How Unprecedented Was the February 2021 Texas Cold Snap?

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Human Impacts

- Electricity demand would have broken all-season record [3]
- Over 30 000 MW of lost output (mostly natural gas; see ref. [4])
- Grid within minutes of catastrophic failure (fig. 1)
- Over 100 people died [5]
- Estimated $130 billion damages [6]
- Cascading failures of water supply and other critical infrastructure
- Marginalized communities disproportionately affected [7]

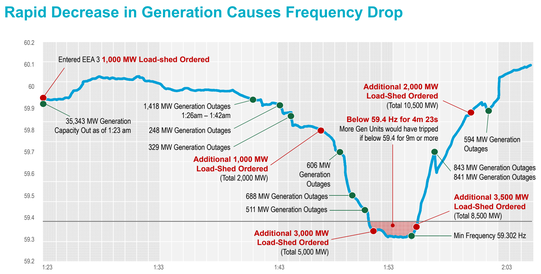

Figure 1: As demand spiked and generation failed, the Texas grid came within minutes of catastrophic failure. Figure from ERCOT [8].

Key Insights

1. Had they occurred today, the December 1989 cold snap would have caused more demand for heating than the February 2021 storm, and several other storms would have caused at least 90% as much
2. The Texas grid is designed for summer peaks, but is highly vulnerable to rare winter freezes
3. Weather at least as cold as that observed during February 2011, which formed and forms the basis for season-ahead preparation [9, 10], should be expected with probability $\approx 1/10$
4. Population growth and electrification necessitate investment in Texas's energy supply; these must consider system resilience

References

[1] J. Doss-Gollin et al. *Environmental Research Letters* (2021). [2] J. Doss-Gollin. *Research Codes for 'How Unprecedented Was the 2021 Texas Cold Snap?'* Version 1.0. 2021. [3] ERCOT. *February 2021 Extreme Cold Weather Event: Preliminary Report on Causes of Generator Outages and Derates.* Electric Reliability Council of Texas, 2021. [4] ERCOT. *Update to April 6, 2021 Preliminary Report on Causes of Generator Outages and Derates during the February 2021 Extreme Cold Weather Event.* Electric Reliability Council of Texas, 2021. [5] S. Mulcahy. *The Texas Tribune* (2021). [6] J. W. Busby et al. *Energy Research & Social Science* (2021). [7] J. Dobbins and H. Tabuchi. *The New York Times. Climate* (2021). [8] B. Magness. "Review of February 2021 Extreme Cold Weather Event". Urgent Board of Directors Meeting, ERCOT. 2021. [9] ERCOT. *Final Seasonal Assessment of Resource Adequacy for the ERCOT Region (SARA): Winter 2020/2021.* Electric Reliability Council of Texas, 2020. [10] ERCOT. *Final Seasonal Assessment of Resource Adequacy for the ERCOT Region (SARA): Winter 2021/2022.* Electric Reliability Council of Texas, 2021. [11] H. Hersbach et al. *Quarterly Journal of the Royal Meteorological Society* (2020). [12] CIESIN. *Gridded Population of the World, Version 4 (GPWv4): Population Density.* Palisades, NY: Center for International Earth Science Information Network - CIESIN - Columbia University, 2016. [13] USEIA. *Preliminary Monthly Electric Generator Inventory (Based on Form EIA-860M as a Supplement to Form EIA-860).* 2021. [14] USEIA. *North American Electric Reliability Corporation (NERC) Regions.* 2021.

Historic Cold Snaps

Visualizing temperature anomalies facilitates identification of large-scale weather patterns superimposed on long-term climatological averages. We compare the February 2021 cold snap (bottom row) to four historic cold snaps.

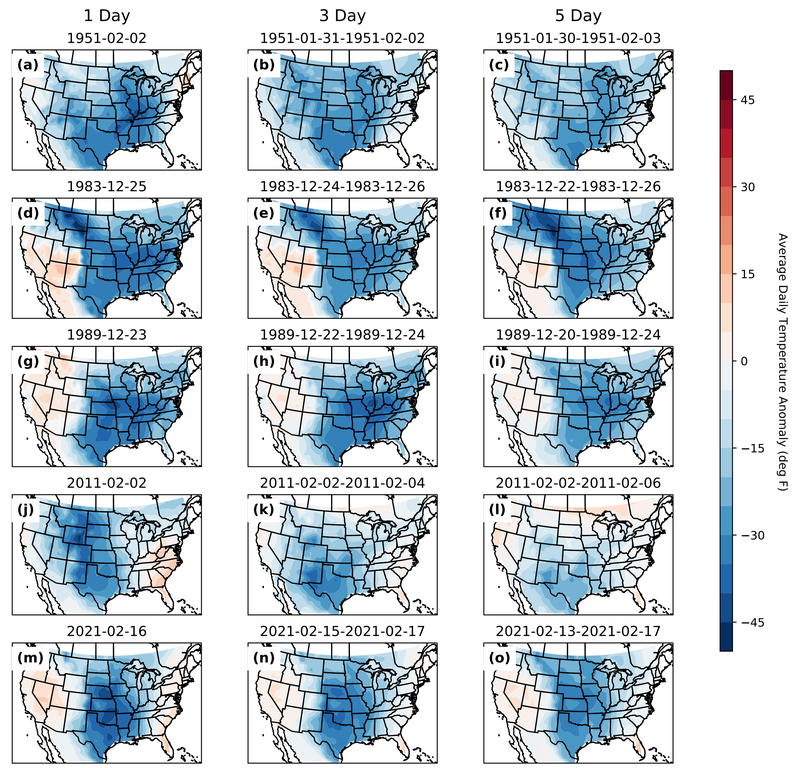

Figure 2: **Previous cold snaps demonstrate a qualitative precedent for severe cold.** Data shows anomalies of daily mean temperatures from the ERA-5 reanalysis [11].

