

Forecasting Wind Plant Output
During the Recent TX Extreme Weather Event



Primary Challenges of Wind Power Prediction during the Event



- Complicated weather pattern and nearly unprecedented daily high temperature forecasts
- Moisture at various levels in the lower atmosphere – high uncertainty in spatial coverage
- Icing efficiencies in both high and low wind scenarios
- Uncertainty in arrival time of sub-freezing air
- Uncertainty in arrival time of Arctic air mass, with temperatures below turbine operating limits
- Potential ice melt during the event
- Communication of feedback on operations during the event
- Mostly a problem of predicting generation loss – when and where it occurs; not all wind generation sources were affected!

Key Tools of the Analysis



1. The Composite Conditions

- NOAA ASOS station data (57 stations, with 10-minutely data)
- ECMWF Reanalysis and NASA MERRA 2 Reanalysis Data (Boundary Layer and Upper-Atmospheric)
- Wind power data, available publicly via www.ercot.com Market Reports
- Approximate wind plant locations (to nearest county) available publicly

2. The Forecast

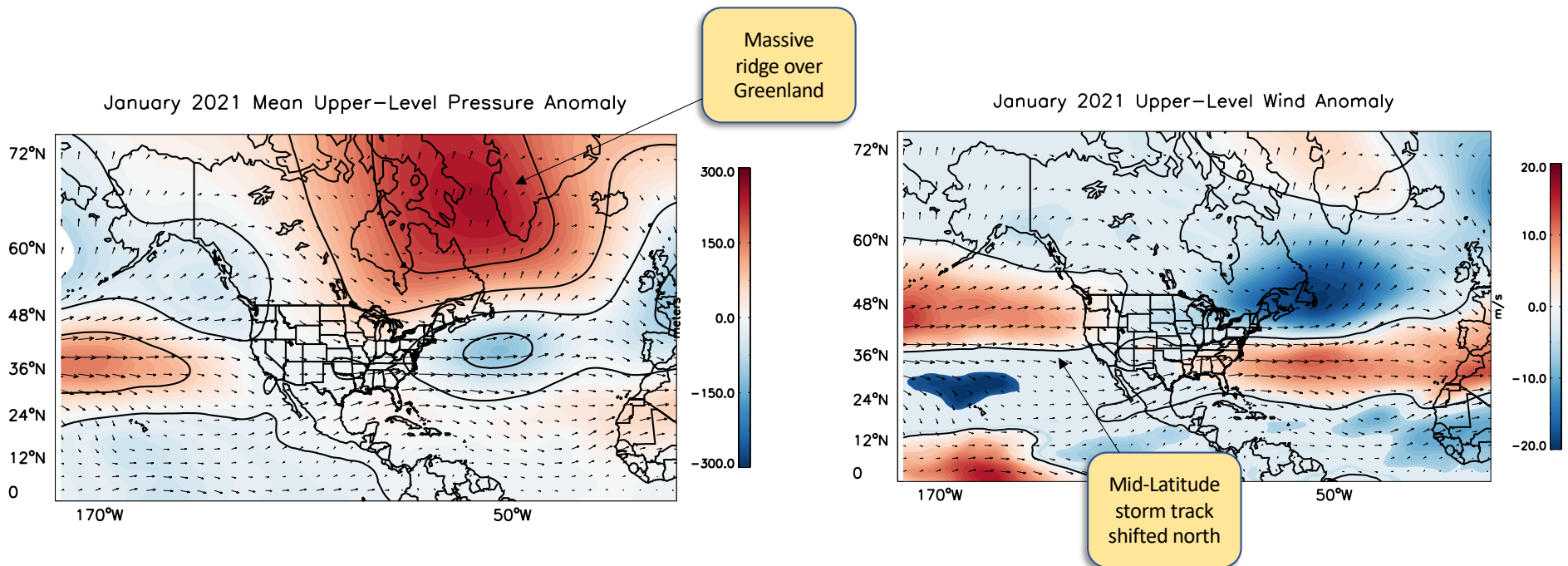
- NOAA GFS, GEFS, NAM, RAP, HRRR
- ECMWF HIRes, Integrated Forecast System Ensemble
- Environment Canada (Regional Deterministic and MSC Ensemble)

Estimating Power and Loss



- Primary method for estimating actual power is to use scheduled generation data from ERCOT, by generator
- Potential Power determined via a weighted aggregation of
 - Reanalysis data
 - Fixed tower measurement data
 - High-resolution (e.g., 1 km) model initial condition data
 - Application of a theoretical power conversion model
- Loss determined by subtracting estimated actual from potential
- Event-attributable loss is defined within the time bounds of the weather event (roughly Feb 8 – Feb 22), and exceeds the limit of non-weather-related losses (e.g., from curtailment or other transmission limits).

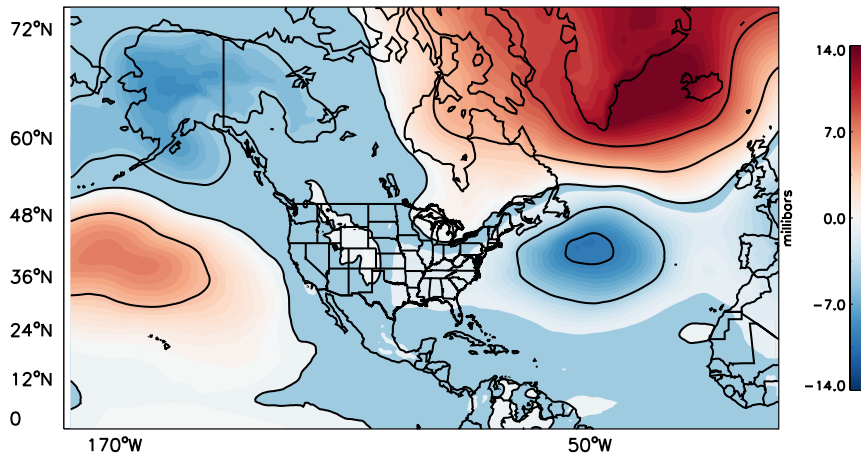
Precursors to the Main Event



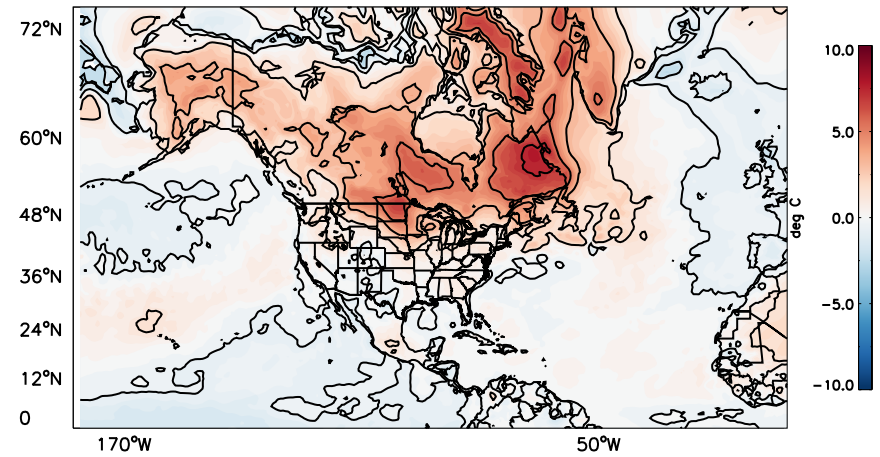
- Intense ridging over Greenland with weakened shear and westerlies over North Atlantic – coincident with and a suspect factor in the sudden stratospheric warming (SSW) event.
- ENSO-shifted mid-latitude storm track – incidental but potentially consequential.

Precursors to the Main Event

January 2021 Mean Sea Level Pressure Anomaly



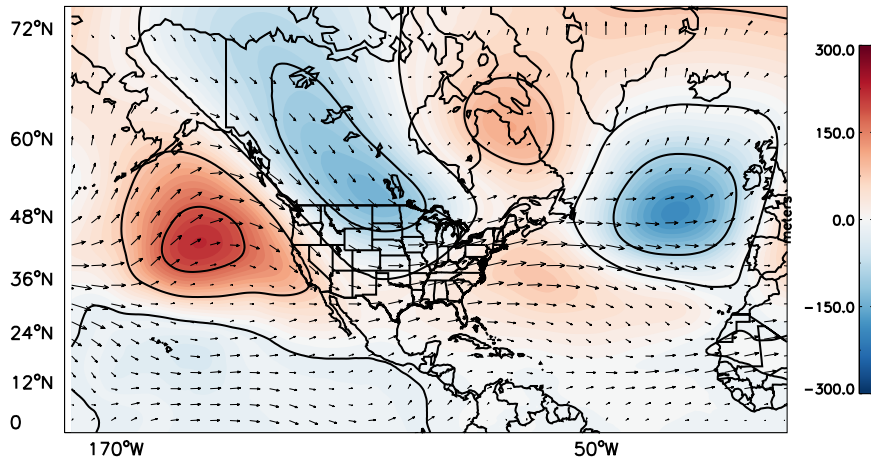
January 2021 Temperature Anomaly



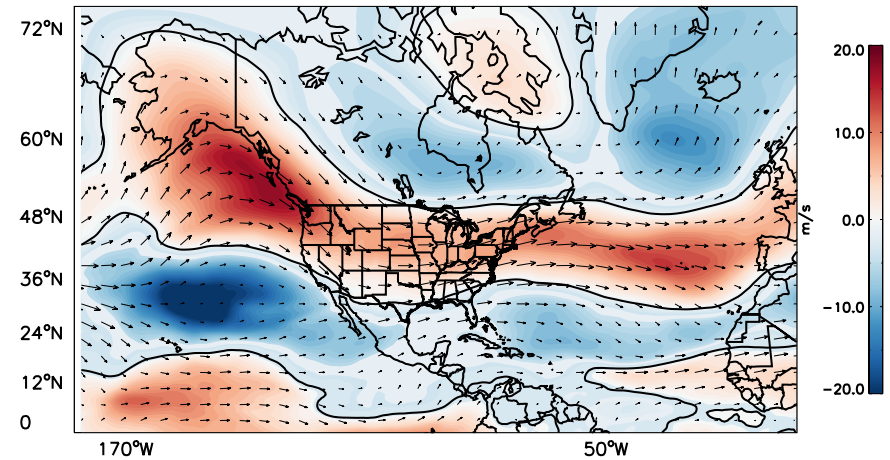
- Near surface warming over northern ½ of the N. American continent
- Suggestive of hemispheric-scale phenomena

