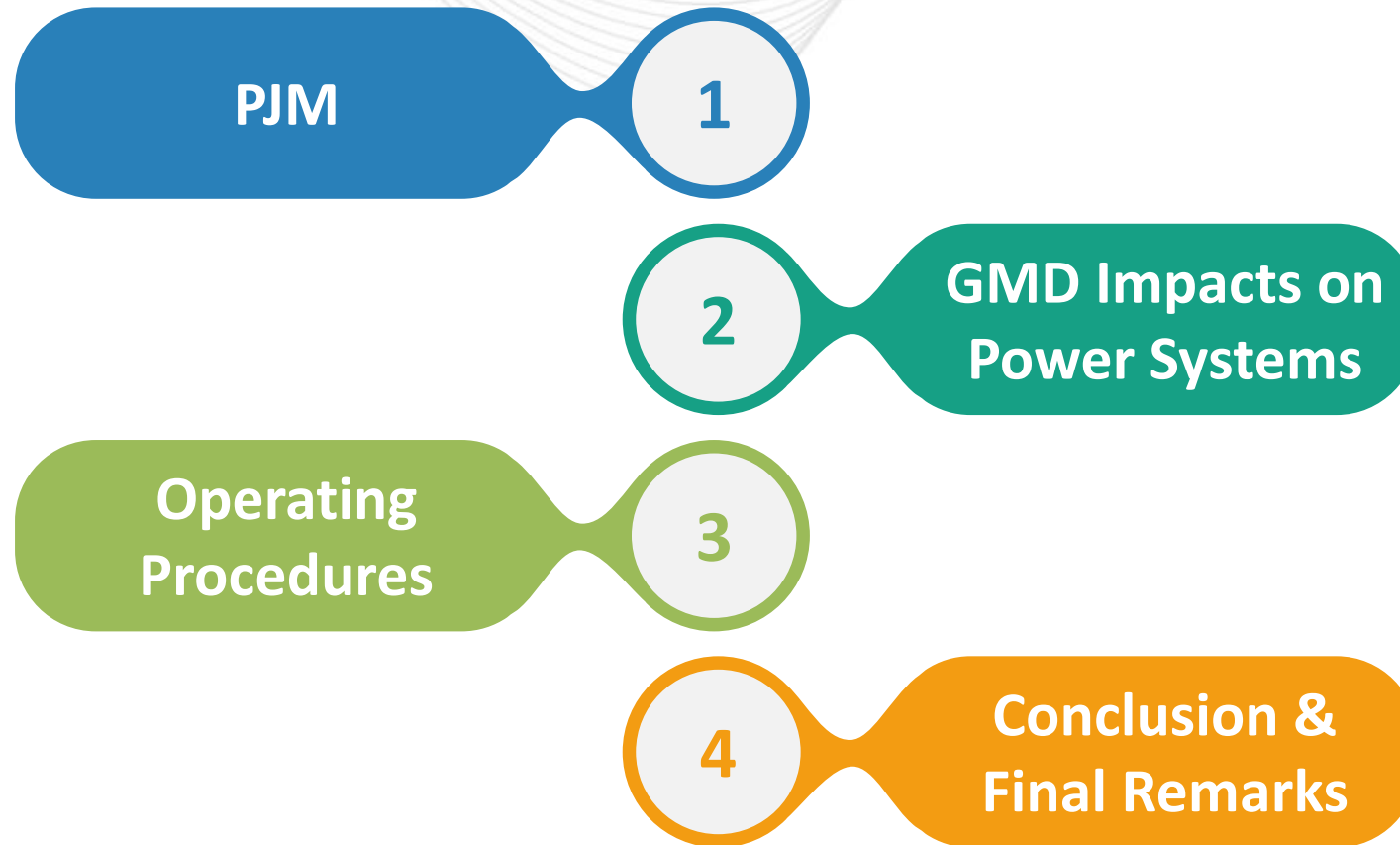


GMD Vulnerability Assessment

PJM's Operating Procedures

Space Weather Workshop – April 2018

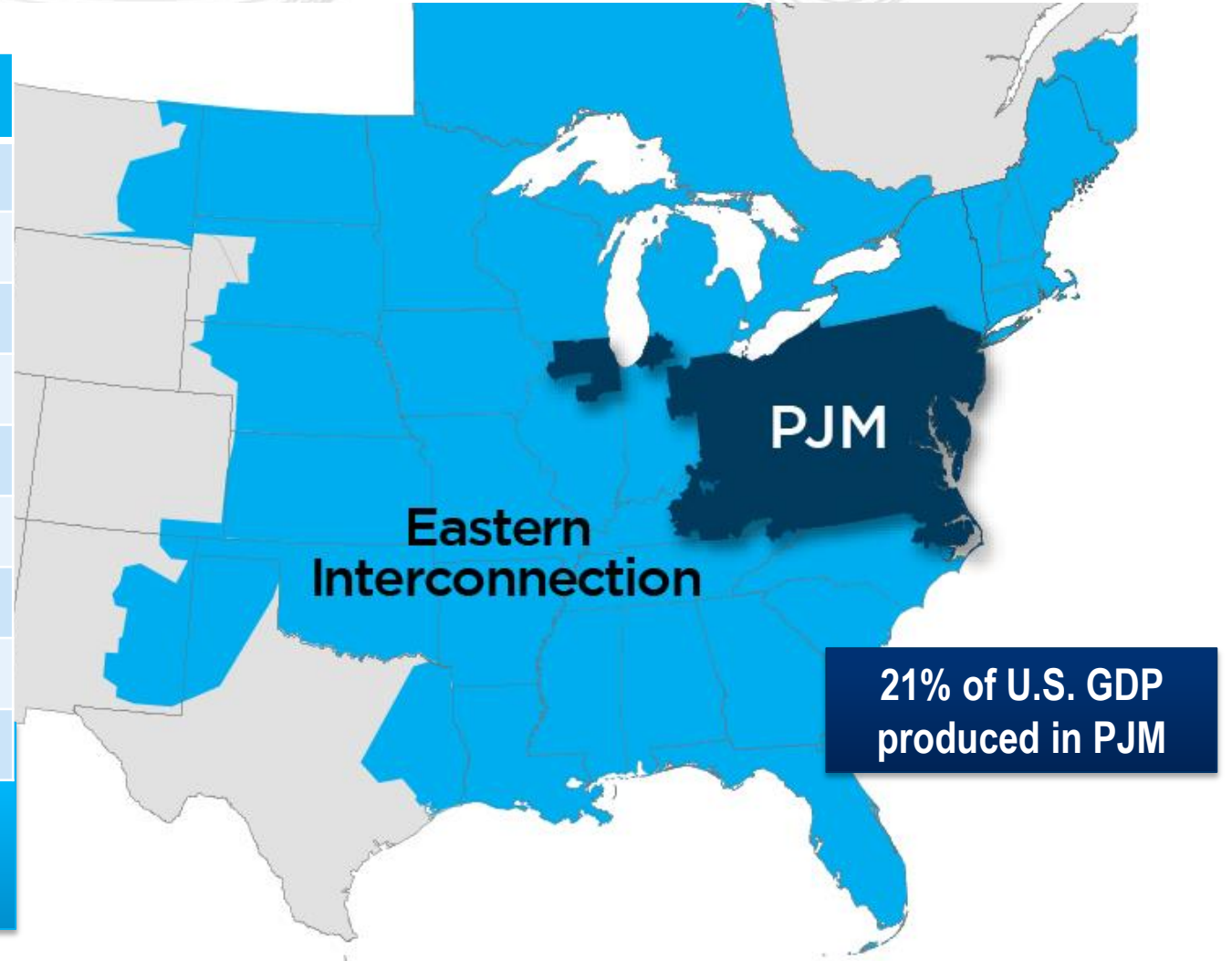
Emanuel Bernabeu, Ph.D.
Director Applied Innovation & Analytics
PJM Interconnection.



