Texas A&M Smart Grid Center Webinar

An Approach for the Direct Inclusion of Weather Information in the Power Flow

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Acknowledgments

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- Slides also include contributions from many of my students, postdocs, staff and colleagues at TAMU

- The views presented here are my own, and are partially contained in a paper submitted to the 2023 Hawaii International Conference on System Sciences (HICSS)
- The simulations and visualizations shown here are done using the PowerWorld Simulator version 23 beta

Overview

- The purpose of this presentation is to show the benefits of having weather information become a standard part of power flow analysis (with weather including the insolation)
  - The results also apply to related applications such as optimal power flow (OPF), contingency analysis, security-constrained OPF
- The power flow models grid operations past, present and future
- While it is widely recognized that weather impacts electric grid operations, in general weather information has only been implicitly included in the power flow
- The presentation shows how weather could be incorporated into the standard power flow with little changes to existing models, and demonstrates results on grids with more than 80,000 buses.

Weather in Electric Grid Planning and Operations

- Weather information has been used in electric grid planning and operations going back to the initial grids in the 1880’s
- In operations real-time weather information has been long used in control rooms, with computerized information used at least since the 1980’s; current applications are quite sophisticated
- In planning weather information plays many roles, including load forecasting, outage scheduling and in the development of planning power flow cases (summer, winter, spring, fall)
- The focus of this talk is on direct inclusion of weather information in the power flow, with the talk showing this is relatively simple to do with potentially very good benefits

The Power Flow

- The power flow (also called the load flow) is used to determine how the power flows from the generators through the transmission system to the load
  - Prior to digital computers analogs simulators were used; digital computer approaches started to develop in the mid to late 1950's with the algorithms needing to solve the set of nonlinear power balance equations
- In its simplest form the inputs are a power grid model, a set of fixed loads (real and reactive), fixed generator real power outputs and voltage setpoints; the power flow then determines the bus voltages
- Commonly many control values are also adjusted including sometimes the generator real power outputs
- The OPF and SCOPF add additional optimizations

The Power Flow as a System

- The word "system" is can be defined as "a set of connected things or devices that operate together." [Cambridge Dictionary]
- The term power flow is sometimes thought of as just the core algorithm [e.g., Newton-Raphson power flow] but more broadly it is a system the includes
  - The core algorithm for solving the power balance equations
  - External algorithms for modifying controls (e.g., AGC, taps)
  - The set of models used in the algorithms
  - The input data including its format
  - The associated human machine interface (HMI) including visualizations
- The determination of the input parameters could be thought of at the edge of, or outside, the power flow system

This talk focuses mostly on including weather here

A Few Background Thoughts

- "All models are wrong but some are useful," George Box, *Empirical Model-Building and Response Surfaces*, (1987, p. 424)
  - George Box (1919-2013) formed the Department of Statistics at UW-Madison, and has a more than 200,000 Google Scholar citations
  - Models are an approximation to reality, not reality, so they always have some degree of approximation
  - Box went on to say that the practical question is how wrong to they have to be to not be useful
- A good part of engineering is deciding what is the appropriate level of modeling, and knowing under what conditions the model will fail
- The point of this talk is directly including weather information can be very useful, even if it necessarily involves some approximation

Of course Models Should be Implemented Correctly

- Saying the models are always wrong (at least to some degree) does not mean one should be sloppy in implementing the models
  - A power flow example is looking for quadratic convergence to ensure that the Jacobian is being calculated correctly
- Engineering is also balancing the degree of wrongness in the models, tolerating it more when it matters less
- This certainly occurs with the models used in the power flow
  - Positive sequence versus full three-phase
  - Load models
  - Generator PV buses
  - AC versus DC power flow

Engineering Model Tradeoffs

- In any engineering analysis tools (e.g., the power flow here) there are tradeoffs associated with the models to use
  - The existence of the models themselves (i.e., do we understand the physics)
  - The availability of the model parameters and the memory required to store them
  - The computational complexity required to utilize the model
  - The impact of the model on the ultimate results
  - Compatibility with existing software, etc.
- The focus of this talk is to present an approach for the direct inclusion of weather information in the power flow that does not require substantial changes to existing algorithms, and is expandable moving forward

A Little Bit of Power Flow History

- When the power flow was first introduced in the mid 1950's, 50 bus systems were being solved on computers with 4KB of memory [a] and by the mid 1960's 700 buses were solved with 32KB or memory
  - Comments in [c] indicate that by the early 1970's power flows contained up to 4000 buses and 7000 lines
- Hence initial power flows were very much memory constrained
- Into the mid 1980's many computers had on the order of 512KB of memory
- Adding non-crucial parameters like location was not worth the memory

[a] J.B. Ward, H.W. Hale, "Digital Computer Solution of Power Flow Problems," *AIEE Transactions*, vol. 75, pp. 394-404, June 1956

[b] W.F. Tinney, C.E. Hart, "Power Flow Solution by Newton's Method, *IEEE Trans. Power App. & Syst.*, vol. pas-86, pp. 1449-1460, Nov. 1967

[c] "Common Format for Exchange of Solved Load Flow Data," *IEEE Trans. Power App. & Syst.*, vol. pas-92, pp. 1916-1925, Nov/Dec 1973

The Power Flow of Today

- In comparing power flow applications of today versus those of the past, much as changed
- The grid sizes in interconnection level models can be 25 times larger
- Computer memory has increased by at least a factor of 100,000
- However, the key model parameters are mostly the same, contrasting say [a] with [b] and [c]
  - There are now more model parameters, individual objects for loads, generators, switched shunts, three-winding transformers, FACTS, HVDC, impedance correction tables, substations
  - Substation latitude and longitude is now mostly required

[a] "Common Format for Exchange of Solved Load Flow Data," *IEEE Trans. Power App. & Syst.*, vol. pas-92, pp. 1916-1925, Nov/Dec 1973

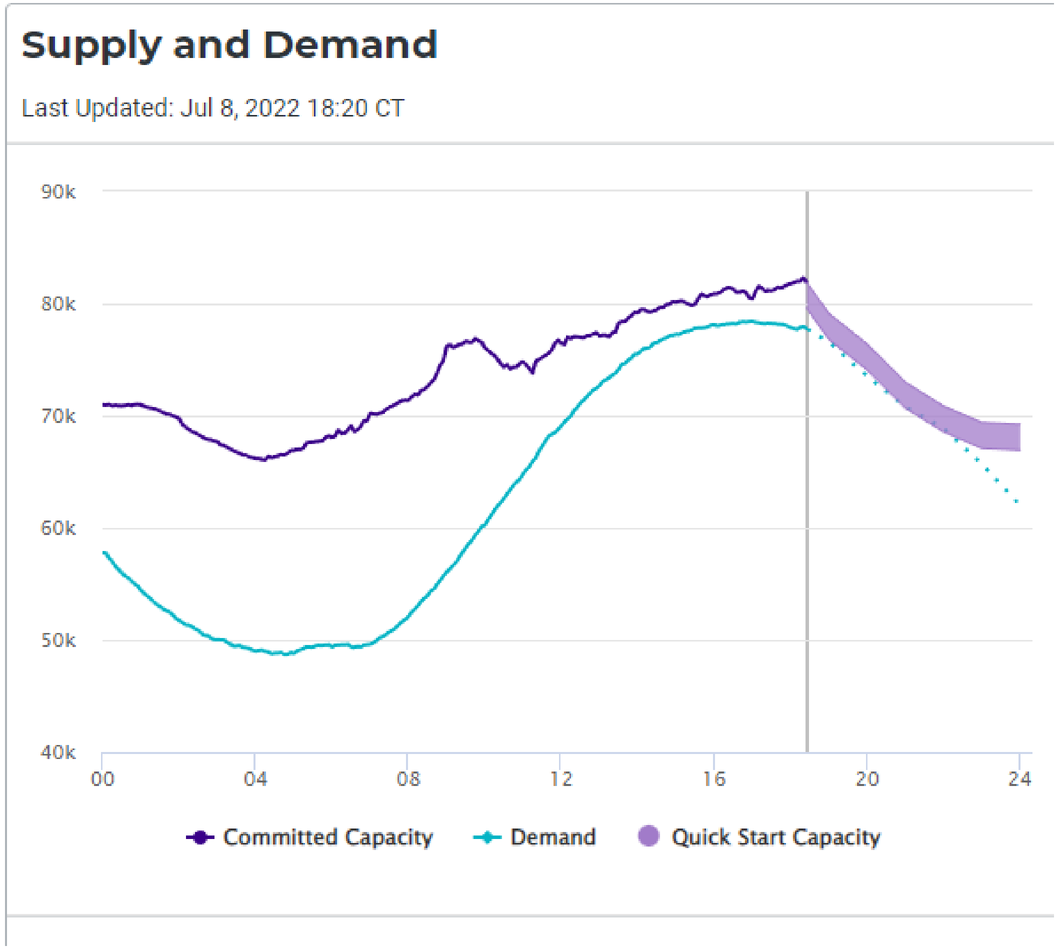
[b] "NERC Library of Standardized Power Flow Parameters and Standardized Dynamic Models, Version 1.0," North American Electric Reliability Corporation, Atlanta, GA, Oct. 2015

[c] "WECC Data Preparation Manual for Interconnection-Wide Cases," WECC, Salt Lake City, UT, 2019.

The Power Flow and Weather

- Human activity depends on the weather, and this has always been reflected in the electric load
- Traditionally some power flow parameters have depended on the weather (e.g., line ratings, combustion turbine max MW, line resistance)
- Over the last several decades this dependence has grown substantially with the increase in wind and solar generation
  - They now provide more than 14% of US electric energy; there are times in which most of the electric power in regions is supplied by these sources
  - They are extremely dependent on the weather
- Major power system input parameters are now heavily weather dependent (e.g., wind and solar generator Max MW)

ERCOT Wind and Solar on 7/8/22



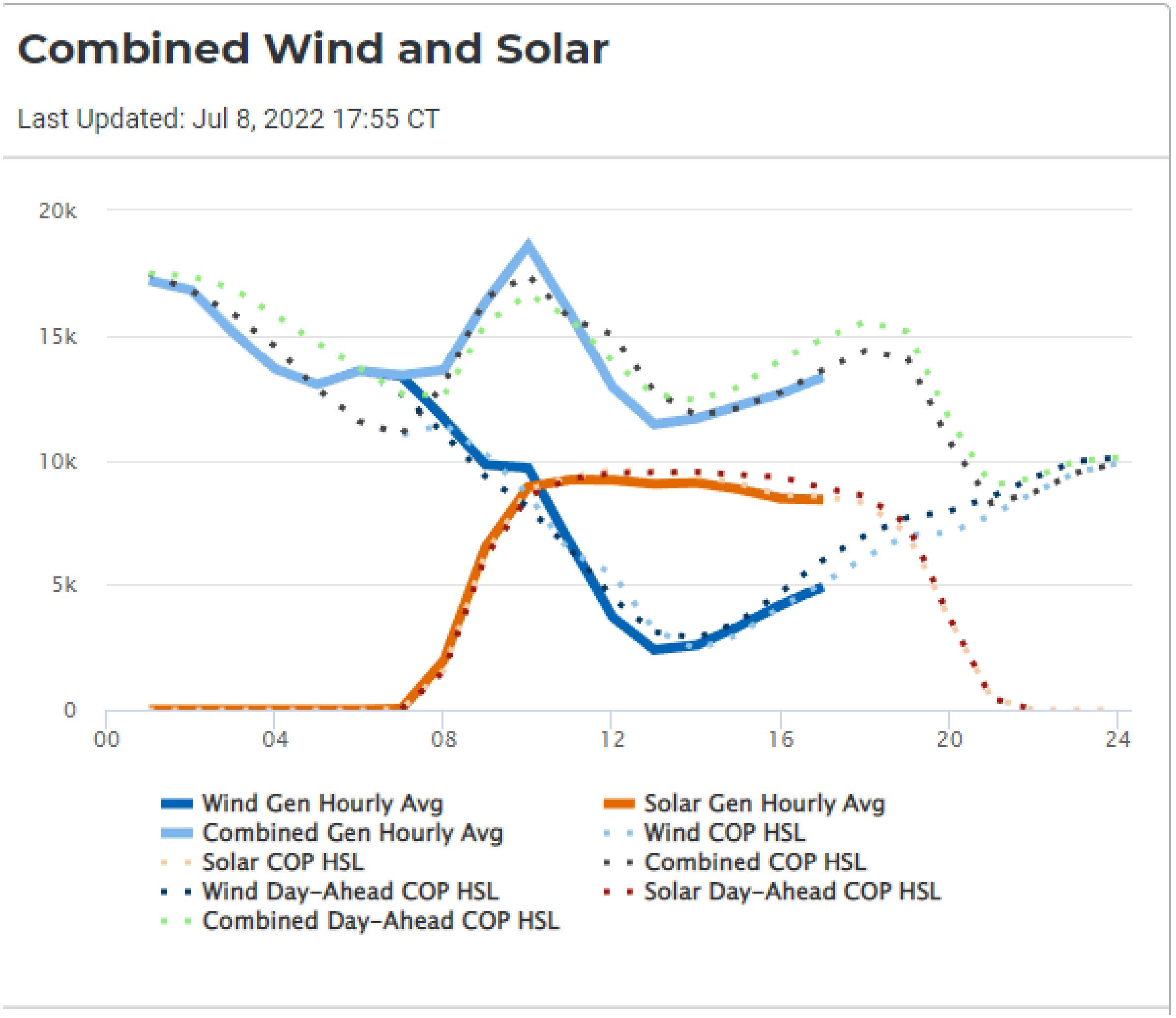


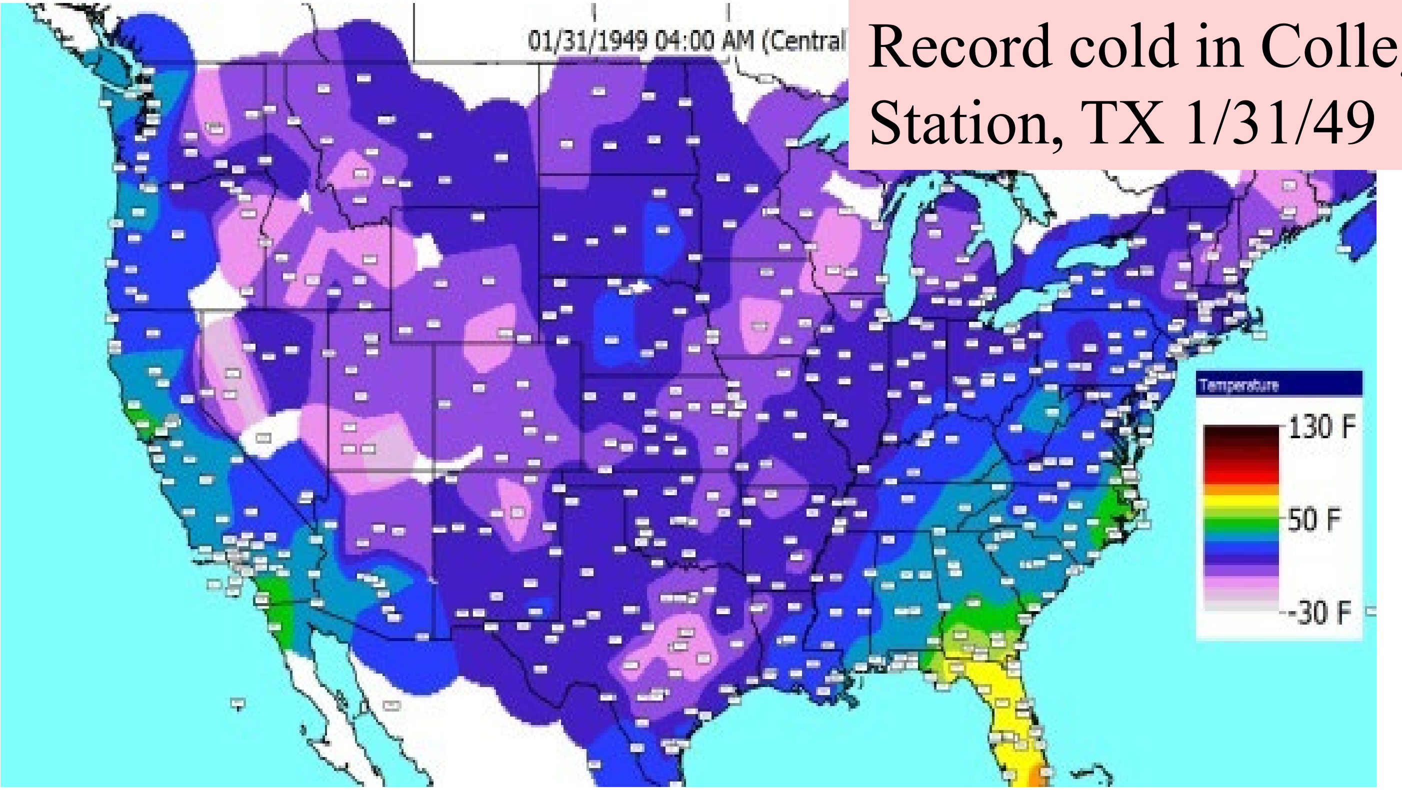
Image Source: ERCOT.com

An Approach for the Direct Inclusion of Weather Information in the Power Flow

- The importance of weather has reached the point in which it should be included as a standard part of the power flow inputs
  - Some models for representing weather impacts already exist, and if weather data is readily available more will be developed
- Requirements for explicitly including weather information in the power flow include
  - Have adequate weather information for the footprint of interest
  - Be able to map the weather information to the pertinent electric grid components
  - Have adequate models of how the weather impacts the grid components
- Remainder of presentation shows that meeting these requirements is relatively straightforward now, and can be improved going forward

Availability of Weather Information: Present and Past

- Current and at least some historical weather information is ubiquitously available
  - Associated with some of the research presented here, we obtained hourly worldwide weather data going back to the 1930's (with the key values being temperature, wind speed, cloud coverage, dew point and wind direction)
  - The number of available stations increases as times get closer to the present

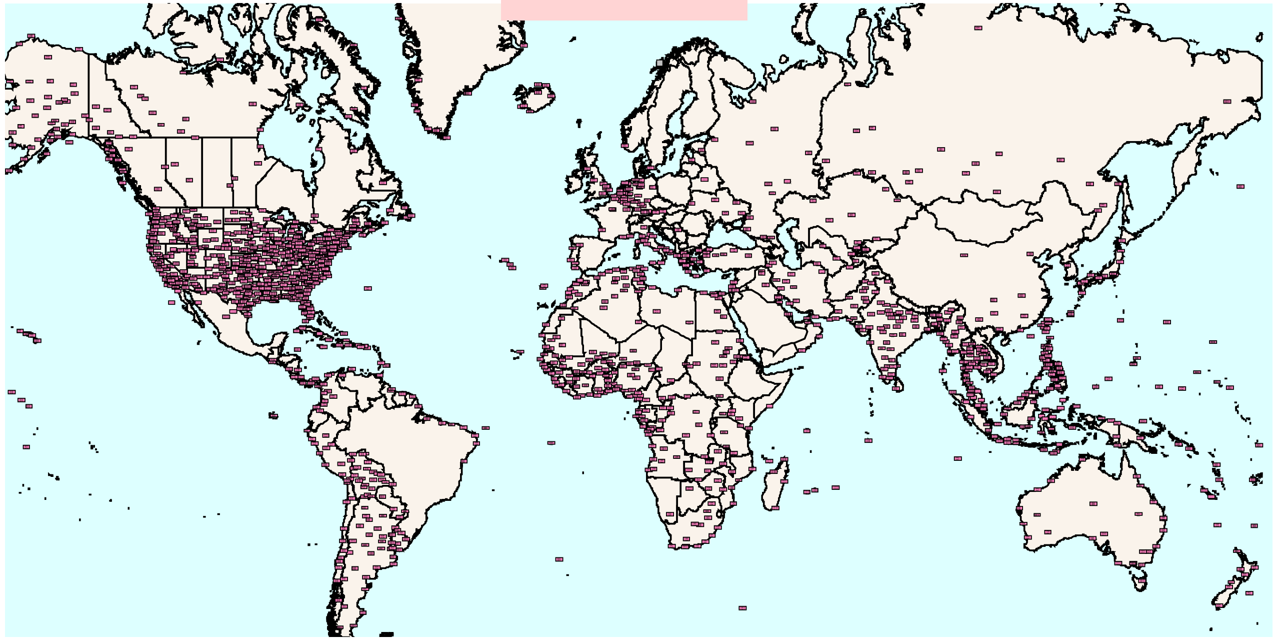


Record cold in College Station, TX 1/31/49

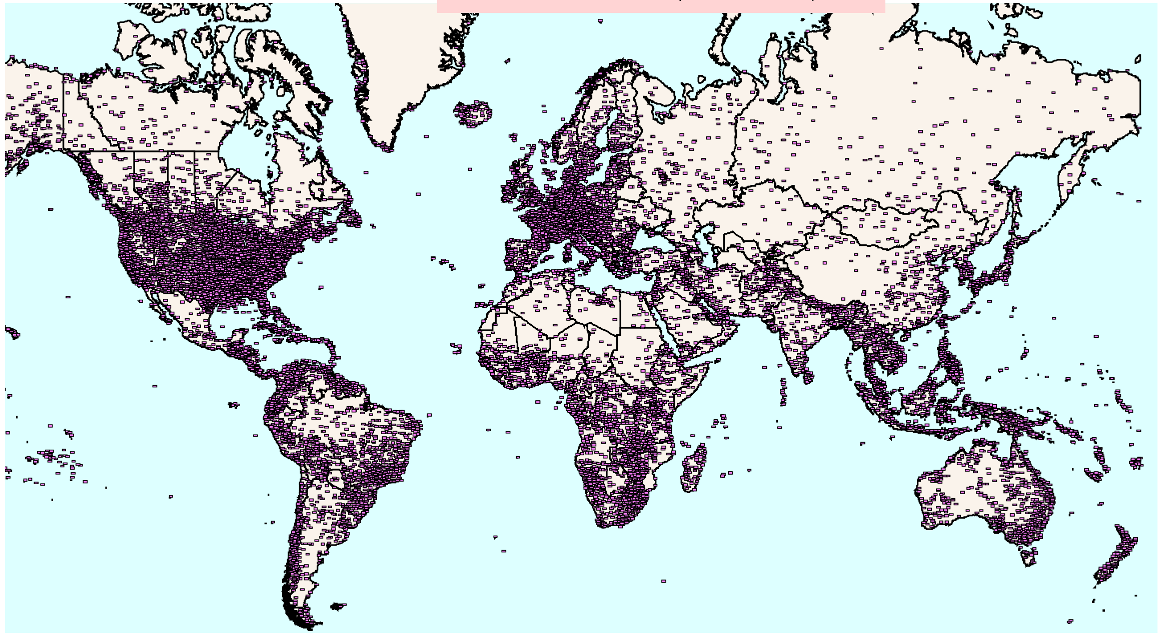
Weather Stations (TAMU Dataset) 1949 vs 2022