Precursors to the Main Event

February 2021 Mean Upper-Level Pressure Anomaly



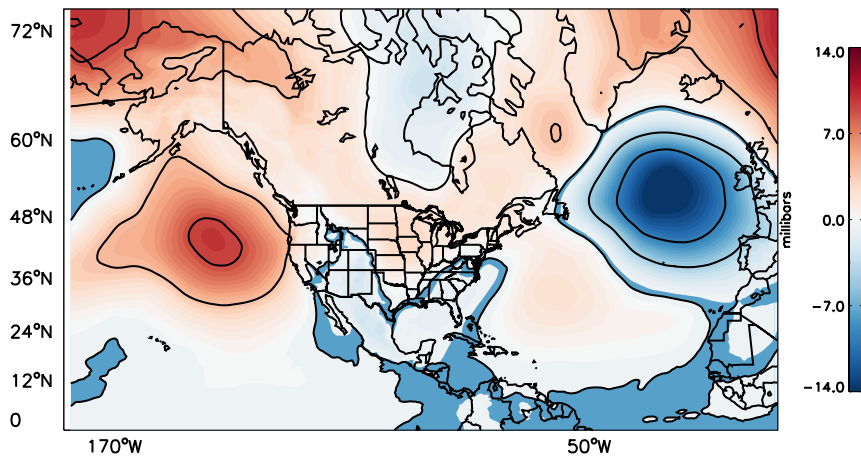
February 2021 Upper-Level Wind Anomaly



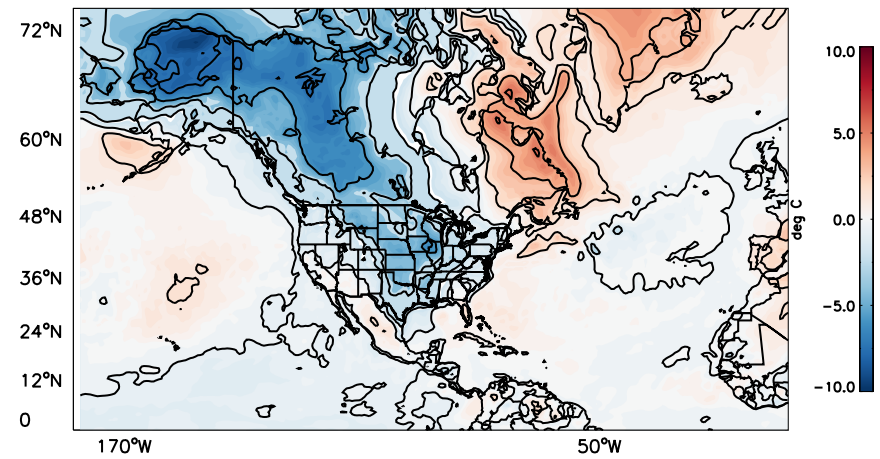
- In February, a highly-amplified upper-level pattern in place
- “Expressway” of polar air into the central U.S. via elongated and northward-shifted storm track.

