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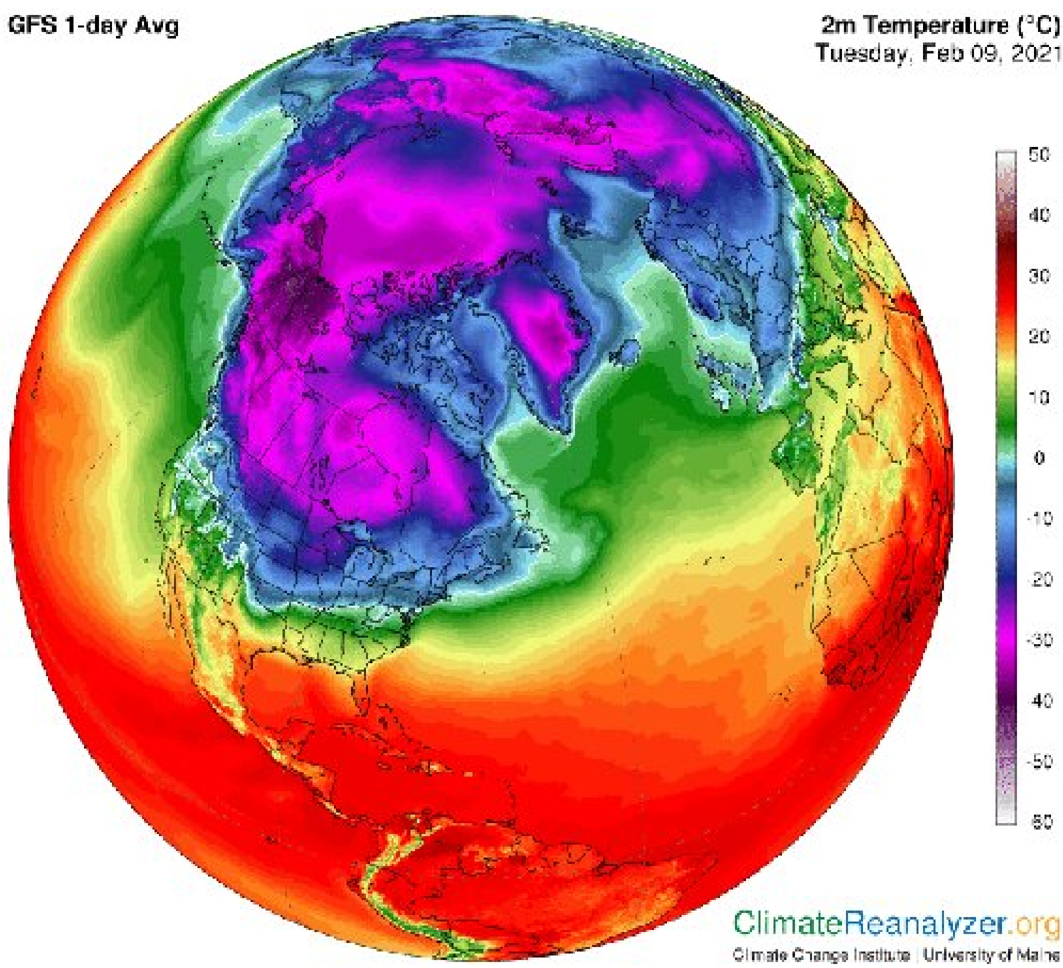
New study questions explanation for last winter's brutal U.S. cold snap

March 7 2022, by Laura Snider



Arctic air spills into the United States on Feb. 9, 2021. Credit: ClimateReanalyzer.org

A new study challenges a commonly accepted explanation that a "sudden stratospheric warming" caused the unusually cold weather over the U.S. early last year, a view which was widely reported in the media and discussed among scientists at the time.

Instead, the research finds that the spike in temperature of the normally frigid air mass locked high above the Arctic on Jan. 5, 2021—and the accompanying disruption of the polar vortex—did not significantly impact weather in the weeks that followed, including the unprecedented and brutal cold snap that gripped Texas that February.

The research findings are valuable for scientists who are working to extend weather forecasts beyond today's two-week window and who are increasingly focused on events in the stratosphere as possible sources of longer-term predictability. Sudden stratospheric warmings, for example, occur on average every other year during winter, and in the month that follows, a predictable pattern of weather tends to unfold, including cold air outbreaks in the United States. However, the mechanism that might connect the events is not well understood.

For the new study, published last week in the journal *Nature Communications*, a team of scientists led by the National Center for Atmospheric Research (NCAR) used a sophisticated Earth system model to analyze the sudden stratospheric warming that occurred on Jan. 5, 2021 and its potential impacts. Using a new method to assess causality, they found that while the subsequent weather did indeed match the expected pattern, the sudden stratospheric warming itself was not likely the cause.

"The mechanisms for how these layers of the atmosphere interact are probably more nuanced than we're giving them credit for, and that's important for making better forecast models," said NCAR scientist Nicholas Davis, who led the study. "Once you know the mechanism, you can model it better."