- In the dataset we obtained there were about 1600 weather stations in the late 1940’s and more than 23,000 today
  - The number of missing values also decreases moving forward in time

1949



Present (2022)



Weather Station Identifiers

- There is no single standard for identifying weather stations, and there are now many different types of weather stations with available data
- The International Civil Aviation Organization (ICAO) provides data for more than 22,000 locations worldwide using 4-letter identifiers
  - Usually these include the common airport IDs with a letter prefix (KCLL for the College Station airport)
  - Current weather data for about 4900 stations using ICAO is available at https://aviationweather.gov/adds/dataserver_current/current/metars.cache.csv
- The World Meteorological Association (WMO) uses five digit identifiers with some overlap with the ICAOs
- For power flow this data could be supplemented with electric utility weather stations

ICAO METAR Example Information

The data provided from the site includes the raw text along with the decoded fields (data from https://aviationweather.gov/adds/dataserver_current/current/metars.cache.csv)

METAR comes from METeorological Aerodrome Reports)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	No errors												
2	No warnings												
3	450 ms												
4	data source=metars												
5	4913 results												
6	raw_text	station_id	observation_time	latitude	longitude	temp_c	dewpoint_c	wind_dir_deg	wind_speed_kt	wind_gust	visibility_	altim_in_	sea_level_
7	KMVH 082105Z AUTO 19007KT 10SM CLR 27/14 A3013 RMK AO2 PWINO	KMVH	2022-07-08T21:05:00Z	46.83	-108.93	27	14	190	7		10	30.12992	
8	KGUL 082105Z AUTO 00000KT 10SM FEW035 31/25 A3005 RMK A01	KGUL	2022-07-08T21:05:00Z	27.3	-93.53	31	25	0	0		10	30.0502	
9	K1U7 082105Z AUTO VRB04KT 10SM CLR 30/05 A3024 RMK A01	K1U7	2022-07-08T21:05:00Z	42.25	-111.33	30	5	0	4		10	30.23917	
10	KSOP 082104Z AUTO 02011G19KT 2SM +RA BR FEW011 BKN021 OVC036 25/24 A2999 RMK AO2 VIS 3/4V5 RAB2059 P0016 TSNO	KSOP	2022-07-08T21:04:00Z	35.23	-79.4	25	24	20	11	19	2	29.99114	
11	KDWU 082104Z AUTO 00000KT 10SM -RA FEW004 SCT019 SCT050 23/ A2997 RMK AO2 P0000	KDWU	2022-07-08T21:04:00Z	38.55	-82.73	23		0	0		10	29.97047	
12	KCNB 082104Z AUTO 06005KT 10SM CLR 29/16 A3015 RMK AO2	KCNB	2022-07-08T21:04:00Z	44.73	-96.27	29	16	60	5		10	30.15059	
13	YSDU 082103Z AUTO 33003KT 0500 // ////// 02/// Q1020 RF00.0/000.0 CLD:SKY MAY BE OBSC	YSDU	2022-07-08T21:03:00Z	-32.22	148.57			330	3		0.31	30.11811	
14	SBBG 082103Z AUTO 06015KT 9999 TS //////CB 12/06 Q1020	SBBG	2022-07-08T21:03:00Z	-31.38	-54.12	12	6	60	15		6.21	30.11811	
15	KOKK 082103Z AUTO 11013KT 10SM SCT018 SCT027 A3000 RMK AO2 FZRANO $	KOKK	2022-07-08T21:03:00Z	40.53	-86.07			110	13		10	30	
16	KNYC 082103Z AUTO VRB04KT 2 1/2SM -RA BR SCT046 OVC055 23/22 A2998 RMK AO2 RAB2059 P0000 T02280217 $	KNYC	2022-07-08T21:03:00Z	40.78	-73.97	22.8	21.7	0	4		2.5	29.97933	
17	KFKS 082103Z AUTO 35007G15KT 310V020 10SM OVC080 22/14 A3013 RMK AO2	KFKS	2022-07-08T21:03:00Z	44.63	-86.2	22	14	350	7	15	10	30.12992	
18	KABY 082103Z 20009KT 10SM FEW055 35/22 A3001 RMK AO2 LTG DSNT NW-NE T03500217	KABY	2022-07-08T21:03:00Z	31.53	-84.2	35	21.7	200	9		10	30.00886	
19	PAHX 082102Z AUTO VRB03KT 10SM CLR 22/13 A2970 RMK AO2 SLP056 T02170128 50000	PAHX	2022-07-08T21:02:00Z	62.7	-159.57	21.7	12.8	0	3		10	29.69882	1005.6
20	KEND 082102Z AUTO 36014G21KT 10SM CLR 38/21 A2999 RMK AO2 WSHFT 2055 SLP139 $	KEND	2022-07-08T21:02:00Z	36.33	-97.92	38	21	360	14	21	10	29.99114	1013.9
21	KCSM 082102Z 01015KT 10SM CLR 37/19 A3003 RMK AO2 LTG DSNT SE-W T03670194	KCSM	2022-07-08T21:02:00Z	35.35	-99.2	36.7	19.4	10	15		10	30.02953	
22	CYZY 082102Z AUTO VRB07KT 9SM TSRA FEW040 SCT055 SCT068 BKN092 16/09 A2996 RMK PRESRR SLP153 DENSITY ALT 2900FT	CYZY	2022-07-08T21:02:00Z	55.3	-123.13	16	9	0	7		9	29.95866	1015.3
23	SBFN 082101Z AUTO 12015G26KT 9999 FEW023 SCT043 26/23 Q1015	SBFN	2022-07-08T21:01:00Z	-3.85	-32.42	26	23	120	15	26	6.21	29.97047	
24	PAFS 082101Z AUTO 12008G16KT 090V150 10SM CLR 23/07 A2969 RMK AO2 SLP058 T02330067 58003	PAFS	2022-07-08T21:01:00Z	63.02	-154.35	23.3	6.7	120	8	16	10	29.68996	1005.8
25	KRTN 082101Z AUTO 03015KT 10SM VCTS -RA SCT080 BKN090 BKN110 19/13 A3040 RMK AO2 WSHFT 2044 LTG DSNT ALQDS TSE01 P0000 T01	KRTN	2022-07-08T21:01:00Z	36.73	-104.5	19.4	12.8	30	15		10	30.39862	
26	KLSF 082101Z AUTO 17008KT 10SM VCTS FEW027 FEW065 27/23 A3002 RMK AO2 TSE01 PRESRR SLP169 $	KLSF	2022-07-08T21:01:00Z	32.32	-84.97	27	23	170	8		10	30.02067	1016.9
27	KHUF 082101Z VRB04KT 10SM SCT015 SCT110 28/23 A2995 RMK AO2 T02780233	KHUF	2022-07-08T21:01:00Z	39.45	-87.32	27.8	23.3	0	4		10	29.9498	
28	KARB 082101Z AUTO 11004KT 3SM -RA BR SCT030 BKN070 OVC090 21/19 A3006 RMK AO2 P0001 T02060194	KARB	2022-07-08T21:01:00Z	42.22	-83.73	20.6	19.4	110	4		3	30.05906	
29	CYAH 082101Z AUTO 32010G16KT 290V350 9SM BKN041 OVC055 13/05 A2997 RMK SLP160	CYAH	2022-07-08T21:01:00Z	53.75	-73.67	13	5	320	10	16	9	29.97047	1016
30	ZYTX 082100Z 15002MPS 5000 BR SCT030 23/23 Q1000 NOSIG	ZYTX	2022-07-08T21:00:00Z	41.63	123.48	23	23	150	4		3.11	29.52756	
31	ZYTL 082100Z VRB01MPS CAVOK 26/21 Q1001 NOSIG	ZYTL	2022-07-08T21:00:00Z	38.97	121.55	26	21	0	2		6.21	29.55709	
32	ZYHB 082100Z 25004MPS CAVOK 21/17 Q0998 NOSIG	ZYHB	2022-07-08T21:00:00Z	45.62	126.25	21	17	250	8		6.21	29.4685	
33	ZYCC 082100Z 21004MPS 9999 FEW030 20/16 Q1001 BECMG TL2230 TS	ZYCC	2022-07-08T21:00:00Z	43.98	125.68	20	16	210	8		6.21	29.55709	

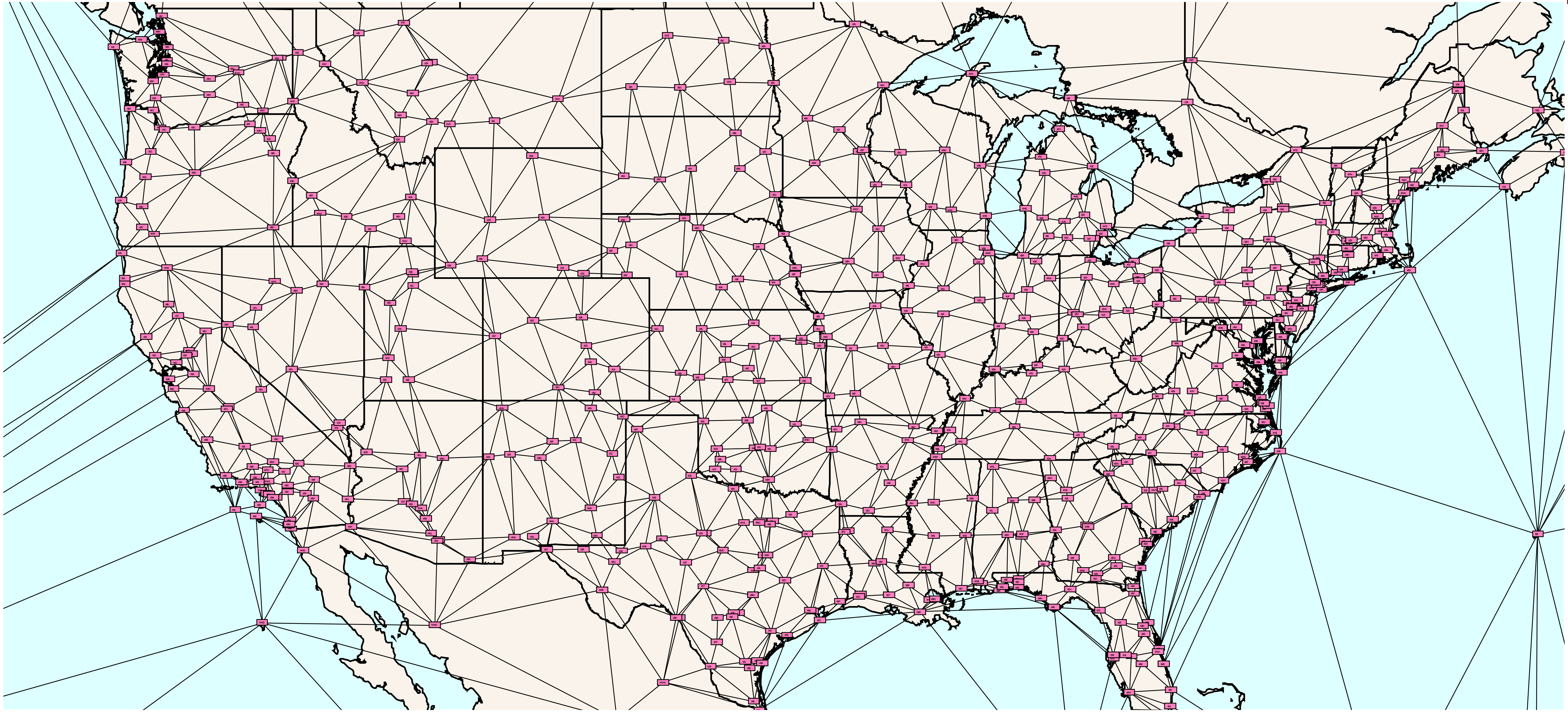
Future Weather

- Given that power flow studies often look at future conditions, there are several options for getting this information
  - Grid organizations (e.g., NERC, EROs, etc.) could select a set of times from the past to study and standardize on them (peak summer is 3pm CDT on xx-xx-xxxx)
  - Grid organizations could develop or obtain future representative weather conditions (many different organizations already do such studies)
  - Entirely fictional conditions could be used (e.g., high temperature, high wind, etc.)
- Inclusion of weather in a power flow data file would have very little impact on the file size
- An advantage of including the weather is the underlying weather assumptions would become explicit

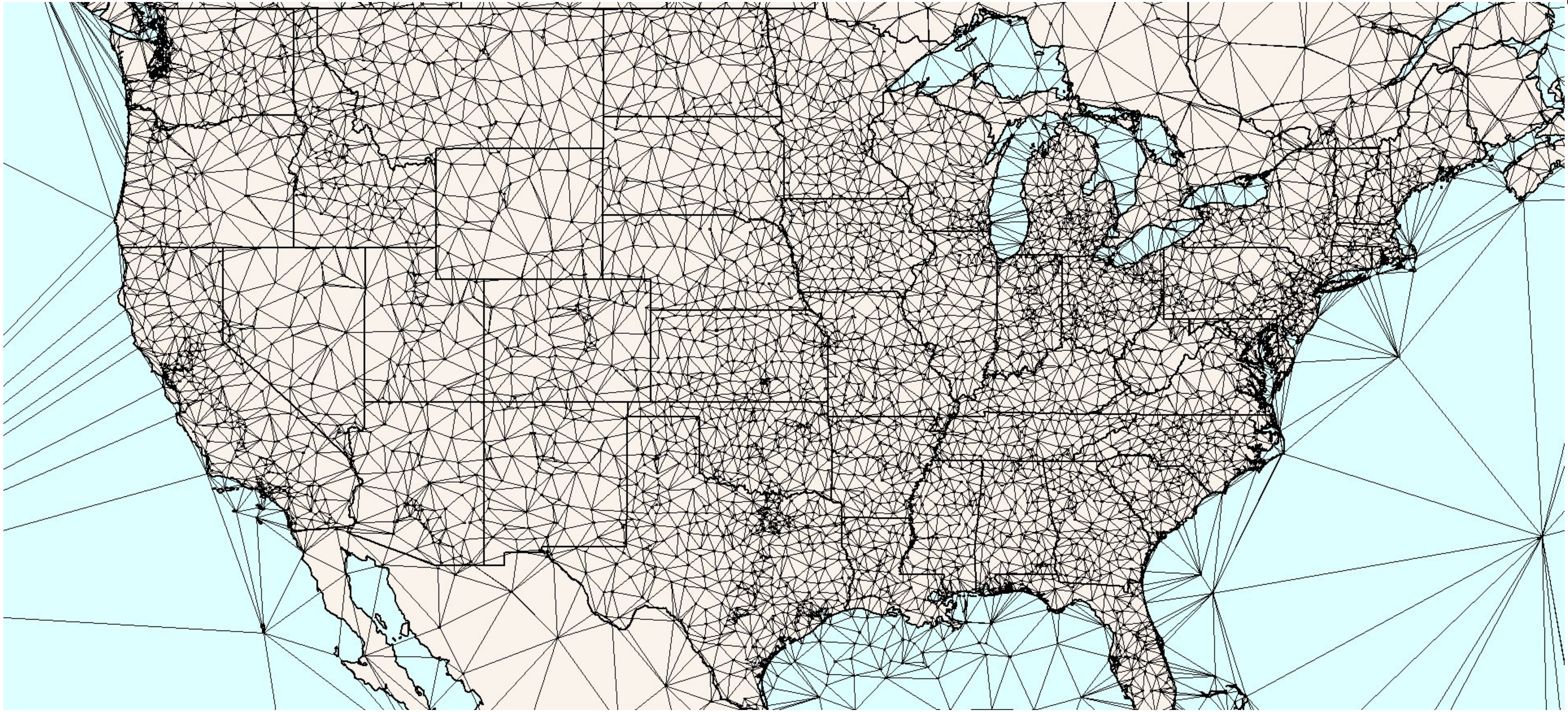
Mapping Weather to the Electric Grid Components

- As noted, geographic information is now available in most power flow cases, either in the main file or a supplemental file
  - Large-scale synthetic grids with geographic information are also available
- Given the number of weather station data available even in the 1940's, close by meteorological measurements are usually available for electric grid infrastructure
- There is no single best algorithm for doing the needed 2D scattered data interpolation, but there are a number of good and fast algorithms (Delaunay Triangulation, Shepherd's, closest neighbor)
- Usually places in which the weather changes rapidly with geography (e.g., mountains) don't have much electric infrastructure (the exceptions are covered next)

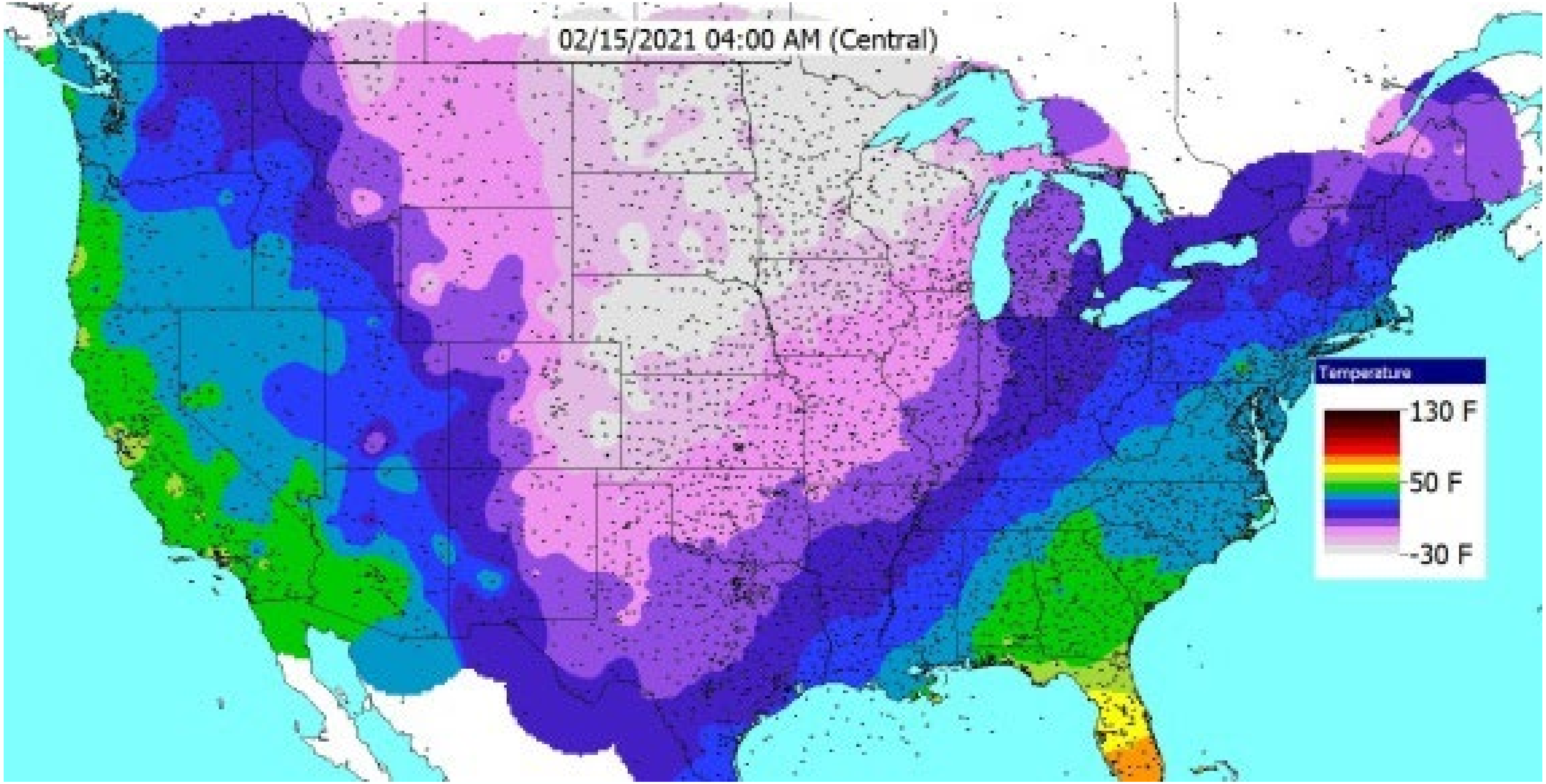
Delaunay Triangulation of 1949 Weather Stations



Delaunay Triangulation of 2022 Weather Stations

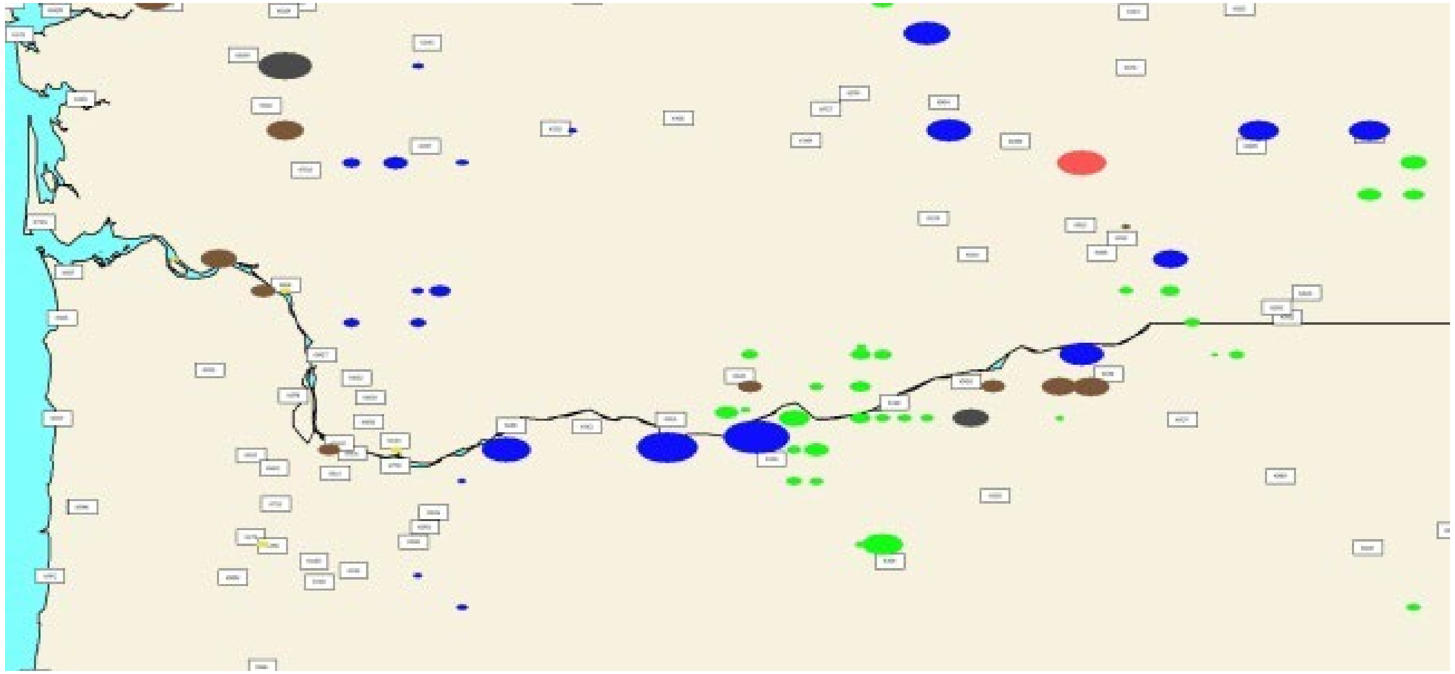


Temperature Contour for February 15, 2021



Mapping Weather to the Electric Grid Components

- In situations in which interpolation does not work well (e.g., valleys, mountains, some coastal regions), specific weather stations could be assigned to the electric grid devices (e.g., a wind farm)
  - A example is the Columbia River Gorge with a length of 190 km and an average width of 5 km; the gorge has a unique and complex climate often with high winds
  - Image shows the generation (ovals, with green for wind and blue for hydro) and the weather stations (as white rectangles)