Precursors to the Main Event

February 2021 Mean Sea Level Pressure Anomaly

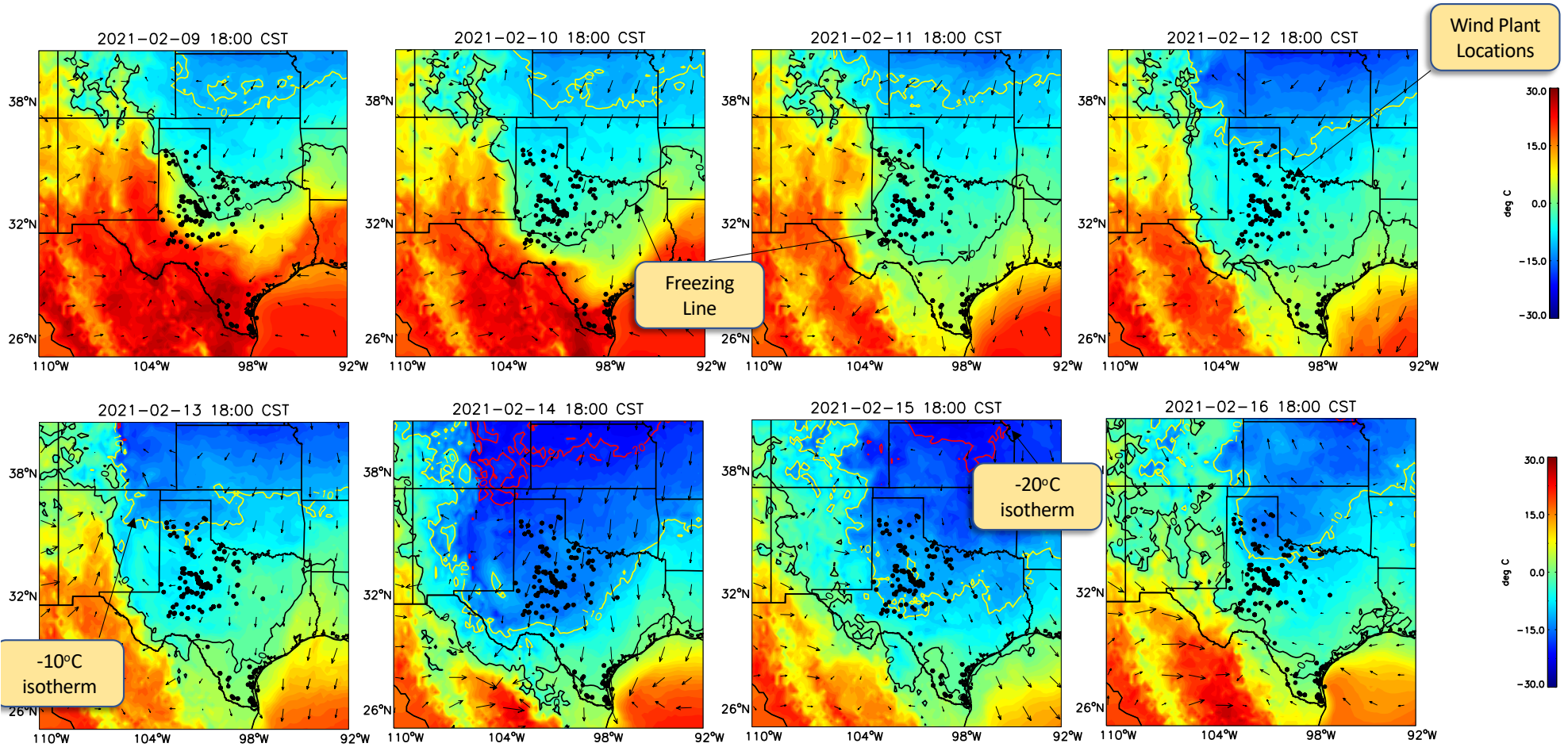


February 2021 Temperature Anomaly

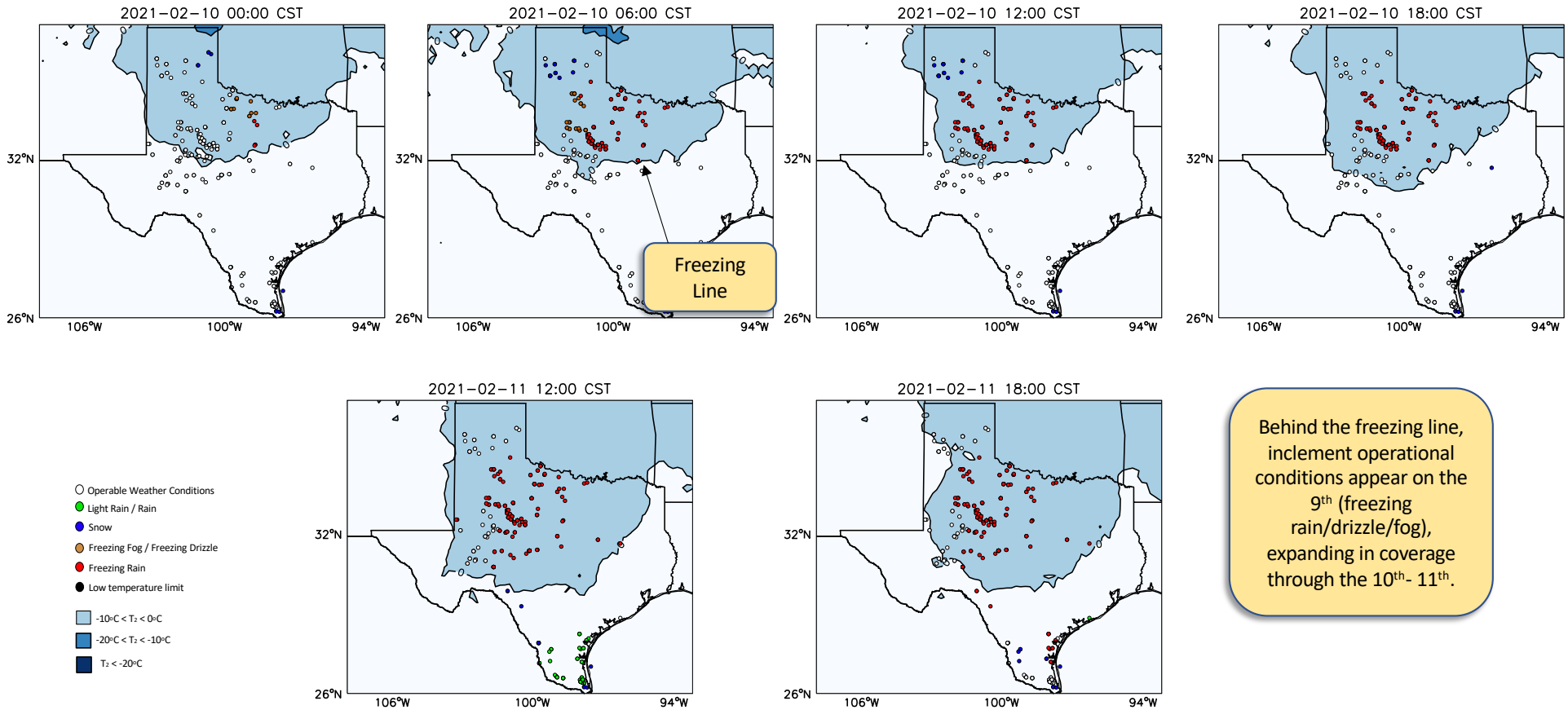


- Extreme cold bias at the surface for $\frac{3}{4}$ of the continental U.S.

A Frigid Airmass in Motion over 8 days in February

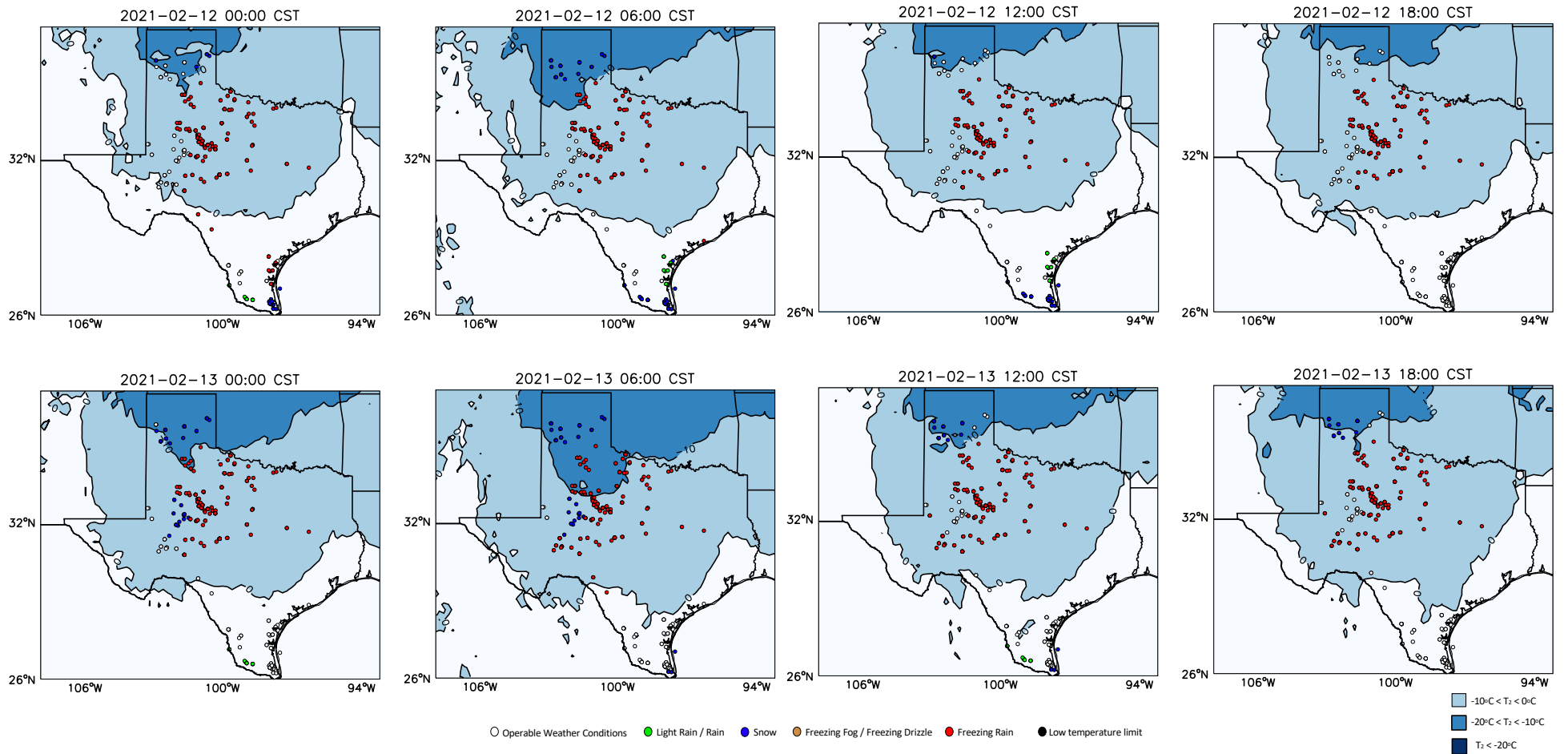


Estimated Wind Power Generation Conditions, Every 6 Hours

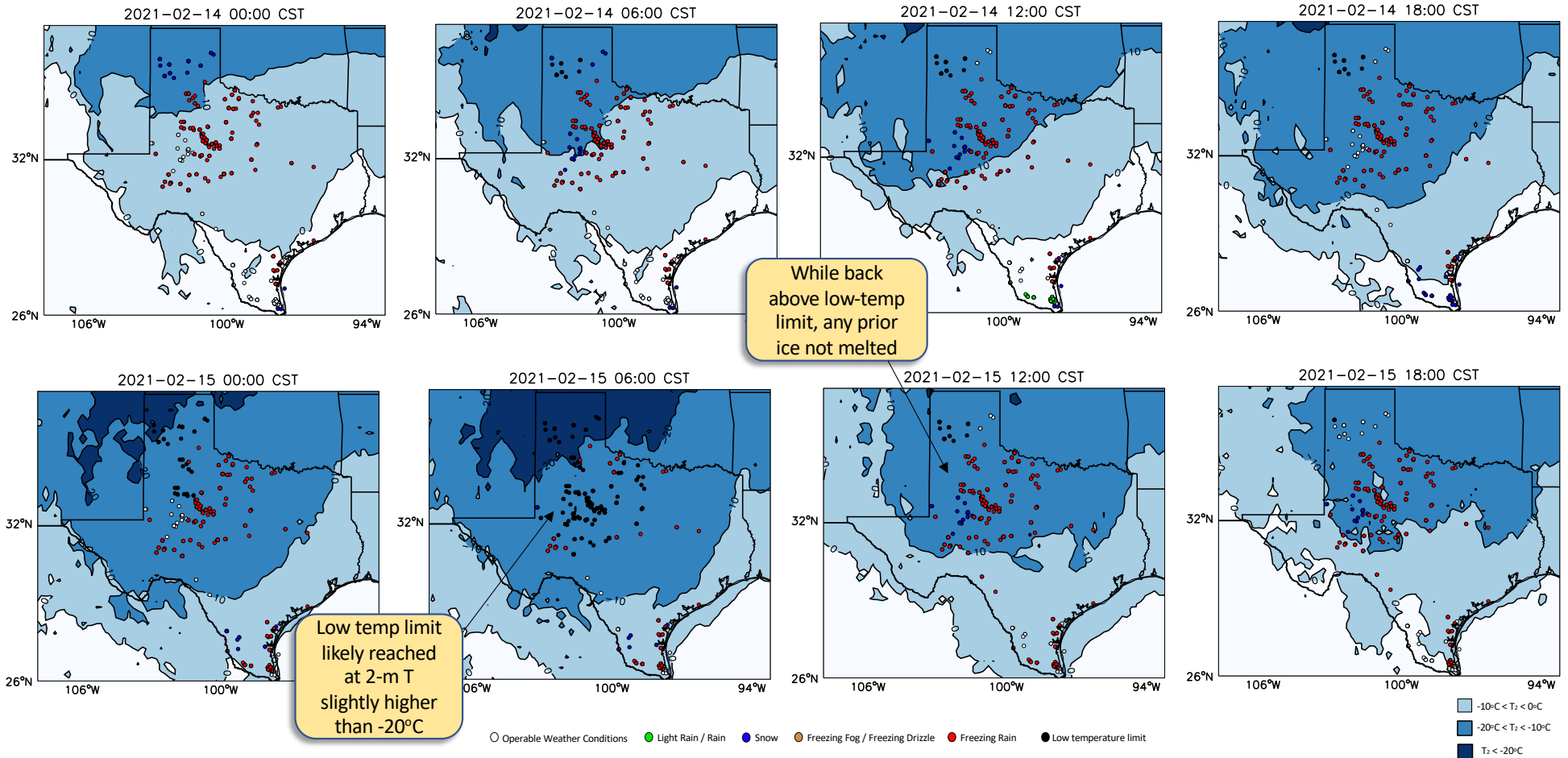


Behind the freezing line, inclement operational conditions appear on the 9th (freezing rain/drizzle/fog), expanding in coverage through the 10th- 11th.