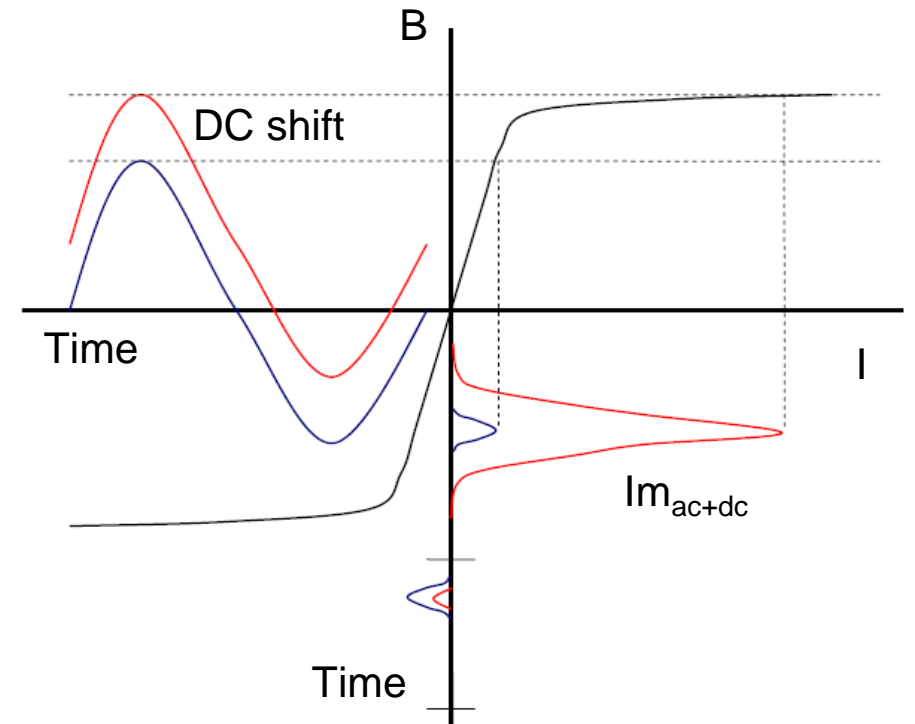
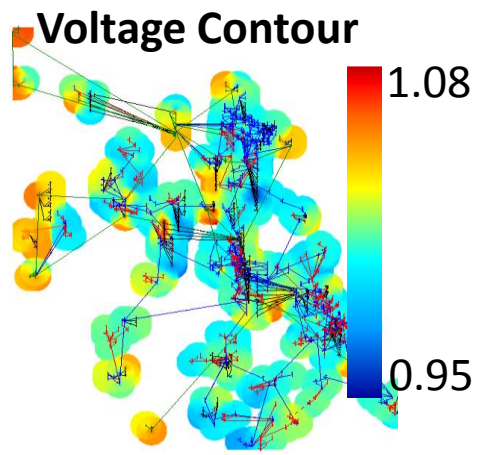
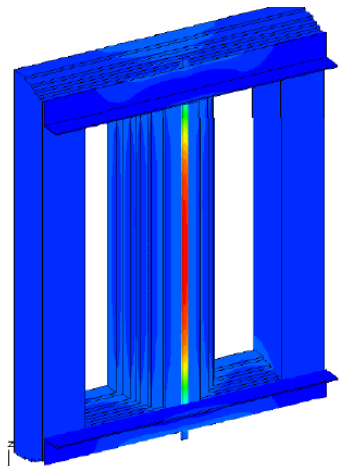
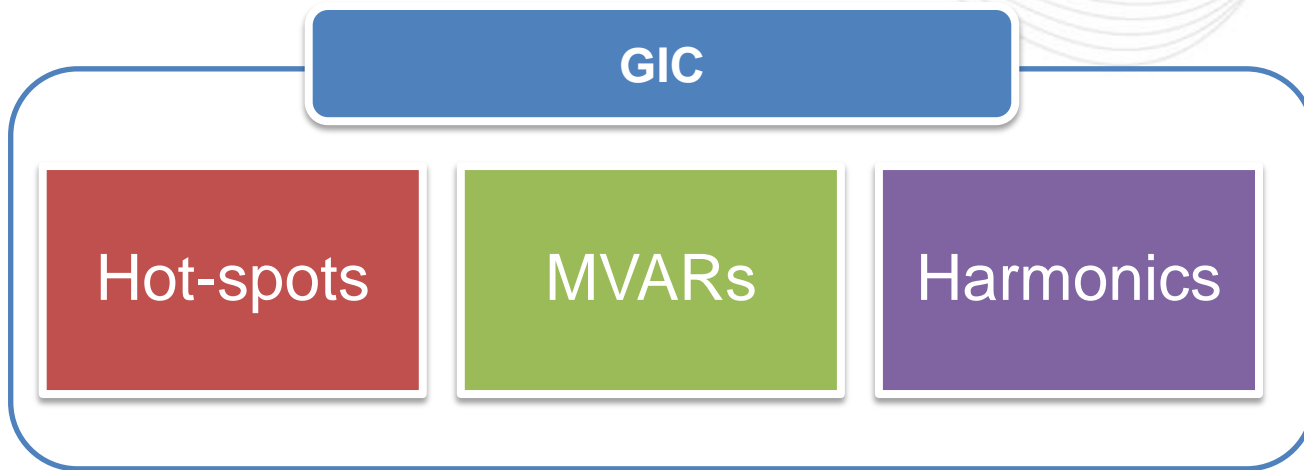
Key Statistics

