

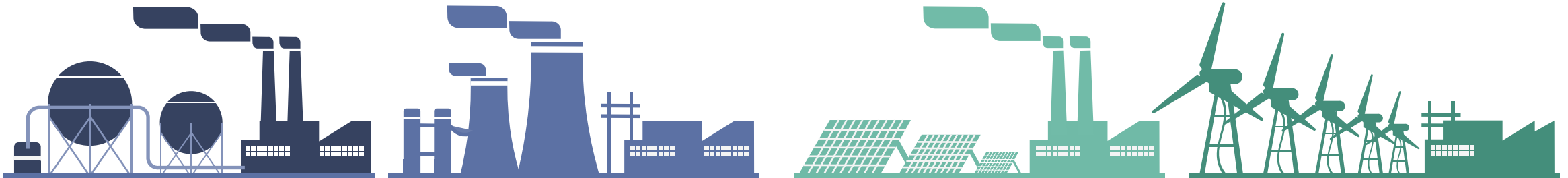
Studying Important Weather Factors in the 2021 Texas Power Crisis

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Texas Power Outage Background

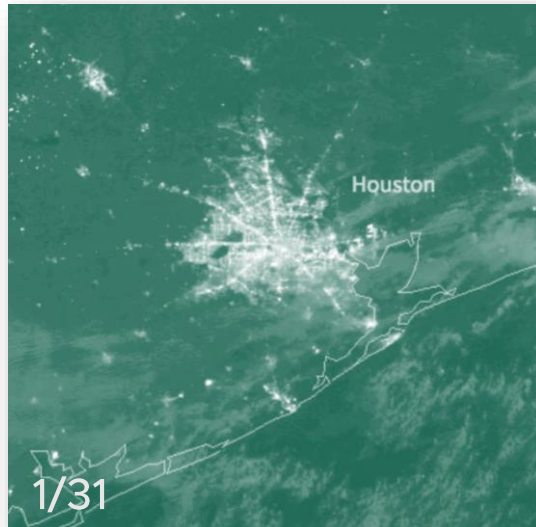
- Failure to winterize power equipment left natural gas facilities and wind turbines vulnerable to the extreme winter storms in February 2021
- Recommendations made by the North American Electricity Reliability Corporation as a result of the 2011 blackouts were ignored due to cost considerations
- Many oil producers were willing to take the risk of possible “freeze-ups”
- The Electric Reliability Council of Texas (ERCOT) decided to impose rolling blackouts on Texas residents, leaving many in crisis conditions



Timeline

2/13

“Winter Storm Uri” hits Texas, already suffering from freezing temperatures



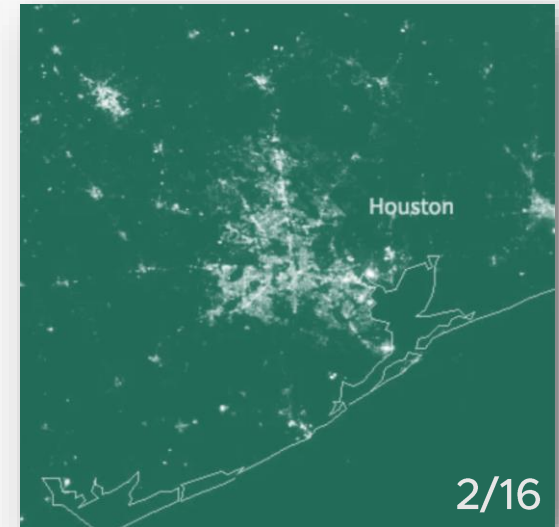
2/14

Electricity demand hit 69,150 MW, 3,200 higher than the record set in 2018



2/15

ERCOT begins rotating power outages, 4.4 million people are left without power



2/19

ERCOT ends emergency conditions and ceases rolling blackouts

Presentation Objectives

- Find out which weather factors such as humidity, temperature, and dew point had the greatest impact on the Houston outage situation
- Utilize Quantile Range Outliers, Principal-Component Statistical Process Control Chart, and Cluster Variables to determine which markers differed the most from past years
- Compare the 2021 climate to the past decade using the Heat Map and the Score Plot
- **Connect the outlier analyses results to environmental science to ultimately determine the most representative indicator(s) of similar crises in the future**

The Crisis in Houston

What weather factor had the greatest contribution?

- Houston was hit much harder by the crisis than Dallas (but both used the same power system)
- Houston has higher temperature and higher dew point
- Is dew point the most important weather indicator of “freeze-up” risks?