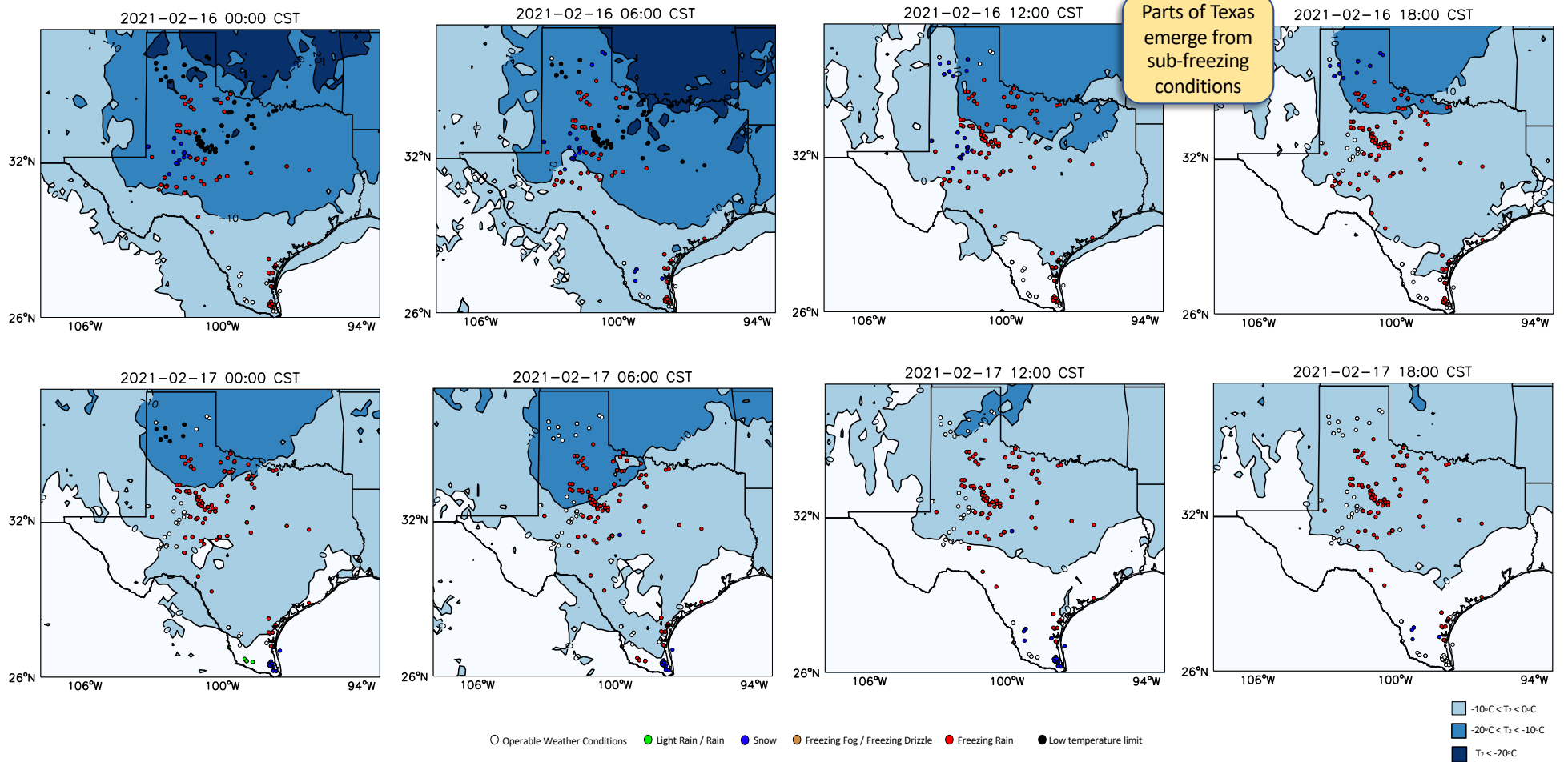
Estimated Wind Power Generation Conditions, Every 6 Hours



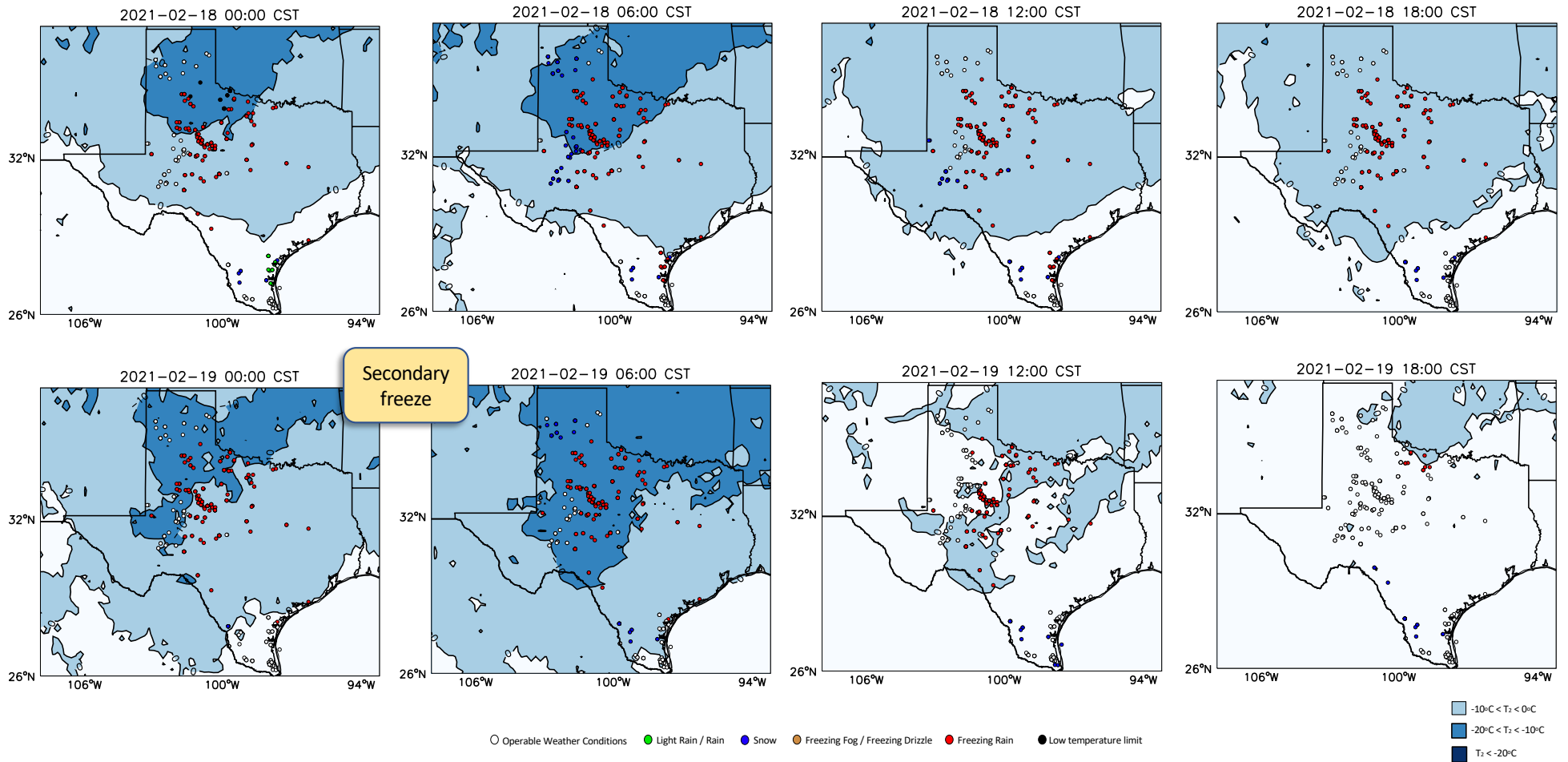
Estimated Wind Power Generation Conditions, Every 6 Hours



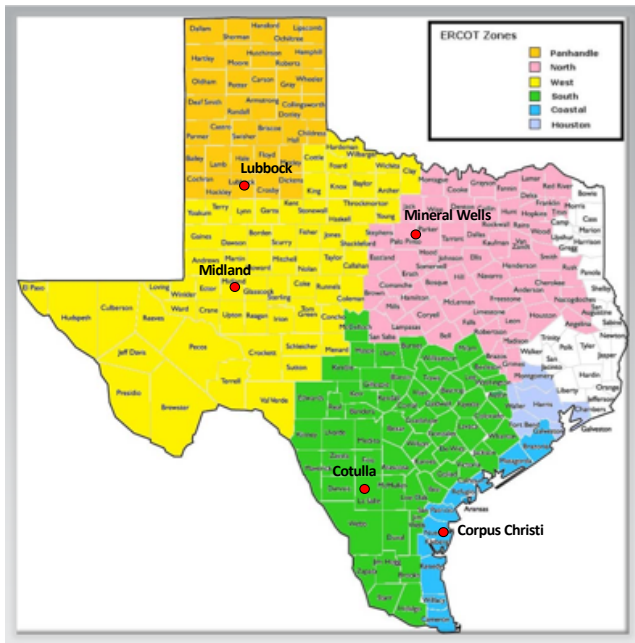
Estimated Wind Power Generation Conditions, Every 6 Hours