Methods and Data

Engineers often use "heating degree days" to quantify the effect of cold temperature on people and buildings. We develop a spatially aggregated time series, which has the straightforward interpretation as the average heating demand experienced by a Texas resident, called "***inferred heating demand per capita***."

1. Gridded (0.250°) hourly temperature data from ERA-5 reanalysis [11] (validated using other datasets – see online supporting information)
2. Gridded 2020 population density from GPWv4 dataset [12]
3. For each hour t and grid cell s: calculate $\mathrm{HD}_{s,t} = \max(65\,^\circ\mathrm{F} - T_{s,t}, 0\,^\circ\mathrm{F})$
4. Average over the region served by the Texas Interconnection (fig. 4a), weighting each grid cell by population density

Finally, we compute return periods using maximum likelihood GEV models (validated using other methods – see online supporting information).

Spatially Aggregated Temperature Extremes

We analyze *inferred heating demand per capita* to understand the potential impacts of historic cold snaps if they occurred with today's population.

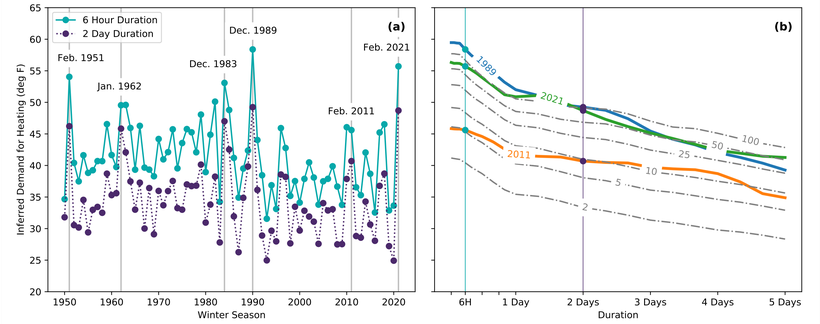

Figure 3: **The *inferred heating demand per capita* induced by the February 2021 cold snap is not unprecedented.** (a): time series of annual maximum *inferred heating demand per capita.* (b): the intensity-duration-frequency (IDF) intervals, estimated using 1950-2020 data, overlaid by annual maxima from 1989, 2011, and 2021. Each dashed line shows a single return level (2, 5, 10, 25, 50, 100 year) for *inferred heating demand per capita* averaged over a given duration (x-axis). Gray dashed lines indicate 2, 5, 10, 25, 50, and 100 year return levels.

Spatially Distributed Temperature Extremes

It is difficult for a single index to capture supply-side risk given complex interlinkages between natural gas, electric, and other systems. We thus estimate the exceedance probability of the February 2021 temperatures at each grid cell separately to shed light on the degree to which cold experienced by installations across the region was unprecedented.

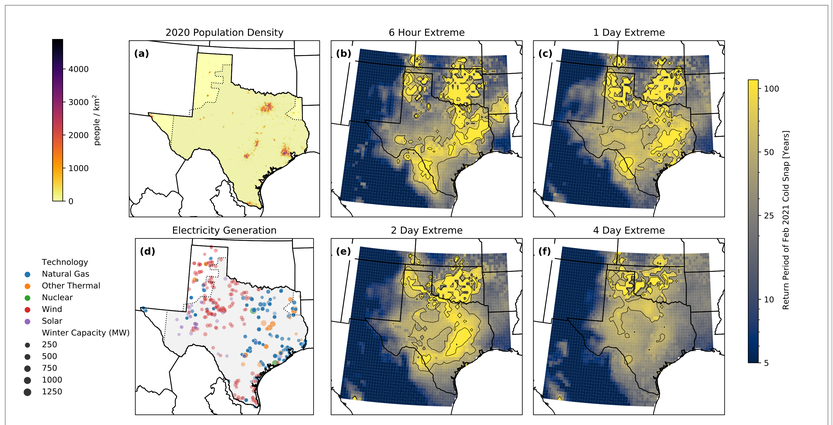

Figure 4: **Although the exceedance probability of February 2021's cold was less than 1/100 for some locations, for most it was between 1/25 and 1/50.** Return periods are calculated separately for each cell. (a): estimates of 2020 population density [12]. (d): energy generation facilities in Texas [13]. (b,c,e,f): local return periods for 6 hour, 1 day, 2 day, and 4 day durations, respectively. Contours enclose regions that recorded 50 and 100 year return levels. The gray region in panels (a) and (d) shows boundaries of the Texas Interconnection [14].

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