GMD Vulnerability Assessment

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Overview and Thanks

- Presentation covers GMD vulnerability assessment in the power flow and transient stability time frame, and research issues
- As an industry we've made tremendous progress over last few years, but more research is needed
- Special thanks to 1) DOE and PSERC, 2) EPRI, 3) BPA and other companies, 4) NSF
  - Started in Aug. 2015, NSF is funding a three year, $2.67 million effort associated with electric grid GMD vulnerability assessment; UIUC is lead (myself, Hao Zhu, Kate Davis, Jonathan Makela, Farzad Kamalabadi, Jana Sebestik), Jenn Gannon (CPI), Andrei Swidinsky (CSM), Zhonghua Xu (VT)

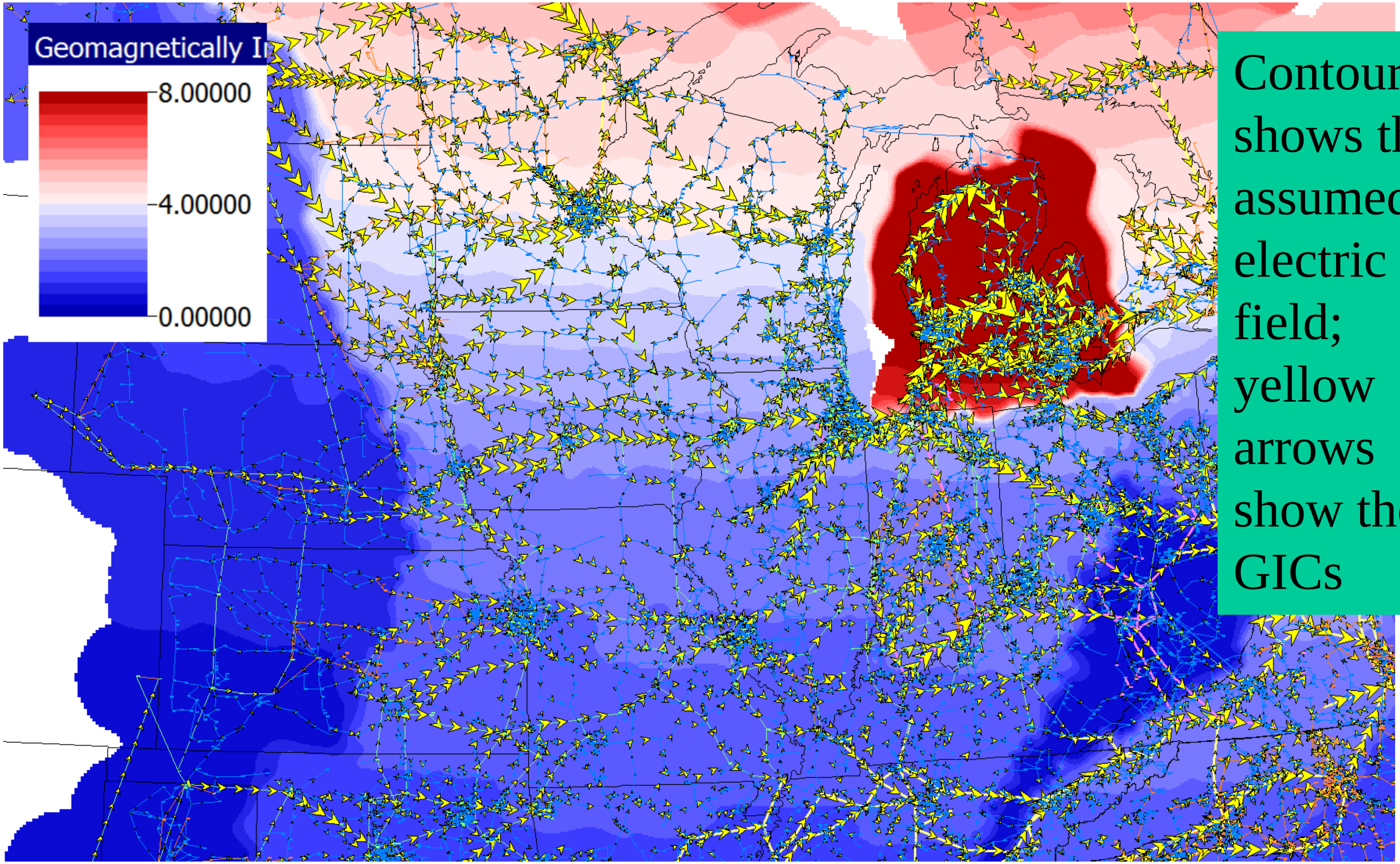
GMD Assessment Software Evolution

- Initial packages were stand alone, not integrated into commercial power flow or transient stability
- In 2011-2012 commercial power flow integration
  - Uniform electric field assumption initially common
- Now more detailed non-uniform electric fields
  - Maximum GICs can be determined directly for most non-uniform models, optional "Hotspot" modeling available, sensitivity of GICs to parameters
- Tools have come a long ways in a short time!
- Goal is to get high quality tools to power engineers who are in best position to do GMD assessment

Benchmark GMD Scenario

- Derived from the March 1989 event
- Peak electric field is 8 V/km for a reference location (60 deg. N, resistive Earth)
- Electric field for other regions scaled by two factors
  - $E_{\text{peak}} = 8 * \alpha * \beta$ V/km
  - "1 in a 100 year" event
  - Details can be found at
    - http://www.nerc.com/pa/Stand/Project201303GeomagneticDisturbanceMitigation/Benchmark_GMD_Event_June12_clean.pdf
- Hotpoint spot modeling can be either constant or scaled