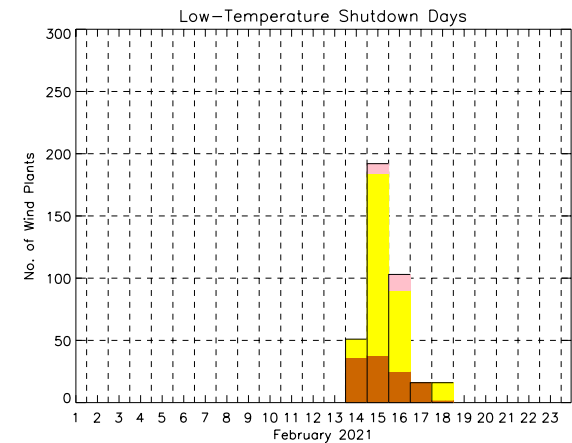
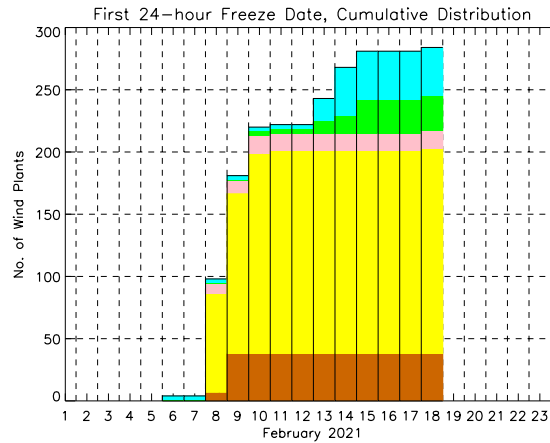
Estimated Wind Power Generation Conditions, Every 6 Hours



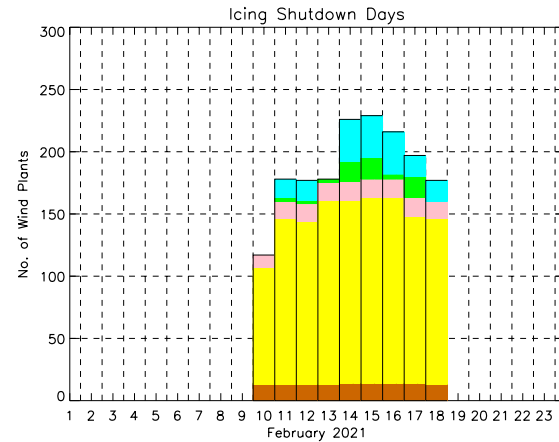
Regional / Zonal Event Statistics (Estimated)



Courtesy ERCOT Monthly Operational Overview (2018)



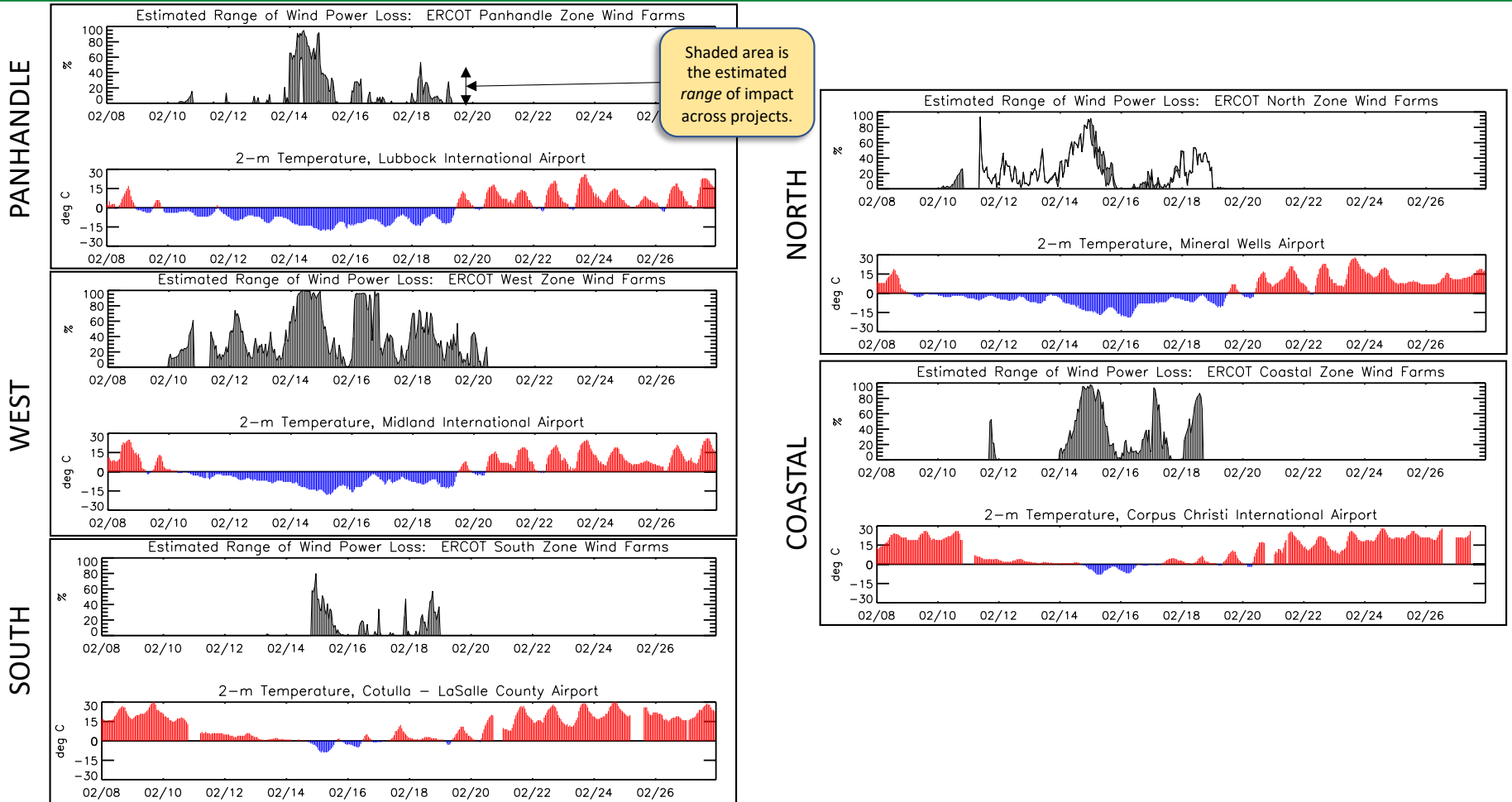
By 2/15, nearly all wind projects are sub-freezing



Estimates based on reported precipitation conditions prior to freezing

Coastal North Panhandle South West

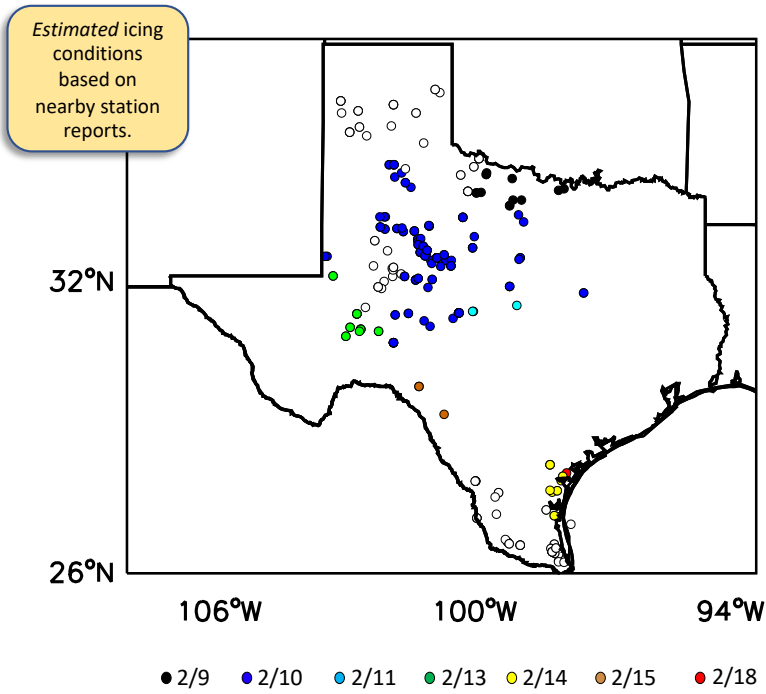
Estimated Event-Attributable Wind Generation Losses



