On the trail of contrails

"The contrails are trapping more heat in the atmosphere."

Douglas Spangenberg
NASA

by Laura Naranjo

Most people have, at some point in their lives, lain on their backs and gazed up at the sky, scouting for clouds that look like puppies or leaping dolphins. Scientists Sarah Bedka and Douglas Spangenberg scan the skies for thin white lines that could be contrails. Contrails are the linear clouds etched across the skies by high-altitude airplanes as more than 90,000 flights per day crisscross the globe.

Whether natural or man-made, clouds can help warm or cool Earth: they reflect incoming sunlight and trap heat in the atmosphere. But until recently, scientists were uncertain how contrails

Contrails, or condensation trails, form when water vapor from airline exhaust condenses and freezes, forming clouds made of ice crystals. Scientists study contrails because, like naturally occurring clouds, they may contribute to a warming or cooling effect in Earth's atmosphere. (Courtesy J. Thomissen) contributed to each of these effects. Bedka and Spangenberg are trying to find out how much contrails warm the atmosphere, and possibly to mitigate their effects. They helped develop a method that harnessed satellite data to spot contrails and calculate how much warming they might cause. Contrails likely have a small effect now, but increasing air traffic may change that.

A trail of cloud

While it is easy to imagine that contrails are just dirty streams of pollutants billowing out of airplanes as they cross the sky, in reality they are mostly ice crystals. Water vapor is already present in the atmosphere, but when the extra vapor from the airplane exhaust rapidly saturates already moist air, the water condenses and freezes into minute ice crystals. In fact, the word contrail is short for "condensation trail."

On top of that, most commercial jets cruise at 26,000 feet or higher, where temperatures are cold enough that the large volumes of condensed vapor instantly freeze and form visible contrail clouds. Spangenberg said, "That's why contrails form at the high altitudes where the jet liners fly. Lower altitude aircraft are not going to create them because the temperature is not low enough." In very humid conditions, some aircraft may also produce wingtip vortices, or contrails that spiral out behind each wing. Low-flying planes at airshows often generate what look like contrails, but are simply special effects created by smoke.

High in the atmosphere, clouds perform a dual role. White cloud tops act like mirrors, reflecting incoming sunlight back out into space and promoting a cooling effect. Clouds can also

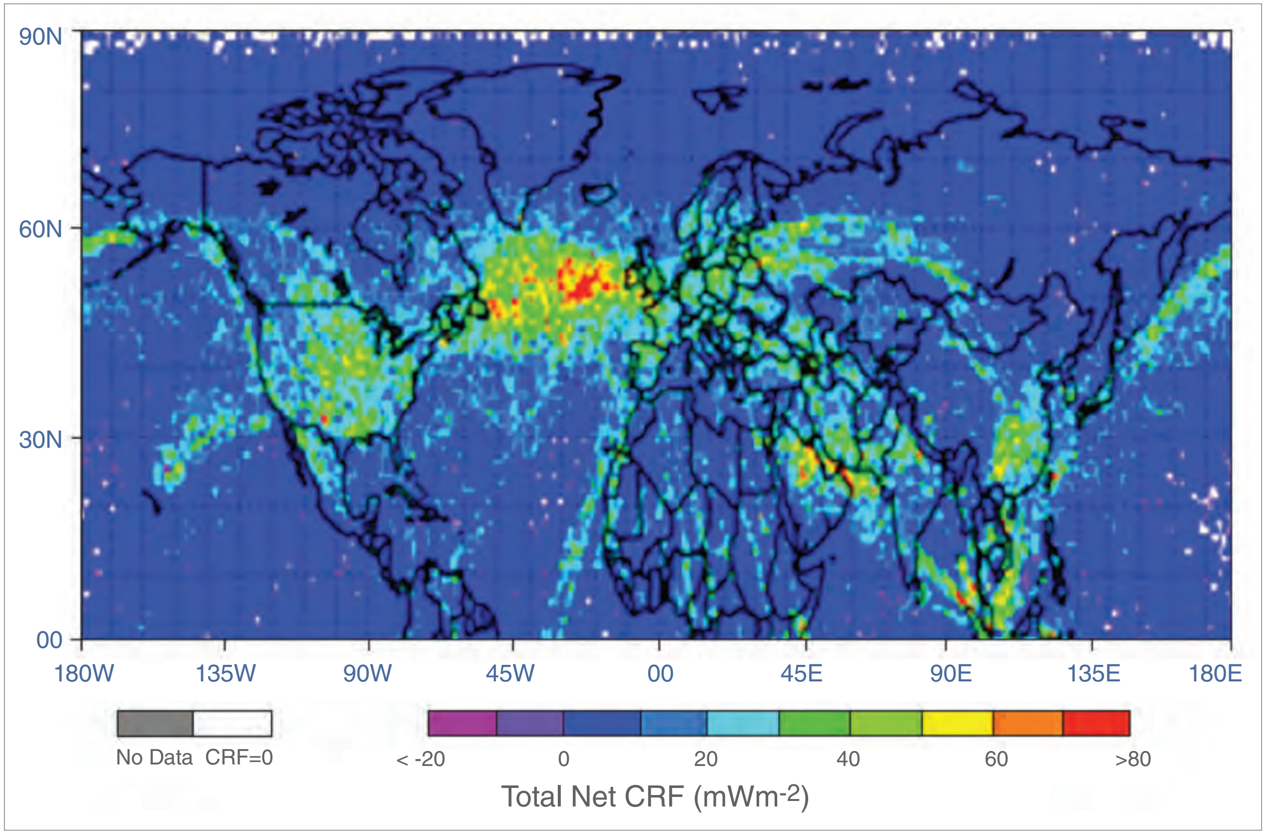
The image on the left shows the sky above Würzburg, Germany, without contrails after air traffic was temporarily grounded in 2010. The image on the right shows the sky with regular air traffic on a day when conditions were right for contrails to form. (Courtesy M. Wegmann)