Non-Uniform Electric Field Results

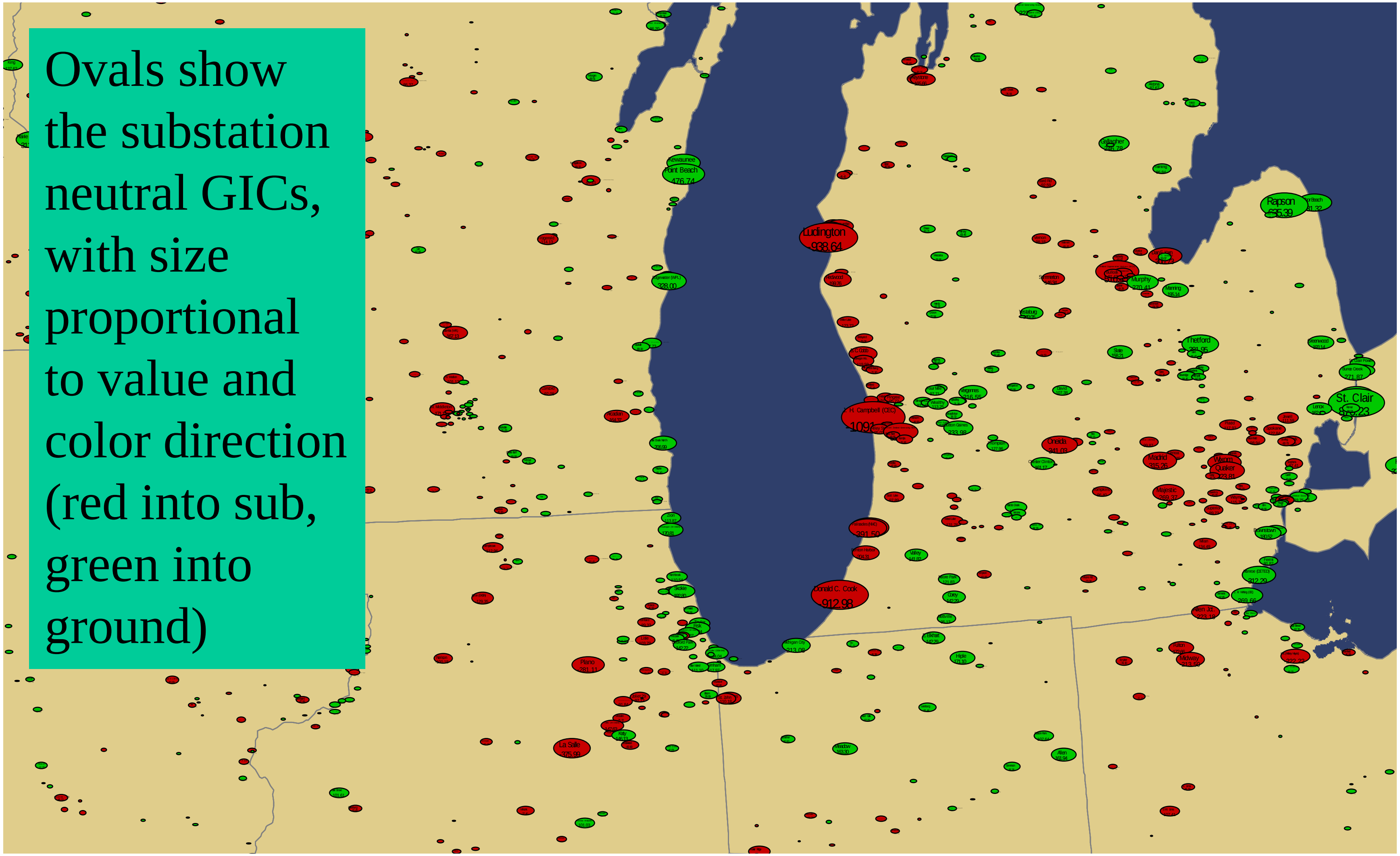


Contour shows the assumed electric field; yellow arrows show the GICs

Results are for illustration only and not represent an actual GMD event

Geographic Data Views can Automatically Visualize Results

Ovals show the substation neutral GICs, with size proportional to value and color direction (red into sub, green into ground)



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Automatic Calculation of the Worst Case Direction

- GICs depend on the non-uniform field direction
- Maximum and/or minimum directions can be analytically determined for the system as a whole, or any subset (such as areas or transformers)

Mvar Losses	Maximum Mvar Losses	Maximum Direction (Degrees)	Minimum Direction Mvar Losses	Minimum Direction (Degrees)
545.68	634.58	53.0	437.41	115.0
355.80	404.65	14.0	345.21	116.0
1587.57	1756.92	153.0	1541.95	58.0
9.54	11.86	126.0	0.38	36.0
11.05	11.05	88.0	8.79	36.0
184.18	220.91	26.0	180.95	133.0
29.23	50.28	152.0	21.58	60.0
26.80	30.52	56.0	10.74	152.0
138.74	151.05	175.0	125.98	70.0
77.	81.85	109.0	21.89	27.0
39.87	74.28	7.0	32.81	110.0
162.80	168.95	57.0	101.62	172.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure shows the area Mvar losses for a non-uniform field for 1) a specified direction, 2) the maximum direction, 3) the minimum direction