Last Issue: Models of Grid Weather Impacts

- Certainly a number of models already exist, and undoubtedly more will be created as weather data is included with power flow cases
- An approach for handling a growing list of models is to mimic what has been done with power system stability – start small and expand
  - Stability codes from 1960 gave some nice results on grids with up to 96 generators using a total of three models (a machine, an exciter, and a governor)
  - Current stability codes support hundreds of models

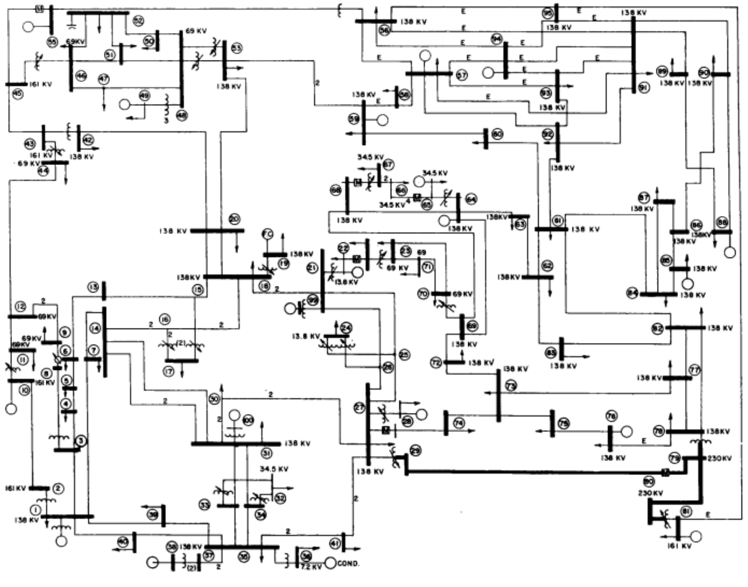
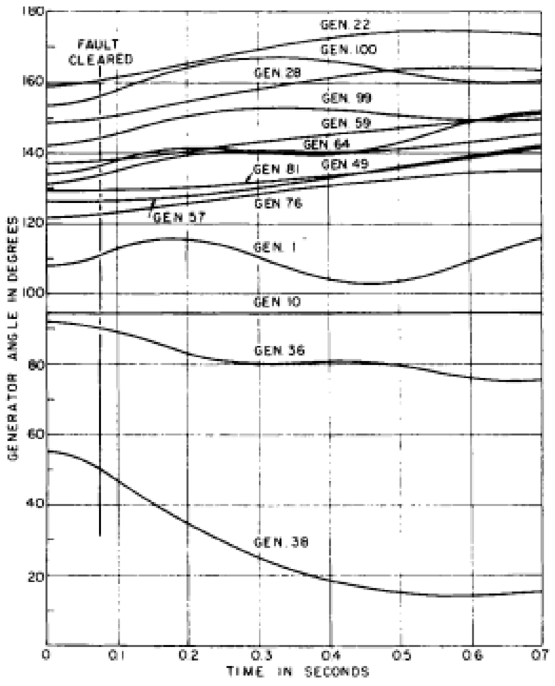


Fig. 4. One-line diagram of Union Electric Company system



[a] M. S. Dyrkacz, C. C. Young, and F. J. Maginniss, "," *AIEE Trans. (Power App. & Syst.)*, vol. 79, pp. 1245-1257, Feb. 1961.

Example of Model Evolution: Exciters for Stability

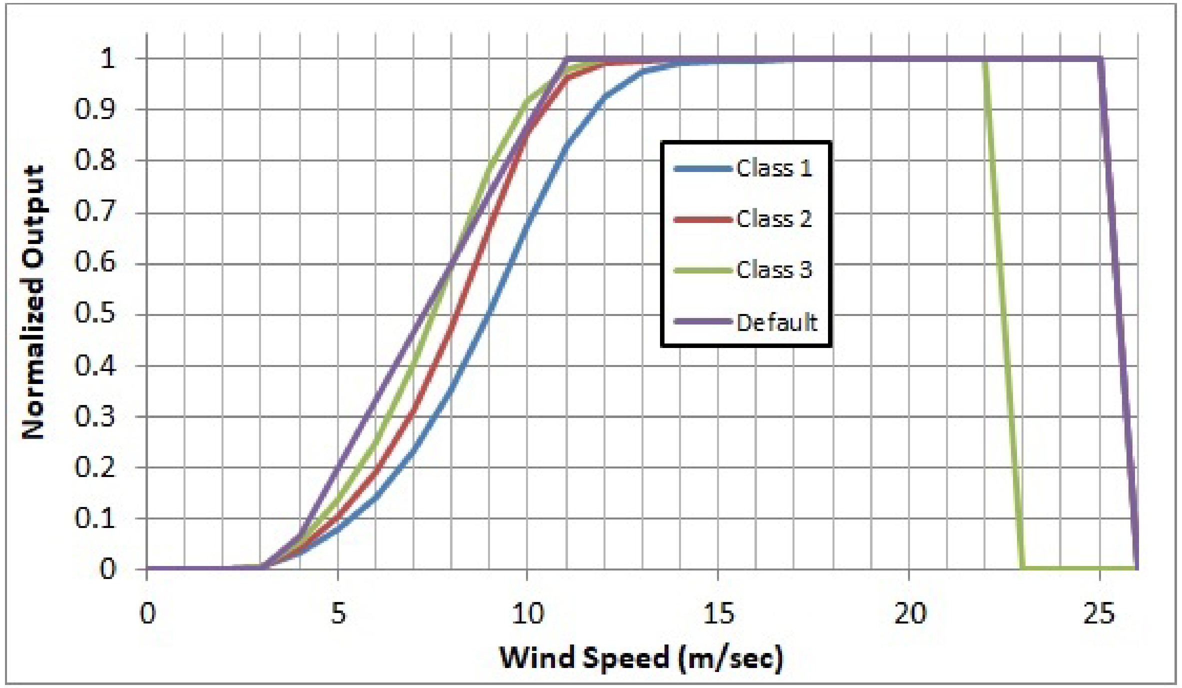
- In previous 1961 article the exciter had one differential equation
- In 1968 the IEEE type 1 to 4 exciters were defined [a]
- In 1981 updated exciters are provided (modeled as EX…) [b]
- In 1992 IEEE Std. 421.5-1992 provides more updates (modeled as ES…) and also includes power system stabilizers
- In 2005 IEEE Std. 421.5-2005 provides more updates and includes over and underexcitation limiters, and power factor and reactive controllers and regulators
- In 2016 IEEE Std. 421-5-2016 provides more updates

[a] "Computer Representation of Excitation Systems," *IEEE Trans. Power App. and Syst.*, vol. PAS-87, pp. 1460-1464, June 1968

[b] "Excitation System Models for Power Stability Studies," *IEEE Trans. Power App. and Syst.*, vol. PAS-100, pp. 494-509, February 1981

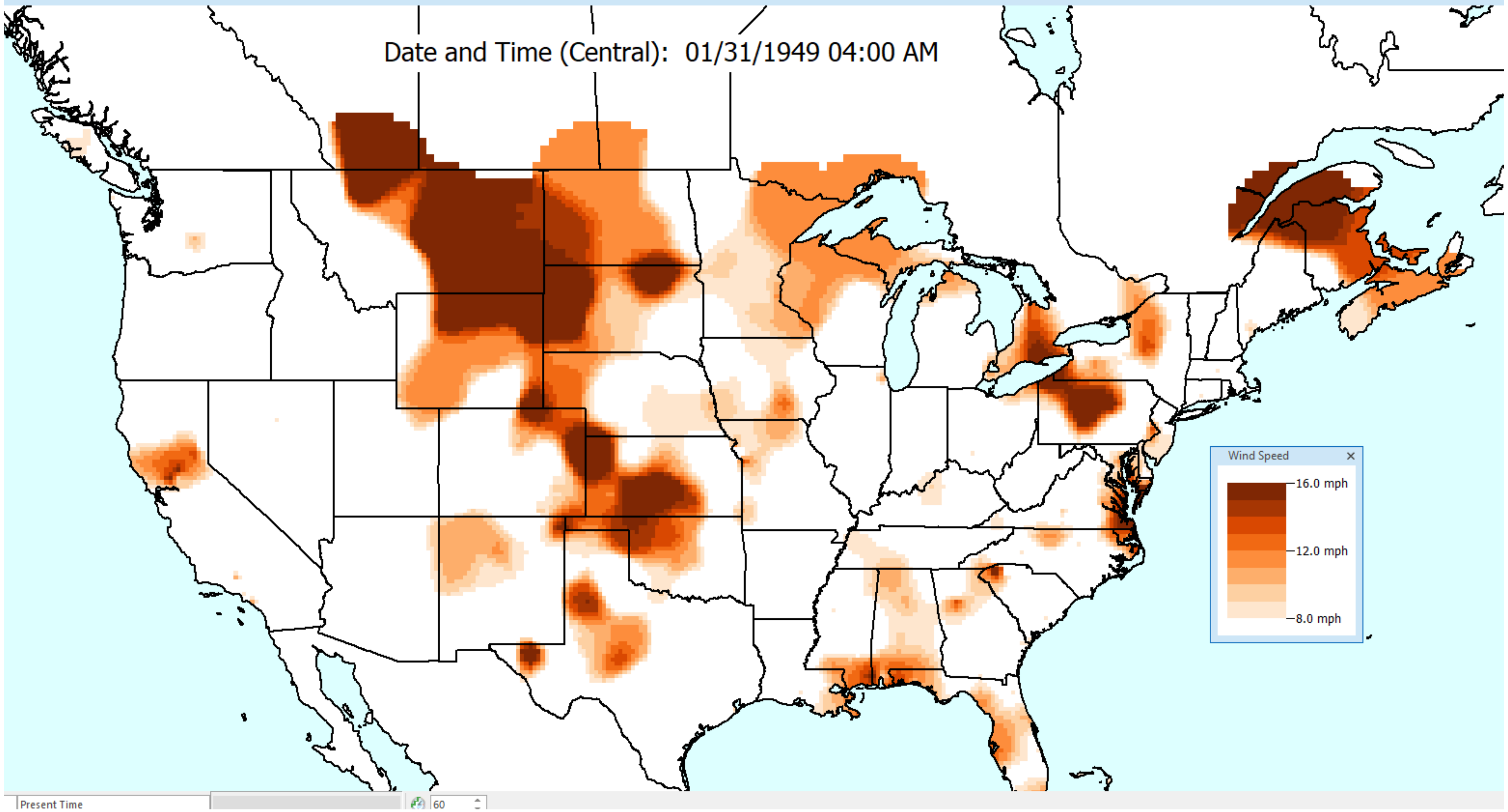
Initial Models: Gen MaxMW Wind and Solar

- Initially we've code just six different models, all relating weather to generator maximum MW values (four wind turbines, a generic solar and a generic temperature)
  - The wind turbine models are based on the turbine classes using data from [a]
  - The solar PV model uses the standard equations for insolation based on location and time of day including cloud cover, combining it with whether the solar has tracking and, if needed, its tilt and azimuth

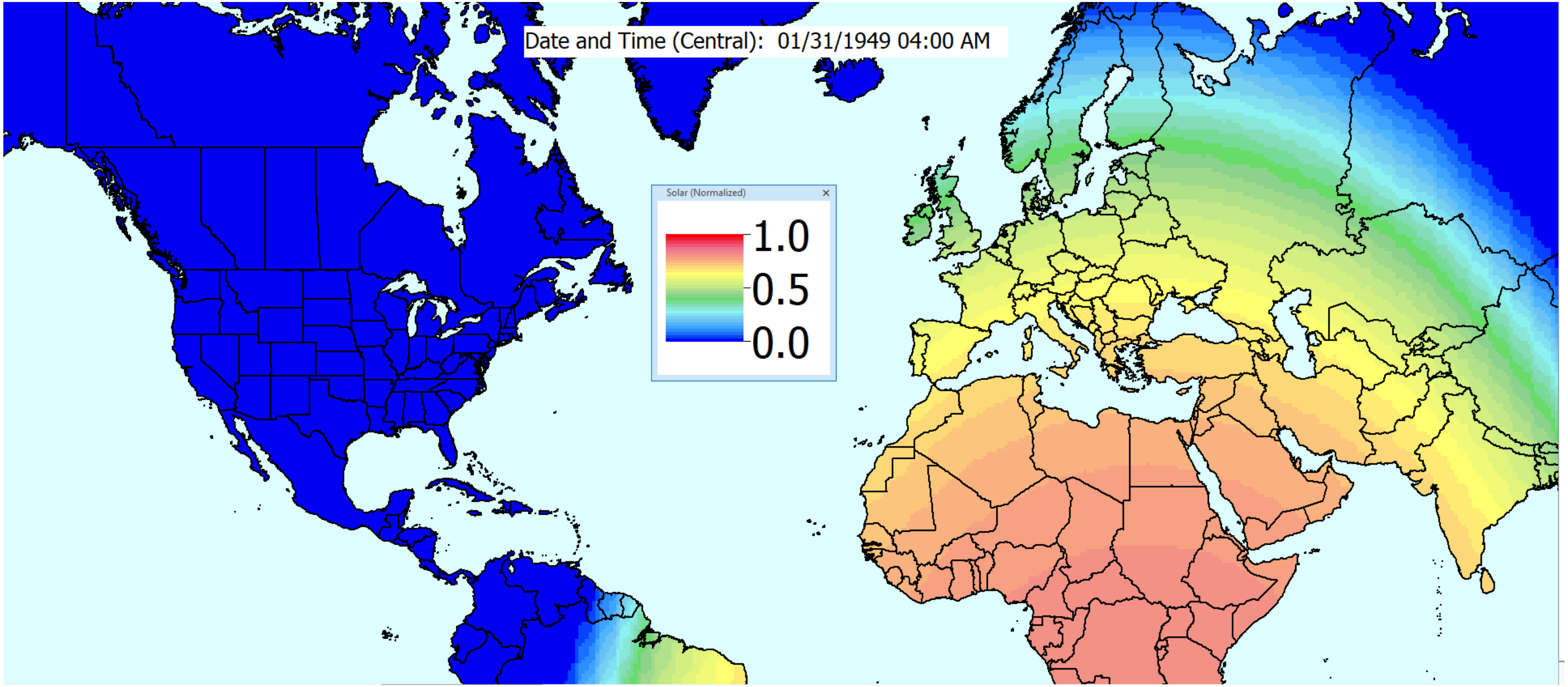


[a] C. Draxl, A. Clifton, B. Hodge, J. McCaa, "The Wind Integration National Dataset (WIND) Toolkit," *Applied Energy*, vol. 151, pp. 355-366, 2015.

Example: Wind During Record Cold in Texas (1949)



Example: Solar at 4am (Central) on 1/31/49



Needed Wind and Solar Data is in EIA 860

- For generation in the US the data needed to setup the wind and solar models is in the EIA 860 data
  - For wind this includes the wind quality class, the design speed, the turbine model, and the hub height
  - For solar this includes the type of tracking (single or dual), tilt angle and azimuth angle

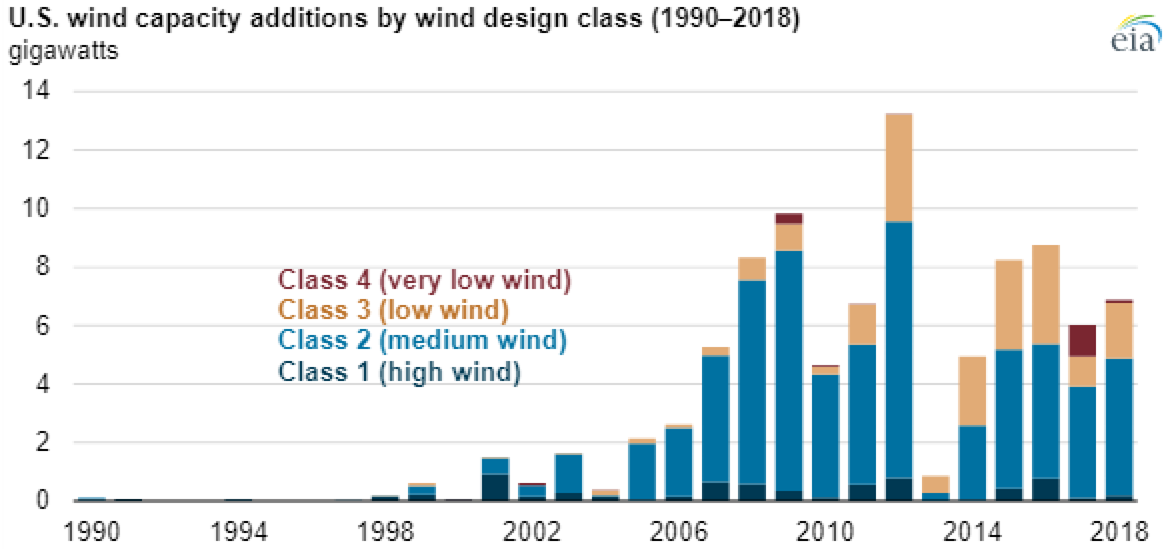
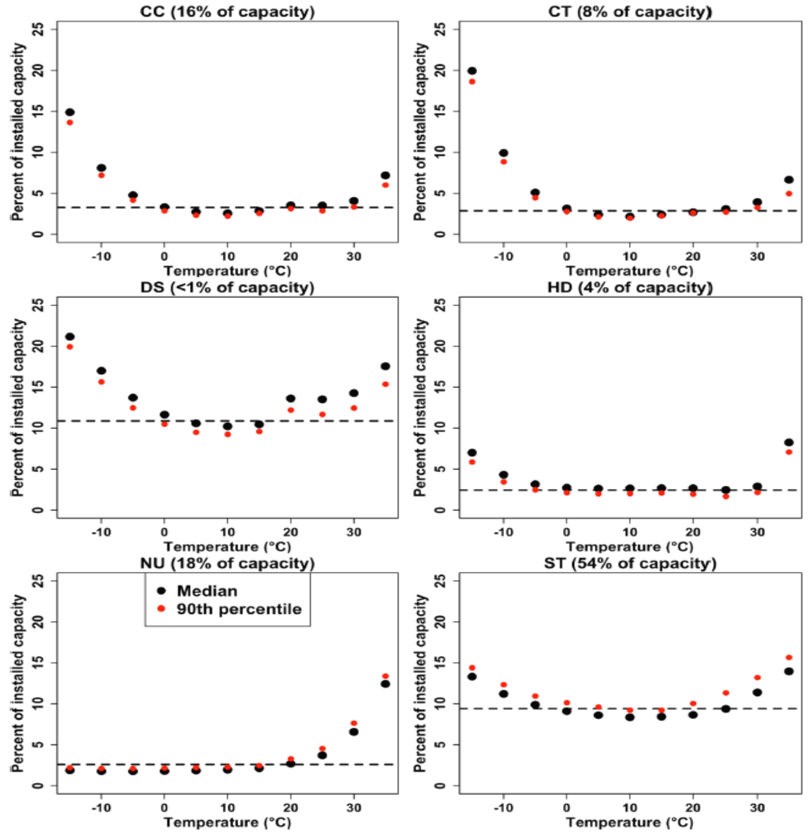


Image source: www.eia.gov/todayinenergy/detail.php?id=41474

Initial Model: Generation Max MW and Temperature

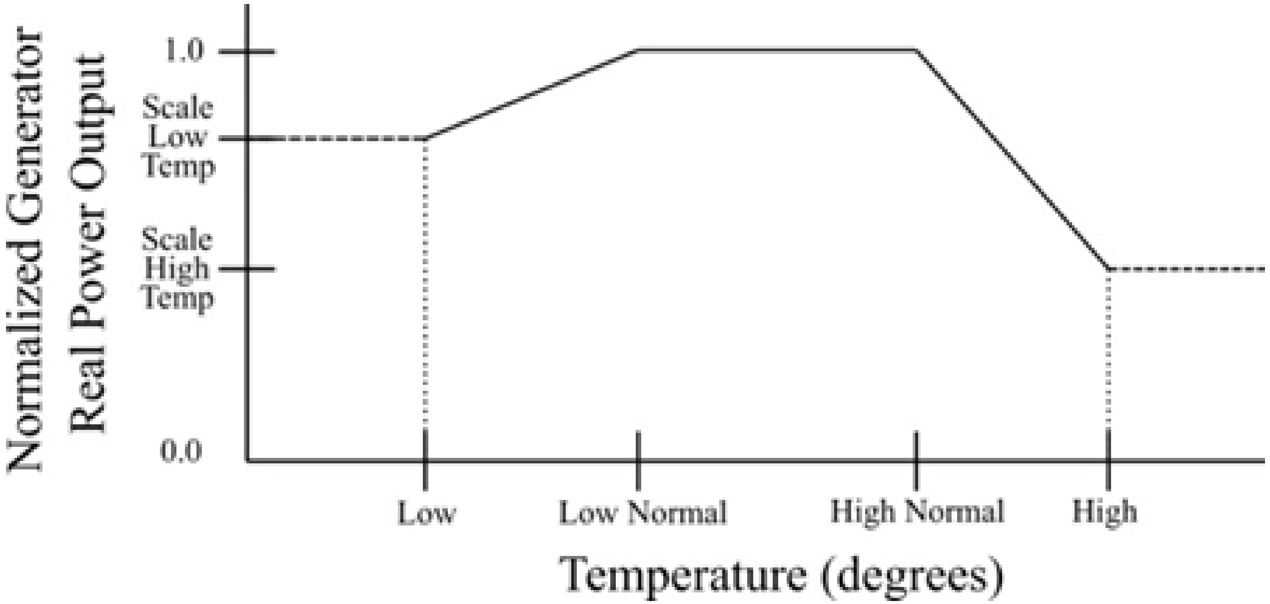
- The impact of ambient temperature on some types of generators is well known, with their output decreasing as the temperature rises
- As demonstrated in Feb 2021 generators can be impacted by low temperatures, but the relationship is less well defined
- As presented in [a] the failure rate for generators does show some strong temperature dependency (left image is Figure 6 from [a]



[a] S. Murphy, F. Sowell, J. Apt, “A time-dependent model of generator failures and recoveries captures correlated events and quantifies temperature dependence,” *Applied Energy*, vol. 253, 2019.