Houston

Temperature (° F)	Max	Average	Min
Max Temperature	82	61.68	27
Avg Temperature	74.82	53.32	21.67
Min Temperature	71	45.68	15
Dew Point (° F)	Max	Average	Min
Dew Point	69	43.88	3

Dallas

Temperature (° F)	Max	Average	Min
Max Temperature	79	51.61	14
Avg Temperature	65.31	42.45	9.47
Min Temperature	56	34.11	3
Dew Point (° F)	Max	Average	Min
Dew Point	66	30.57	-5

Air Temperature, Dew Point, Humidity

- **Air temperature** (commonly known as just temperature) is the measure of the average kinetic energy of air molecules (condensation depends on air temperature)
- **Relative humidity** (commonly known as just humidity) expresses how much energy available has been used for evaporation
- **Dew point temperature** (commonly known as just dew point) is the temperature at which condensation first begins (**measure of moisture**)
- **Humidity depends on both temperature and dew point (which are both independent variables)** as the greater the difference between air temperature and dew point, the lower the relative humidity
- Dew point is independent of atmospheric pressure, but temperature and humidity are directly related to pressure

Data Collection

Time	Temperature (° F)			Dew Point (° F)			Humidity (%)			Wind Speed (mph)			Pressure (Hg)		
	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min
Feb															
1	65	53.8	44	34	29.5	20	68	42.8	20	16	9.7	3	30.4	30.3	30.2
2	66	54.7	47	43	36.1	29	80	51.3	35	13	6.6	0	30.3	30.2	30.1
3	68	59.3	49	56	50.2	43	89	73.0	55	15	9.6	0	30.1	30.0	29.9
4	79	69.6	61	61	58.0	44	87	68.1	48	23	12.4	6	29.9	29.8	29.7
5	61	53.0	48	44	41.1	36	80	65.4	47	21	12.7	7	30.0	29.9	29.8
6	68	57.8	50	56	49.8	43	89	75.0	64	17	8.3	3	30.0	29.8	29.8
7	63	52.6	43	47	42.6	38	86	69.9	50	15	8.8	5	30.1	30.0	29.9
8	71	62.3	53	61	56.1	48	93	80.9	63	15	9.5	5	30.0	29.9	29.9
9	71	66.0	64	65	62.6	60	96	88.9	78	14	6.1	0	30.0	30.0	29.9
10	68	62.1	48	64	59.2	46	97	90.3	78	16	7.9	0	30.0	29.9	29.9
11	47	43.1	40	45	40.3	38	93	89.7	85	21	14.5	10	30.0	30.0	29.9
12	42	38.2	36	37	34.6	32	93	87.1	79	22	16.4	12	30.1	30.1	30.0
13	44	39.7	36	32	31.6	31	82	72.8	63	18	14.1	9	30.1	30.0	30.0

- Cluster sampling – collected daily weather statistics in the month of February from 2012 to 2021
- Sample size = 283 (28 days *10 years + 3 days from leap years)
- Weather parameters that were collected were temperature, dew point, humidity, wind speed, pressure, and precipitation

2012-2021 Quantile Range Outliers

Quantile Range Outliers

Outliers are values Q times the interquantile range past the lower and upper quantiles.

Tail Quantile

Select columns and choose an action.

Q

Restrict search to integers

Show only columns with outliers

Some quantiles were stretched to avoid a large group at the median.

Column	25% Quantile	75% Quantile	Low Threshold	High Threshold	Number of Outliers	Outliers (Count)	
Temp-Max	62	76	41	97	6	27 36 38 39 40(2)	Temperature
Temp-Avg	53	67.1	31.85	88.25	2	21.7 26.3	
Temp-Min	43	59	19	83	2	15 18	
Dew Point-Max	47	66	18.5	94.5	0		Dew Point
Dew Point-Avg	39	61.3	5.55	94.75	0		
Dew Point- Min	32	55	-2.5	89.5	0		
Humidity%-Max	86	97	69.5	113.5	19	46 49 53 54(2) 55 56 59 63 64 65 66(2) 67(2) 68(2) 69(2)	Humidity
Humidity%-Avg	64.5	87	30.75	120.75	1	29.9	
Humidity%-Min	39	69	-6	114	0		
Wind Speed-Max	14	20	5	29	5	30(2) 31(2) 32	Wind Speed
Wind Speed-Avg	6.9	11.4	0.15	18.15	1	18.4	
Wind Speed-Min	0	5	-7.5	12.5	2	13(2)	
Pressure-Max	30	30.3	29.55	30.75	0		Pressure
Pressure-Avg	29.9	30.2	29.45	30.65	0		
Pressure-Min	29.8	30.1	29.35	30.55	0		
Precipitation	0	0.06	-0.09	0.15	21	0.16 0.19 0.22 0.23 0.26(2) 0.27 0.41(2) 0.43 0.61 0.7 0.71 0.76 0.89 0.92 0.93 1.13 1.41 1.48 1.82	