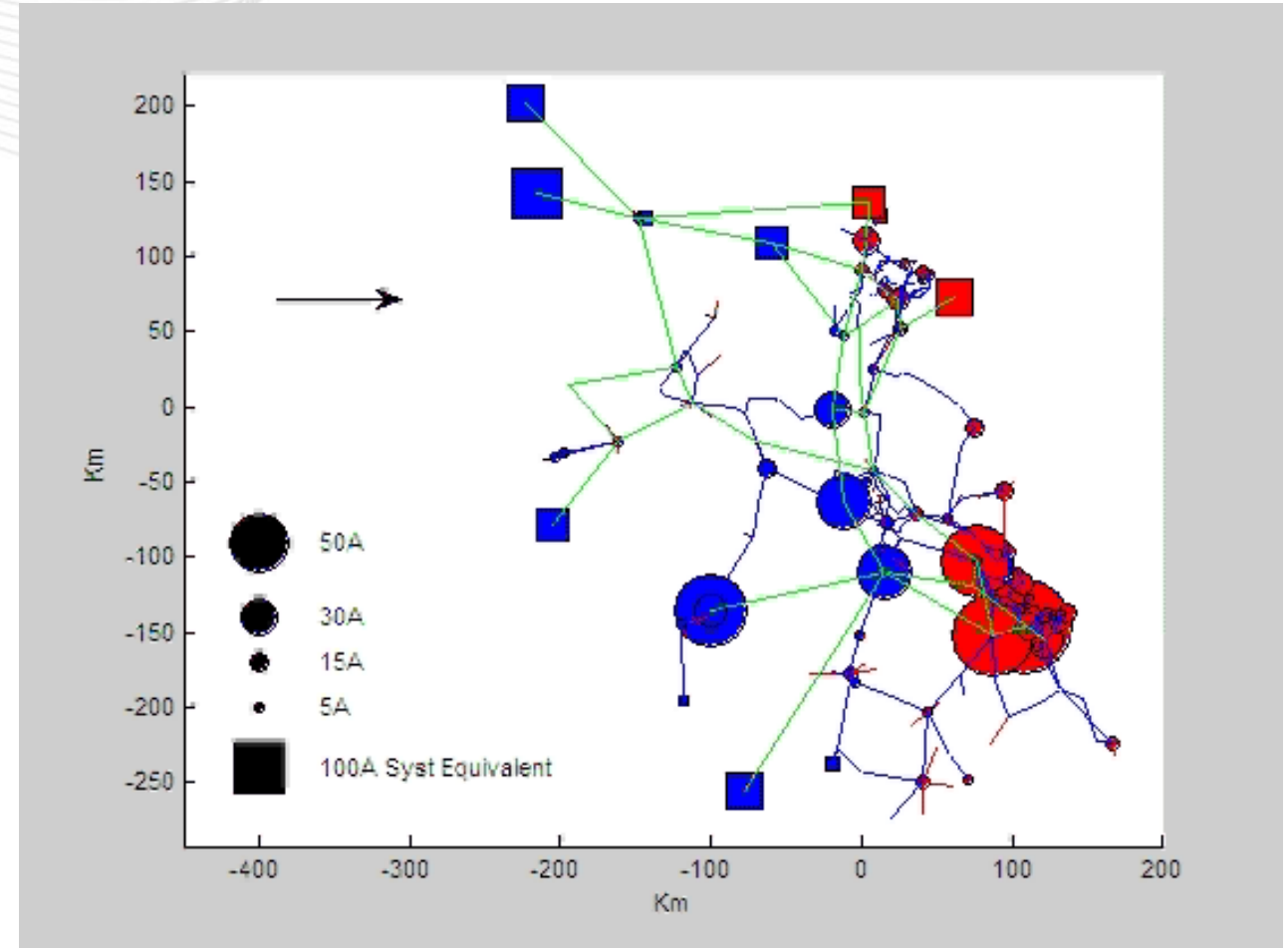
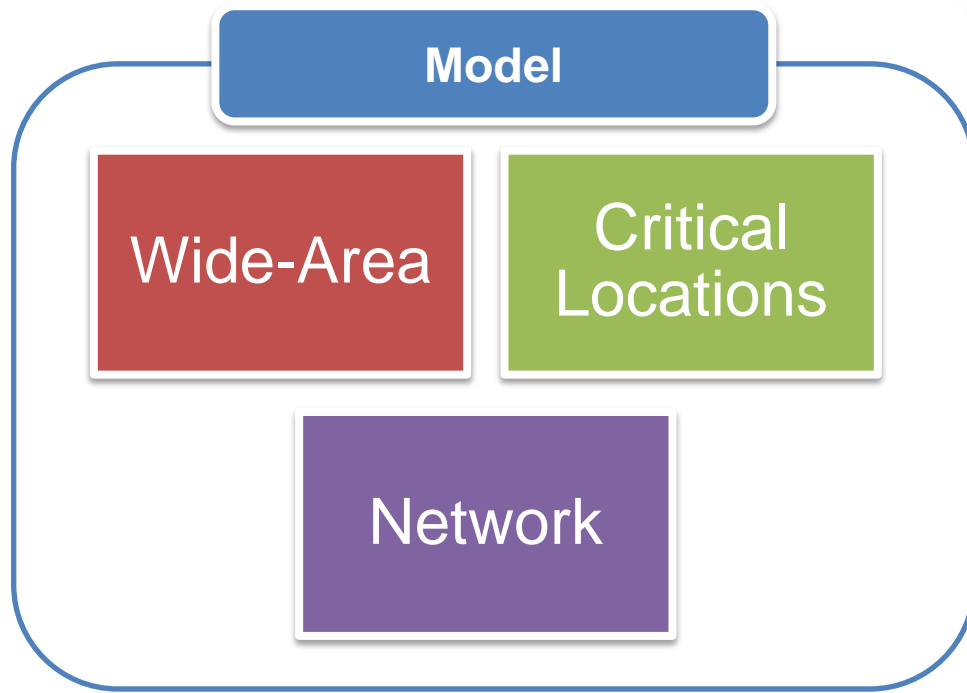
Member companies	1,040+
Millions of people served	65
Peak load in megawatts	165,492
MW of generating capacity	178,563
Miles of transmission lines	84,042
2017 GWh of annual energy	773,522
Generation sources	1,379
Square miles of territory	243,417
States served	13 + DC

