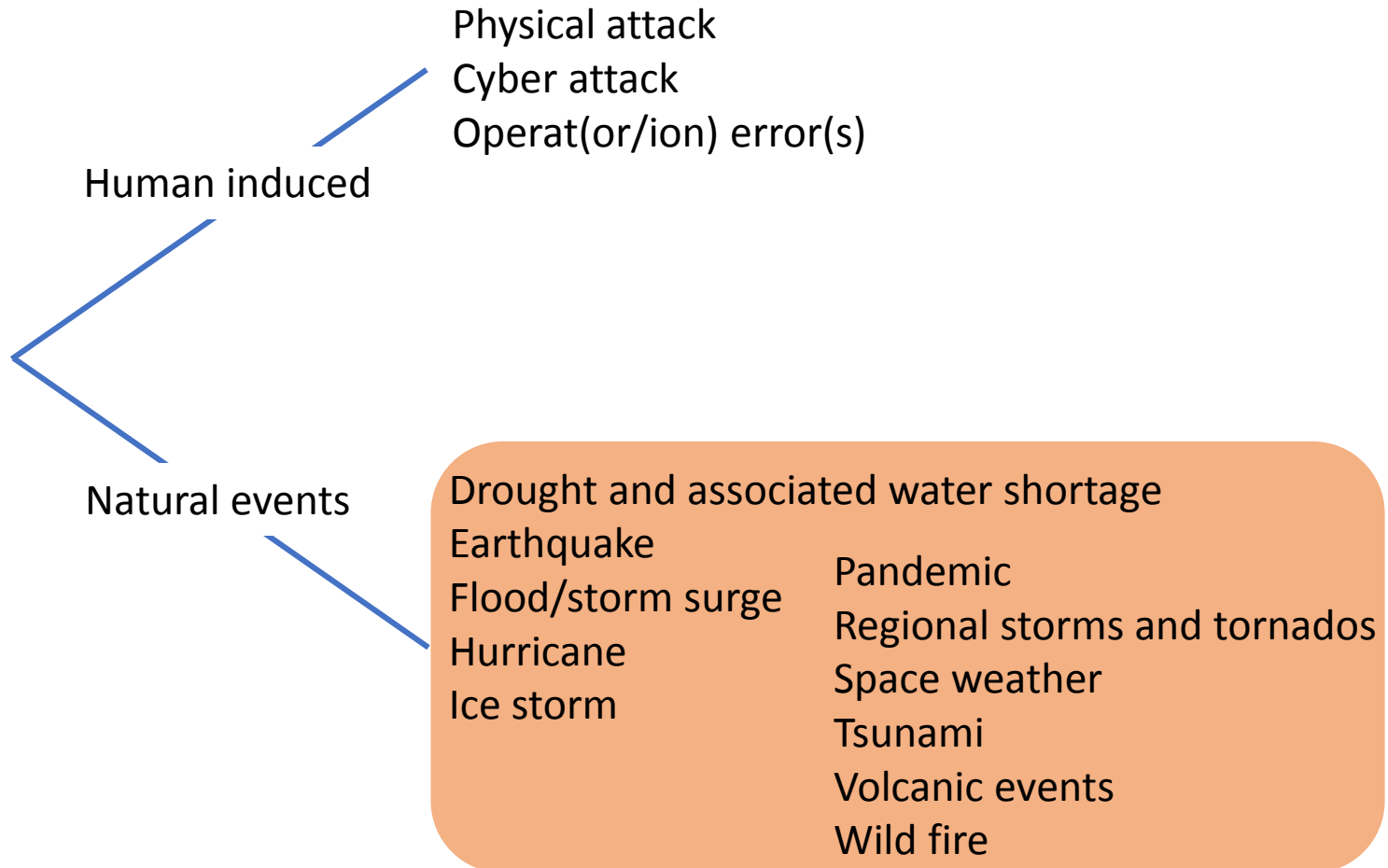


Image source: New York Times

Situational awareness is critically important.