Initial Model: Generation Max MW and Temperature

- More R&D is needed to determine how this dependence should be reflected in power flow models
  - This temperature dependence could be represented either in a deterministic or in a stochastic model (e.g., for power flow Monte Carlo simulations)
- One simple model is shown below

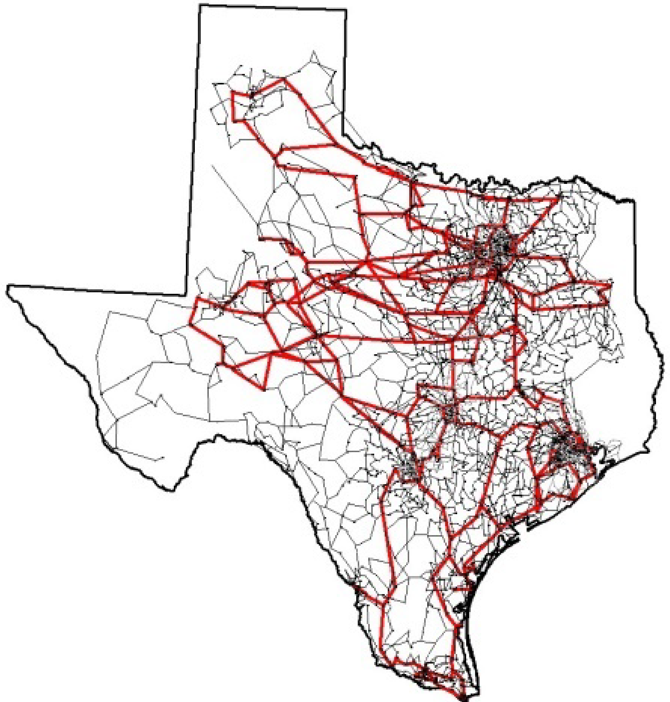


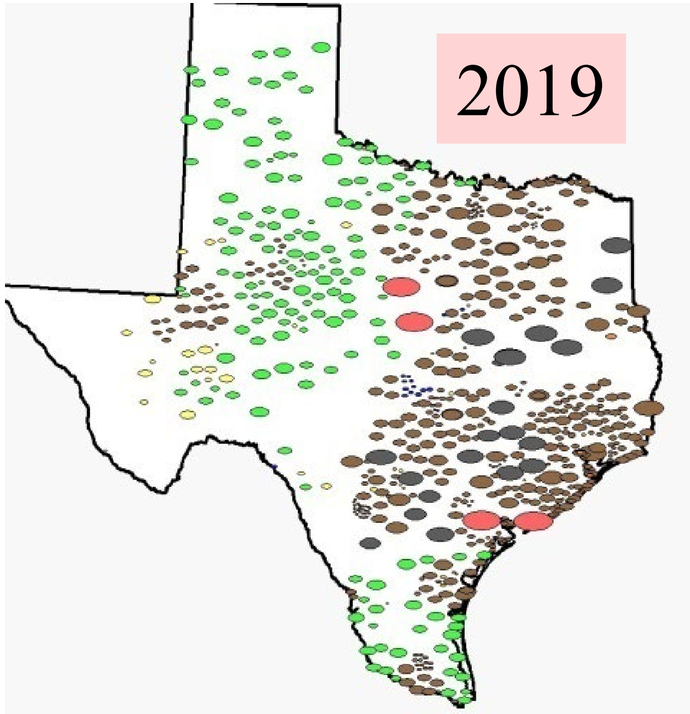
Some Potential Additional Models

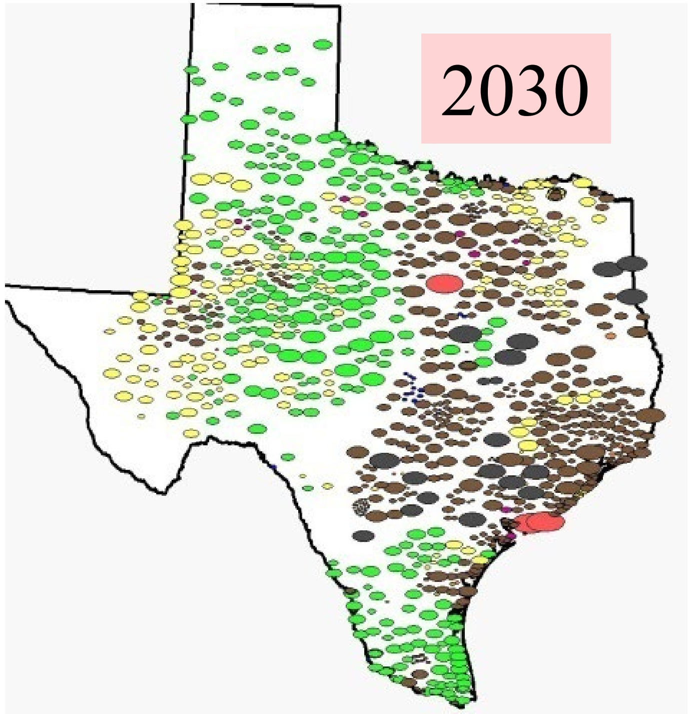
- With weather information a part of the power flow a wide variety of additional power flow model enhancements become possible. Some examples are given below, recognizing that many are already done using external analysis
  - Transmission line limits that depend on temperature, wind and insolation along the right-of-way
  - Transformer limits
  - Load models (recognizing that the load depends on many factors, initial models could be linearizations about a specified value)
  - Line resistance (though this would be more complex since it is operating point dependent
  - Etc.

A 6700 Bus Synthetic Grid Example

- Next slides give some specific examples, with the first example using a 6700 bus synthetic grid on the ERCOT footprint.
  - The transmission grid is shown on the left (red is 345 kV, black 138 kV), with the generation shown using a geographic data view (GDV) visualization with green wind, yellow solar, red nuclear, brown natural gas





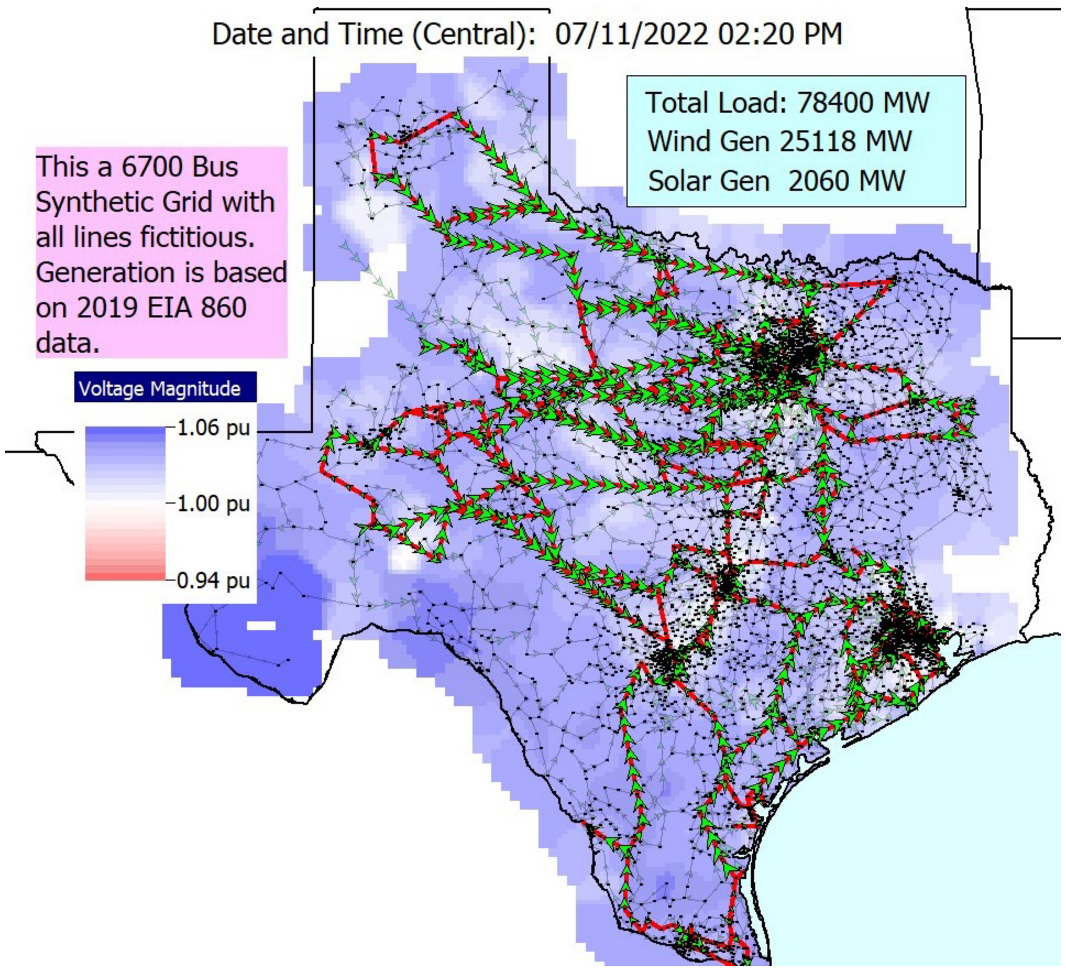


Applying July 11 and 12, 2022 Weather to Case

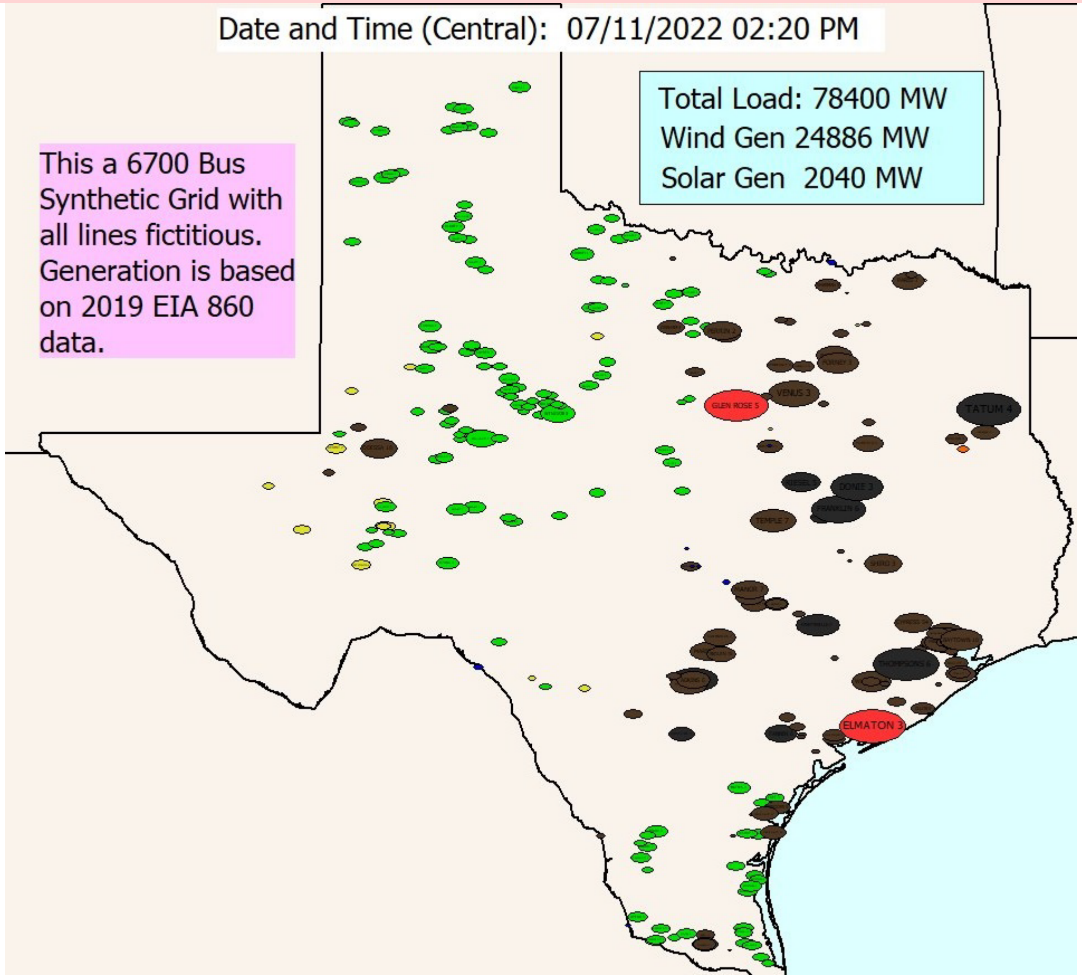
- Given that ERCOT set an all time peak on 7/11/22 (78,379 MW) with a conservation appeal (driven in part by low wind availability) for between 2 and 8 pm, the first example shows how weather can be quickly applied to this situation
- According to the ERCOT 7/10/22 news release their capacity is 80,083 MW dispatchable, 35,162 MW wind , and 11,787 MW solar
  - On July 11 only about 8% of the wind was forecasted to be available at peak
- The example uses the 6700 bus case with 2019 capacity of 25,700 MW wind, 2335 MW solar and 76,900 dispatchable
- The power flow case was initially set to all generation online with a load of 78,400 MW

6700 Bus Power Flow Solution: No Weather

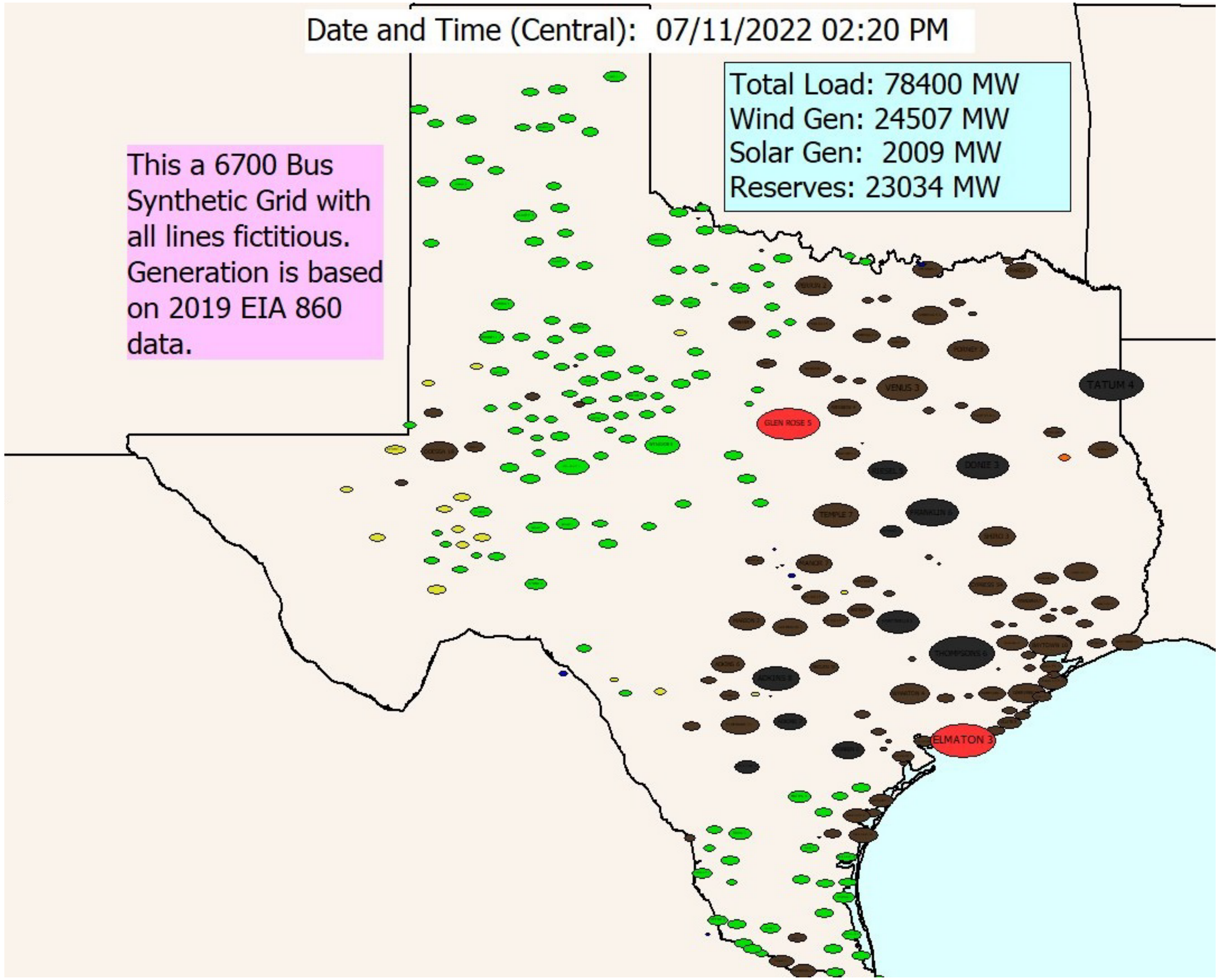
Standard Voltage Contour



GDV of generation dispatch, size is MW, color is fuel type (green is wind, yellow solar)

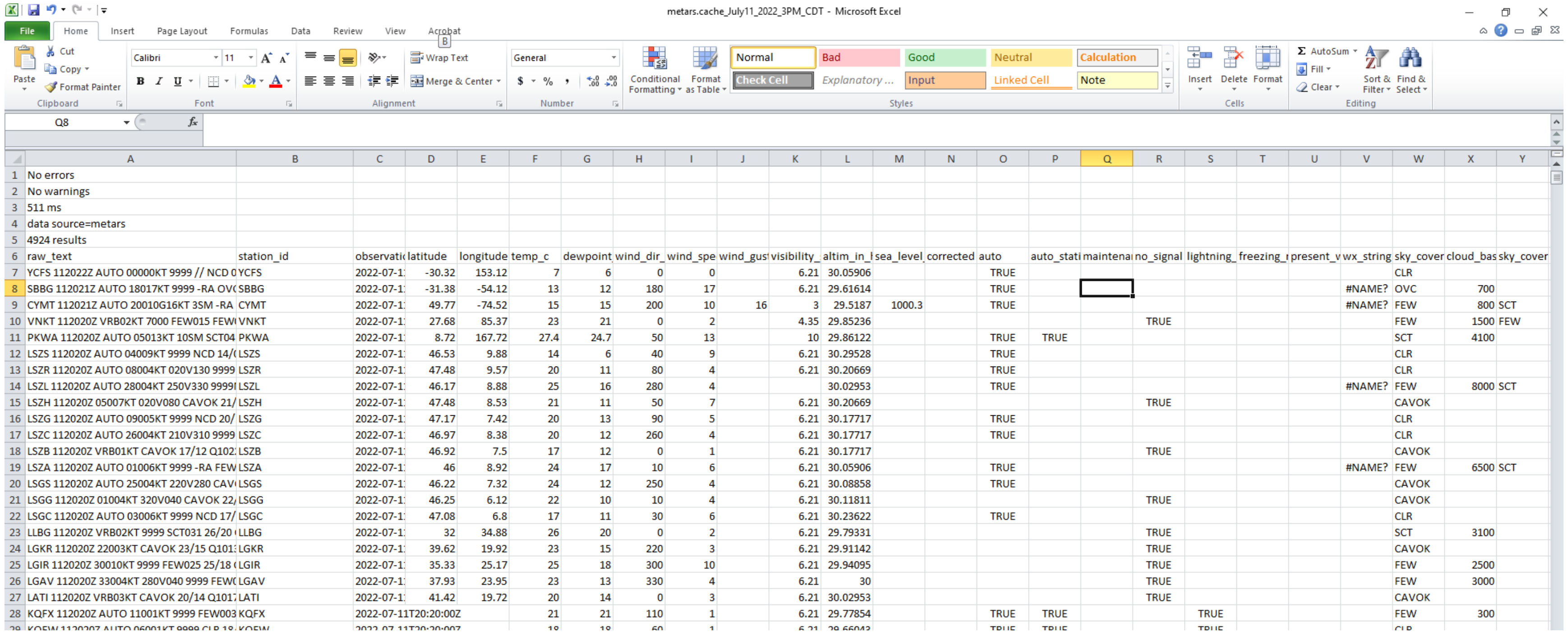


GDV of Generation with Layout with No Weather



Adding the Weather

- On July 11 at about 3pm CDT I downloaded the worldwide weather data from
  - https://aviationweather.gov/adds/dataserver_current/current/metars.cache.csv
  - There are many sources for weather information; this is just one easy to get example



metars.cache_July11_2022_3PM_CDT - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	No errors																								
2	No warnings																								
3	511 ms																								
4	data source=metars																								
5	4924 results																								
6	raw_text	station_id	observati	latitude	longitude	temp_c	dewpoint_	wind_dir_	wind_spe	wind_gust	visibility_	altim_in_I	sea_level_	corrected	auto	auto_stati	maintena	no_signal	lightning_	freezing_r	present_v	wx_string	sky_cover	cloud_bas	sky_cover
7	YCFS 112022Z AUTO 00000KT 9999 // NCD 0	YCFS	2022-07-1:	-30.32	153.12	7	6	0	0		6.21	30.05906			TRUE								CLR		
8	SBBG 112021Z AUTO 18017KT 9999 -RA OV(	SBBG	2022-07-1:	-31.38	-54.12	13	12	180	17		6.21	29.61614			TRUE							#NAME?	OVC	700	
9	CYMT 112021Z AUTO 20010G16KT 3SM -RA	CYMT	2022-07-1:	49.77	-74.52	15	15	200	10	16	3	29.5187	1000.3		TRUE							#NAME?	FEW	800	SCT
10	VNKT 112020Z VRB02KT 7000 FEW015 FEW(	VNKT	2022-07-1:	27.68	85.37	23	21	0	2		4.35	29.85236						TRUE					FEW	1500	FEW
11	PKWA 112020Z AUTO 05013KT 10SM SCT04	PKWA	2022-07-1:	8.72	167.72	27.4	24.7	50	13		10	29.86122			TRUE	TRUE							SCT	4100	
12	LSZS 112020Z AUTO 04009KT 9999 NCD 14/(	LSZS	2022-07-1:	46.53	9.88	14	6	40	9		6.21	30.29528			TRUE								CLR		
13	LSZR 112020Z AUTO 08004KT 020V130 9999	LSZR	2022-07-1:	47.48	9.57	20	11	80	4		6.21	30.20669			TRUE								CLR		
14	LSZL 112020Z AUTO 28004KT 250V330 9999I	LSZL	2022-07-1:	46.17	8.88	25	16	280	4			30.02953			TRUE							#NAME?	FEW	8000	SCT
15	LSZH 112020Z 05007KT 020V080 CAVOK 21/	LSZH	2022-07-1:	47.48	8.53	21	11	50	7		6.21	30.20669						TRUE					CAVOK		
16	LSZG 112020Z AUTO 09005KT 9999 NCD 20/	LSZG	2022-07-1:	47.17	7.42	20	13	90	5		6.21	30.17717			TRUE								CLR		
17	LSZC 112020Z AUTO 26004KT 210V310 9999	LSZC	2022-07-1:	46.97	8.38	20	12	260	4		6.21	30.17717			TRUE								CLR		
18	LSZB 112020Z VRB01KT CAVOK 17/12 Q102:	LSZB	2022-07-1:	46.92	7.5	17	12	0	1		6.21	30.17717						TRUE					CAVOK		
19	LSZA 112020Z AUTO 01006KT 9999 -RA FEW	LSZA	2022-07-1:	46	8.92	24	17	10	6		6.21	30.05906			TRUE							#NAME?	FEW	6500	SCT
20	LSGS 112020Z AUTO 25004KT 220V280 CAV(	LSGS	2022-07-1:	46.22	7.32	24	12	250	4		6.21	30.08858			TRUE								CAVOK		
21	LSGG 112020Z 01004KT 320V040 CAVOK 22/	LSGG	2022-07-1:	46.25	6.12	22	10	10	4		6.21	30.11811						TRUE					CAVOK		
22	LSGC 112020Z AUTO 03006KT 9999 NCD 17/	LSGC	2022-07-1:	47.08	6.8	17	11	30	6		6.21	30.23622			TRUE								CLR		
23	LLBG 112020Z VRB02KT 9999 SCT031 26/20 (	LLBG	2022-07-1:	32	34.88	26	20	0	2		6.21	29.79331						TRUE					SCT	3100	
24	LGKR 112020Z 22003KT CAVOK 23/15 Q101:	LGKR	2022-07-1:	39.62	19.92	23	15	220	3		6.21	29.91142						TRUE					CAVOK		
25	LGIR 112020Z 30010KT 9999 FEW025 25/18 (	LGIR	2022-07-1:	35.33	25.17	25	18	300	10		6.21	29.94095						TRUE					FEW	2500	
26	LGAV 112020Z 33004KT 280V040 9999 FEW(	LGAV	2022-07-1:	37.93	23.95	23	13	330	4		6.21	30						TRUE					FEW	3000	
27	LATI 112020Z VRB03KT CAVOK 20/14 Q1017	LATI	2022-07-1:	41.42	19.72	20	14	0	3		6.21	30.02953						TRUE					CAVOK		
28	KQFX 112020Z AUTO 11001KT 9999 FEW003	KQFX	2022-07-11T20:20:00Z			21	21	110	1		6.21	29.77854			TRUE	TRUE			TRUE				FEW	300	