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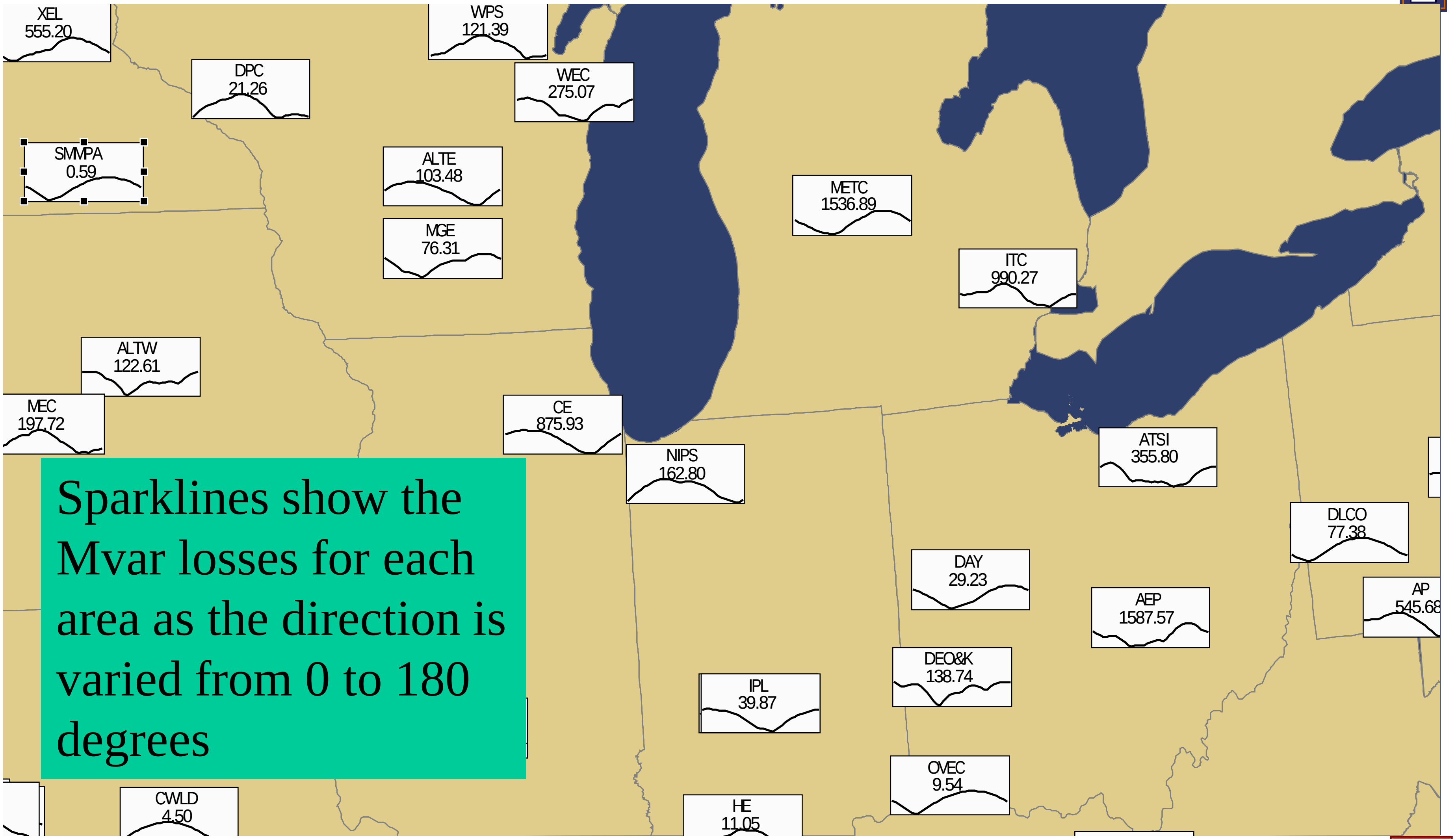
Sparklines Showing Area GMD Losses by Assumed Direction



Sparklines show the Mvar losses for each area as the direction is varied from 0 to 180 degrees

