

Geomagnetic Disturbance Modeling Enhancements



2020 Western Region PowerWorld
Users Group Meeting
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Acknowledgement



- Much of the content herein was contributed by PowerWorld Corporation co-founder Thomas Overbye, PhD
 - Currently a professor at Texas A&M University
 - Still active as a part-time developer and innovator of PowerWorld software



<https://engineering.tamu.edu/electrical/profiles/overbye-thomas.html>

Overview



- This slide set shows a few PowerWorld modifications to better handle GMD analysis with non-uniform, time and spatially varying fields
- All changes are available in PowerWorld Simulator Version 21 and 22, except the ability to save the input electric field data in the pwb is Version 22 only

GIC Analysis Form Additions



- Support for binary and new text file formats for time and spatially-varying E-field inputs
- The binary (*.b3d) format has been updated to version 2 to better support data that is specified by individual points rather than from a grid
- Delaunay triangulation is now used for electric field interpolation between specified input points

Non-Uniform E-Fields



- This discussion deals with improvements and enhancements in the “Time Varying Electric Field Inputs” GIC Calculation Mode

GIC Analysis Form

Calculation Mode

- Single Snapshot
- Time Varying Series Voltage Inputs
- Time Varying Electric Field Inputs
- Spatially Uniform Time-Varying E-Field

Calculate GIC Values Clear GIC Values Include GIC in Power Flow and Transient Stability Validate

Current Time: 3180.00 Calculate GIC on Time Change Use EMP as Input

Select Step

- Field/Voltage Input
- Options
 - DC Current Calculation
 - AC Power Flow Model
- Tables and Results
 - Areas
 - Buses
 - Generators
 - DC Lines
 - Lines

Field/Voltage Input

Non-uniform Electric Field Files (*.b3d, *.dat, *.json)

G:\Scott\GIC\3D E-Feild Inputs\Geo JSON\20200508 sample set\20200 Browse...

Clear Existing Time Points or Merging

- Clear Existing
- Merge

Setup Time-Varying Series on Load Save Non-uniform Fields in PWB File

Options for Loading Multiple Files of S

- Just selected file
- All after last time in Time Points Lis
- All before first time in TimePoints L
- All files of selected type

Input Summary

Starting Time (Seconds): 0.00 Starting Latitude: 24.00 Starting Longitude: -125.00

A Note on Terminology



- “3D models” or “3D inputs” here refer to the Earth conductivity transfer functions, not the surface Electric Field itself
 - The industry has long used 1D earth models (e.g. NERC TPL-007)
 - R&D is focused on 3D earth models (e.g. EarthScope and successors)
- The E-Field vector is always “2D” at a given location and time, with eastward and northward components; it can vary with geographic location and time
- PowerWorld Simulator presently takes E-Field as an input and is indifferent to the type of earth model (1D or 3D) used to generate the E-Field

Time and Spatially Varying E-Field



- Input file format (*.b3d) version 1 required the E-field spatial domain to be a rectangular grid of constant lat/long degree resolution
- CSV example using 10° spacing, starting at -135 long, +25 lat:

		Eastward magnitude							Northward magnitude
Time 0.0		10, -135.0, 7, 10, +25, 4							
		0.0							
		1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 7.8, 9.9	+25						
		1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 7.8, 9.9	+35						
		1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 7.8, 9.9	+45						
Time 1.0		1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 7.8, 9.9	+55						
		1.0							
		1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 7.8, 9.9	+25						
		1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 7.8, 9.9	+35						
		1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 7.8, 9.9	+45						
	1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 1.2, 0.2, 4.5, 1.2, 2.5, 6.5, 7.8, 9.9	+55							
		-135	-125	-115	-105	-95	-85	-75	
		Longitudes							

Geo JSON Format



- Input file format version 2 (*.b3d) allows arbitrary specification of spatial points
- Simulator can now read an E-field input time series represented in the GeoJSON format (file extension *.json)