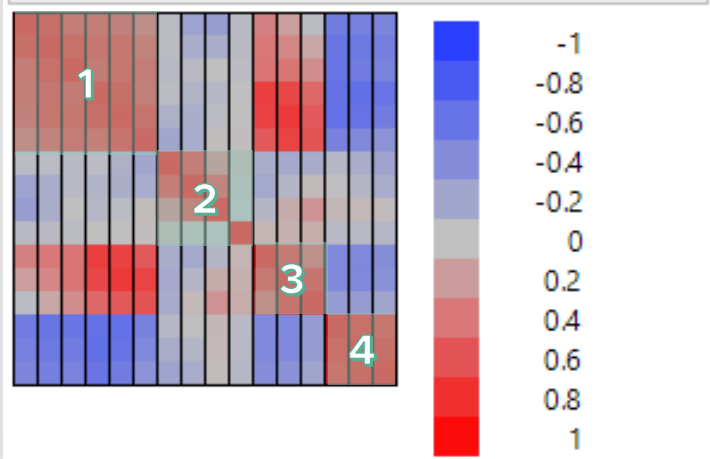
February 2021 Quantile Range Outliers

Year	Feb	Temp-Max	Temp-Avg	Temp-Min	Dew Point-Max	Dew Point-Avg	Dew Point- Min	Humidity%-Max	Humidity%-Avg	Humidity%-Min	Wind Speed- Max
2021	2	66	54.7	47	43	36.1	29	80	51.3	35	13
2021	3	68	59.3	49	56	50.2	43	89	73	55	15
2021	4	79	69.6	61	61	58	44	87	68.1	48	23
2021	5	61	53	48	44	41.1	36	80	65.4	47	21
2021	6	68	57.8	50	56	49.8	43	89	75	64	17
2021	7	63	52.6	43	47	42.6	38	86	69.9	50	15
2021	8	71	62.3	53	61	56.1	48	93	80.9	63	15
2021	9	71	66	64	65	62.6	60	96	88.9	78	14
2021	10	68	62.1	48	64	59.2	46	97	90.3	78	16
2021	11	47	43.1	40	45	40.3	38	93	89.7	85	21
2021	12	42	38.2	36	37	34.6	32	93	87.1	79	22
2021	13	44	39.7	36	32	31.6	31	82	72.8	63	18
2021	14	38	34.1	28	33	28.8	24	86	80.9	70	22
2021	15	27	21.7	18	23	14.1	7	88	73.3	58	25
2021	16	36	26.3	15	26	12.5	3	67	56.5	42	14
2021	17	39	36.4	33	37	32.6	30	93	86.4	76	22
2021	18	44	35.8	32	33	27.7	20	92	73.2	58	23
2021	19	51	38.5	26	28	22.1	19	78	54.2	32	14
2021	20	60	46.2	32	43	35.3	27	83	67.8	44	14
2021	21	72	59.1	46	54	49.5	42	93	72.8	44	20
2021	22	76	61.8	51	54	40.6	24	90	53.9	15	13
2021	23	79	61.6	45	53	45.5	37	89	62.3	23	17
2021	24	80	70.1	58	66	62.1	52	90	76.8	56	17
2021	25	72	69.3	66	67	65.1	64	93	86.5	78	15

Quantile outlier analysis fails to consider any multicollinearity among the weather patterns

Cluster Variables

Color Map on Correlations



1. Temperature and Dew Point
2. Wind Speed and Precipitation
3. Humidity
4. Pressure

Cluster Members

Cluster	Members	RSquare with Own Cluster	RSquare with Next Closest	1-RSquare Ratio
1	Temp-Avg	0.922	0.316	0.114
1	Dew Point-Avg	0.923	0.535	0.166
1	Temp-Min	0.88	0.294	0.17
1	Dew Point-Max	0.87	0.457	0.24
1	Temp-Max	0.771	0.255	0.307
1	Dew Point- Min	0.741	0.457	0.478
2	Wind Speed-Avg	0.936	0.022	0.065
2	Wind Speed-Max	0.697	0.031	0.313
2	Wind Speed-Min	0.616	0.012	0.388
2	Precipitation	0.014	0.009	0.995
3	Humidity%-Avg	0.975	0.298	0.036
3	Humidity%-Min	0.807	0.135	0.224
3	Humidity%-Max	0.754	0.325	0.365
4	Pressure-Avg	0.975	0.343	0.038
4	Pressure-Min	0.927	0.273	0.1
4	Pressure-Max	0.921	0.377	0.127