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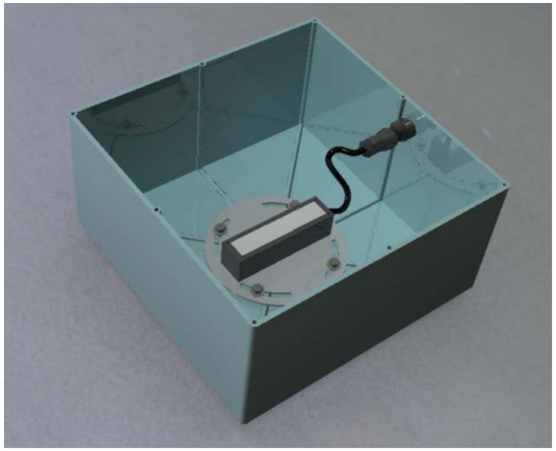
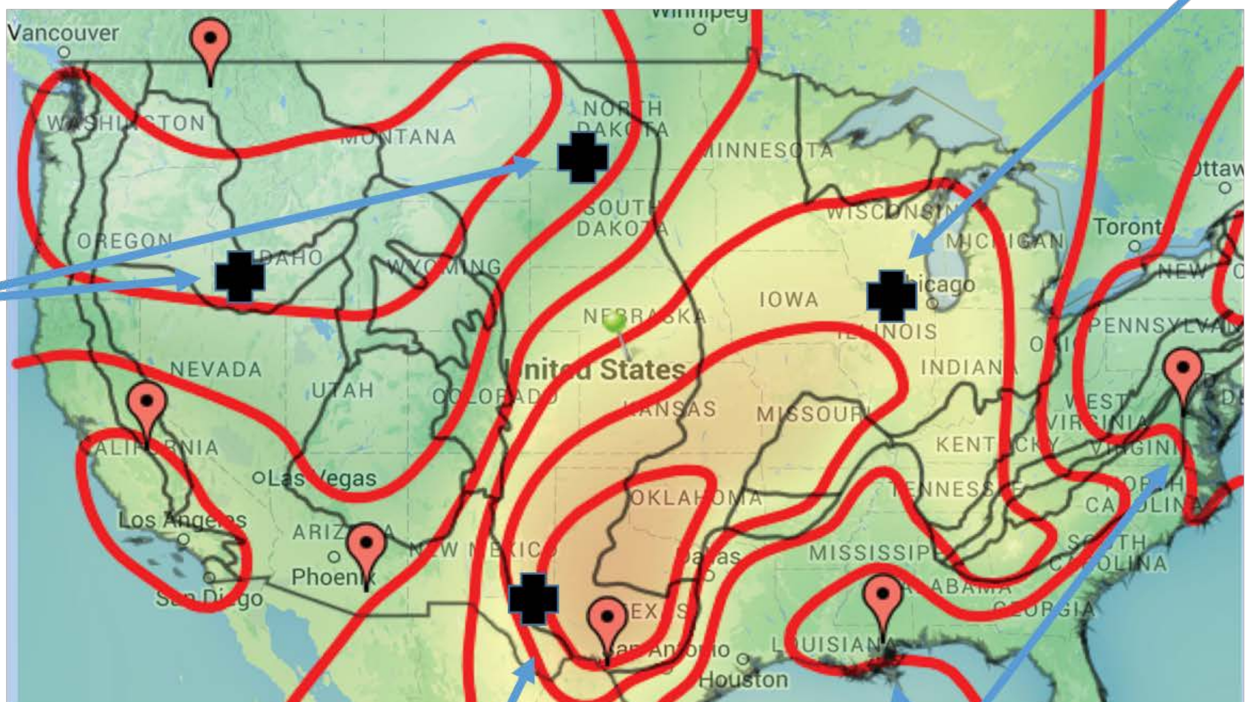
NSF Hazards GMD Project

- NSF award 1520864, focus is on better understanding of GMD impacts on the power grid
- Involves an interdisciplinary team
  - Tom Overbye, Hao Zhu, Kate Davis, Jonathan Makela, Farzad Kamalabadi, Jana Sebestik, Jenn Gannon (CPI), Andrei Swidinsky (CSM), Zhonghua Xu (VT)
- Strongly desire utility participation!
  - One activity is the deployment of four magnetic and electric field monitors with one second resolution
  - At Odessa TX, Univ. Illinois, two other TBD locations in US