NOAA Resources



- NOAA publishes near-real time electric field data at 2 degrees lat/long and 60 second resolution for CONUS at
<https://services.swpc.noaa.gov/text/lists/rgeojson/geoelectric/geojsons/>
 - Files must be downloaded to local or network location
 - Each time period is a separate file, but multiple files may be loaded to Simulator in a single step
- Experimental Data, including data based on the 3D EarthScope transfer function
<https://www.swpc.noaa.gov/products/geoelectric-field-1-minute-empirical-emptf-3d-model>
 - Navigate to the *Data* tab for available resources

Geo JSON Example with 3 Data Points



```
{ "type": "FeatureCollection", "features":  
[  
  { "type": "Feature", "geometry": { "type": "Point",  
    "coordinates": [-81.0, 24.0] }, "properties": { "Ex": 0.22,  
    "Ey": -0.22, "quality_flag": 5,  
    "distance_nearest_station": 1107.47 } },  
  { "type": "Feature", "geometry": { "type": "Point",  
    "coordinates": [-99.0, 26.0] }, "properties": { "Ex": -0.46,  
    "Ey": -0.39, "quality_flag": 5,  
    "distance_nearest_station": 1037.79 } },  
  { "type": "Feature", "geometry": { "type": "Point",  
    "coordinates": [-97.0, 26.0] }, "properties": { "Ex": -0.4,  
    "Ey": -0.38, "quality_flag": 5,  
    "distance_nearest_station": 869.3 } }  
]  
}
```

Loading Electric Field Input Files



- Options are available for automatically loading multiple *.JSON files, clearing or merging with any existing Time Points
- Once loaded data can either be stored in an external *.B3D file or in the pwb (the pwb option is V22 only)
- When the files are loaded there is an option to automatically setup the Time-Varying Series Line Voltages

Field/Voltage Input

Non-uniform Electric Field Files (*.b3d, *.dat, *.json)
 C:\Projects_2020\GMD_Scott\TennesseeExampleEfieldV2.b3d Browse...

Options for Loading Multiple Files of Selected Type
 Just selected file
 All after last time in TimePoints List
 All before first time in TimePoints List
 All files of selected type

Clear Existing Time Points or Merging
 Clear Existing
 Merge

Setup Time-Varying Series on Load
 Save Non-uniform Fields in PWB File

Input Summary

Starting Time (Seconds) 0.00 Starting Latitude 24.00 Starting Longitude -125.00
 Ending Time (Seconds) 31674360.00 Ending Latitude 50.00 Ending Longitude -67.00
 Number of Time Points 14 Number Data Points 283
 Interpolated Offset Time 0.00 View Interpolated Offset Time (Seconds) Starting Date and Time 5/3/2019 4:42:30 PM (UTC)

Save Selected Time Points in B3D Format Clear All Time Points Change Start Date and Time to Zero Time Offset

Time Points (Select Point to Preview)						Time Point Grid Preview (First Entry is the Eastward)				
	Time Offset, Seconds	Maximum Electric Field, V/km	Maximum Electric Field Longitude	Maximum Electric Field Angle Latitude	Save in File	Date/Time String		Longitude	Latitude	Dist. Status
1	0.00	0.006	-89.0000	50.0000	YES	5/3/2019 4:42:30 PM	1	-81.0000	24.0000	1
2	31673520.00	0.002	-99.0000	50.0000	YES	5/4/2020 6:00:00 AM	2	-99.0000	26.0000	1
3	31673640.00	0.002	-99.0000	50.0000	YES	5/4/2020 6:00:00 AM	3	-97.0000	26.0000	
4	31673760.00	0.001	-77.0000	44.0000	YES	5/4/2020 6:00:00 AM	4	-83.0000	26.0000	
5	31673820.00	0.001	-77.0000	44.0000	YES	5/4/2020 6:00:00 AM	5	-81.0000	26.0000	
6	31673880.00	0.002	-77.0000	44.0000	YES	5/4/2020 7:00:00 AM	6	-79.0000	26.0000	1
7	31673940.00	0.002	-77.0000	44.0000	YES	5/4/2020 7:00:00 AM	7	-103.0000	28.0000	

Manually Setting Up the Line Voltages



- As noted, when input files are loaded the Time-Varying Series Line Voltage data can either be setup automatically or manually
 - The automatic setup will delete any existing data
- A manual option is still available for a specified time range, with by time point or a Sampled Time Points; If the State Time = End Time = 0

Non-uniform Electric Field Files (*.b3d, *.dat, *.json)
C:\AProjects_2020\GMD_Scott\TennesseeExampleEfieldV2.b3d Browse...