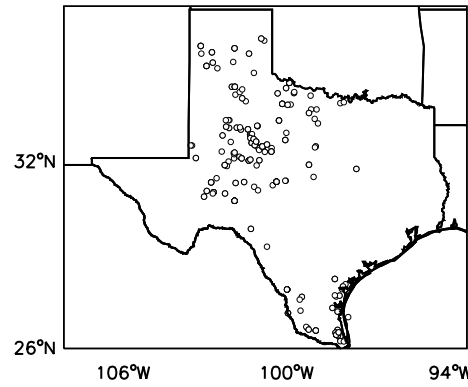
Forecasting the first day of icing



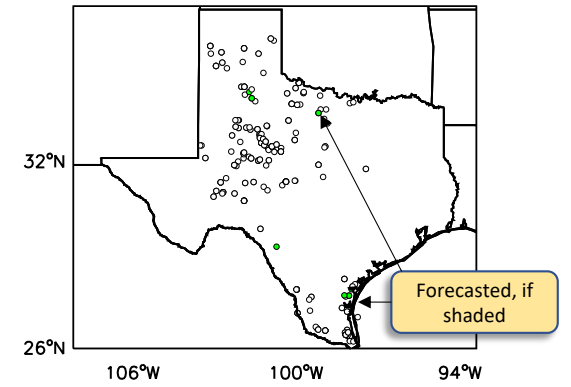
First Day of Icing



Icing Forecast, T+72

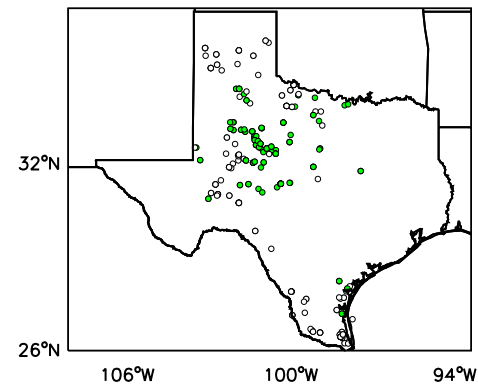


Icing Forecast, T+48

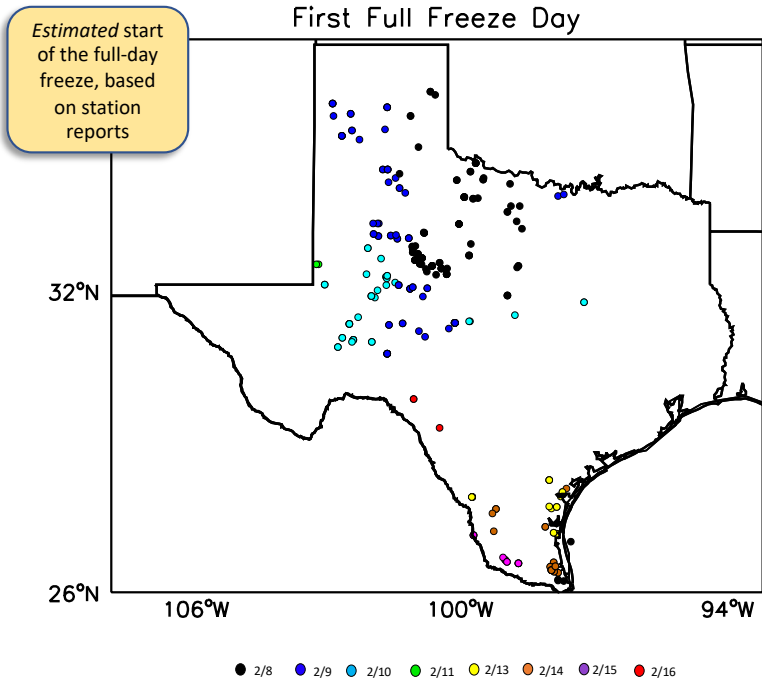


Icing Forecast, T+24

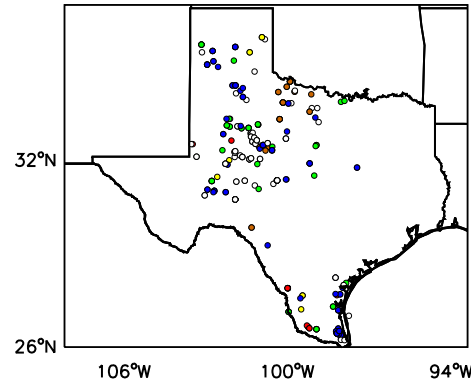
Icing due to freezing rain/drizzle under-forecasted, particularly 2-3 days out.



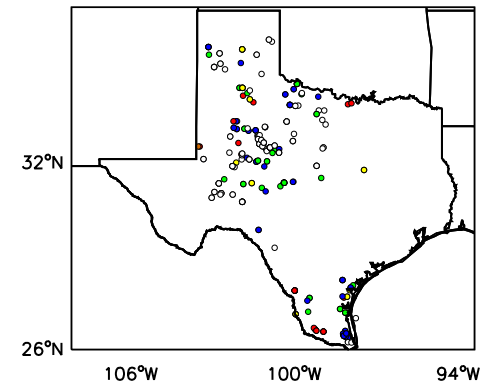
The first 24-hour freeze – how did models predict it?



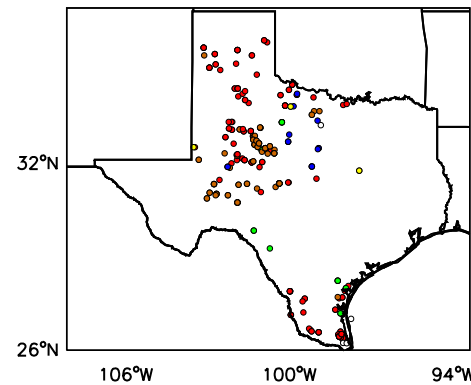
NWP First Full Freeze Day at T-72



NWP First Full Freeze Day at T-48



NWP First Full Freeze Day at T-24

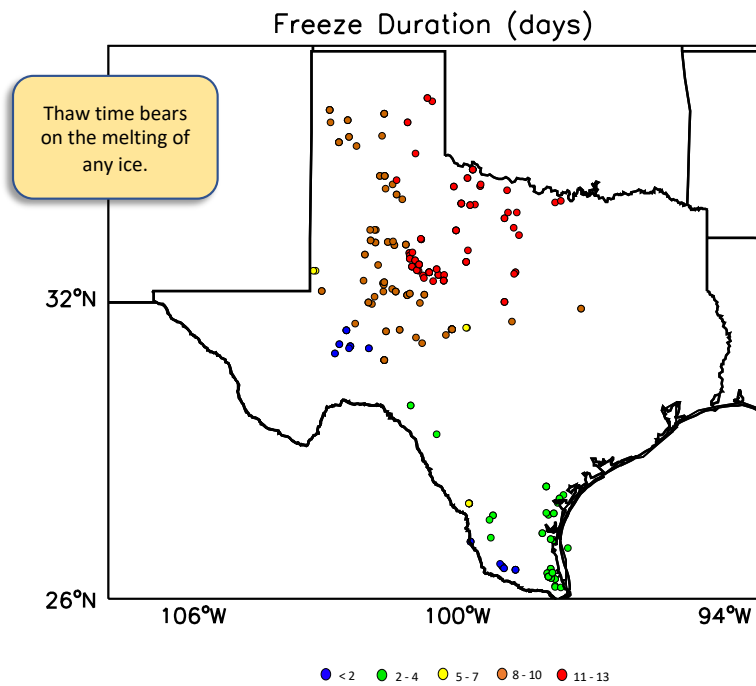


Warmer colors indicate a larger consensus of prediction

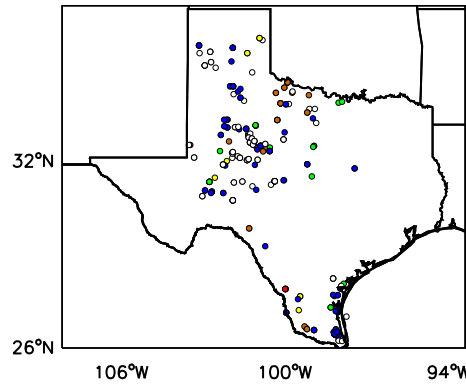
Percentage of sources predicting the event

- 0%
- <25%
- 25 - 35%
- 35-45%
- 45-65%
- > 65%

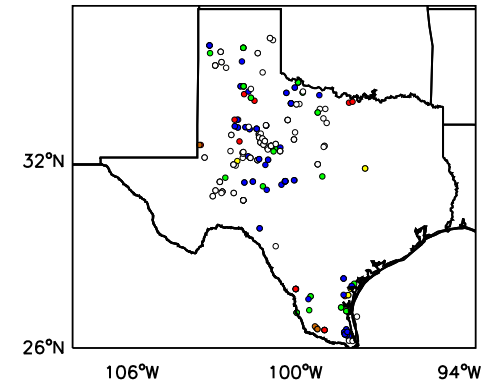
Predicting the length of the freeze, in days