- 28% of load in Eastern Interconnection
- 20% of transmission assets in Eastern Interconnection

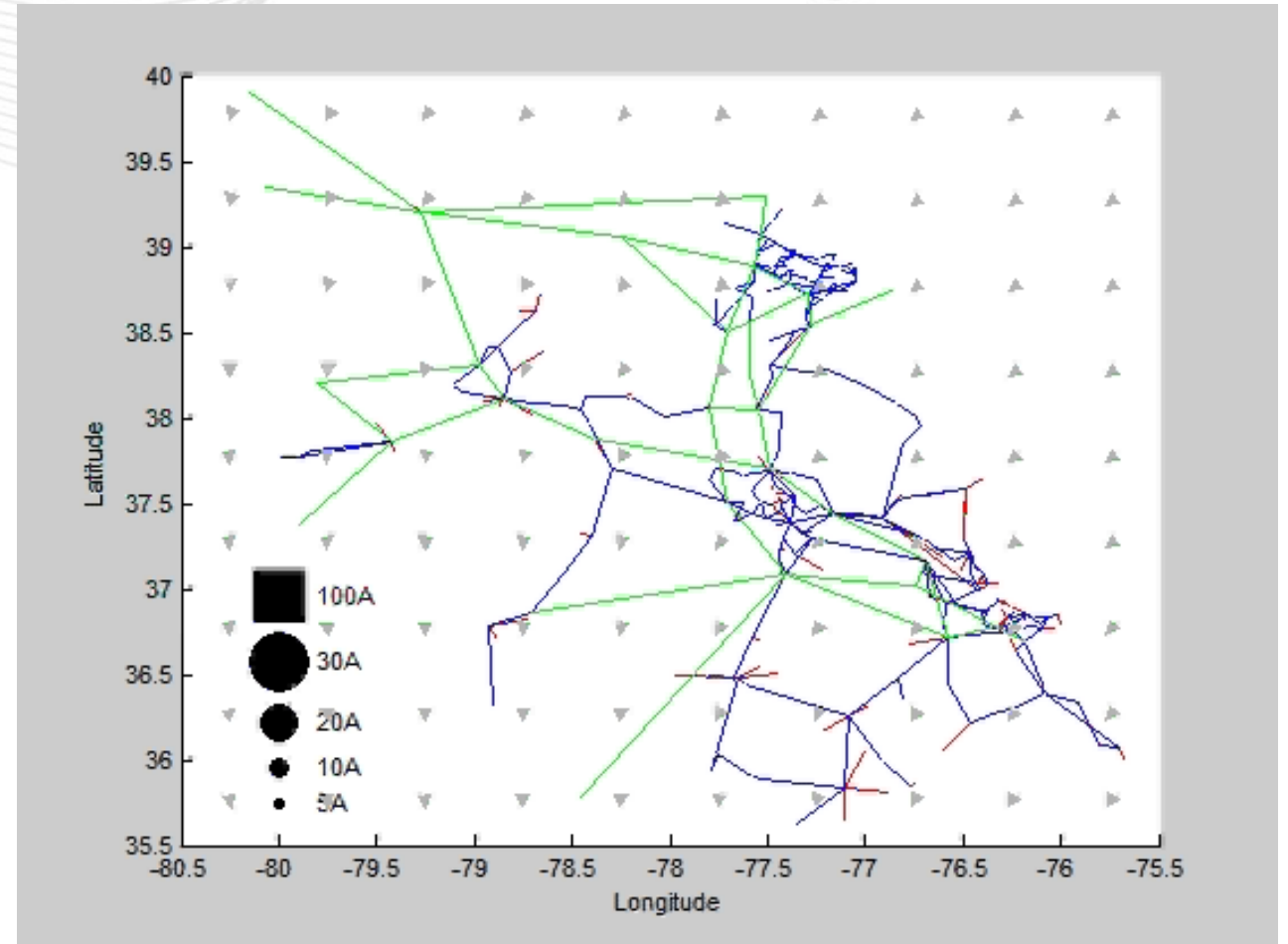
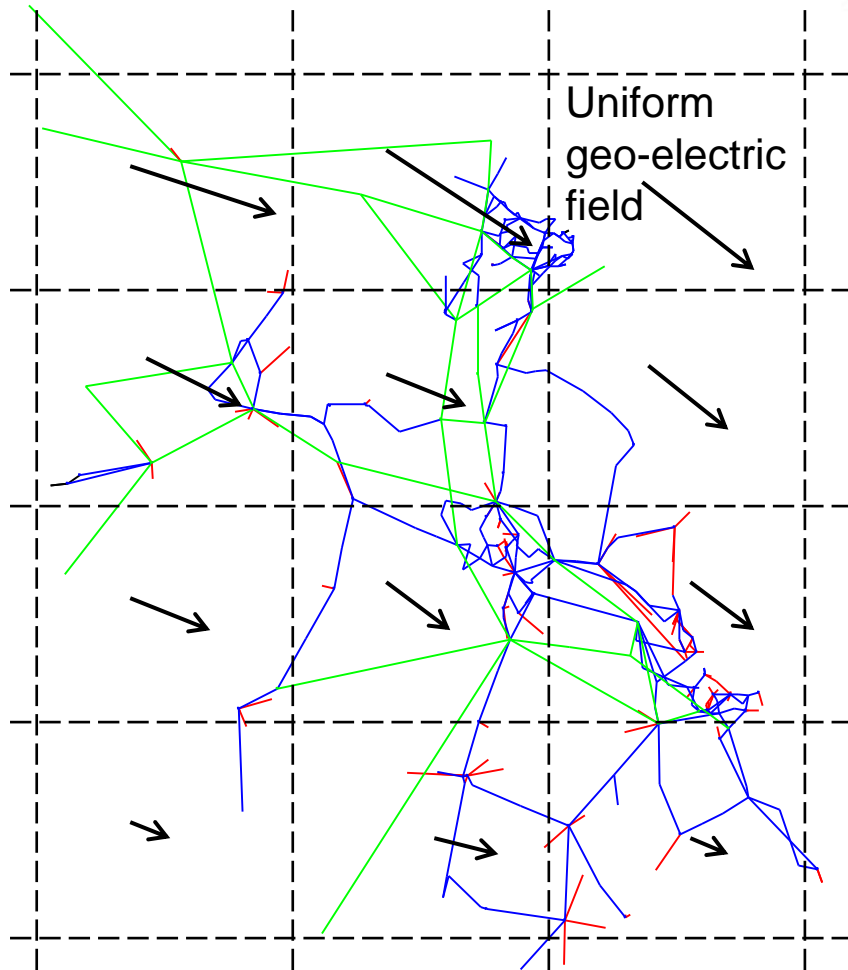