While information technology can be very helpful, if operators become overly dependent it can be hard to get up to speed when a serious problem develops.

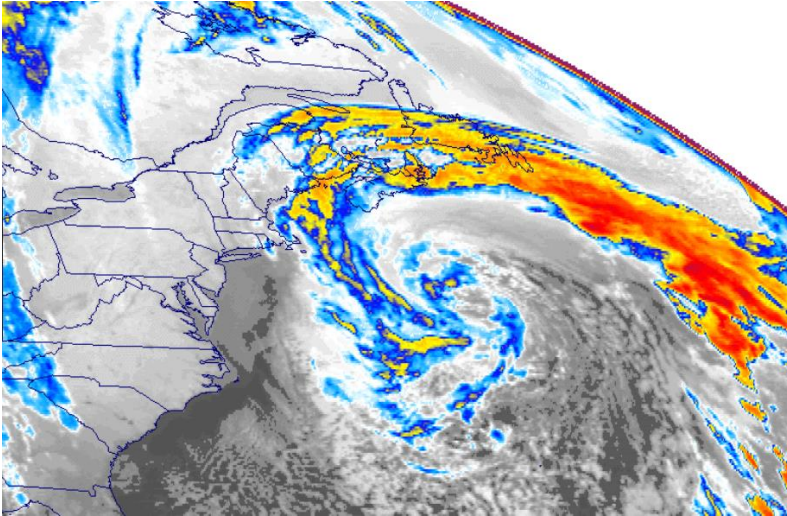
Past and possible future sources of large disruptions



Extreme Weather

Hurricane (TCs)

