Horizontal winds become major movers of carbon dioxide during cold fronts

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What happens to atmospheric carbon dioxide when low-pressure systems move in has largely remained a mystery, but Penn State-led research is offering new insights that may help improve global carbon models. Credit: Sean Waugh, NOAA/NSSL

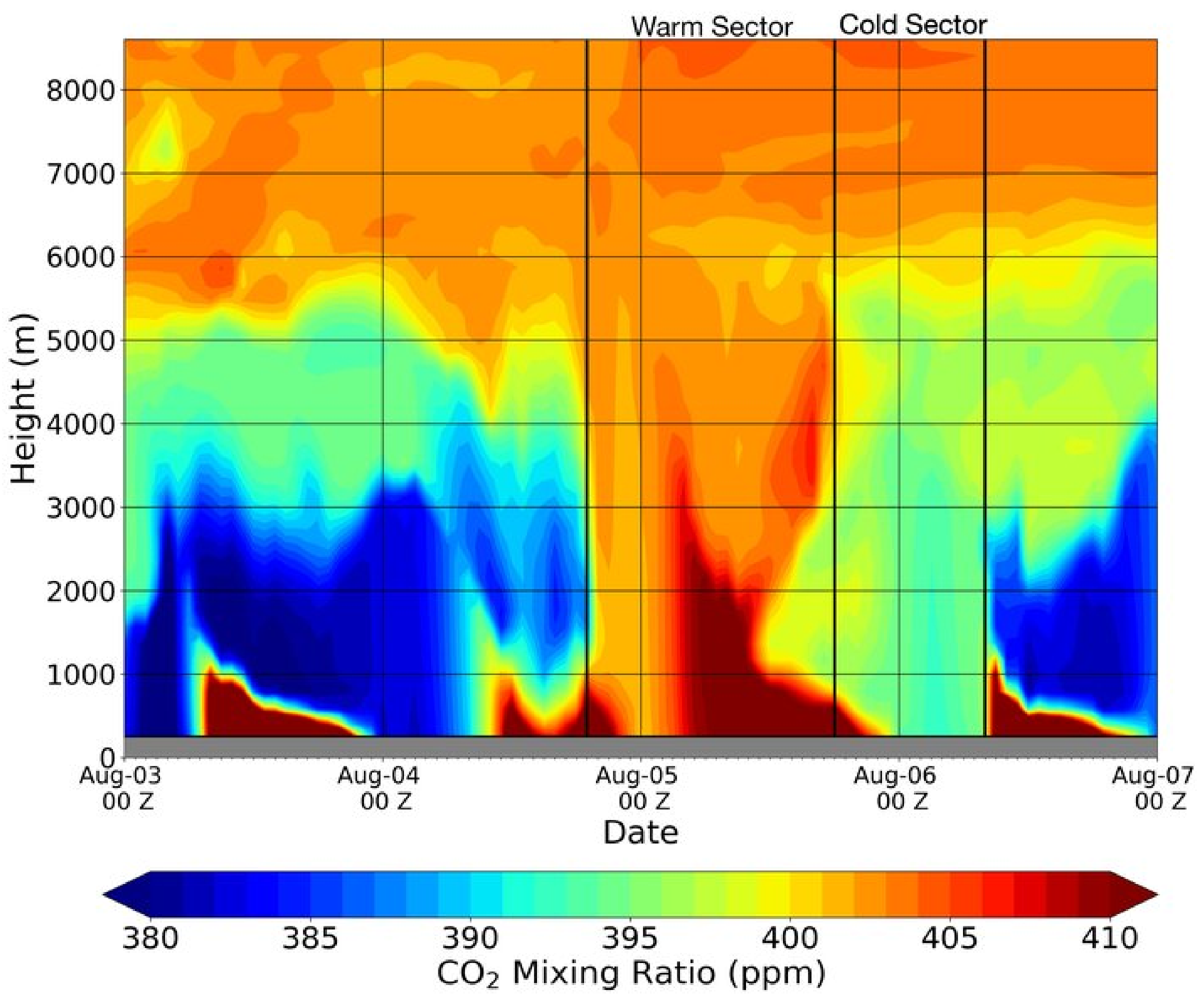
Trees, crops and other vegetation in the midwestern United States act as large carbon sinks during summer, taking in carbon dioxide (CO_2) and limiting the amount of the greenhouse gas that enters the atmosphere. What happens to carbon dioxide when a cold front moves in has largely remained a mystery, but Penn State-led research is offering new insights that may help improve global carbon models.

"The focus of this research is to understand and quantify how low-pressure systems transport carbon dioxide in the atmosphere," said Ken Davis, professor of atmospheric and climate science at Penn State. "This is part of a bigger effort, the Atmospheric Carbon and Transport-America (ACT-America) project, to learn how to interpret measurements of carbon dioxide in the atmosphere to properly infer sources and sinks of carbon dioxide at the earth surface. To do this, we need to know how carbon dioxide is mixed by the atmosphere, and there has not been much past focus on how low-pressure systems slosh around this greenhouse gas."