Example NSF Project Activity: Improved Electric Field Estimates

SHM 2: UIUC



SHM 3,4: TBD locations

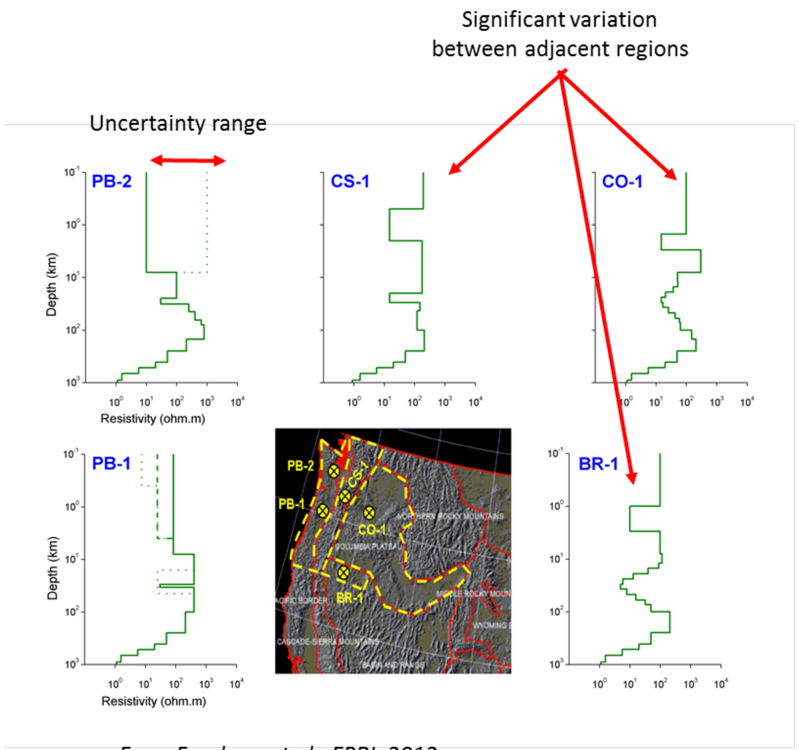
SHM 1: Odessa, TX

USGS observatories

Activity will work with power grid models and real-time transformer neutral current measurements

Example NSF Project Activity: Validation of Methods and Models

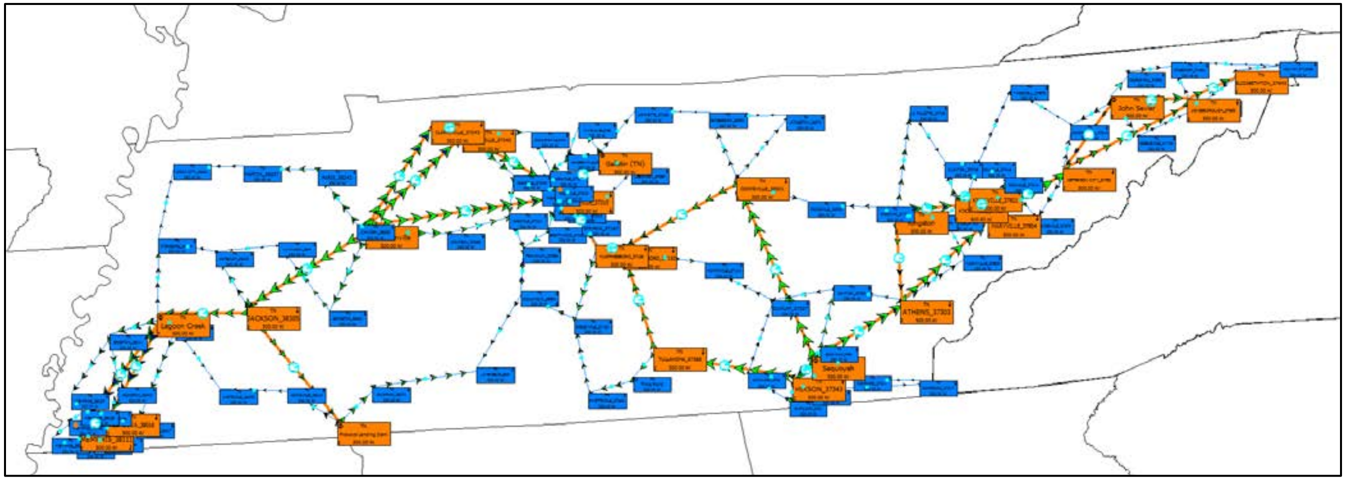
- ***How much does 3D conductivity contribute?*** Comparisons of electric field calculations using 1D, 2D and 3D conductivity models from increasingly complex geology, using historical magnetic storm data.
- ***Are the estimation methods for E equivalent?*** Comparisons of electric field calculation algorithms and methods (time domain, frequency domain, wavelet).
- ***Do estimates match reality?*** Validation using available and newly measured magnetic and electric field data.



From Fernberg et al., EPRI, 2012

GMD Synthetic Cases

- GMD software comparison is limited by the availability of public cases
- This is being address by a new ARPA-E project in which the goal is to create large-scale, geographic synthetic cases that can be freely distributed
- Below image shows a prototype 150 bus case



Cases with up to 100,000 buses will be created

Thank You!