Loading the Weather

- The METAR file can be directly loaded into the power flow software (other options for handling historical weather will be covered shortly)
  - Since the file has the weather station latitudes and longitudes, optionally new stations can be created if they don’t exist, the approach used here

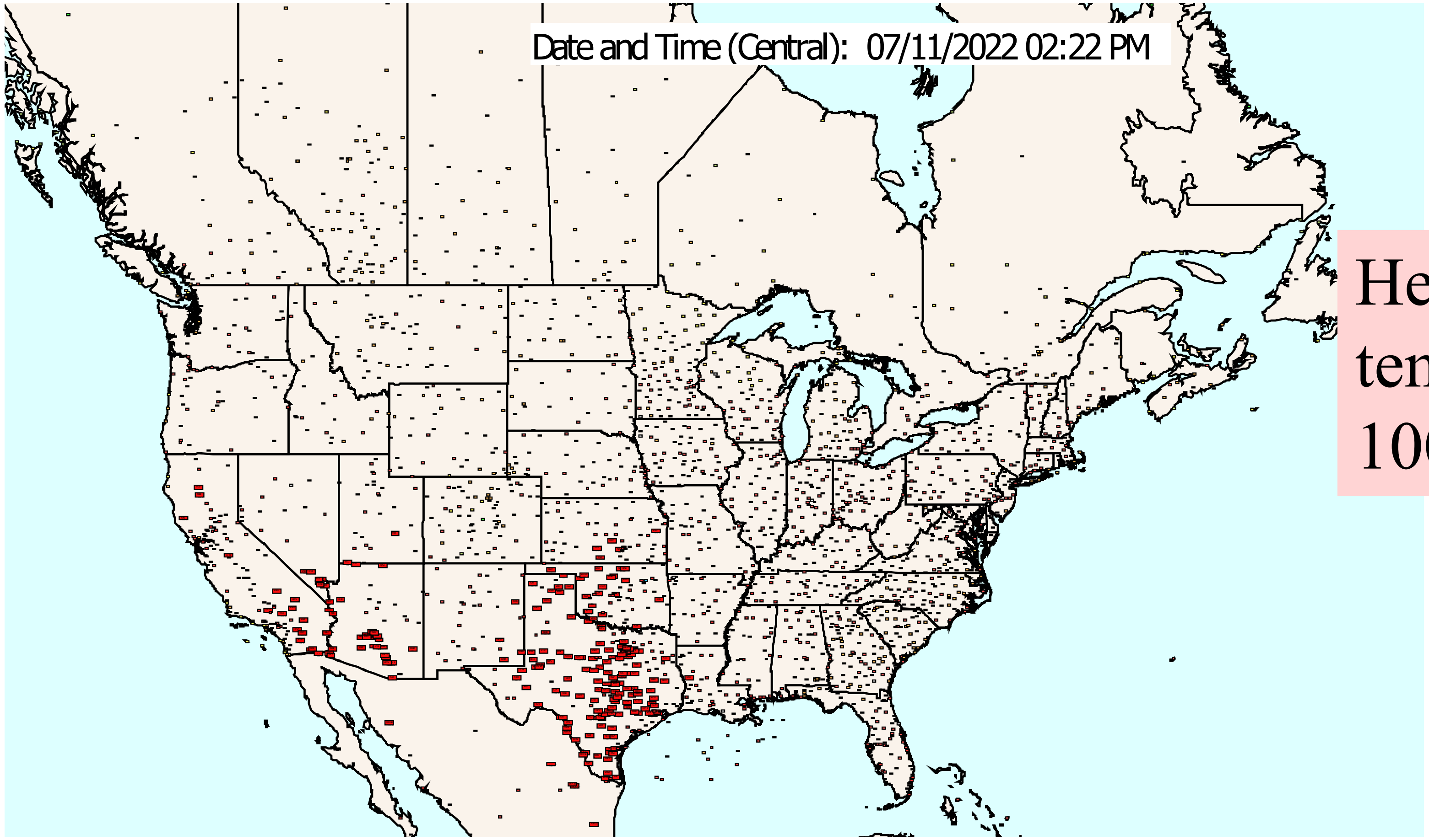
Records ▾ Geo ▾ Set ▾ Columns ▾ f(x) ▾ Options ▾

	Name	Longitude	Latitude	ElevationFt	Observation Time (UTC)	Enabled	Temp F	Dew Point F	Wind Speed m/sec	Wind Speed mph	Wind Direction	Cloud Cover %	Insolation %
1	KEED	114.620000	34.770000	889	2022-07-11T19:56:00.00(	YES	114.1	[illegible]	5.1	11.5	220.0	0.0	81.
2	KLSV	115.050000	36.230000	1847	2022-07-11T19:58:00.00(	NO	113.4	[illegible]	3.1	6.9	230.0	20.0	65.
3	KPSP	116.500000	33.820000	404	2022-07-11T19:53:00.00(	YES	113.0	24.1	2.6	5.8	0.0	0.0	81.
4	KHII	114.370000	34.570000	791	2022-07-11T20:15:00.00(	YES	113.0	33.8	4.1	9.2	[illegible]	0.0	81.
5	KBLH	114.720000	33.620000	390	2022-07-11T19:52:00.00(	YES	111.9	44.1	5.1	11.5	160.0	75.0	20.
6	KPHX	112.020000	33.430000	1109	2022-07-11T19:51:00.00(	YES	111.9	45.0	3.1	6.9	260.0	45.0	44.
7	KLGF	114.400000	32.870000	387	2022-07-11T19:58:00.00(	NO	111.9	45.0	3.1	6.9	190.0	0.0	81.
8	KNJK	115.670000	32.820000	-49	2022-07-11T19:56:00.00(	NO	111.9	30.0	2.6	5.8	100.0	0.0	81.
9	KIFP	114.570000	35.150000	689	2022-07-11T19:47:00.00(	YES	111.2	41.0	4.1	9.2	210.0	45.0	44.
10	KLUF	112.370000	33.530000	1093	2022-07-11T20:18:00.00(	NO	111.2	42.8	6.2	13.8	240.0	45.0	44.
11	KGEU	112.300000	33.530000	1047	2022-07-11T19:50:00.00(	YES	111.2	46.4	5.7	12.7	190.0	45.0	44.
12	KBXK	112.680000	33.420000	994	2022-07-11T20:15:00.00(	YES	111.2	44.6	3.6	8.1	230.0		
13	KL08	116.320000	33.270000	512	2022-07-11T20:15:00.00(	YES	111.2	15.8	4.1	9.2	90.0	0.0	81.
14	KIPL	115.580000	32.830000	-52	2022-07-11T19:53:00.00(	YES	111.0	34.0	3.6	8.1	90.0	0.0	81.
15	KDVT	112.070000	33.680000	1490	2022-07-11T19:53:00.00(	YES	111.0	46.0	6.2	13.8	280.0	0.0	81.
16	KTRM	116.170000	33.630000	-128	2022-07-11T19:52:00.00(	YES	111.0	39.0	4.1	9.2	130.0	0.0	81.
17	KGXF	112.720000	32.880000	856	2022-07-11T19:58:00.00(	YES	110.5	43.5	4.1	9.2	280.0	20.0	65.
18	KFFZ	111.720000	33.470000	1378	2022-07-11T19:54:00.00(	YES	109.9	46.9	4.6	10.4	270.0	0.0	81.
19	KSDL	111.920000	33.620000	1437	2022-07-11T19:53:00.00(	YES	109.9	45.0	4.6	10.4	280.0	0.0	81.
20	KA39	111.920000	32.980000	1283	2022-07-11T20:15:00.00(	YES	109.4	48.2	5.7	12.7	250.0	0.0	81.
21	KIWA	111.650000	33.300000	1378	2022-07-11T19:50:00.00(	YES	109.4	50.0	3.1	6.9	310.0	0.0	81.
22	KGYR	112.370000	33.420000	958	2022-07-11T19:47:00.00(	YES	109.4	50.0	5.1	11.5	240.0	75.0	20.
23	KP08	111.430000	32.930000	1565	2022-07-11T20:15:00.00(	YES	109.4	46.4	6.2	13.8	320.0	0.0	81.
24	KMKN	-98.600000	31.920000	1404	2022-07-11T20:06:00.00(	YES	109.4	62.6	0.0	0.0	0.0	45.0	44.
25	KNOZ	114.500000	32.530000	256	2022-07-11T19:59:00.00(	YES	109.0	55.9	3.1	6.9	170.0	0.0	81.
26	KCOT	-99.220000	28.450000	472	2022-07-11T19:53:00.00(	YES	109.0	63.0	4.1	9.2	110.0	45.0	44.
27	KNYL	114.620000	32.650000	190	2022-07-11T19:57:00.00(	YES	109.0	54.0	4.6	10.4	200.0	0.0	81.
28	KCGZ	111.770000	32.950000	1457	2022-07-11T19:56:00.00(	NO	109.0	48.9	3.6	8.1	220.0	0.0	81.
29	KAPY	-99.250000	26.970000	423	2022-07-11T20:15:00.00(	YES	108.7	61.0	3.1	6.9	70.0	100.0	0.
30	KSJT	100.500000	31.370000	1909	2022-07-11T19:51:00.00(	YES	108.0	46.0	2.6	5.8	0.0	0.0	81.
31	KLAS	115.170000	36.070000	2172	2022-07-11T19:56:00.00(	YES	108.0	42.1	4.6	10.4	100.0	20.0	65.
32	KTUS	110.950000	32.130000	2546	2022-07-11T19:53:00.00(	YES	108.0	48.0	5.1	11.5	360.0	0.0	81.
33	KMZJ	111.320000	32.520000	1883	2022-07-11T20:15:00.00(	YES	107.6	46.4	5.1	11.5	310.0	0.0	81.
34	MMML	115.230000	32.620000	69	2022-07-11T19:40:00.00(	YES	107.6	41.0	3.1	6.9	110.0		
35	KAVK	-98.670000	36.770000	1476	2022-07-11T20:20:00.00(	YES	107.6	48.2	3.6	8.1	190.0	0.0	80.
36	KAVQ	111.220000	32.400000	2028	2022-07-11T20:15:00.00(	YES	107.6	40.6	2.6	5.8	320.0	0.0	81.
37	KBVU	114.870000	35.950000	2146	2022-07-11T20:15:00.00(	YES	107.6	39.2	3.6	8.1	0.0	0.0	81.
38	KCVB	-98.850000	29.350000	768	2022-07-11T20:17:00.00(	YES	107.6	51.8	2.6	5.8	120.0	0.0	80.

Sorted by temperature; it was nice to see that Texas wasn’t the hottest place in the world! Locally (KCLL) we were 76th out of more than 4800

Visualizing the Weather

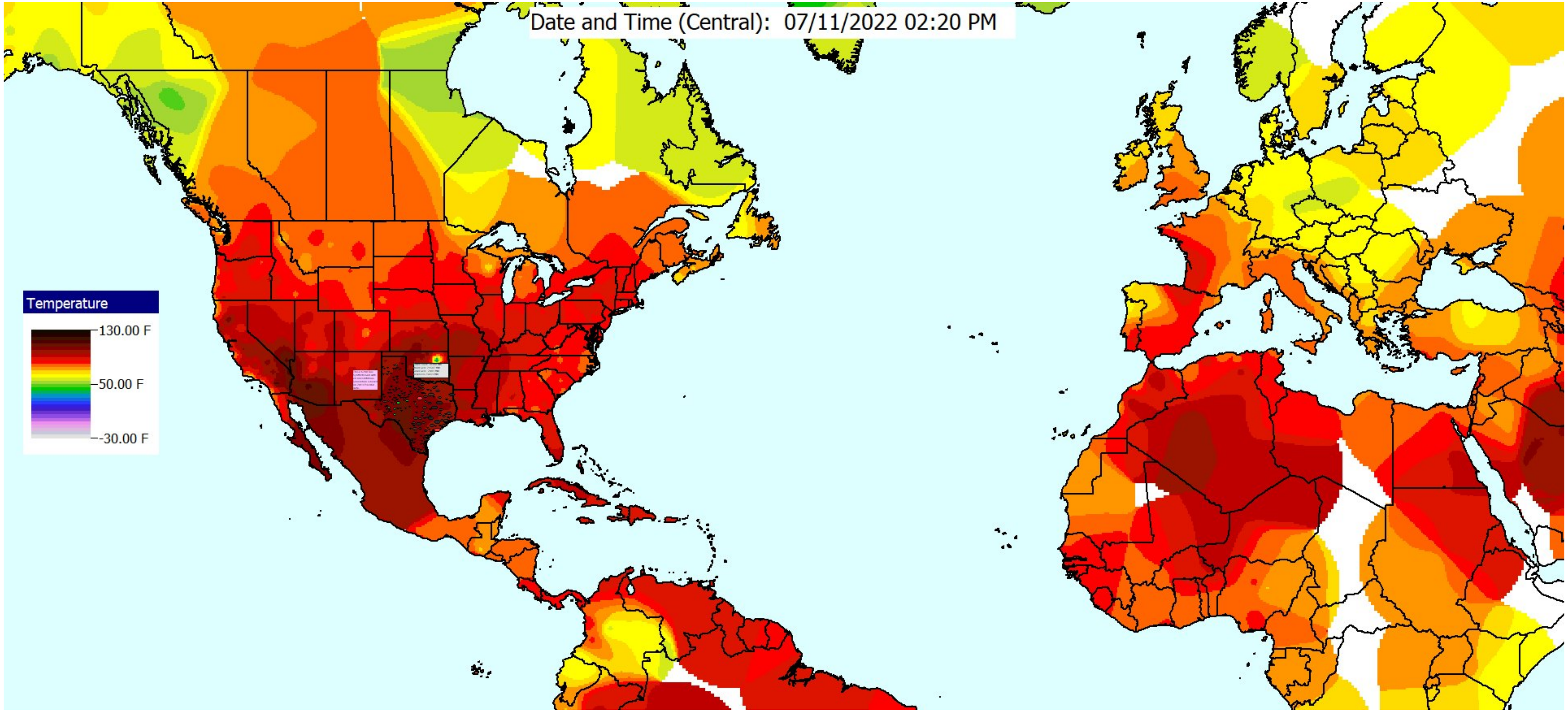
- GDVs can be created for the weather stations for quick visualization with dynamic formatting