As of 2/2018

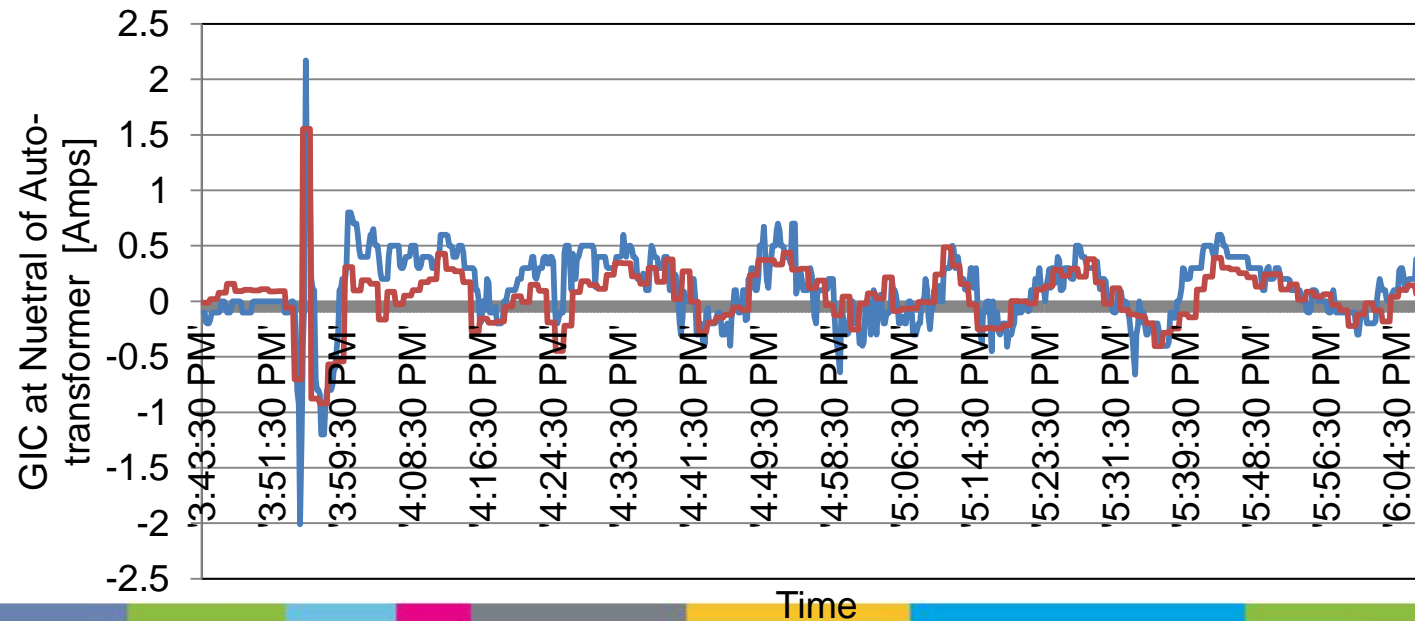
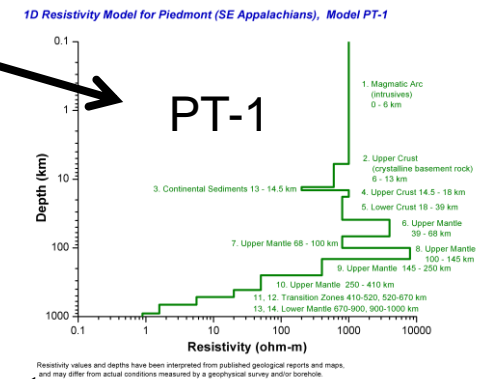
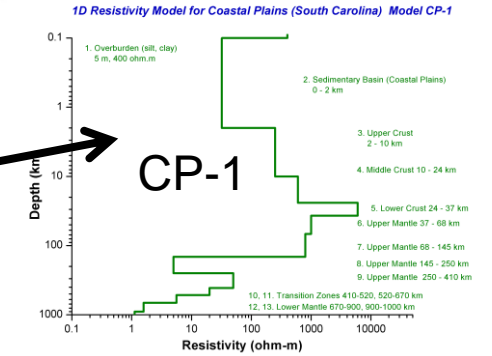
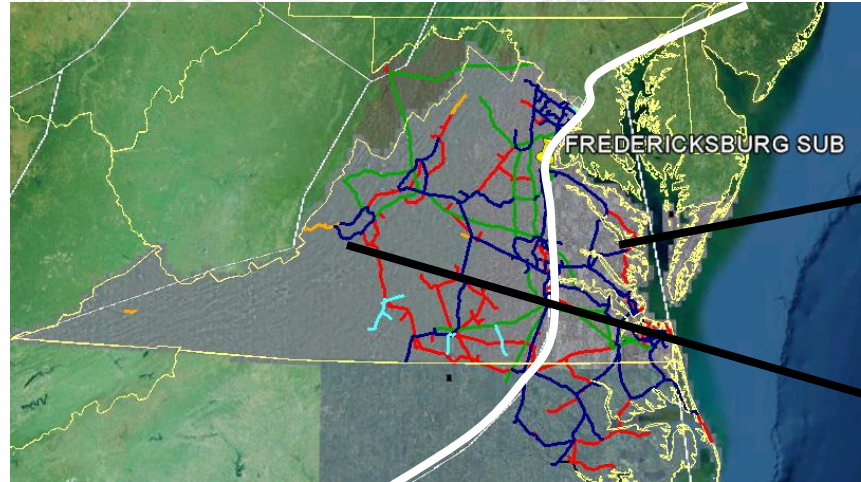
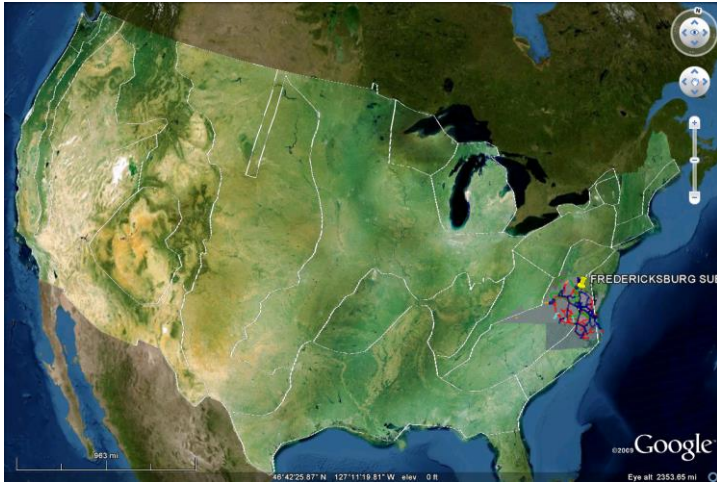