Options for Loading Multiple Files of Selected Type
 Just selected file
 All after last time in Time Points List
 All before first time in TimePoints List
 All files of selected type

Setup Time Varying Series Voltage Inputs
Start Time (Seconds) 0.00
End Time (Seconds) 31674360.00
Sampling Rate (Seconds) 0.00
 Do All if Start and End Time = 0
Setup Time Varying Series

Clear Existing Time Points or Merging
 Clear Existing
 Merge
 Setup Time-Varying Series on Load
 Save Non-uniform Fields in PWB File

Input Summary
Starting Time (Seconds) 0.00 Starting Latitude 24.00 Starting Longitude -125.00
Ending Time (Seconds) 31674360.00 Ending Latitude 50.00 Ending Longitude -67.00
Number of Time Points 14 Number Data Points 283

Input Summary



- A summary is provided for the Electric Field Input data
 - The input data is specified by latitude and longitude points, and all the input data **MUST** use the same points; the points do not need to be uniformly spaced
 - The time can be specified is in UTC or using a local

Input Summary

Starting Time (Seconds)	0.00	Starting Latitude	24.00	Starting Longitude	-125.00	<input type="text"/>
Ending Time (Seconds)	31674360.00	Ending Latitude	50.00	Ending Longitude	-67.00	
Number of Time Points	14	Number Data Points	283			
Interpolated Offset Time	0.00	<input type="button" value="View Interpolated Offset Time (Seconds)"/>		Starting Date and Time	5/3/2019 4:42:30 PM (UTC)	

Time Points and Preview Grid



- A tabular display shows of all the time points
 - Right-click and select **Delete** to delete a range of time points
- Use the Save in File field to save a subset of time points into a B3D file

Number of Time Points: 14 Number Data Points: 283

Interpolated Offset Time: 0.00 View Interpolated Offset Time (Seconds) Starting Date and Time: 5/3/2019 4:42:30 PM (JTC) Use Local Time Zone

Save Selected Time Points in B3D Format Clear All Time Points Change Start Date and Time to Zero Time Offset

Time Points (Select Point to Preview)							Time Point Grid Preview (First Entry is the Eastward Value, the Second the Northward)						
	Time Offset, Seconds	Maximum Electric Field, V/km	Maximum Electric Field Longitude	Maximum Electric Field Angle Latitude	Save in File	Date/Tim String		Longitude	Latitude	Distance to Station (km)	Electric Field East, V/km	Electric Field North, V/km	Electric Field Magnitude, V/km
1	0.00	0.006	-89.0000	50.0000	YES	5/3/2019 4:42:30 PM (JTC)	1	-81.0000	24.0000	1107.4700	0.0002	-0.0005	0.0006
2	31673520.00	0.002	-99.0000	50.0000	YES	5/4/2020 6:00:00 AM (JTC)	2	-99.0000	26.0000	1037.7900	0.0001	-0.0006	0.0006
3	31673640.00	0.002	-99.0000	50.0000	YES	5/4/2020 6:00:00 AM (JTC)	3	-97.0000	26.0000	869.3000	0.0001	-0.0007	0.0007
4	31673760.00	0.001	-77.0000	44.0000	YES	5/4/2020 6:00:00 AM (JTC)	4	-83.0000	26.0000	810.0800	0.0002	-0.0006	0.0006
5	31673820.00	0.001	-77.0000	44.0000	YES	5/4/2020 6:00:00 AM (JTC)	5	-81.0000	26.0000	974.2600	0.0002	-0.0006	0.0006
6	31673880.00	0.002	-77.0000	44.0000	YES	5/4/2020 7:00:00 AM (JTC)	6	-79.0000	26.0000	1148.3800	0.0002	-0.0006	0.0006
7	31673940.00	0.002	-77.0000	44.0000	YES	5/4/2020 7:00:00 AM (JTC)	7	-103.0000	28.0000	876.3200	0.0002	-0.0004	0.0005
8	31674000.00	0.002	-85.0000	34.0000	YES	5/4/2020 7:00:00 AM (JTC)	8	-101.0000	28.0000	1044.4100	0.0002	-0.0007	0.0007
9	31674060.00	0.002	-85.0000	34.0000	YES	5/4/2020 7:00:00 AM (JTC)	9	-99.0000	28.0000	946.4500	0.0002	-0.0007	0.0007
10	31674120.00	0.003	-79.0000	38.0000	YES	5/4/2020 7:00:00 AM (JTC)	10	-97.0000	28.0000	761.8000	0.0002	-0.0007	0.0007
11	31674180.00	0.003	-103.0000	50.0000	YES	5/4/2020 7:00:00 AM (JTC)	11	-95.0000	28.0000	583.2600	0.0001	-0.0007	0.0007