Image source: NOAA, Sandy, 2000



Ice storm

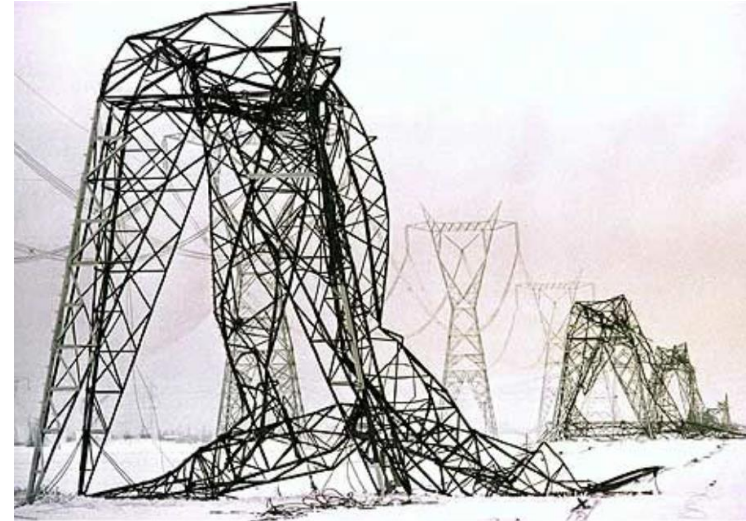


Image from CBC, Quebec, 1998



Images from NWS and Thinglink

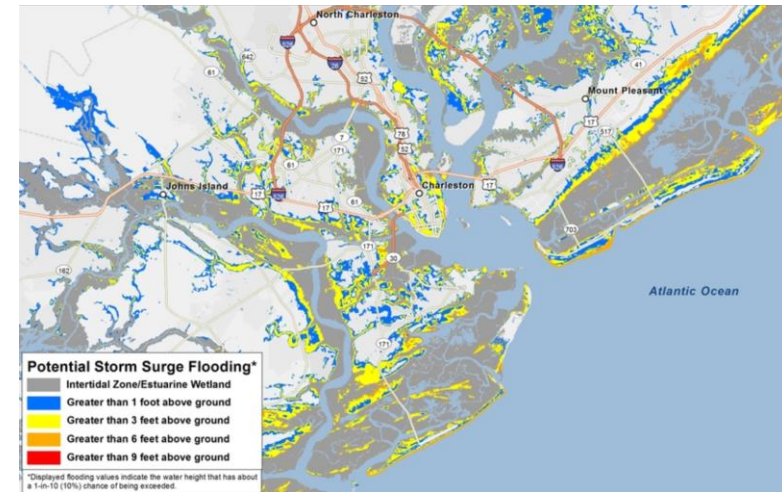
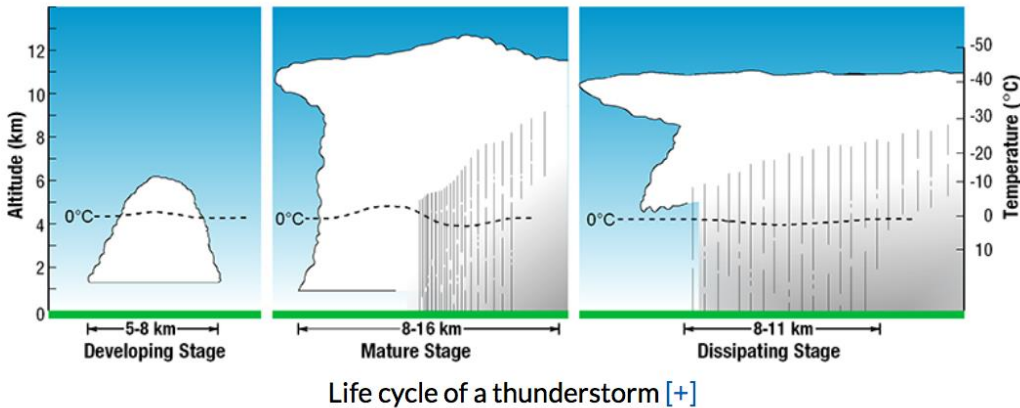
The extensive outages along the East Coast after Hurricane Sandy affected >8 million people. Economic losses were over \$50 billion, and there were at least 147 direct deaths.

The Québec ice storm in 1998 left many customers without power for several weeks in the dead of winter. It affected 2.3 million people, economic losses were >\$4 billion, and there were 44 lost lives.

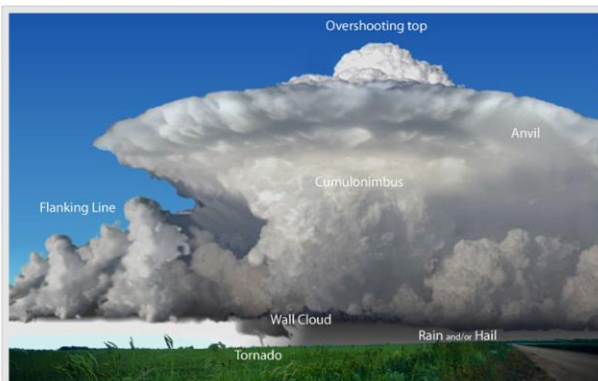
Other extreme weather and flooding

Flood/storm surge

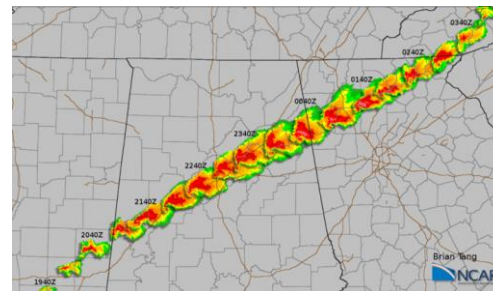
Regional storms and tornados



Images from NOAA and NCAR



Some of the features to be found in a supercell storm. Every storm is different. Not all storms will display all of the features of a classic supercell. [+]



A cluster of tornadoes caused damage across four States in 10 hours from one super cell.