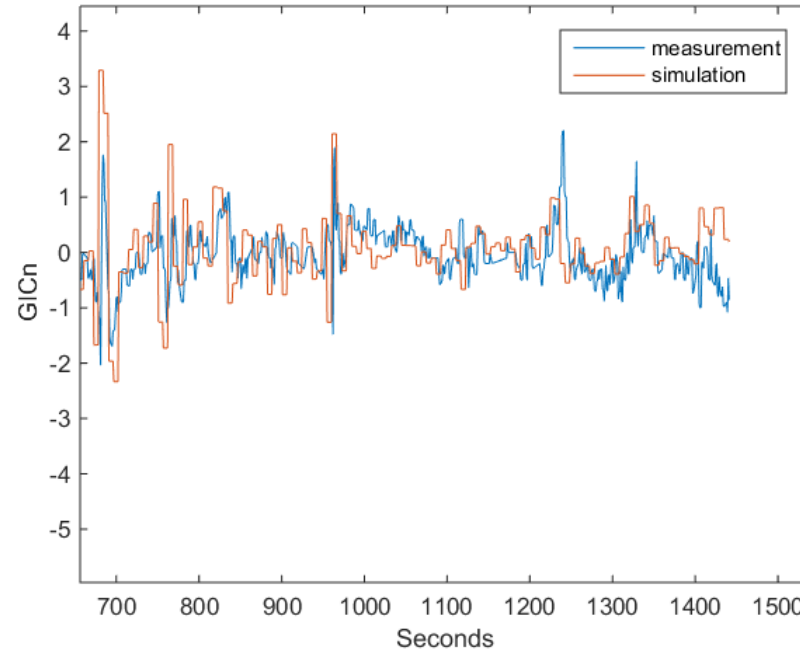
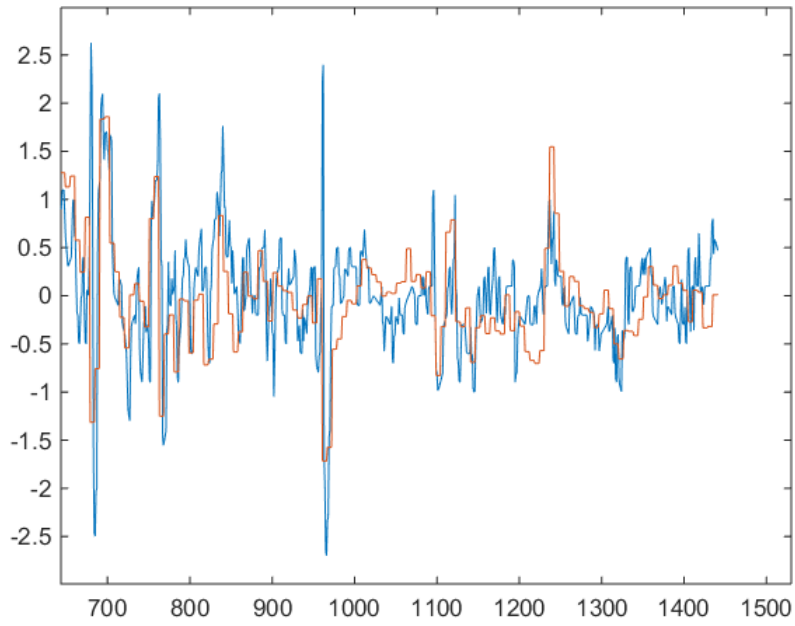
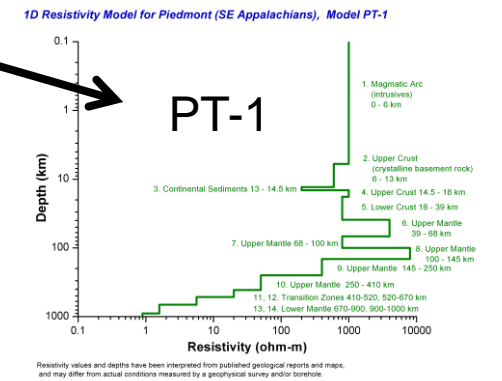
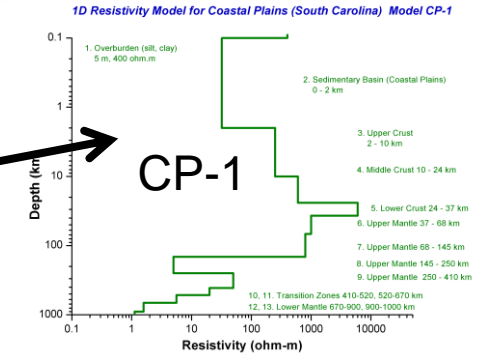
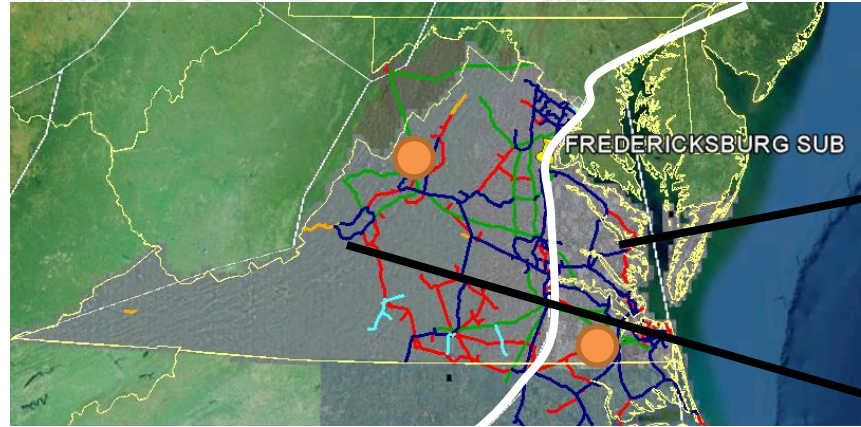
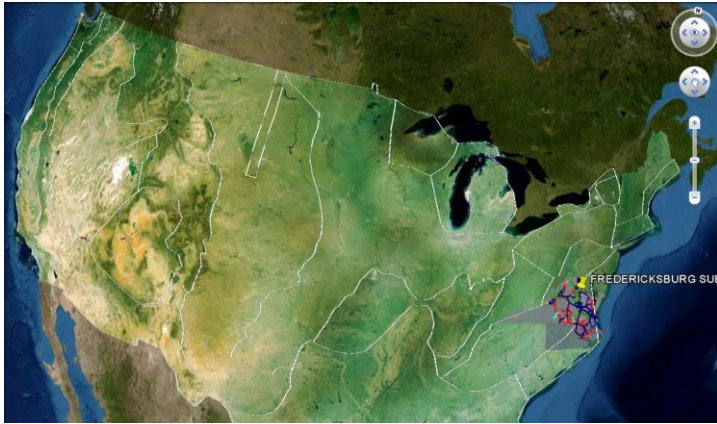
— 500 kV — 230 kV — 115 kV