Changing Time Point Offsets



- The Time Offset for each Time Point is an offset in seconds from the **Starting Date and Time**
 - To zero out an offset, changing the **Starting Date and Time**, just left-click on the Time Point and select **Change Start Data and Time to Zero Time Offset**

Number of Time Points: Number Data Points:

Interpolated Offset Time: Starting Date and Time:

Time Points (Select Point to Preview)							Time Point Grid Preview (First Entry is the Eastward Value, the Second is the Northward Value)				
	Time Offset, Seconds	Maximum Electric Field, V/km	Maximum Electric Field Longitude	Maximum Electric Field Angle Latitude	Save in File	Date/Time String		Longitude	Latitude	Distance to Station (km)	Electric Field East, V/km
1	-31673520.00	0.006	-89.0000	50.0000	YES	5/3/2019 4:...	1	-113.0000	32.0000	214.7600	0.006
2	0.00	0.002	-99.0000	50.0000	YES	5/4/2020 6:...	2	-111.0000	30.0000	242.7400	0.002
3	120.00	0.002	-99.0000	50.0000	YES	5/4/2020 6:...	3	-115.0000	32.0000	402.8300	0.002
4	240.00	0.001	-77.0000	44.0000	YES	5/4/2020 6:...	4	-111.0000	32.0000	31.7100	0.001
5	300.00	0.001	-77.0000	44.0000	YES	5/4/2020 6:...	5	-111.0000	34.0000	205.1000	0.001
6	360.00	0.002	-77.0000	44.0000	YES	5/4/2020 7:...	6	-115.0000	34.0000	446.9200	0.002
7	420.00	0.002	-77.0000	44.0000	YES	5/4/2020 7:...	7	-121.0000	40.0000	342.2900	0.002
8	480.00	0.002	-85.0000	34.0000	YES	5/4/2020 7:...	8	-109.0000	48.0000	603.2300	0.002

Time Point Grid Preview



- The Time Point Grid Preview allows data for a Time Point or an interpolated point to be seen
 - To view a Time Point, just left-click on the entry in the Time Points tabular display
 - To view an interpolated time, enter the seconds in the Interpolated Offset Time field and select View Interpolated Offset Time (Seconds)

The East and North fields are enterable, but aux file and pasting is not available

Number of Time Points: Number Data Points:

Interpolated Offset Time: View Interpolated Offset Time (Seconds) Starting Date and Time:

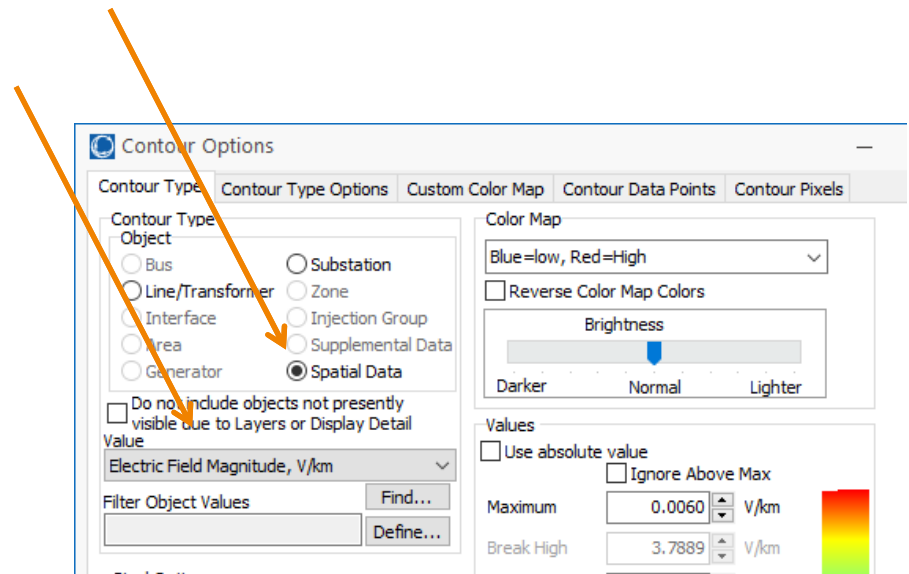
Save Selected Time Points in B3D Format Clear All Time Points Change Start Date and Time to Zero Time Offset

Time Points (Select Point to Preview)							Time Point Grid Preview (First Entry is the Eastward Value, the Second the Northward)								
	Time Offset, Seconds	Maximum Electric Field, V/km	Maximum Electric Field Longitude	Maximum Electric Field Angle Latitude	Save in File	Date/Tim String		Longitude	Latitude	Distance to Station (km)	Electric Field East, V/km	Electric Field North, V/km	Electric Field Magnitude, V/km	Electric Field Angle, Degrees	Data C
1	-31673520.00	0.006	-89.0000	50.0000	YES	5/3/2019 4:...	1	-81.0000	24.0000	1107.4700	0.0003	-0.0008	0.0008	156.1757	
2	0.00	0.002	-99.0000	50.0000	YES	5/4/2020 6:...	2	-99.0000	26.0000	1037.7900	0.0000	-0.0010	0.0010	178.2643	
3	120.00	0.002	-99.0000	50.0000	YES	5/4/2020 6:...	3	-97.0000	26.0000	869.3000	0.0000	-0.0010	0.0010	177.0492	
4	240.00	0.001	-77.0000	44.0000	YES	5/4/2020 6:...	4	-83.0000	26.0000	810.0800	0.0003	-0.0009	0.0009	160.9744	
5	300.00	0.001	-77.0000	44.0000	YES	5/4/2020 6:...	5	-81.0000	26.0000	974.2600	0.0003	-0.0008	0.0009	159.5196	
6	360.00	0.002	-77.0000	44.0000	YES	5/4/2020 7:...	6	-79.0000	26.0000	1148.3800	0.0003	-0.0008	0.0009	158.0782	
7	420.00	0.002	-77.0000	44.0000	YES	5/4/2020 7:...	7	-103.0000	28.0000	876.3200	0.0001	-0.0003	0.0003	156.3706	
8	480.00	0.002	-85.0000	34.0000	YES	5/4/2020 7:...	8	-101.0000	28.0000	1044.4100	0.0000	-0.0011	0.0011	179.4974	
9	540.00	0.002	-85.0000	34.0000	YES	5/4/2020 7:...	9	-99.0000	28.0000	946.4500	0.0000	-0.0011	0.0011	178.4657	