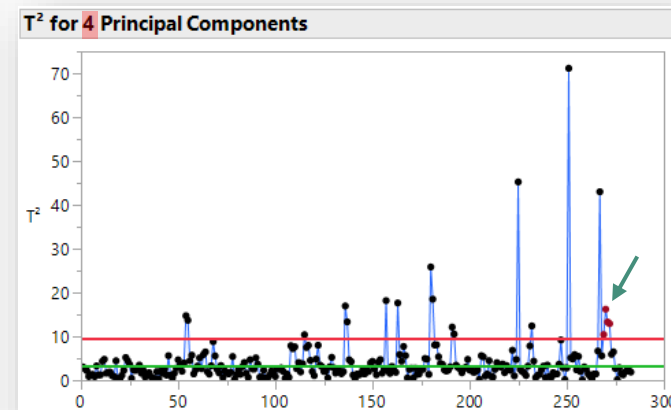
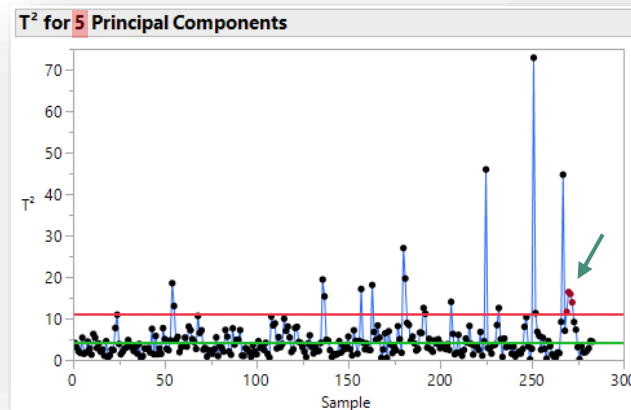
Cluster Summary

Cluster	Number of Members	Most Representative Variable	Cluster Proportion of Variation Explained	Total Proportion of Variation Explained
1	6	Temp-Avg	0.851	0.319
4	3	Pressure-Avg	0.941	0.176
3	3	Humidity%-Avg	0.845	0.158
2	4	Wind Speed-Avg	0.566	0.141

Statistical Process Control (SPC) Charts

Principal Component Analysis (PCA)-driven Statistical Process Control Chart (SPC) cannot detect the 2021 weather situation very well

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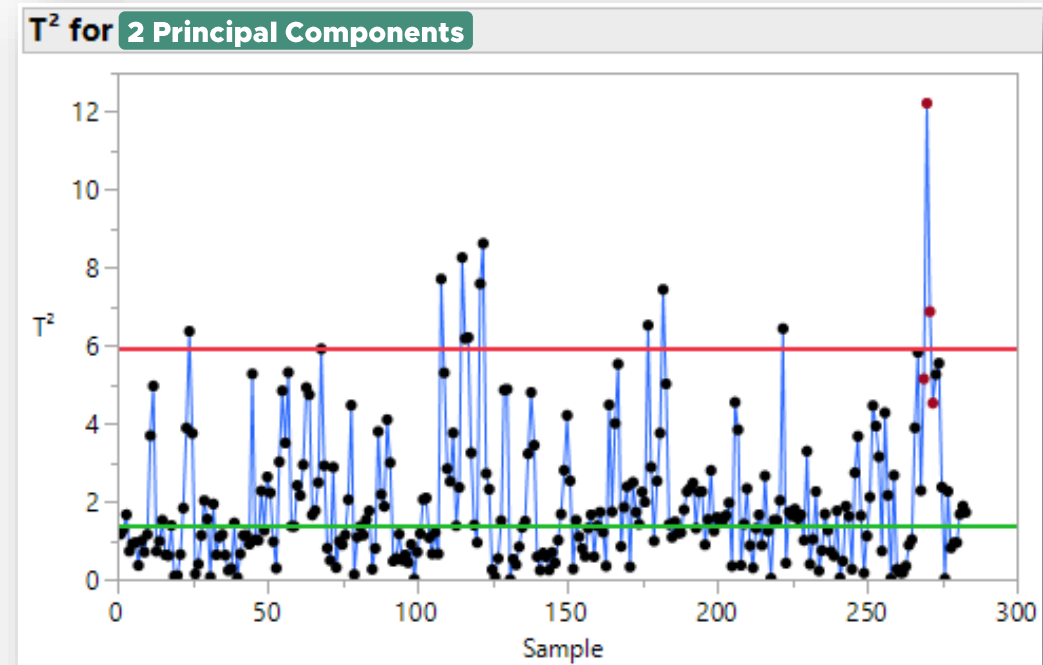