Most models that deal with atmospheric carbon tend to focus on global rather than regional trends, he added, and may not properly represent the changes in atmospheric carbon dioxide that occur during these systems.

To better understand the phenomenon, the researchers studied carbon dioxide levels over Lincoln, Nebraska, before, during and after a cold front that passed through the area in August 2016. Cold fronts occur when a cold air mass pushes into a warmer air mass, and they can cause thunderstorms to form and temperatures to drop dramatically. The research team took measurements from two airplanes. The aircraft crossed the system's frontal boundary—where the warm and cold air masses meet—multiple times. They also flew at multiple altitudes, between approximately 1,000 and 26,000 feet, and recorded the changes in carbon dioxide levels in the warm and cold sectors of the system.

The scientists entered the data into a computer model that looked at carbon dioxide levels at three different resolutions. The resolutions ranged from being nine to 1,600 times higher areal resolution than what is used in global models, giving the researchers a more precise look at what happens to carbon dioxide as the system passes. They also focused on three categories of carbon dioxide sources and sinks—biogenic fluxes, or carbon dioxide taken in and respired by plants, bacteria and animals, including humans; fossil fuel sources like cars and factories; and boundary fluxes, or in this case sources and sinks of carbon dioxide beyond the North American continent. They reported their findings in the May issue of *JGR Atmospheres*.



Researchers studied CO_2 levels over Lincoln, Nebraska, in the days before, during and after a cold front that passed through the area in August 2016 to see how frontal systems affect atmospheric CO_2 levels. Amounts of CO_2, measured in parts per million, are depicted at different altitudes over a five-day period, with blue and green colors signifying lower levels and orange and red colors signifying higher levels of the greenhouse gas. Credit: Arkayan Samaddar, Penn State

"We found a huge band of carbon dioxide trapped around the frontal system," said Arkayan Samaddar, a doctoral candidate in the Department of Meteorology and Atmospheric Science at Penn State. The study is part of Samaddar's doctoral dissertation. "By analyzing it at such a high resolution, we see that it's not just one uniform band of carbon dioxide. We see a lot more structure and get more information than we would if we looked at it globally. Looking at carbon dioxide on a regional scale helps us better determine sources and sinks."

The researchers found that during this summer front, biological sources and sinks accounted for the largest changes in atmospheric carbon dioxide, which isn't surprising since plants, animals and humans continually take in and respire carbon dioxide and biological activity peaks in the summer, according to Davis.

"With plants you can't readily tell the difference between photosynthesis, when they take in carbon dioxide, and respiration, when they release it. Atmospheric carbon dioxide responds to the net exchange," Davis said.

The difference between the biogenic and fossil fuel categories, Davis added, is that the former category acts as both a source and a major sink that helps to mitigate fossil fuel emissions, whereas the fossil fuel category is a continuous source of carbon dioxide.

The scientists noted that the sources and sinks created a consistent pattern of carbon dioxide in the atmosphere. At night, carbon dioxide levels near the earth surface spiked to more than 410 parts per million before falling to 380 parts per million during the day due to photosynthesis by plants. Levels of the gas in the atmospheric boundary layer, which is the lowest part of the atmosphere and can extend to an altitude of approximately 16,400 feet, remained relatively consistent, ranging from 380 parts per million in the lower part of the boundary layer to roughly 395 parts per million in the upper layers. Levels of carbon dioxide above the atmospheric boundary layer, up to an altitude of approximately 28,000 feet, ranged from 400 to 405 parts per million.

The researchers found that when the frontal system moved in, horizontal winds disrupted this pattern and stirred up the atmosphere, moving carbon dioxide into the upper atmosphere.

"When the warm sector of the front passes, we see this almost constant field of higher carbon dioxide that extends from the earth surface all the way up to 28,000 feet," Samaddar said. "We've never seen this before."

The scientists think the high carbon dioxide in the warm sector came from ecosystems in the Gulf Coast region. Ecosystems there may have been respiring more than they photosynthesized when the data were collected, while crops and forests in the U.S. Midwest and Canada appear to have been net sinks of carbon dioxide, said Davis.

The warm sector is immediately followed by the cold sector, which is a cold air mass with lower carbon dioxide levels that comes from Canada. The cold sector lowers carbon dioxide levels in the atmospheric boundary layer all the way to the earth surface, and then the regular pattern of carbon dioxide kicks back in, said Samaddar.

"This information is useful not only for scientists trying to figure out carbon dioxide sources and sinks, but also for modelers to see if the movement of carbon dioxide in their global carbon models is correct," he said.

The researchers are now trying to measure how much carbon dioxide gets pushed into the upper atmosphere by these frontal systems.

More information: Arkayan Samaddar et al, Carbon Dioxide Distribution, Origins, and Transport Along a Frontal Boundary During Summer in Mid-Latitudes, *Journal of Geophysical Research: Atmospheres* (2021). DOI: 10.1029/2020JD033118

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