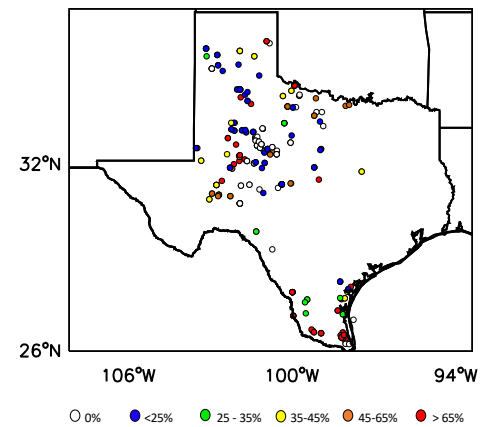
NWP Freeze Duration (days) at T-72



NWP Freeze Duration (days) at T-48



NWP Freeze Duration (days) at T-24

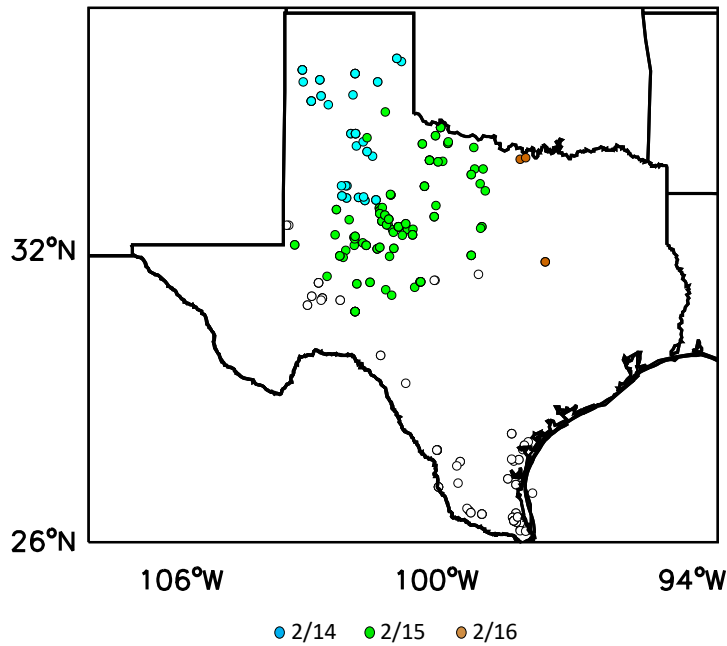


Predicting the initial thaw day is challenging – even day prior.

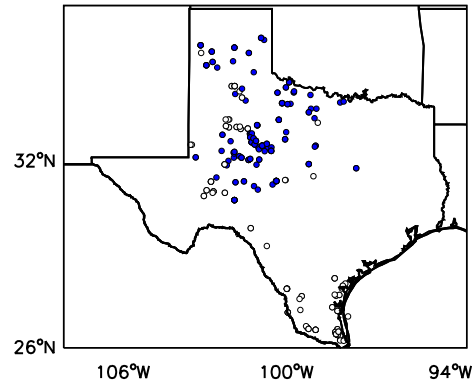
Reaching the Low Temperature Shutdown Limit ...



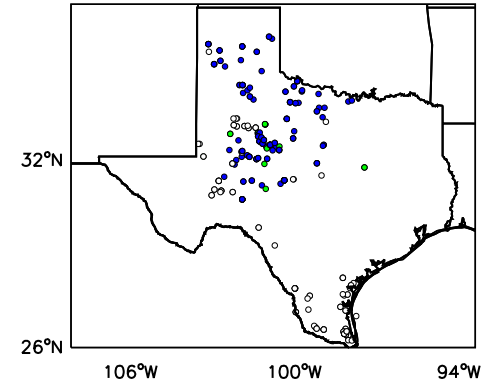
Cold Temperature Limit Reached



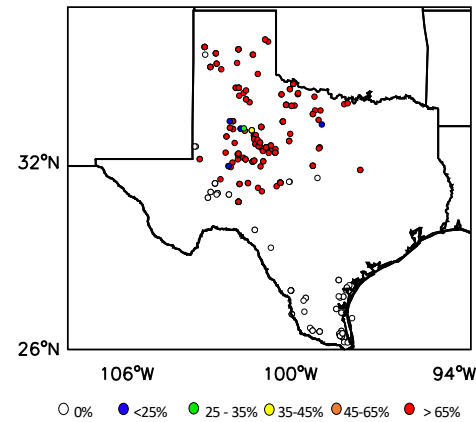
NWP Temp. Limit Reached at T-72



NWP Temp. Limit Reached at T-48



NWP Temp. Limit Reached at T-24

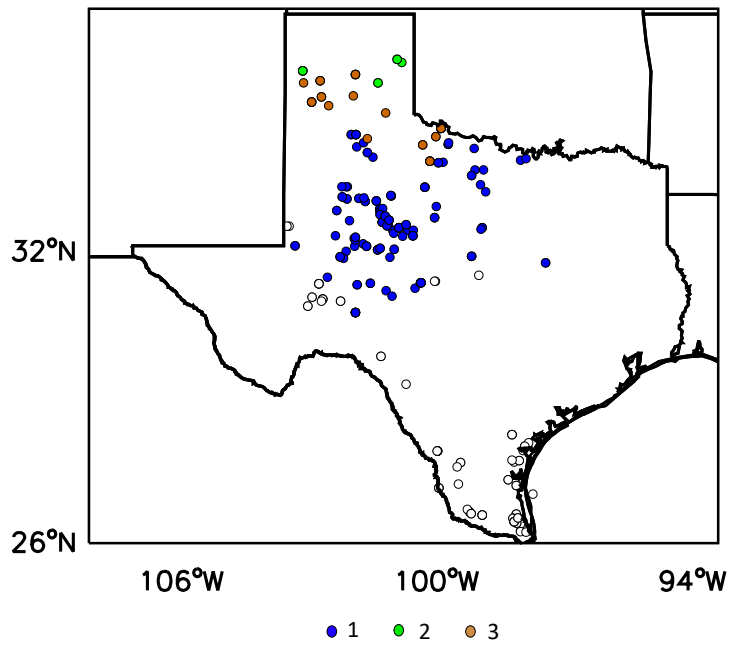


Significant increase in model consensus on this critical feature between 48 & 24 hours.

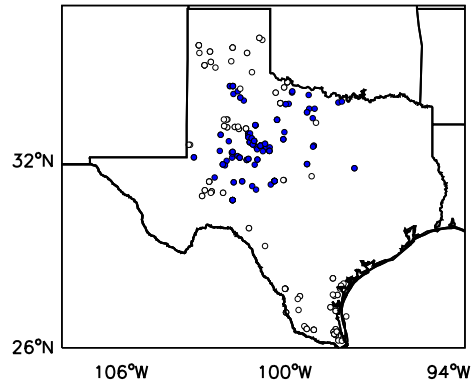
Probable Duration of Low Temperature Shutdown, in Days



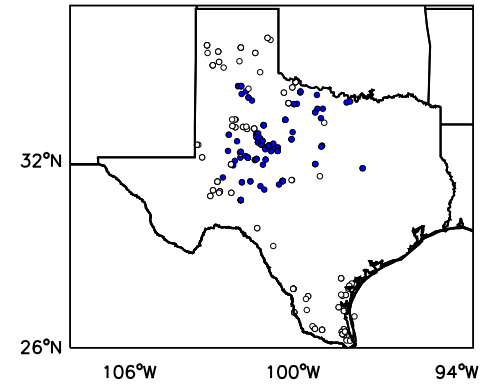
Temp. Limit Duration (days)