Revised SPC Analysis

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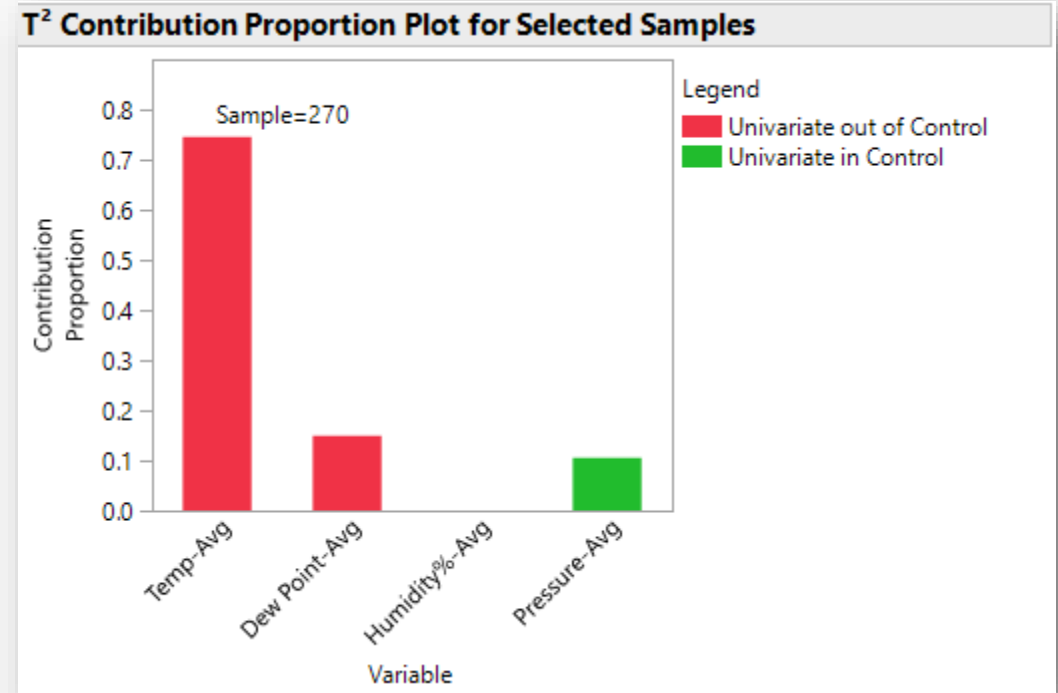
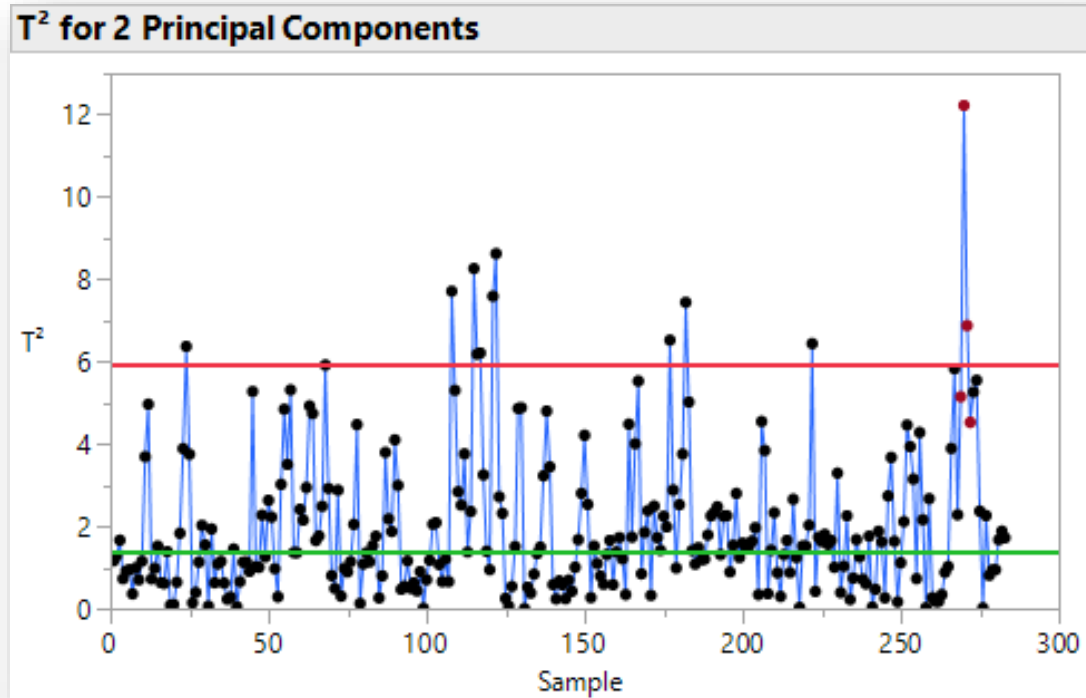
Average parameters are more representative than Minimum and Maximum