Here the stations with temperatures above 100 F are shown larger

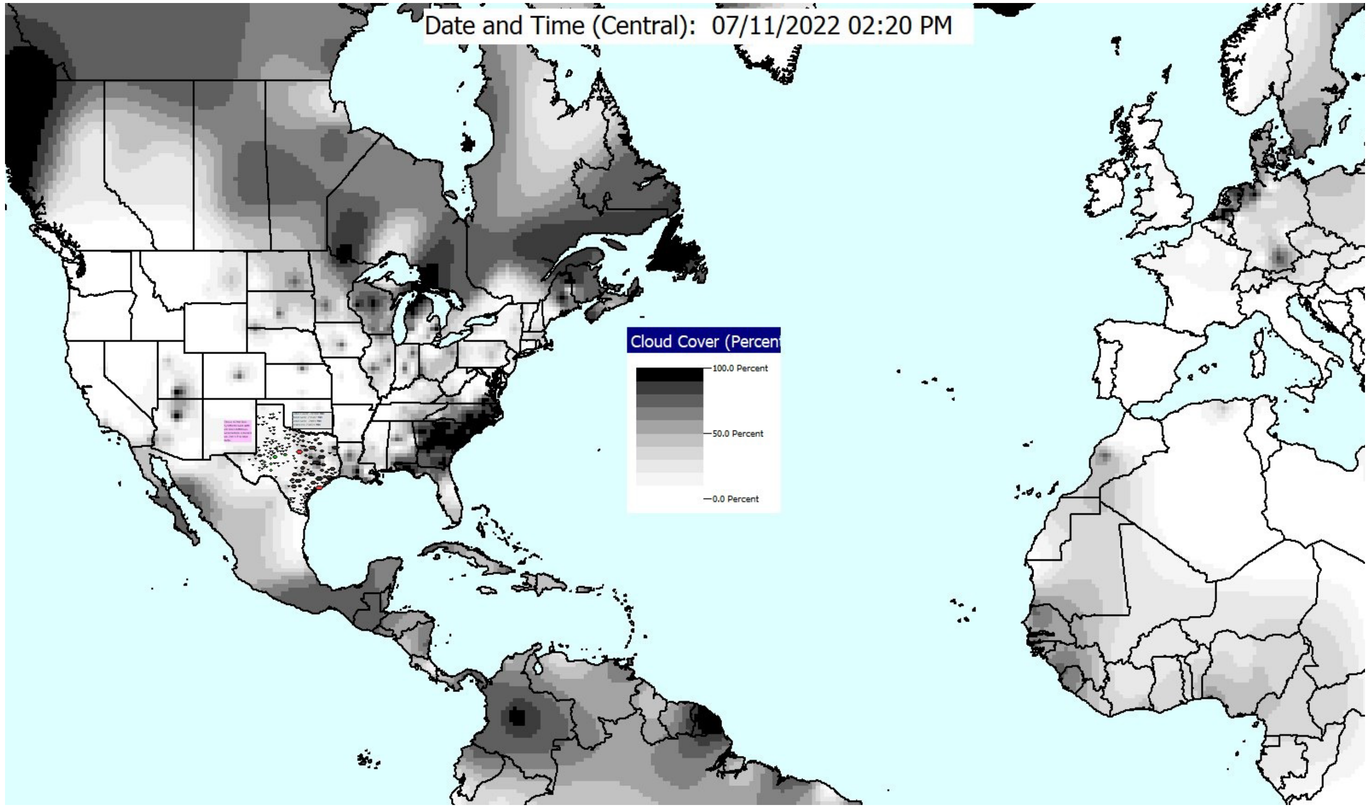
Contouring the Data

- If desired the data can be readily contoured

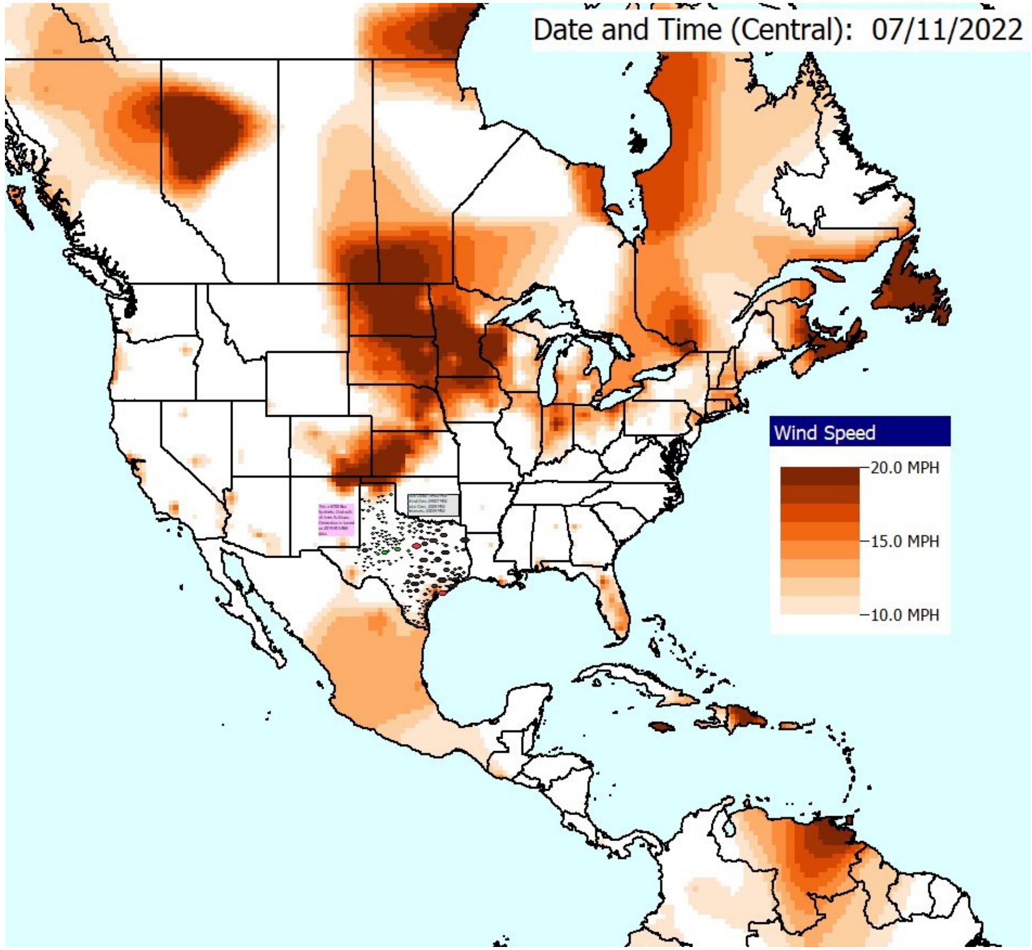


Cloud Cover and Wind Speed

Cloud Cover Percent

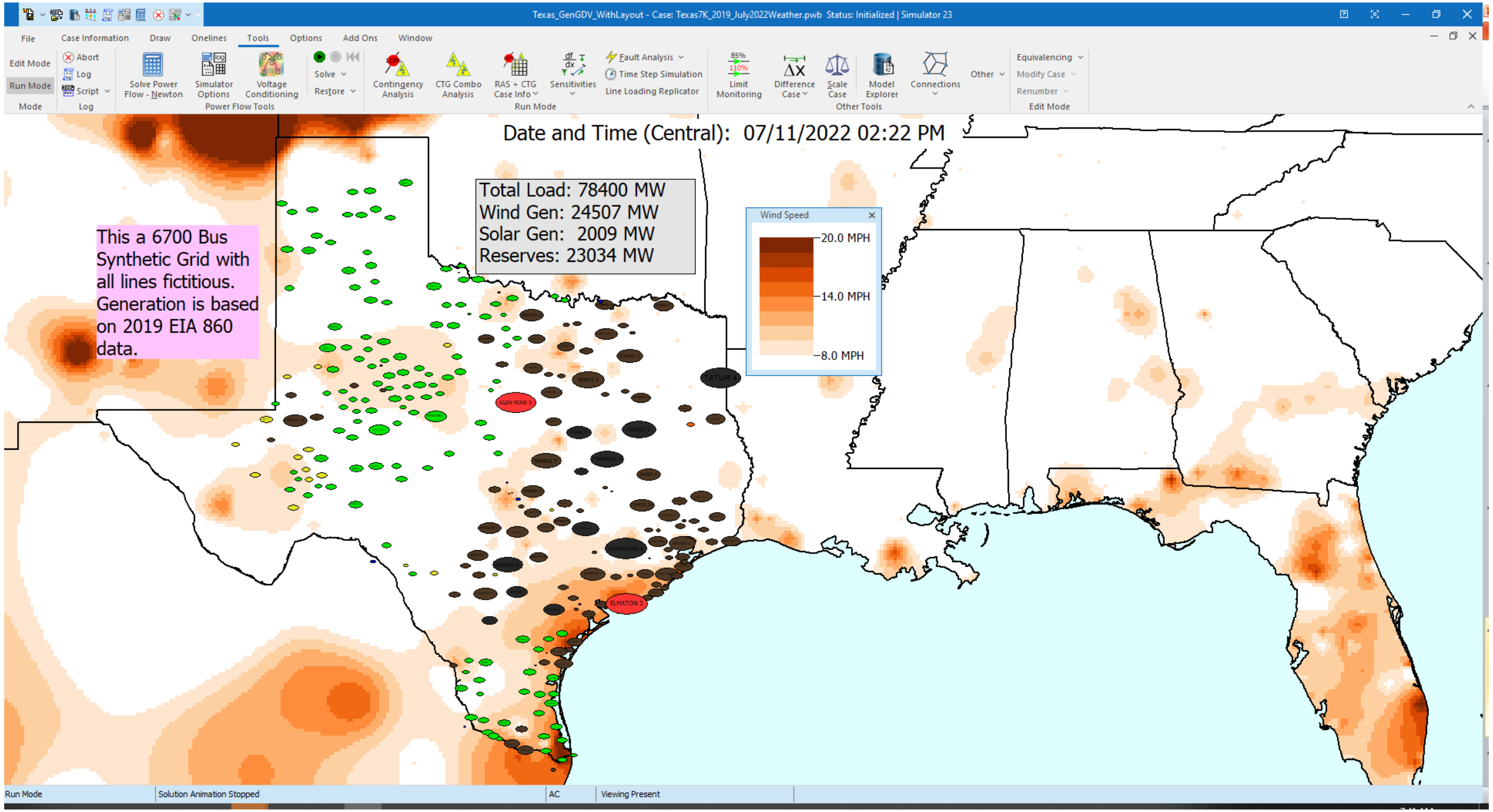


Wind speed



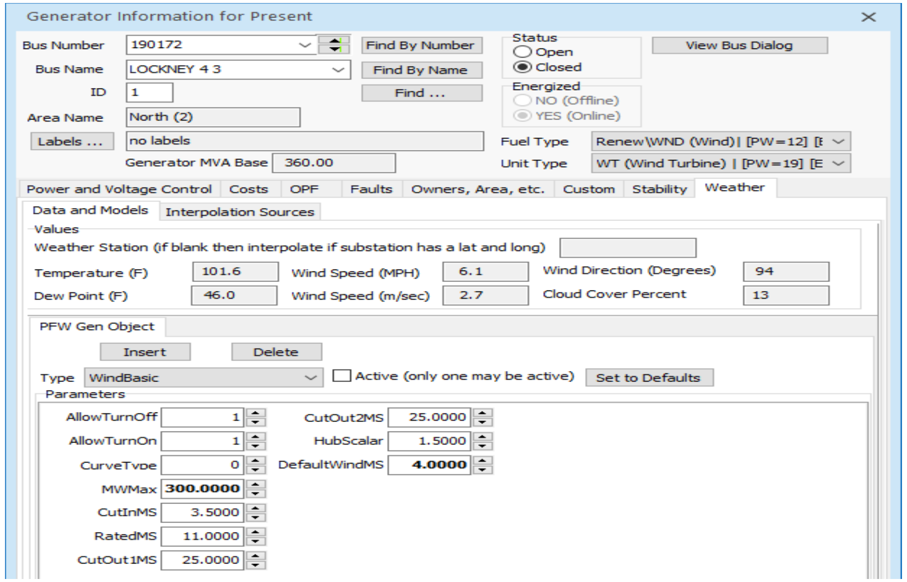
Wind Speed in the Focus Area of Texas

- There is a disconnect between the power flow assumption for wind and what was actually occurring



Mapping Weather to Power Flow Parameters

- Using the new models the weather can be mapped to power system values (all generator MaxMW here)



Save All PFW Models in Aux

Load PFW Model Aux File

	Model Class	Object Type	Active and Online Count	Active Count	Inactive Count
1	_All PFW Models	_All PFW Models	853	853	0
2	Gen MWMax	WindBasic	153	153	0
3	Gen MWMax	SolarPVBasic1	36	36	0
4	Gen MWMax	TemperatureBasic1	664	664	0

Close

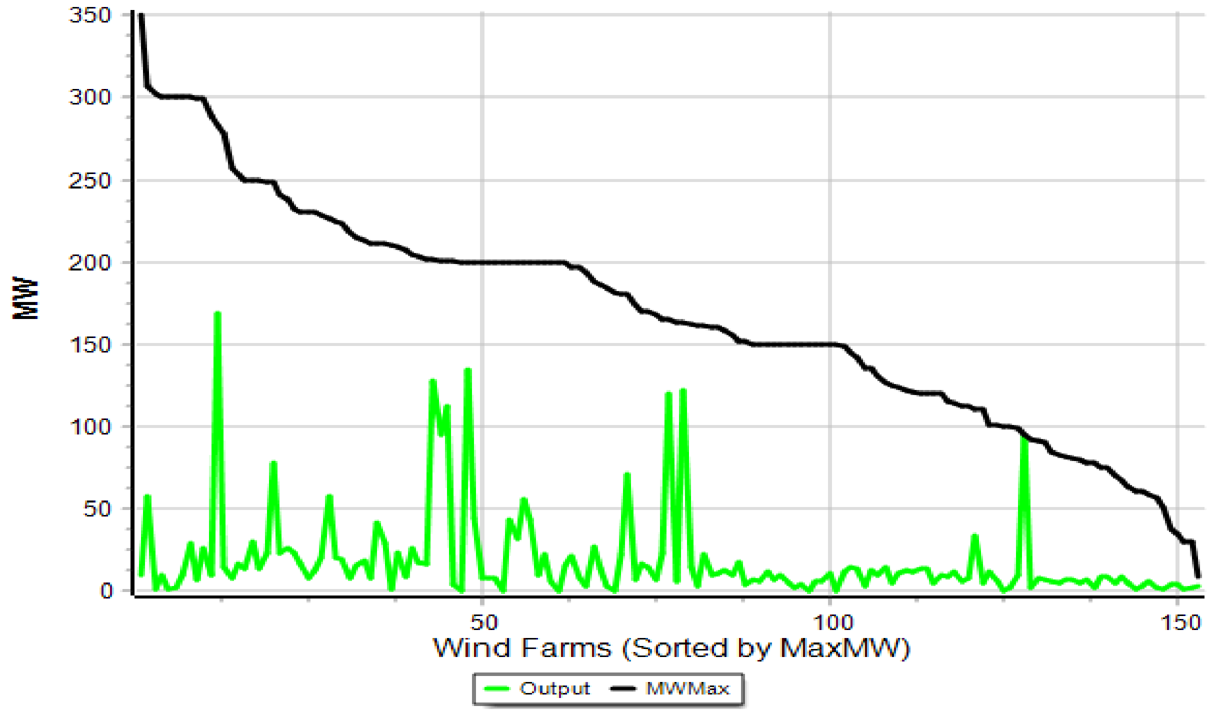
	Active and Online	Active	Inactive
Number of Models	153	153	0

Records Set Columns Options

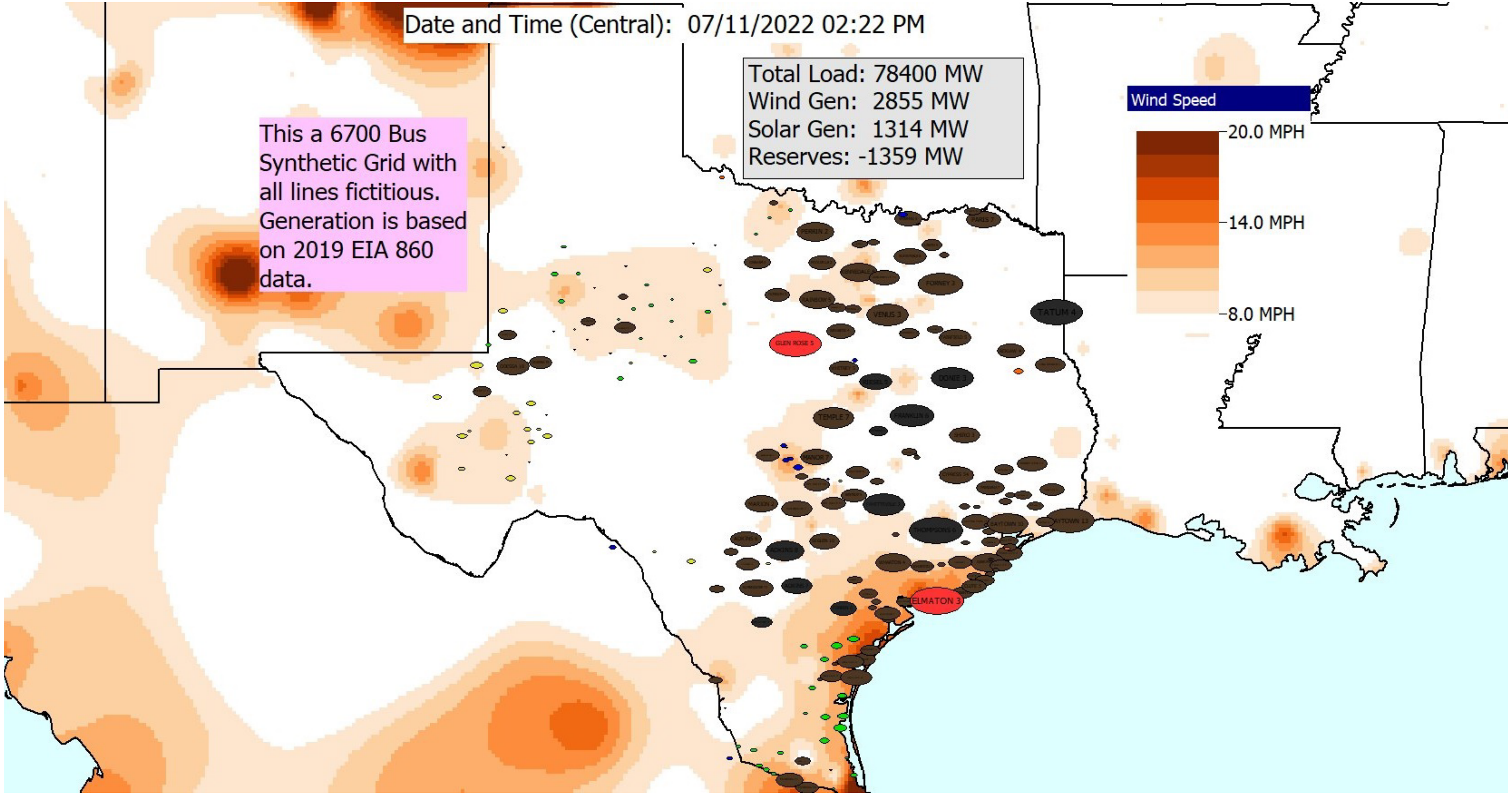
	Number of Bus	ID	Name_Nominal kV of Bus	Area Name of Gen	Model Type	MVA Base	Device Status	Criteria	Model Class	Input Value	Input Valid	Input Source	Output	Output Scalar	Output Valid	AllowTurnOff	AllowTurnOn	CurveType	MWMax	CutInMS	RatedMS	CutOut1MS	CutOut2MS	HubScalar	DefaultWin
1	120493	1	BRACKETTVILLE 4 2_13.80	West	WindBasic	119.76	Active		Gen MWMax	1.9702	Yes		0	0	Yes	1	1	0	99.8	3.5	11	25	25	1.5	
2	150492	1	DESDEMONA 3 2_13.80	North Central	WindBasic	72	Active		Gen MWMax	2.7162	Yes		4.5941	0.0766	Yes	1	1	0	60	3.5	11	25	25	1.5	
3	150496	1	BRYSON 1 2_18.00	North Central	WindBasic	144	Active		Gen MWMax	2.8997	Yes		13.593	0.1133	Yes	1	1	0	120	3.5	11	25	25	1.5	
4	150499	1	OLNEY 2 3_18.00	North Central	WindBasic	270	Active		Gen MWMax	3.992	Yes		74.6393	0.3317	Yes	1	1	0	225	3.5	11	25	25	1.5	
5	150502	1	WINDTHORST 2 3_20.00	North	WindBasic	193.2	Active		Gen MWMax	3.82	Yes		47.8704	0.2973	Yes	1	1	0	161	3.5	11	25	25	1.5	
6	150505	1	BRYSON 2 3_13.80	North Central	WindBasic	180	Active		Gen MWMax	3.0881	Yes		22.6417	0.1509	Yes	1	1	0	150	3.5	11	25	25	1.5	
7	150507	1	MUENSTER 5 2_13.80	North	WindBasic	135	Active		Gen MWMax	2.0639	Yes		0	0	Yes	1	1	0	112.5	3.5	11	25	25	1.5	
8	150510	1	ODELL 1 2_13.80	North	WindBasic	162.48	Active		Gen MWMax	2.0265	Yes		0	0	Yes	1	1	0	135.4	3.5	11	25	25	1.5	
9	150512	1	JACKSBORO 3 2_13.80	North Central	WindBasic	132	Active		Gen MWMax	2.642	Yes		6.7896	0.0617	Yes	1	1	0	110	3.5	11	25	25	1.5	
10	150515	1	WINDTHORST 3 3_13.80	North	WindBasic	244.8	Active		Gen MWMax	3.3669	Yes		42.1682	0.2067	Yes	1	1	0	204	3.5	11	25	25	1.5	
11	150517	1	WINDTHORST 4 2_13.80	North	WindBasic	81.12	Active		Gen MWMax	3.6485	Yes		17.7805	0.263	Yes	1	1	0	67.6	3.5	11	25	25	1.5	
12	150520	1	SEYMOUR 3 2_24.00	North	WindBasic	180	Active		Gen MWMax	3.198	Yes		25.939	0.1729	Yes	1	1	0	150	3.5	11	25	25	1.5	
13	150528	1	OKLAUNION 2 3_18.00	North	WindBasic	276	Active		Gen MWMax	2.7604	Yes		19.6474	0.0854	Yes	1	1	0	230	3.5	11	25	25	1.5	
14	150531	1	MUENSTER 6 3_18.00	North	WindBasic	150	Active		Gen MWMax	1.9491	Yes		0	0	Yes	1	1	0	125	3.5	11	25	25	1.5	
15	150534	1	MINGUS 4 3_18.00	North Central	WindBasic	120.6	Active		Gen MWMax	2.5313	Yes		3.9801	0.0396	Yes	1	1	0	100.5	3.5	11	25	25	1.5	
16	150549	1	SEYMOUR 4 2_18.00	North	WindBasic	36.24	Active		Gen MWMax	3.6916	Yes		8.2039	0.2717	Yes	1	1	0	30.2	3.5	11	25	25	1.5	
17	150552	1	VERNON 2 3_13.80	North	WindBasic	220.56	Active		Gen MWMax	2.561	Yes		8.3705	0.0455	Yes	1	1	0	183.8	3.5	11	25	25	1.5	

Mapping Weather to Power Flow Parameters

- Actual ERCOT wind between 2pm and 3pm gradually rose from about 2200 to 3670 MW
- Using the real-time weather with the default Class 2 wind turbine models the wind generation in the power flow decreased from 24.5 GW to 3.3 GW
  - This is based on an assumed hub height to surface wind scaling of 1.4; the value is 2.8 GW with a scaling of 1.25

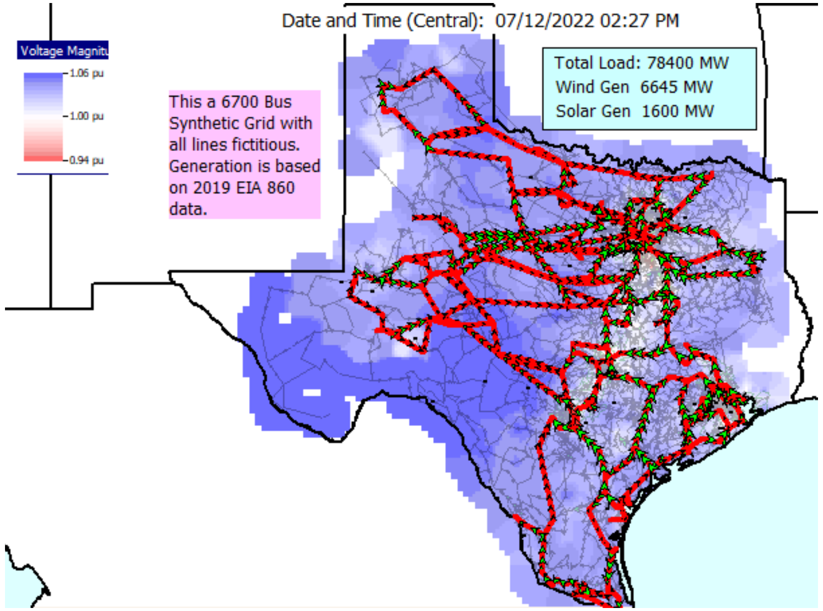


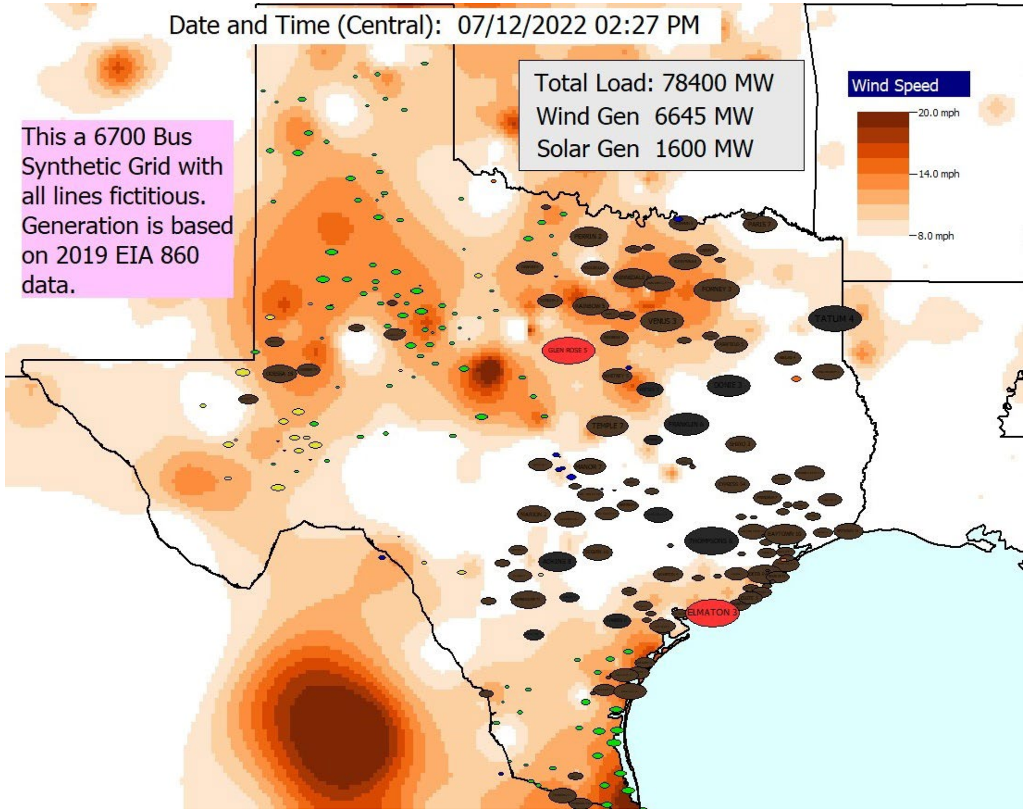
Weather Scaled Generation Values, 7/11/2022