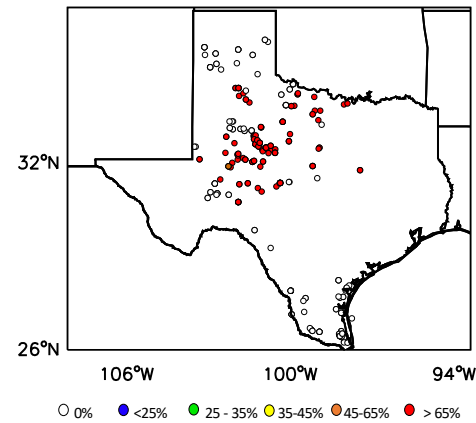
NWP Temp. Limit Duration at T-72



NWP Temp. Limit Duration at T-48



NWP Temp. Limit Duration at T-24



Similarly, large boost in model consensus on warming, between 48 & 24 hours

Multi-Model Ensemble Forecast Guidance, Direct Adjustment



Icing Predicted

Wind Power Forecast (WPF) \rightarrow 0

% of predictions below freezing

10%

WPF = WPP

30%

WPF = WPP

50%

WPF = WPP

Time since event

WPF: Wind Power Forecast
WPP: Wind Power Potential
LTL: Low Temperature Limit

Rainfall predicted

Wind Power Forecast (WPF) = WPP

% of predictions below freezing

10%

WPF \rightarrow 0

30%

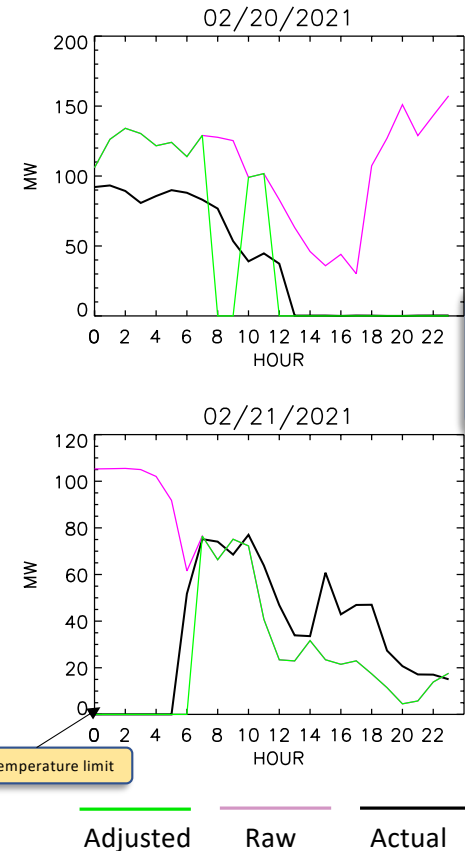
WPF \rightarrow 0

50%

WPF = WPP

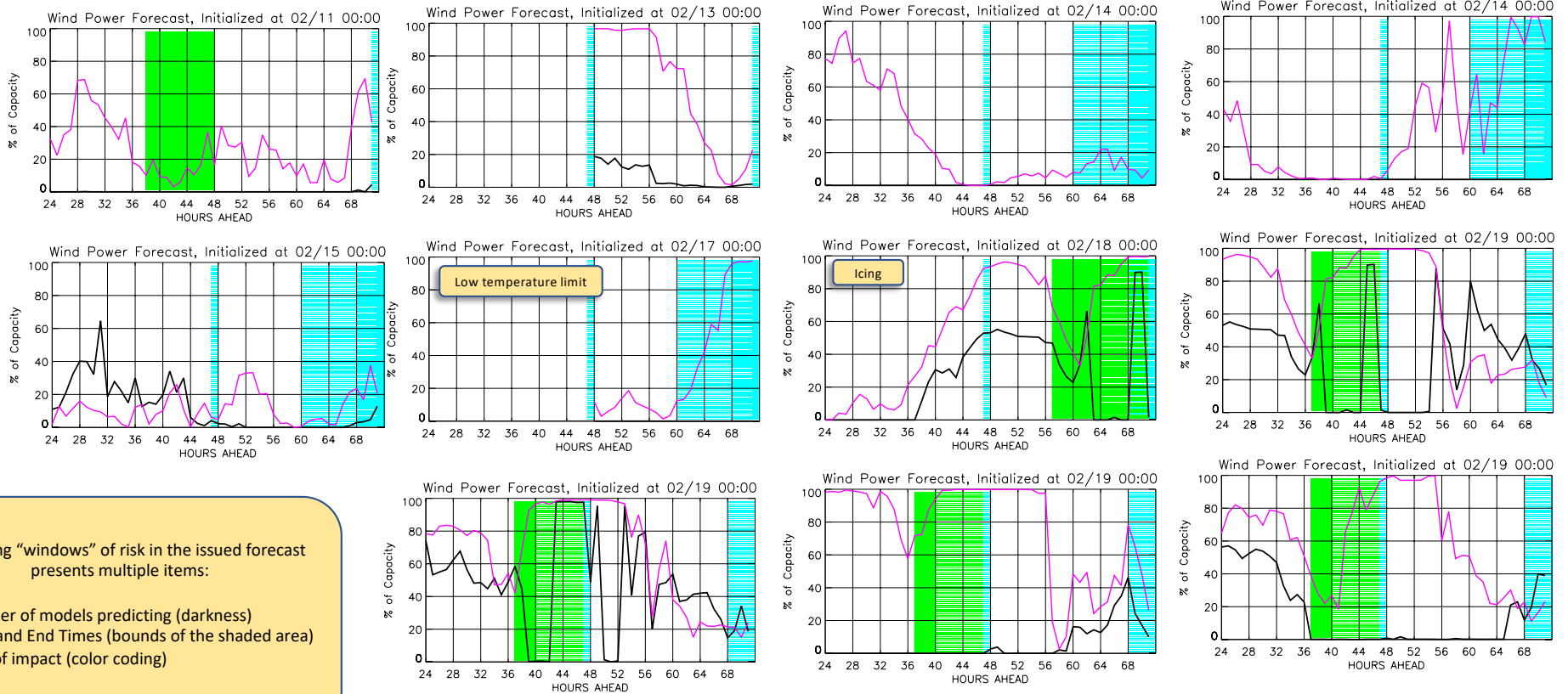
Time since event

LTL Predicted



Adjusted and unadjusted wind power forecasts for 2 projects, near end of event.

Multi-Model Ensemble Forecast Guidance, Windowing Events



Expressing “windows” of risk in the issued forecast presents multiple items:

- (a) Number of models predicting (darkness)
- (b) Start and End Times (bounds of the shaded area)
- (c) type of impact (color coding)

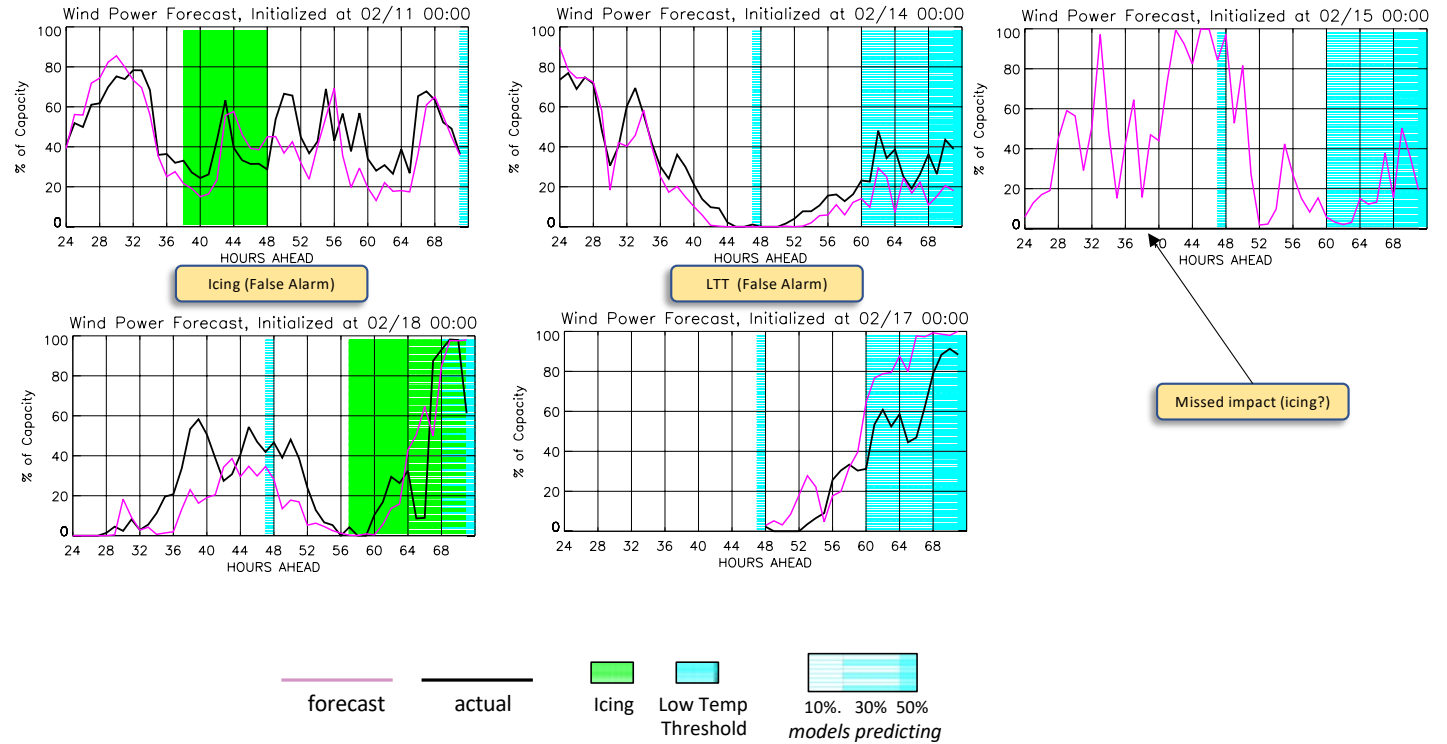


Multi-Model Ensemble Forecast Guidance, Windowing Events



False positives (and negatives) were a challenge to address for some plants.

Un-forecasted impacts can be more damaging.



Applying Multi-Model Ensemble Forecast Guidance



Direct Adjustment Success*: 2/12 – 2/22	
Day 1	51%
Day 2	46%



*Success defined as forecast error reduced for 70% of all hours in the period.

Windowed Loss Range: 2/12 – 2/22	
Day 1	0 - 56% (of all losses)
Day 2	0 - 70% (of all losses)

	Windowed Losses	Frequency
Day 1	50%	30-70%
Day 2	44%	30-70%

Days 1 & 2	
Max Windowed Losses	2/20
Max Average Total Loss	2/14, 2/20 (tied)

False Positive Range: 2/12 – 2/22	
Day 1	0 - 16% (of total gen)
Day 2	4 - 24% (of total gen)

Summary & Conclusions



- Multiple observational and assimilation based datasets compose the February Texas Event on a range of scales and provide useful forensics.
- Due to progression of various meteorological events, wind power generation losses were high but distinctly regional – with West and North zones experiencing high relative losses (highly location-dependent in the West, and nearly uniformly high in the North).
- On operational/planning time scales, weather predictions across multi-model and multi-member ensembles demonstrate fitness in prediction of key events: freezing precipitation and icing, freeze event start and duration, and low-temperature threshold timing and duration.
- Model consensus on all events was weak until T-24, where it was strong for temperature-related events.
- Icing not well predicted prior to T-24 – a significant problem.
- Two major meteorological events incurred shut-downs (icing and Low Temperature Threshold) and likely conspired with each other for some wind plants.
- Wind power prediction quality depends entirely on prediction of shutdown-induced losses. Available NWP - applied in direct adjustment approach – improved prediction on a majority of days for only 50% of plants.
- “Windowing” events in the forecast is more effective at conveying details of risk and uncertainty.
- 44-50% of losses windowed in the 1-day and 2-day ahead time frames for half of projects sampled with false positive losses of up to 16% (total 8-day generation) next day to 24% two days ahead.