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Cluster	Members	RSquare with Own Cluster	RSquare with Next Closest	1-RSquare Ratio
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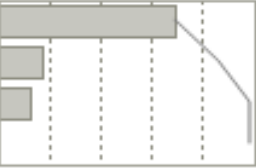


Contribution Proportion Plot

Temperature and Dew Point are the main contributors to the weather situation of the 2021 outage crisis



Principal Component Analysis

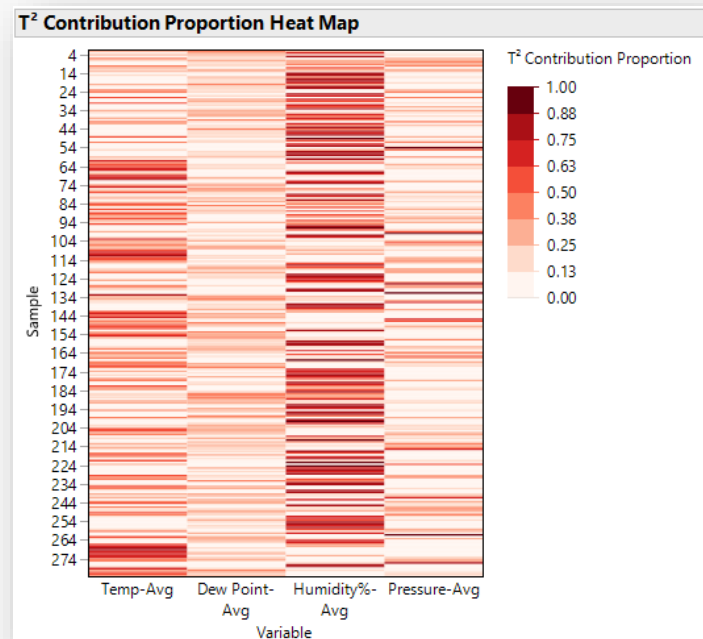
Eigenvalues								
Score	Eigenvalue	Score Std Dev	Percent	20	40	60	80	Cum Percent
1	2.784	1.6684	69.593					69.593
2	0.701	0.8372	17.524					87.116
3	0.510	0.7142	12.753					99.869
4	0.005	0.0723	0.131					100.000

Eigenvectors				
	Prin1	Prin2	Prin3	Prin4
Temp-Avg	0.50198	-0.55380	0.40120	0.52949
Dew Point-Avg	0.58275	0.04105	0.31481	-0.74807
Humidity%-Avg	0.44385	0.80166	0.02369	0.39972
Pressure-Avg	-0.45980	0.22128	0.85987	0.01582

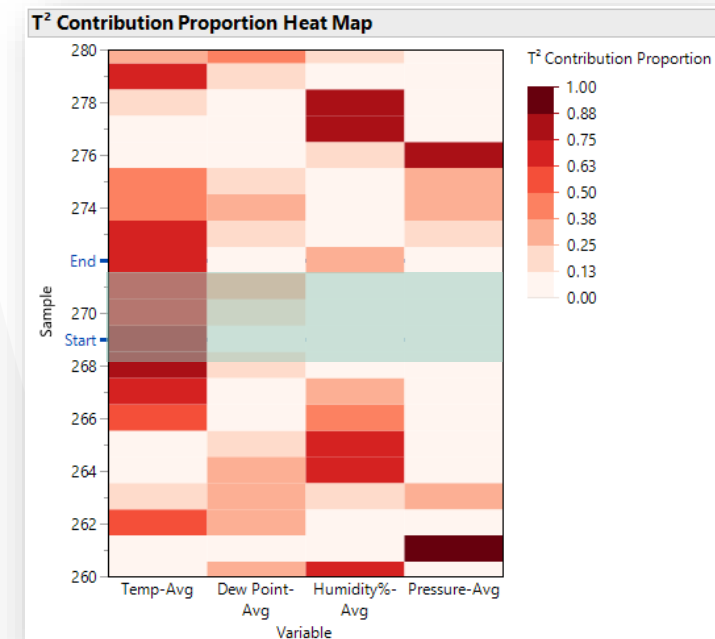
- Principal Component 1 and 2 can explain more than 80% of the variation (Pareto principle)
- First eigenvector is quite evenly distributed among the four parameters
- Second eigenvector mainly considers temperature and humidity