Easily Using Models or Weather with Other Power Flows: First the Same Grid with New Weather

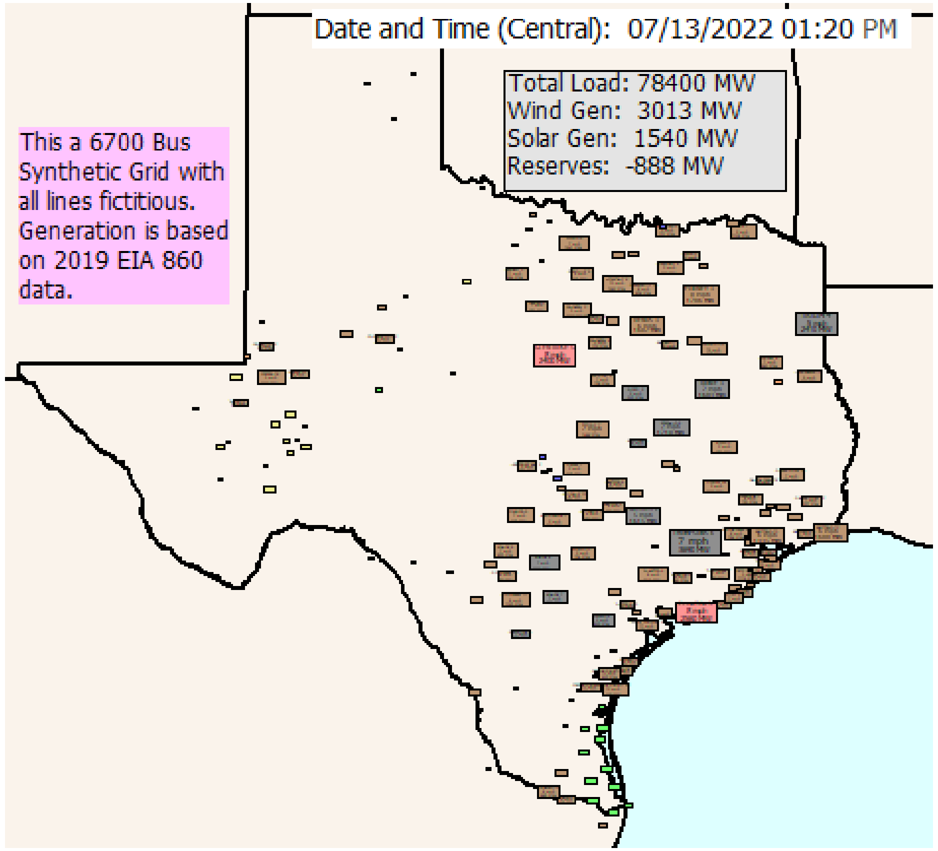
- With the weather and associated models available, both can be readily used with other cases. The below example takes the previous power flow and applies the July 12, 2022 weather (a hot day but with more wind in Texas)
  - As before the input is the METAR weather, now from 2pm on July 12

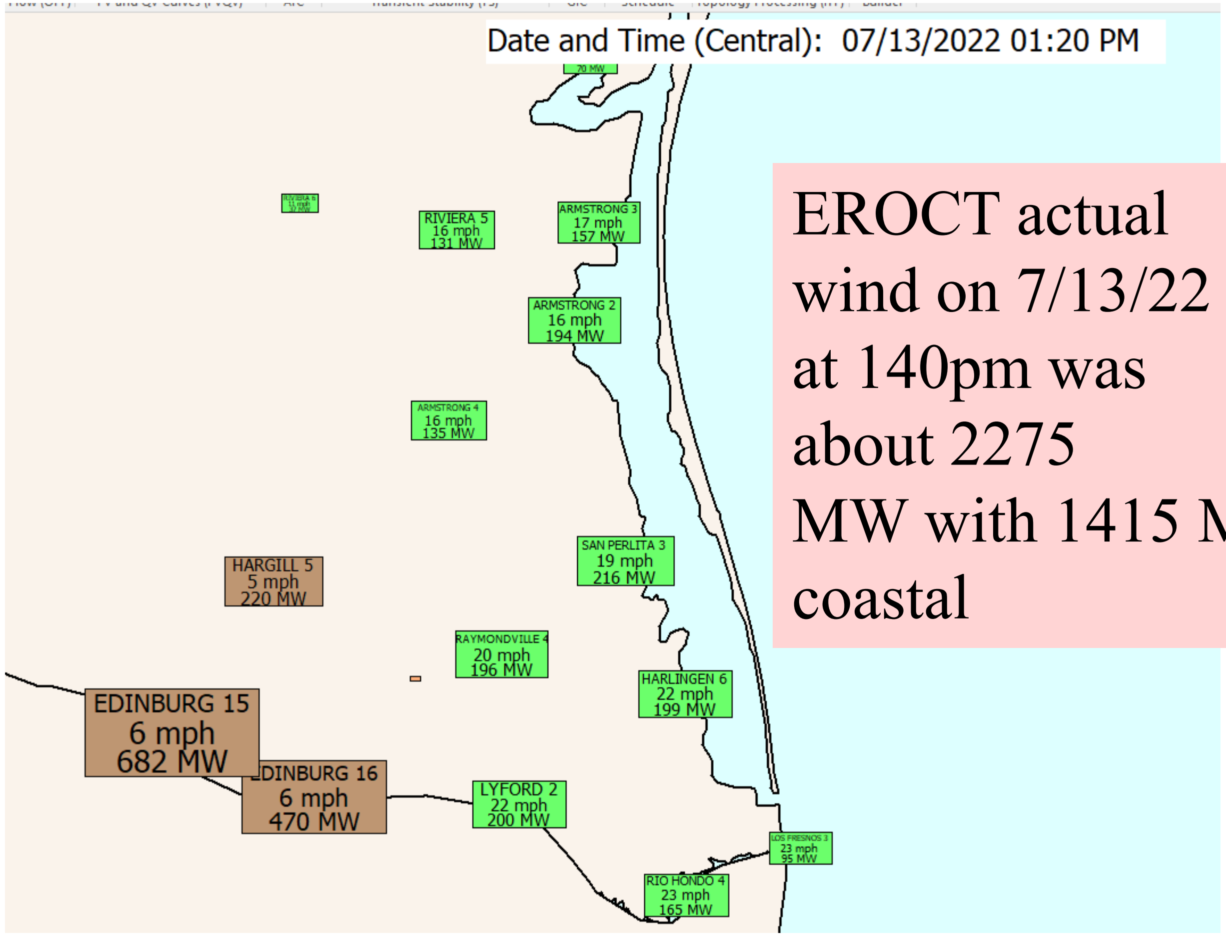




Easily Using Models or Weather with Other Power Flows: July 13, 2022 about 130pm

- One of the advantages of using actual generator locations in the synthetic grids coupled with actual weather is validation, something we have just started

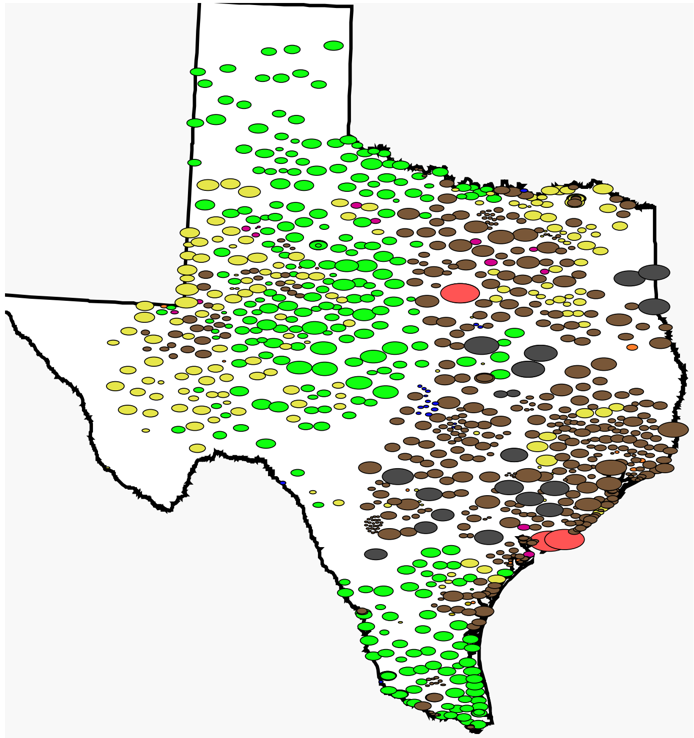


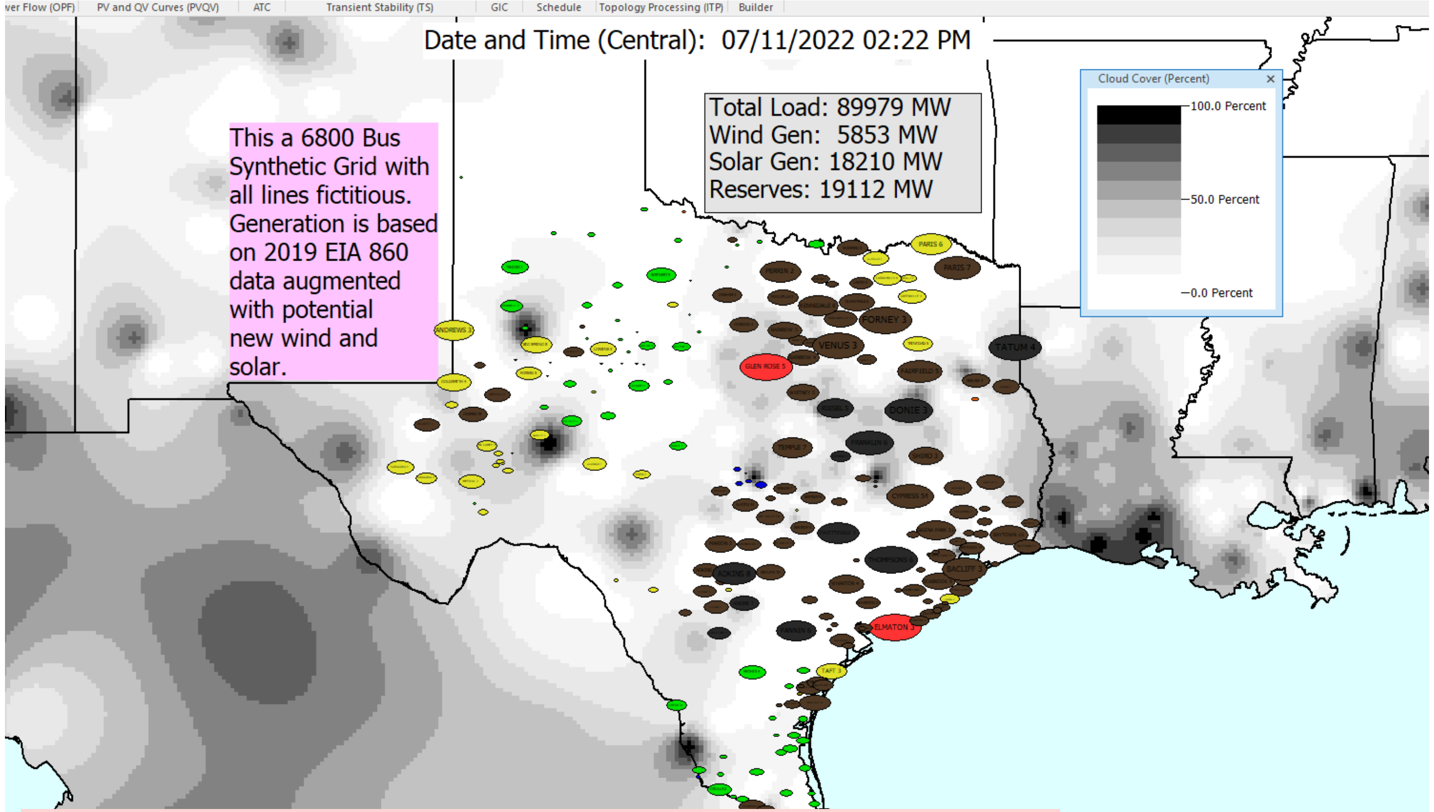


EROCT actual wind on 7/13/22 at 140pm was about 2275 MW with 1415 MW coastal

Easily Using Models or Weather with Other Power Flows: Now a New Grid with July 11 Weather

- Historical weather can also be applied to future grids. The below example is for a 2030 extreme renewable Texas synthetic scenario
  - This grid has 26.8 GW of solar and 55.7 GW of wind



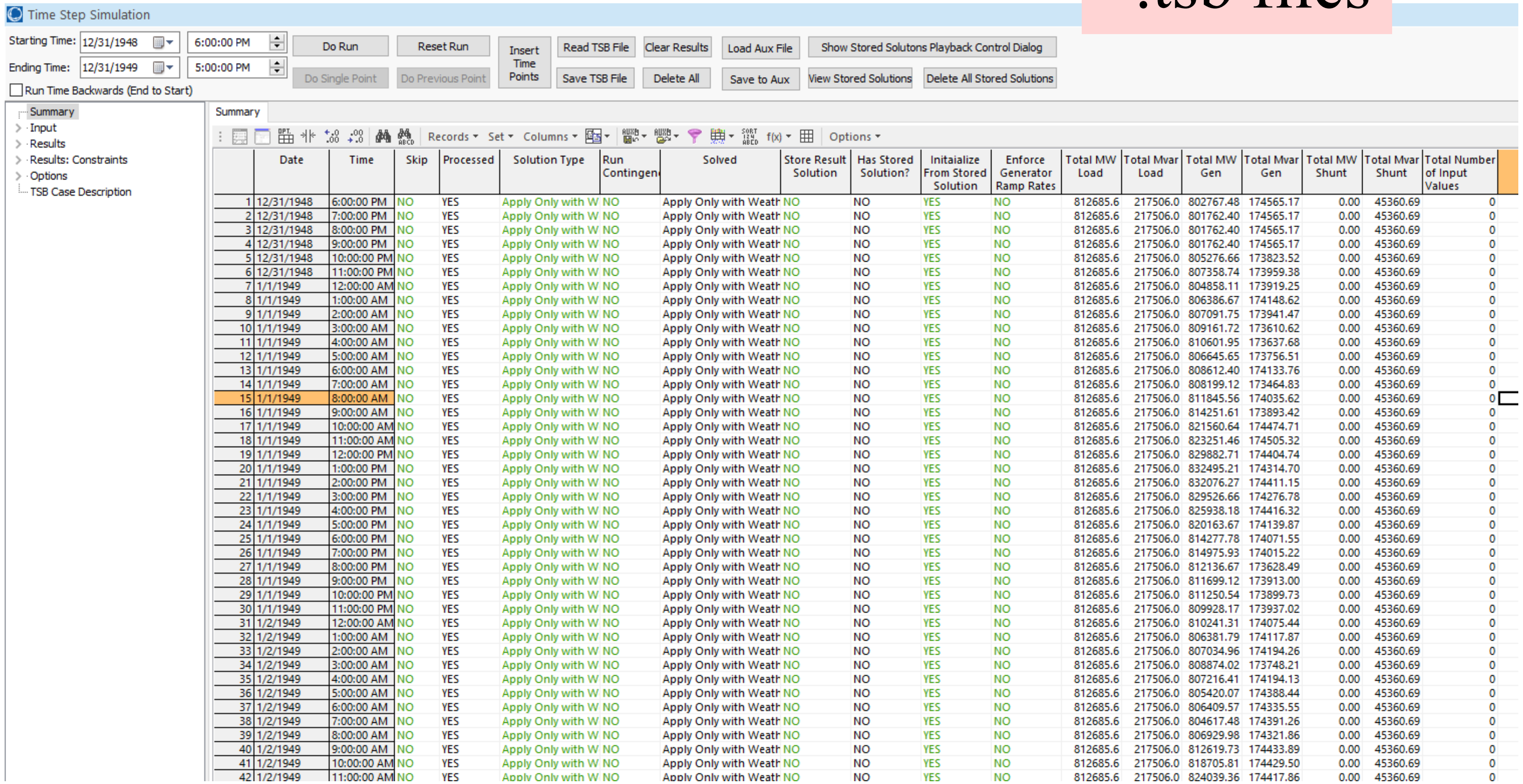


This was solved using a DC OPF

Using Large Amounts of Historical Data

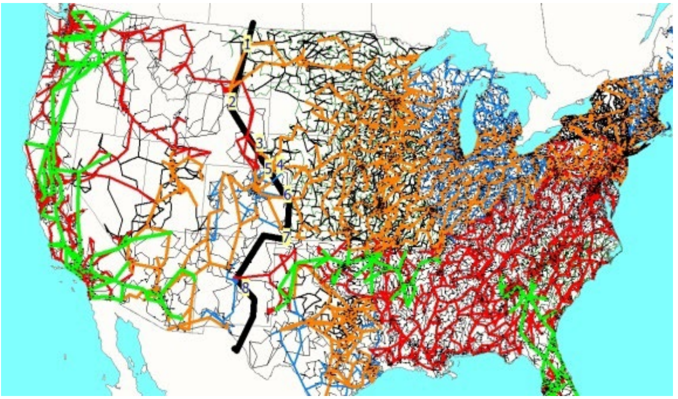
- We have now setup historical data going back to the 1940's in a form that allows different weather scenarios to be quickly applied to grids of today or the future