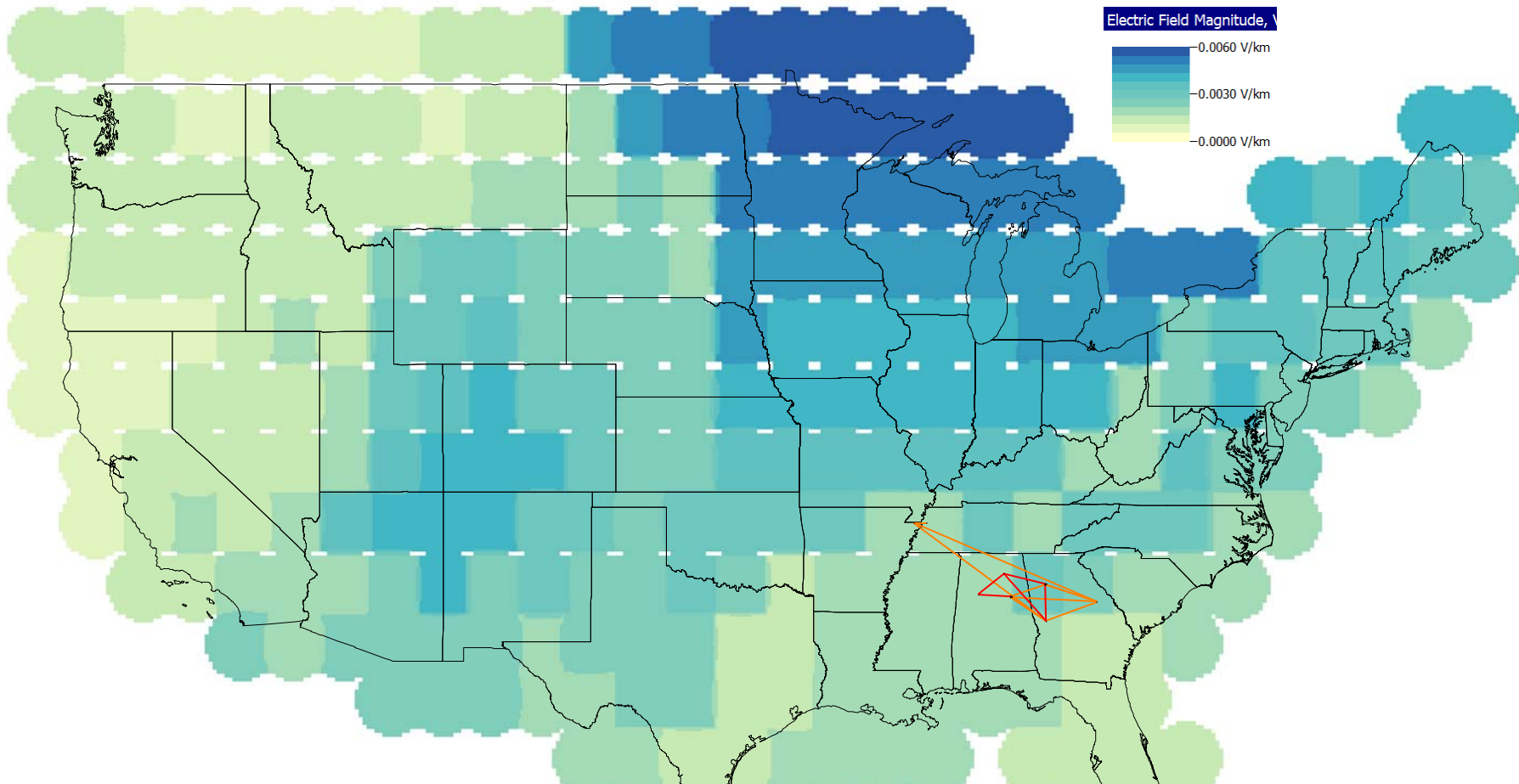
Contouring the Electric Field Data



- The electric field data (magnitude or direction) can be visualized with contours without the need to add explicit points to the contour
 - This is available on the online Contour Dialog by selecting the new Spatial Data type
 - Currently the only data types are for the Electric Fields
 - With spatial data the contour data points are implicitly setup using the data in the Time Point Grid Preview; hence a time point must first be selected



NOAA JSON Electric Field Data Contour Using Shephard's Method



Here the influence distance was set low to show the input data points. However, in the JSON file these points are NOT measurement locations. Rather, they are interpolated based upon a small set of measurement points.

NOAA JSON Electric Field Data Contour Using Delaunay Method