Heat Map Analysis

Temperature and Humidity% are the main contributors across February 2012 to 2021

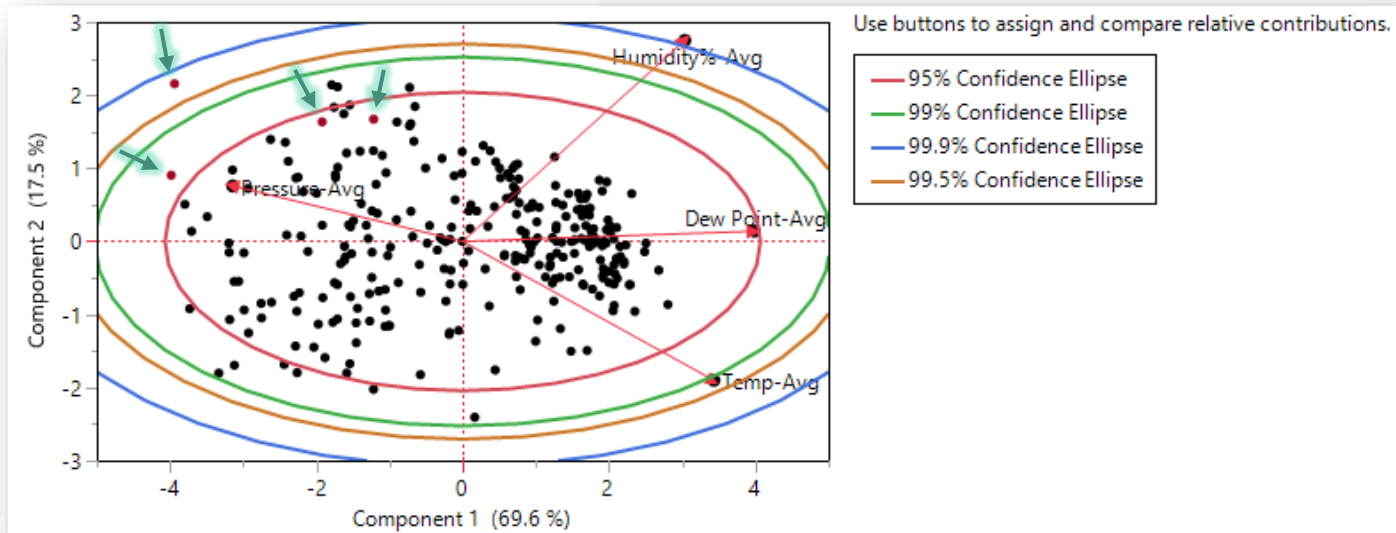


Temperature and Dew Point are the main contributors for the 2021 outage crisis



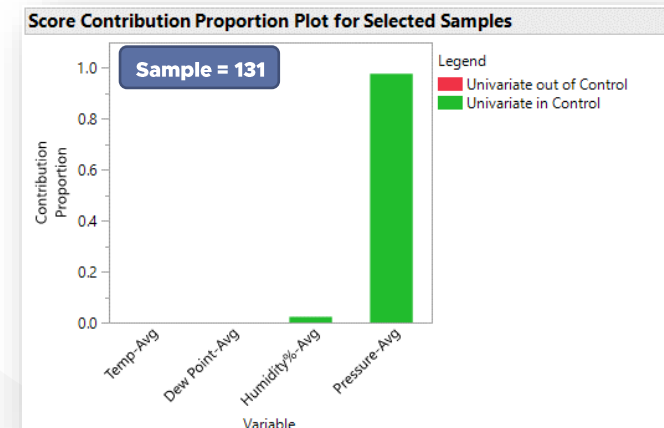
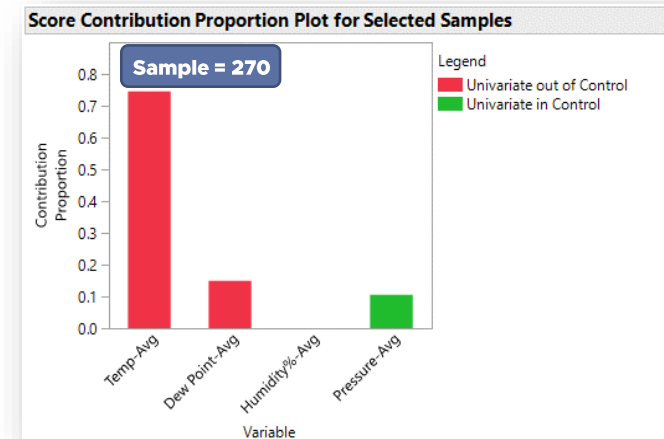
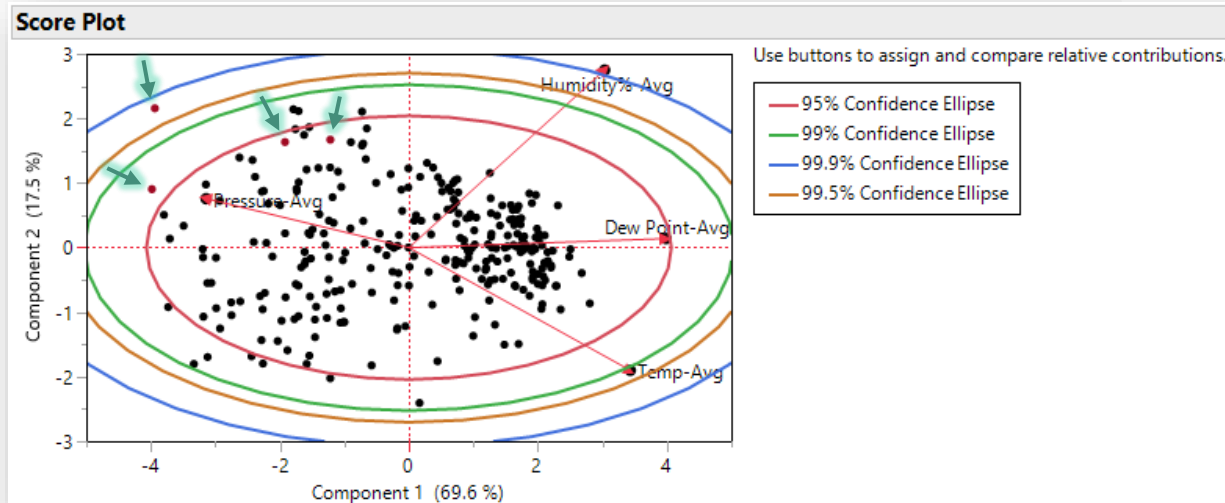
Score Plot

- February 15th (the day with the worst weather situation) is outside the 99.5% confidence ellipse (occurs once every 7 years when disregarding other factors)
- The four days with the worst weather situation lie opposite to the temperature and dew point eigenvectors



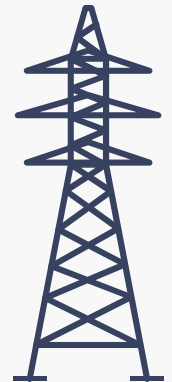
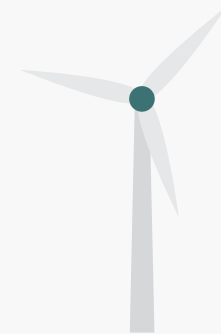
Contribution Comparison

- Temperature and Dew Point are the main contributors for February 15th (Sample 270)
- Humidity is much more important for the center point (Sample 131)



Response

- On February 24th, Governor Abbott called for the Texas grid to be winterized
- Many critics believe that the new legislation does not go far enough to prevent another power crisis
- Utilities should plan for the future and consider the increased risks associated with climate change instead of looking just at the past



Conclusion

- Studied different weather indicators such as temperature, humidity, and dew point
- Used Cluster Variables to address the limitations of the general Quantile Outliers tool
- Implemented Cluster Variables and the Principle Component Analysis to more efficiently reduce the number of parameters and distinguish the weather pattern
- Compared the February 2021 weather situation with the past decade using the Statistical Process Control (SPC) chart, the Heat Map, and the Score plot
- Investigated the different contribution proportions of the four most representative variables (temperature, dew point, humidity, and pressure)
- **Temperature and dew point may be the most important weather indicators for future events (instead of humidity and pressure)**