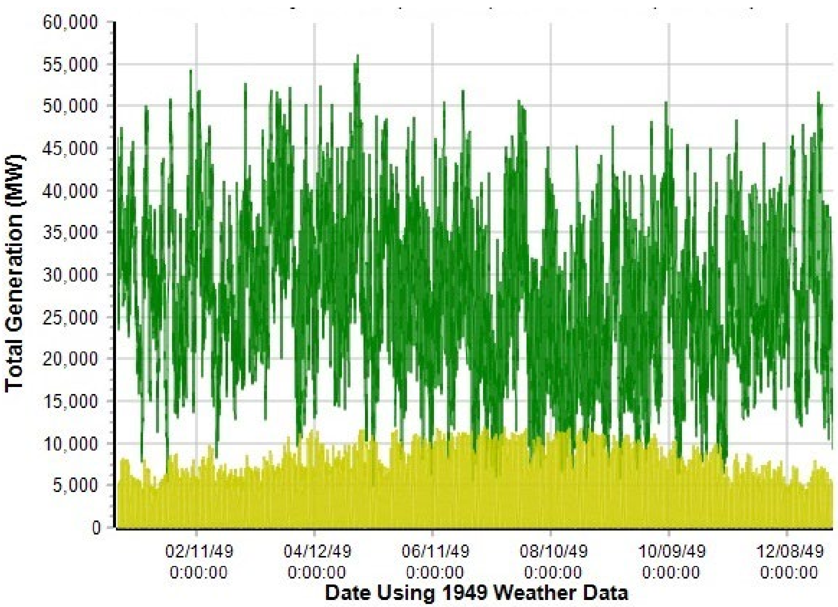
*.tsb files

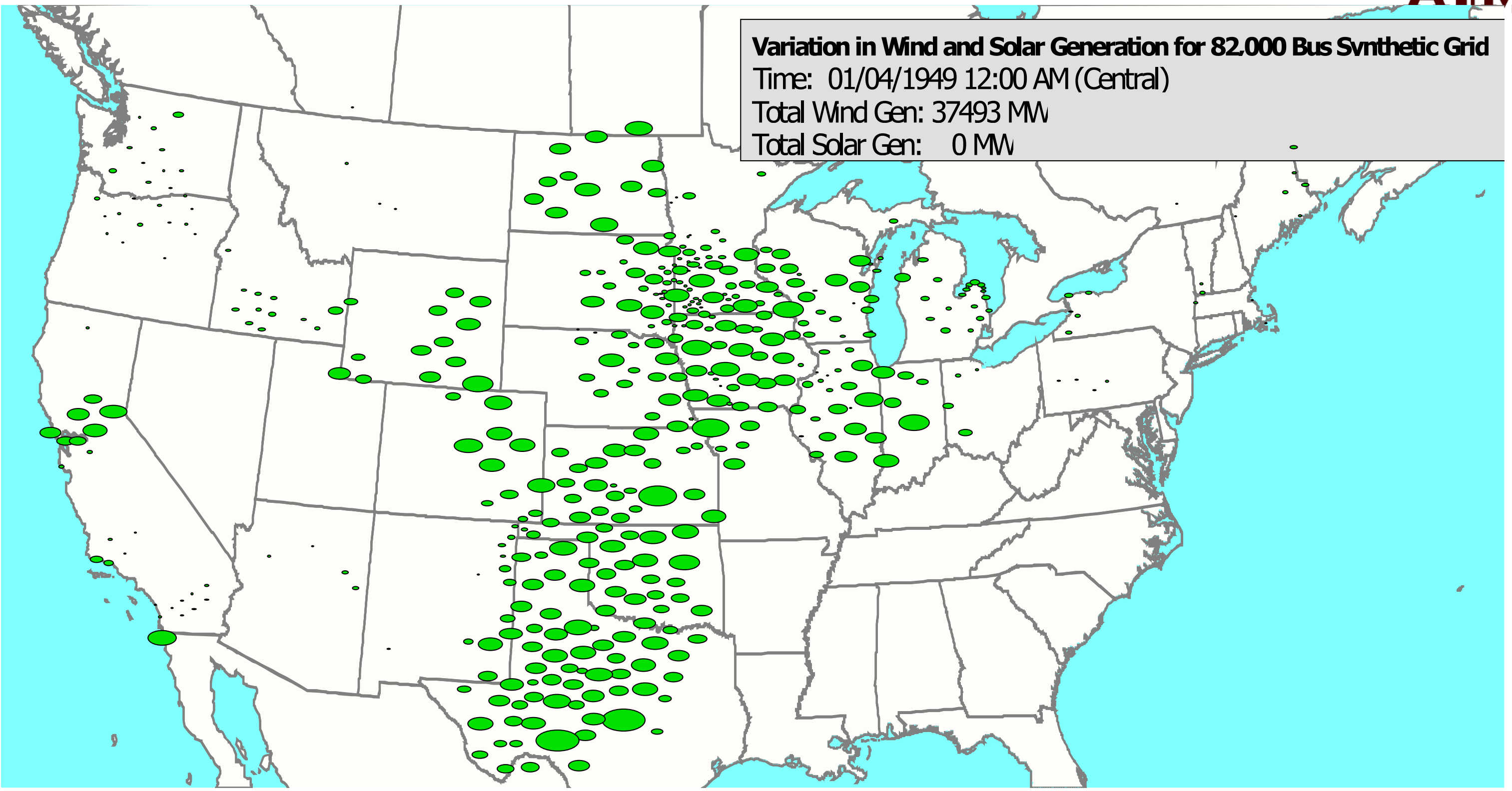


	Date	Time	Skip	Processed	Solution Type	Run Contingen	Solved	Store Result Solution	Has Stored Solution?	Initaialize From Stored Solution	Enforce Generator Ramp Rates	Total MW Load	Total Mvar Load	Total MW Gen	Total Mvar Gen	Total MW Shunt	Total Mvar Shunt	Total Number of Input Values
1	12/31/1948	6:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	802767.48	174565.17	0.00	45360.69	0
2	12/31/1948	7:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	801762.40	174565.17	0.00	45360.69	0
3	12/31/1948	8:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	801762.40	174565.17	0.00	45360.69	0
4	12/31/1948	9:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	801762.40	174565.17	0.00	45360.69	0
5	12/31/1948	10:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	805276.66	173823.52	0.00	45360.69	0
6	12/31/1948	11:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	807358.74	173959.38	0.00	45360.69	0
7	1/1/1949	12:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	804858.11	173919.25	0.00	45360.69	0
8	1/1/1949	1:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	806386.67	174148.62	0.00	45360.69	0
9	1/1/1949	2:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	807091.75	173941.47	0.00	45360.69	0
10	1/1/1949	3:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	809161.72	173610.62	0.00	45360.69	0
11	1/1/1949	4:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	810601.95	173637.68	0.00	45360.69	0
12	1/1/1949	5:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	806645.65	173756.51	0.00	45360.69	0
13	1/1/1949	6:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	808612.40	174133.76	0.00	45360.69	0
14	1/1/1949	7:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	808199.12	173464.83	0.00	45360.69	0
15	1/1/1949	8:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	811845.56	174035.62	0.00	45360.69	0
16	1/1/1949	9:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	814251.61	173893.42	0.00	45360.69	0
17	1/1/1949	10:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	821560.64	174474.71	0.00	45360.69	0
18	1/1/1949	11:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	823251.46	174505.32	0.00	45360.69	0
19	1/1/1949	12:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	829882.71	174404.74	0.00	45360.69	0
20	1/1/1949	1:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	832495.21	174314.70	0.00	45360.69	0
21	1/1/1949	2:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	832076.27	174411.15	0.00	45360.69	0
22	1/1/1949	3:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	829526.66	174276.78	0.00	45360.69	0
23	1/1/1949	4:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	825938.18	174416.32	0.00	45360.69	0
24	1/1/1949	5:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	820163.67	174139.87	0.00	45360.69	0
25	1/1/1949	6:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	814277.78	174071.55	0.00	45360.69	0
26	1/1/1949	7:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	814975.93	174015.22	0.00	45360.69	0
27	1/1/1949	8:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	812136.67	173628.49	0.00	45360.69	0
28	1/1/1949	9:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	811699.12	173913.00	0.00	45360.69	0
29	1/1/1949	10:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	811250.54	173899.73	0.00	45360.69	0
30	1/1/1949	11:00:00 PM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	809928.17	173937.02	0.00	45360.69	0
31	1/2/1949	12:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	810241.31	174075.44	0.00	45360.69	0
32	1/2/1949	1:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	806381.79	174117.87	0.00	45360.69	0
33	1/2/1949	2:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	807034.96	174194.26	0.00	45360.69	0
34	1/2/1949	3:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	808874.02	173748.21	0.00	45360.69	0
35	1/2/1949	4:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	807216.41	174194.13	0.00	45360.69	0
36	1/2/1949	5:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	805420.07	174388.44	0.00	45360.69	0
37	1/2/1949	6:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	806409.57	174335.55	0.00	45360.69	0
38	1/2/1949	7:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	804617.48	174391.26	0.00	45360.69	0
39	1/2/1949	8:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	806929.98	174321.86	0.00	45360.69	0
40	1/2/1949	9:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	812619.73	174433.89	0.00	45360.69	0
41	1/2/1949	10:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	818705.81	174429.50	0.00	45360.69	0
42	1/2/1949	11:00:00 AM	NO	YES	Apply Only with W	NO	Apply Only with Weath	NO	NO	YES	NO	812685.6	217506.0	824039.36	174417.86	0.00	45360.69	0

Example Results Using a 82,000 Bus Synthetic Grid

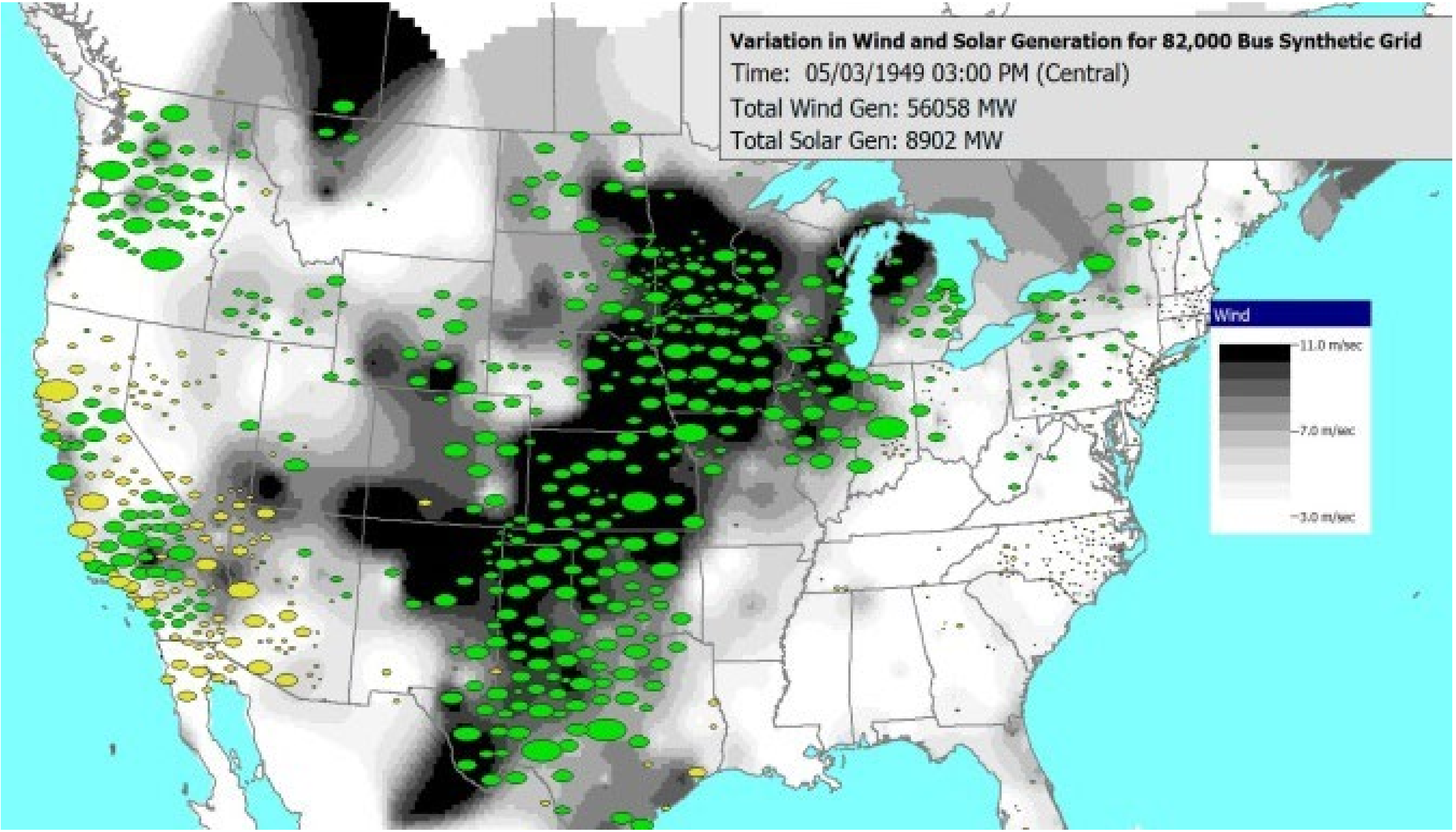




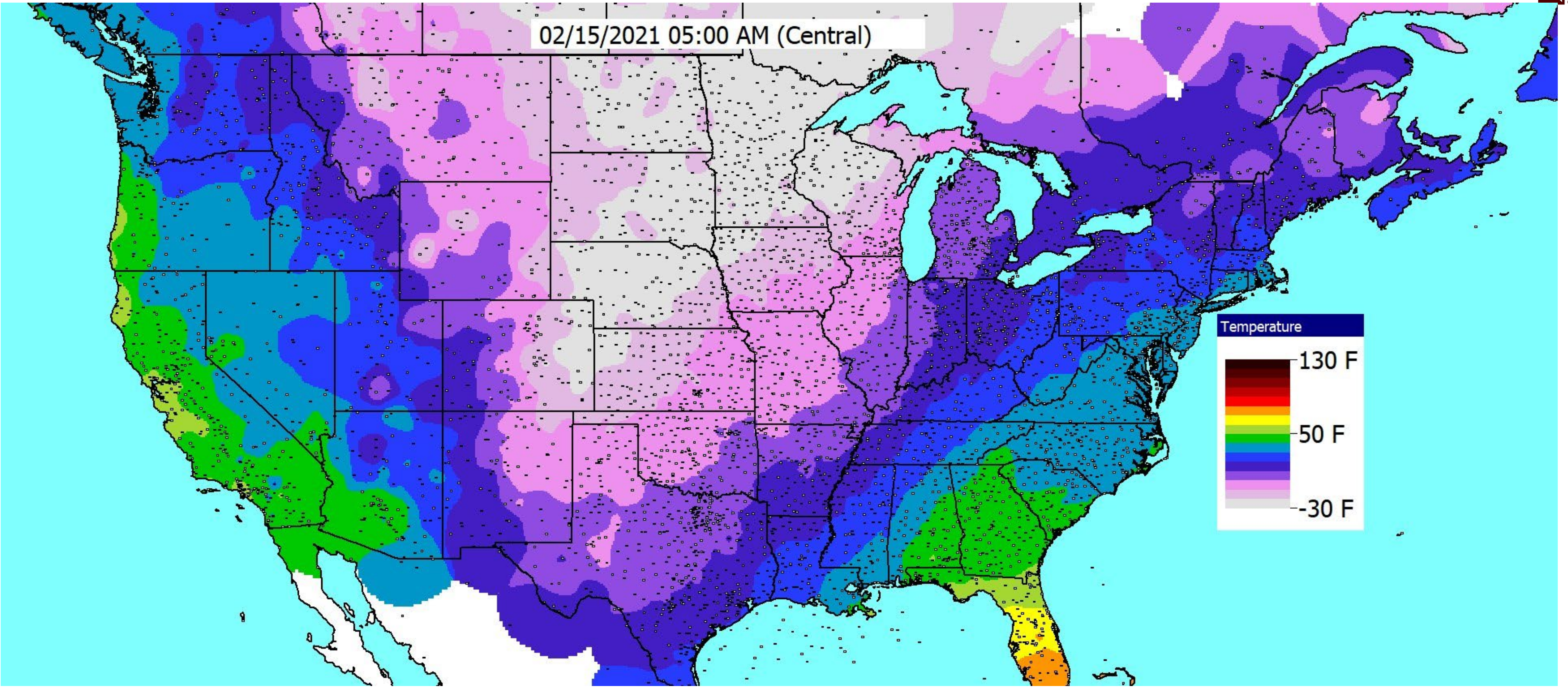


With this approach, any modifications to generator portfolio can be screened using a wide variety of historical points (e.g., we now have hourly world-wide weather values from about 1945 to 2022)

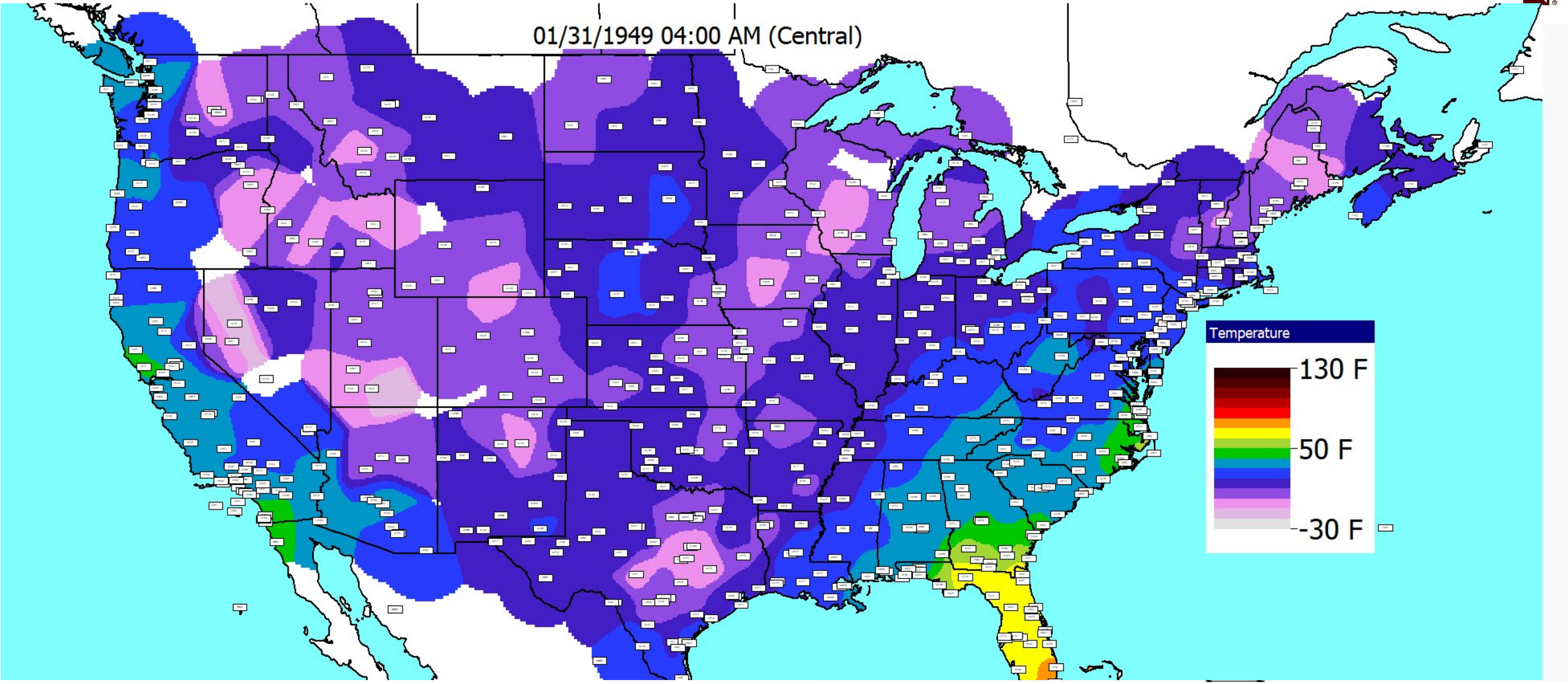
Example Results Using a 82,000 Bus Synthetic Grid



Temperatures February 15, 2021

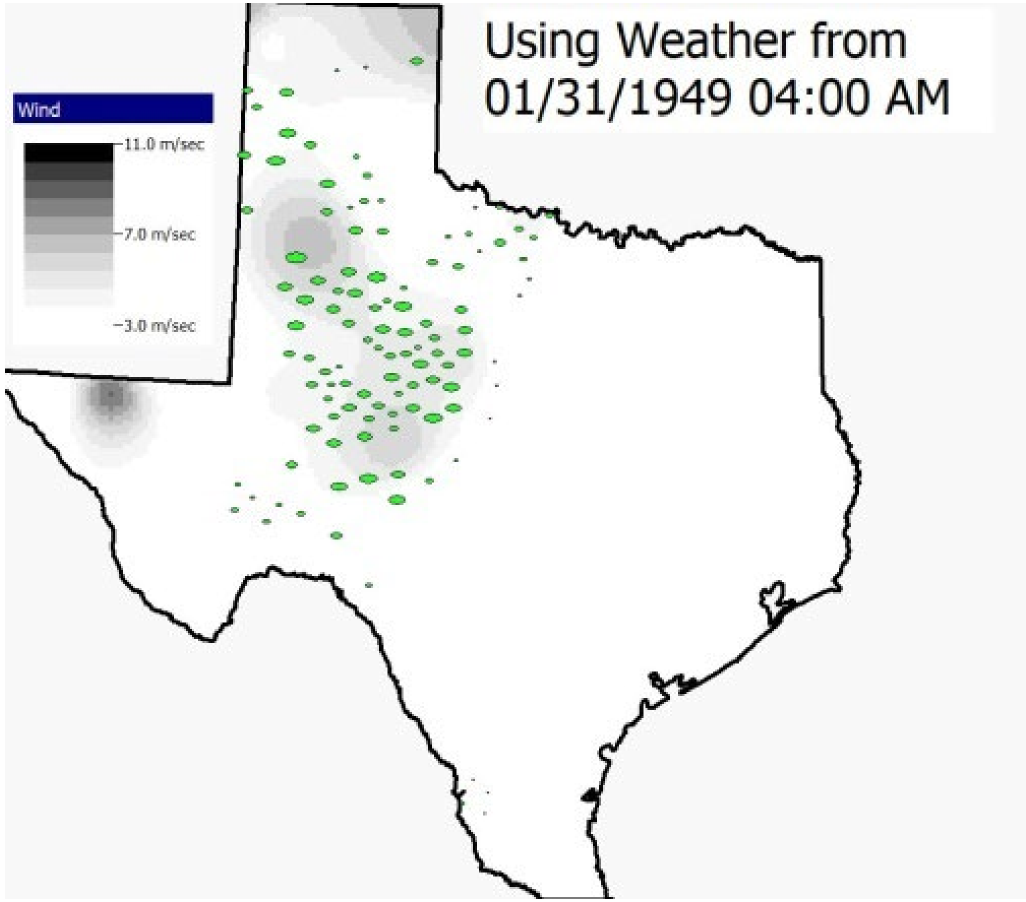


Temperatures January 31, 1949



Potential Grid Impacts of January 31, 1949

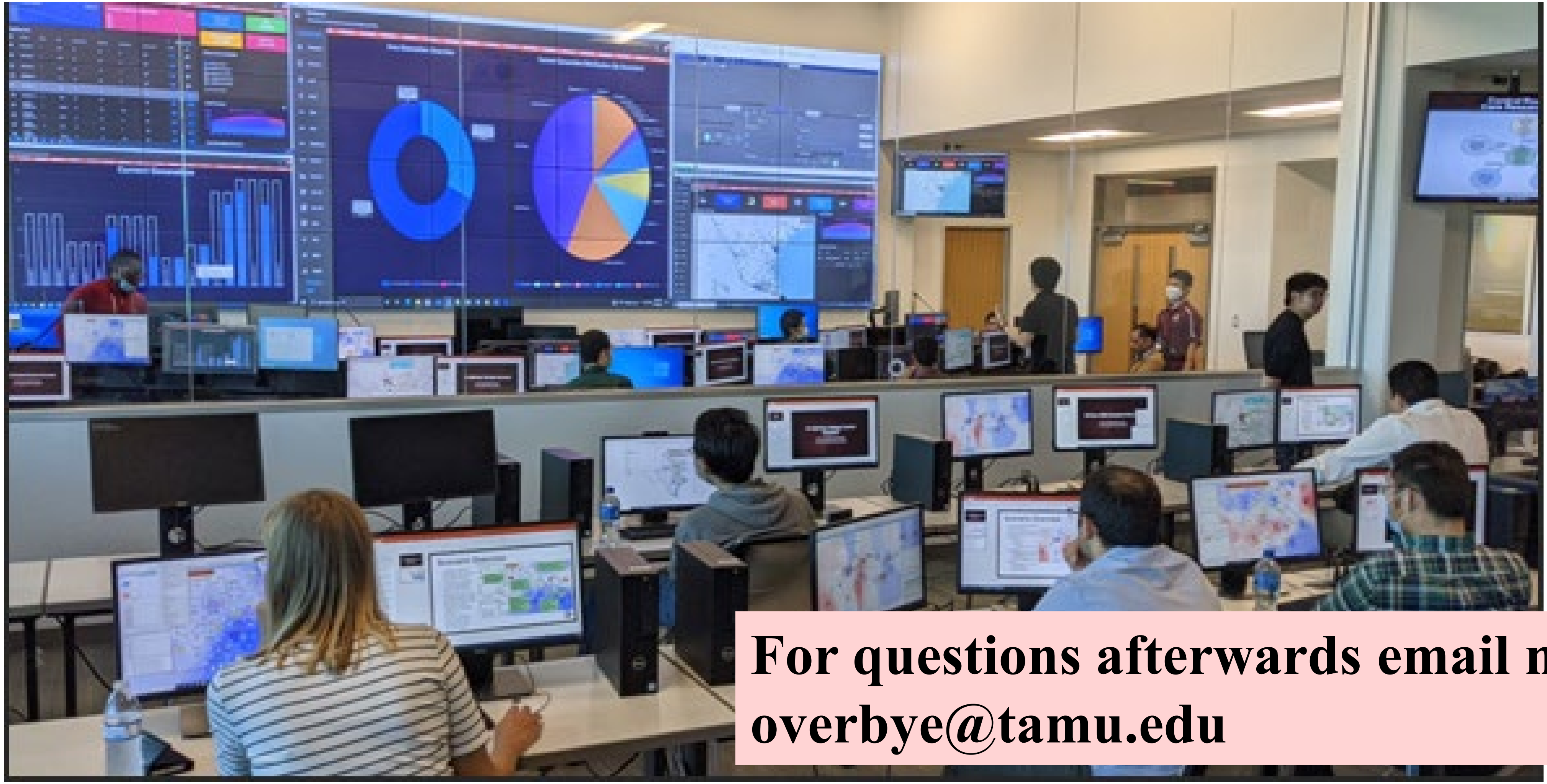
- In comparing 2011 with 1949, in 1949 the temperatures were lower in parts of Central Texas, but not as low further north. However these lower temperatures did occur in locations the now have a large amount of natural gas generation
- The wind in 1949 was substantially lower, with almost no wind in South Texas



Conclusion

- The presentation has shown the weather data can be used effectively in the power flow
- A number of models that relate weather to electric grid values already exist, but more certainly should be developed
- With adequate models historical and/or future forecasted weather can be relatively easily applied to the electric grids of today and the future

Thank You! Questions?



For questions afterwards email me at overbye@tamu.edu