Wind-driven waves and storm surge threaten to inundate homes in Miami, Florida - 1945

Tsunami



Image from NOAA (Alaska 1964)

Earthquake

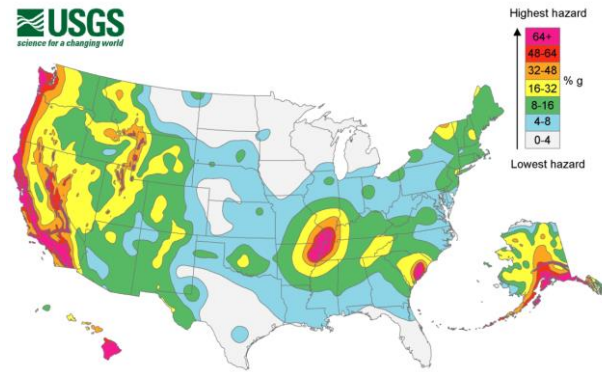
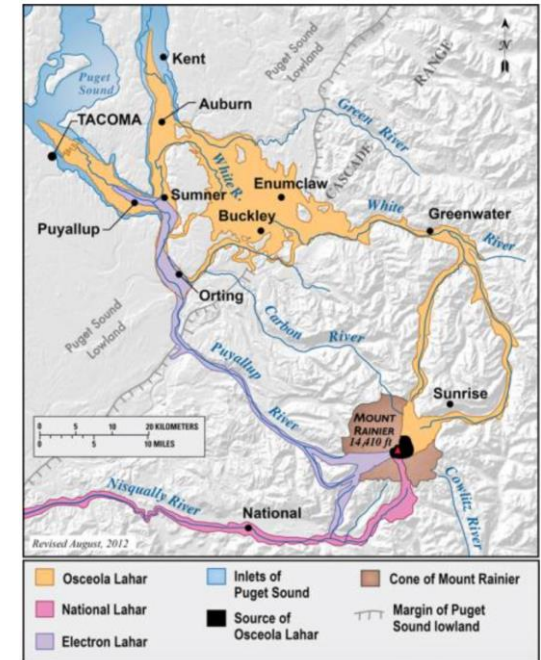