The research was funded by the National Science Foundation, which is NCAR's sponsor, the U.S. Department of Energy, and NOAA.

"Scrambling" the forecast

During the Northern Hemisphere winter, when the North Pole tilts away from the Sun and remains shrouded in darkness, a frigid mass of cold air forms in the stratosphere above the pole. The cold air is locked into place by a jet stream called the stratospheric polar vortex.

Occasionally, the polar vortex is disrupted by planetary-scale waves, which propagate upward from the troposphere, the lowest layer of the atmosphere. When these planetary-scale waves break, they warm the vortex, which can weaken it and cause it to be displaced or split in two—an event known as a sudden stratospheric warming. In the month afterward, it's usually warmer than normal in Canada, Alaska, and the Middle East and colder than normal over Siberia, with more frequent cold air outbreaks in Europe and the United States.

For the new study, the researchers dug into the connections between the stratosphere and troposphere using the NCAR-based Community Earth System Model version 2 (CESM2) configured with an atmospheric component called the Whole Atmosphere Community Climate Model (WACCM).

To start, the team kicked off the model using the atmospheric conditions present in both the stratosphere and the troposphere on Jan. 4, 2021, the day before the sudden stratospheric warming took place. This "standard forecast" did an excellent job of capturing the weather that actually occurred over the following four weeks.

Then the team ran three more forecasts. In one forecast, the troposphere was "scrambled," meaning the conditions in the troposphere did not match the actual weather observations from Jan. 4, 2021. In a second forecast, the stratosphere was scrambled, which removed the sudden stratospheric warming from the forecast.

The scrambling experiments showed that the initial state of the stratosphere had no impact on the weather in the two weeks after the sudden stratospheric warming, and only a minor impact nearly one month later, when the stratosphere acted to sustain the expected weather patterns. Instead, the initial state of the troposphere was the primary driver.

"I think everyone imagined that a pinball is shot up from the troposphere, hits the polar vortex, and breaks it apart," Davis said. "And then another pinball shoots back down and changes the weather. But this study shows that it's not so simple. I think it possible that the events in the troposphere and the stratosphere are feeding back on one another and reinforcing what's happening."

The Texas deep freeze

The research team also analyzed the record-breaking cold temperatures that swept across Texas and the central U.S. in mid-February 2021. Because the cold snap happened about six weeks after the sudden stratospheric warming, it was beyond the timeframe of predictability associated with that event. However, the polar vortex had not yet recovered from the sudden stratospheric warming and remained stretched, looping down over North America, a configuration often associated with cold air outbreaks in the U.S.

Scientists have posited that a disturbed polar vortex can reflect planetary waves back down into the troposphere where they can intensify weather systems and create cold air outbreaks in the United States, but whether this mechanism is at work is unclear.

The research team ran a series of simulations, as before, but this time they kicked them off using atmospheric conditions on Feb. 8, 2021, about a week prior to the onset of the extreme cold. In this case, the team found that the standard forecast did a good job of predicting the vortex stretching, the wave reflection, and the extreme cold conditions over North America. The forecast with the scrambled stratosphere, on the other hand, did not capture the wave reflection nor the full extent of the polar vortex stretching, but its temperature forecast was about the same as the standard forecast, suggesting that the vortex stretching and wave reflection did not contribute to the cold air breakout.

A better forecast

The same atmospheric elements that cause a sudden stratospheric warming—and associated distortion in the polar vortex—may also be causing the weather patterns, though the sudden stratospheric warming may be helping to sustain them over long periods. And because the emergence of a sudden stratospheric warming is predictable weeks in advance, the weather pattern that follows also remains more predictable.

The new research, however, could allow for more accurate predictions in the future, since an improved understanding of the actual mechanisms connecting the two phenomena could improve the forecast models themselves. A better understanding of the mechanisms at play could also help scientists evaluate how the changing climate could amplify or dampen the connections between the troposphere and the stratosphere.

The study is also valuable because of the "scrambling" technique it demonstrates, Davis said. This technique allows the "scrambled" component of the model to drift for a week leading up to the date that the actual forecast is started on, while the "unscrambled" components are nudged to align with observations during the same time. This new ability to experimentally separate out resolved components of the Earth system, while also keeping the whole system physically consistent, could allow scientists to undertake an array of attribution studies to look at causal relationships in the atmosphere and larger Earth system.

"This forecast model set-up and approach will allow us to answer some urgent questions about attribution—what is really the underlying cause of weather and climate events—in nearly real time," Davis said. "If we have a hypothesis about what the mechanism for an event is, this technique can provide us with a more direct answer."

More information: N. A. Davis et al, Limited surface impacts of the January 2021 sudden stratospheric warming, *Nature Communications* (2022). DOI: 10.1038/s41467-022-28836-1

Provided by National Center for Atmospheric Research