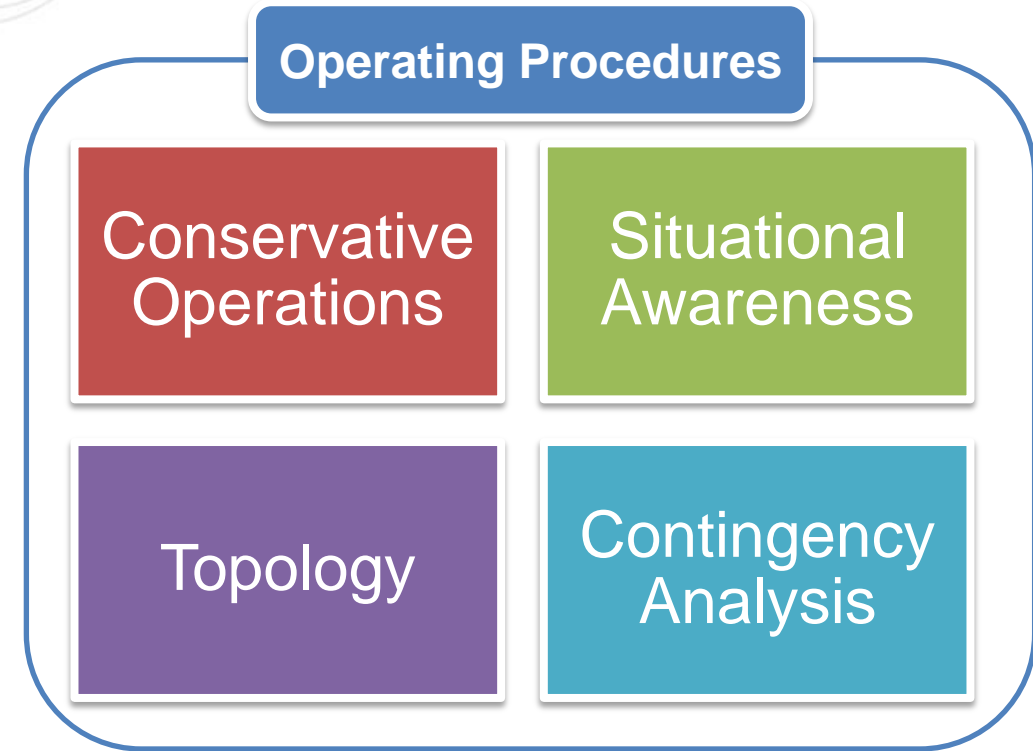
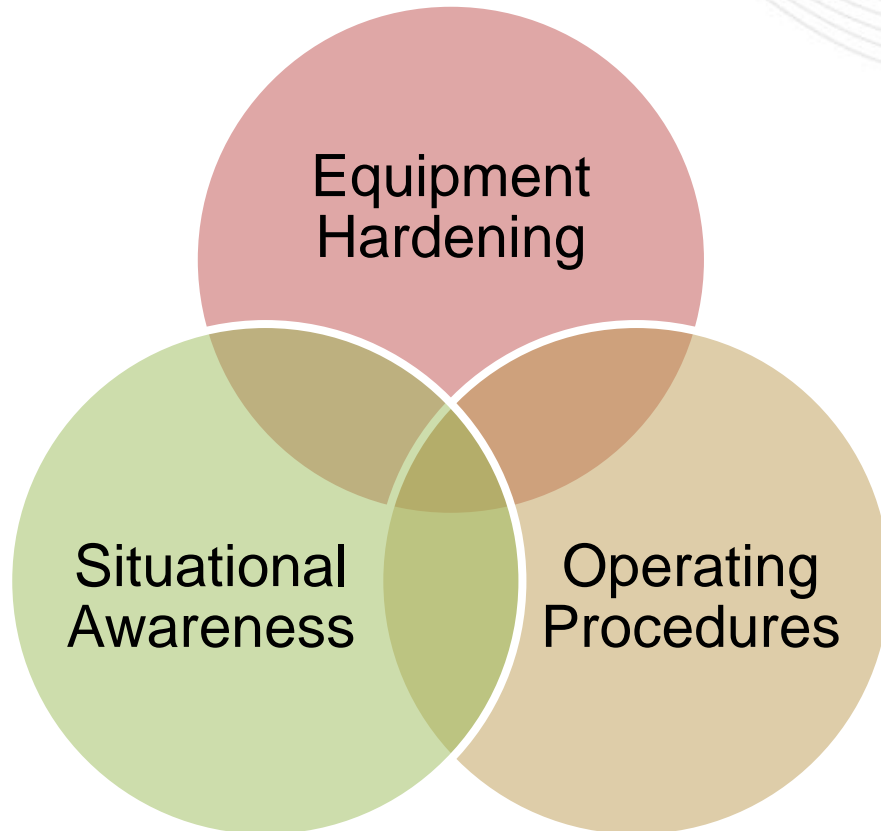