Image from teara.govt.nz

Volcanic events



Images from NOAA

Wild fire

A few others

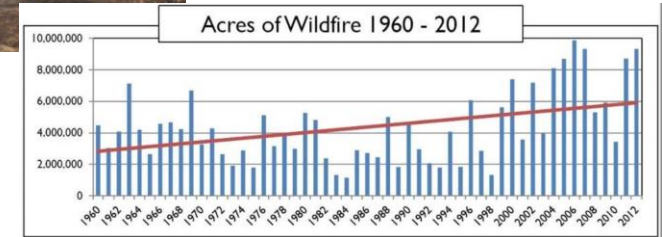
Drought and associated water shortage



Image USGS and VenturaCountyTrails



Images: Chloeta, PSCo



Pandemic

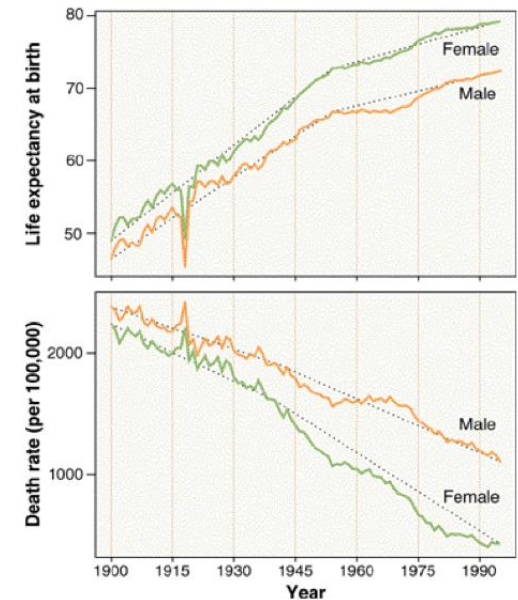


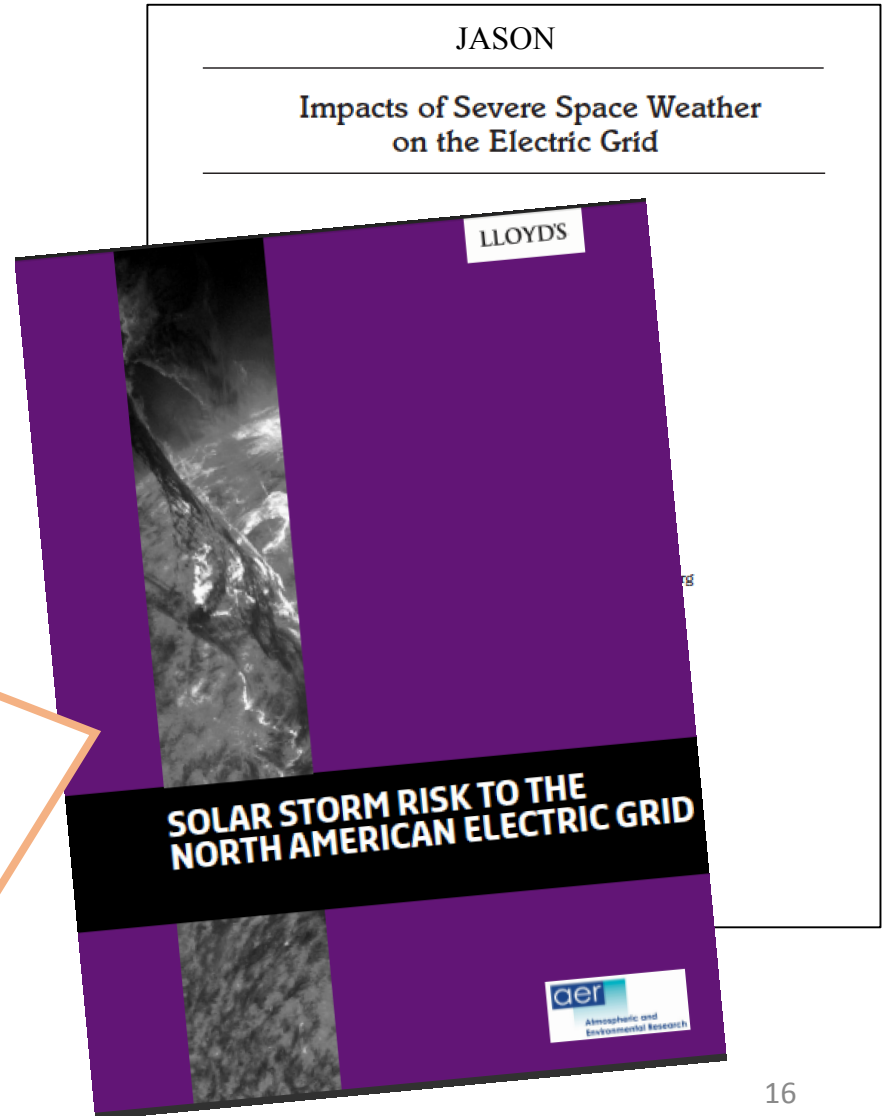
Image from Wilmoth, 1998

1918: 50 to 100 million deaths (3-5% of the world's population)

Space weather

A Carrington-level, extreme geomagnetic storm is almost inevitable in the future. While the probability of an extreme storm occurring is relatively low at any given time, it is almost inevitable that one will occur eventually. Historical auroral records suggest a return period of 50 years for Quebec-level storms and 150 years for very extreme storms, such as the Carrington Event that occurred 154 years ago.

As the North American electric infrastructure ages and we become more and more dependent on electricity, the risk of a catastrophic outage increases with each peak of the solar cycle. Our society is becoming increasingly dependent on electricity. Because of the potential for long-term, widespread power outage, the hazard posed by geomagnetic storms is one of the most significant.



A final thought w.r.t. storage

Local storage can help with ride-through for short term local outages.

If inverter designs and regulations are changed, local storage can also be combined with local PV to provide limited resilience in the face of larger, long duration outages.

Central bulk storage can help both with short-term ride through on the bulk power system and with black start.