— 500 kV — 230 kV — 115 kV



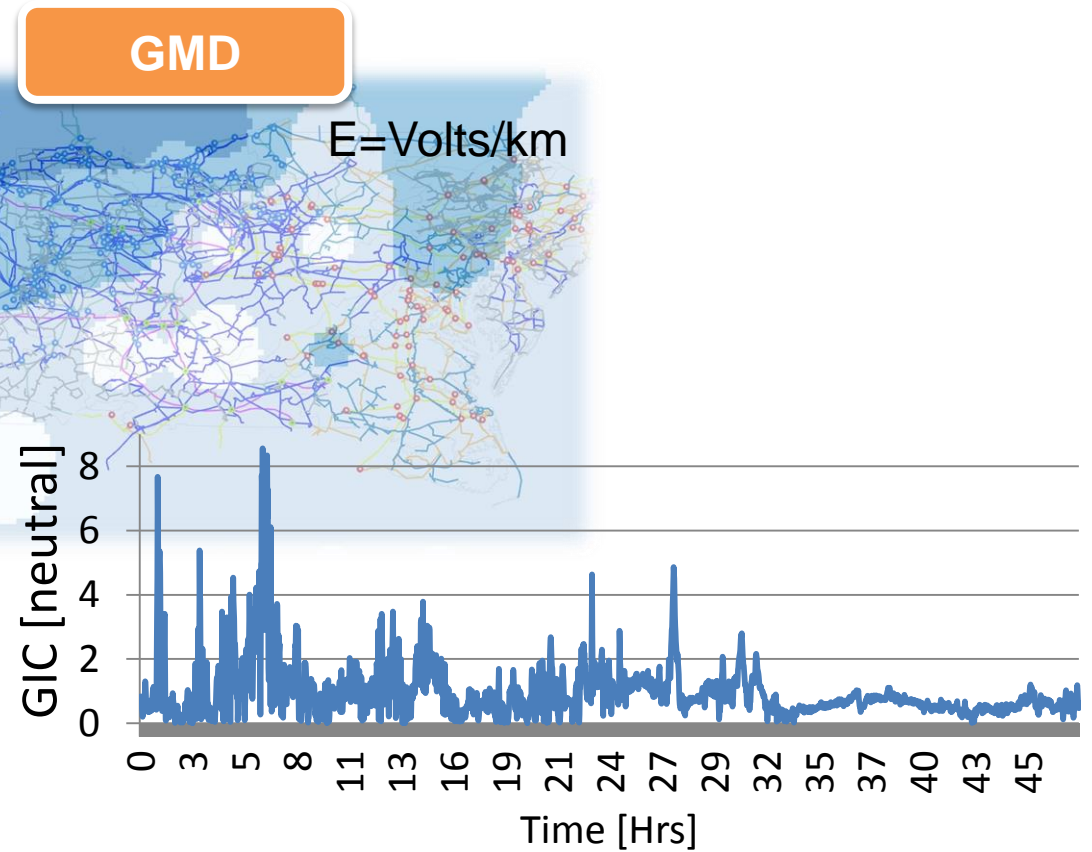
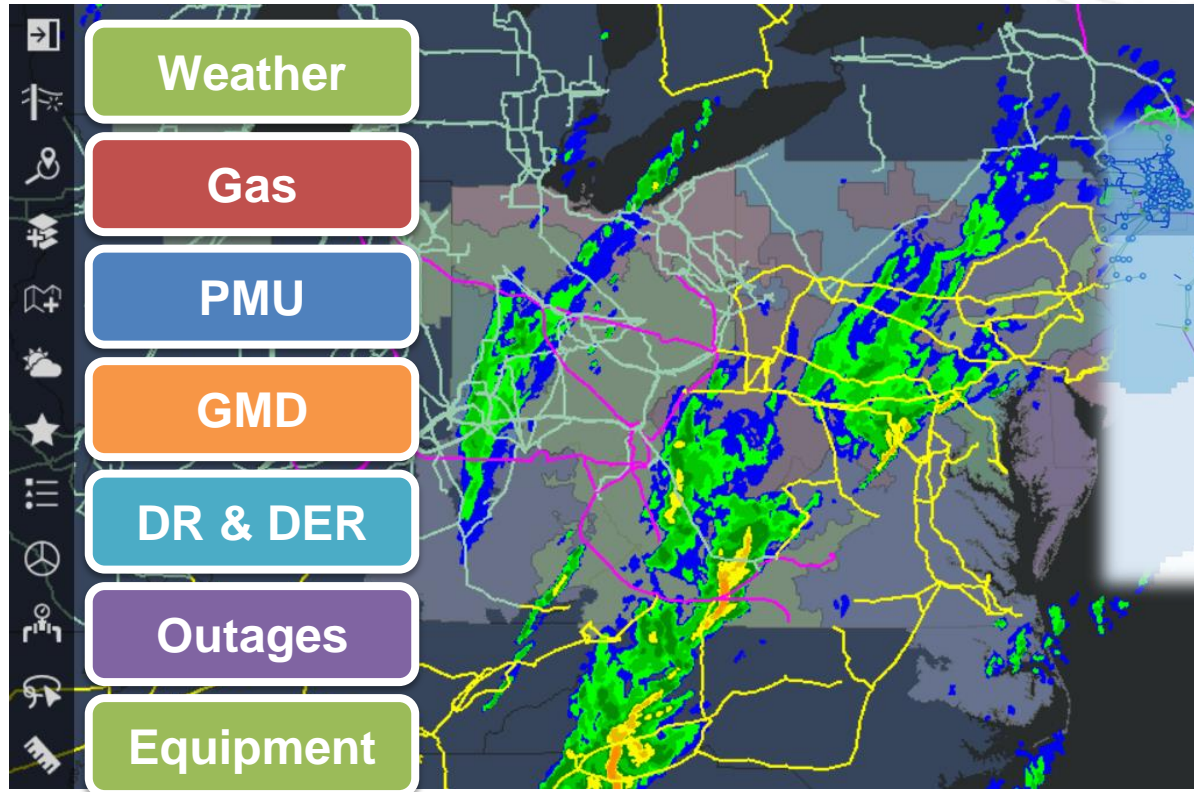
— Measurement
— Simulation





Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	<u>Power systems:</u> widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. <u>Spacecraft operations:</u> may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. <u>Other systems:</u> pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).**	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	<u>Power systems:</u> possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. <u>Spacecraft operations:</u> may experience surface charging and tracking problems, corrections may be needed for orientation problems. <u>Other systems:</u> induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).**	Kp=8	100 per cycle (60 days per cycle)
G 3	Strong	<u>Power systems:</u> voltage corrections may be required, false alarms triggered on some protection devices. <u>Spacecraft operations:</u> surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. <u>Other systems:</u> intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).**	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	<u>Power systems:</u> high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. <u>Spacecraft operations:</u> corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. <u>Other systems:</u> HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).**	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	<u>Power systems:</u> weak power grid fluctuations can occur. <u>Spacecraft operations:</u> minor impact on satellite operations possible. <u>Other systems:</u> migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).**	Kp=5	1700 per cycle (900 days per cycle)

Minor impact



Forecast
Used-&-Useful

Mitigation
Ops Procedures

Situational
Awareness