serve as a blanket, trapping heat emitted from Earth's surface, inducing a warming effect. The researchers needed to analyze both to understand whether contrails have a warming or cooling effect in Earth's atmosphere, what they call the net radiative effect.

Masking the spread

To figure out whether contrails contribute more to cooling or to warming, the scientists first needed to isolate contrails from other clouds. But contrails are tricky to identify because they do not always maintain a neat, linear formation that makes them easy to detect. On one hand, contrails must be large enough and persist long enough to be seen in satellite data. Spangenberg said, "Satellites won't be able to see the contrail until it's about one kilometer wide, which is the size of the image pixels." On the other hand, if contrails spread out too much or even merge, they start to mimic the broad layers of cirrus clouds that often occur naturally high in the atmosphere.

So Bedka and Spangenberg, along with their colleague at Science Systems and Applications Incorporated, David Duda, and Patrick Minnis at NASA Langley Research Center, needed to focus



This image shows radiative forcing from contrails (CRF) during January, April, July, and October 2006 from Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) data. Flight corridors over the north Atlantic, north Pacific, southwest Asia, and eastern Europe and Russia stand out remarkably well. (Courtesy D. Spangenberg, 2013, *Geophysical Research Letters*)

on specific contrails. They decided to include only contrails that persisted long enough to be visible in satellite data, yet maintained a linear shape. "It allowed us to apply an automated algorithm to detect those types of contrails," Bedka said. To find contrails, they analyzed satellite data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the NASA Aqua satellite. After running the contrail detection algorithm, the results were matched to known flight paths. This allowed the researchers to find approximately 190 million pixels from linear contrails that they were searching for.

MODIS data also helped the researchers weed out other things on Earth's surface that look linear. Previous studies had produced false alarms, erroneously identifying a variety of features as contrails. "A lot of linear features aren't contrails, like coastlines, rivers, ship tracks, and all kinds of other things," Bedka said, "So we used additional information from the other MODIS bands to help filter those out."

Airplanes and the atmosphere

The researchers found that contrails have an overall warming effect, acting like a light blanket. "The contrails are trapping more heat in the atmosphere compared to cooling from reflected sunlight," Spangenberg said. However, Bedka and Spangenberg said that the effect is still quite small. "When you consider all of the man-made radiative forcing and all the changes we're making that can affect climate, contrails are one of the smaller effects, compared to carbon dioxide and other emissions," Spangenberg said. "Globally, you would have to increase the contrail effect by roughly 100 times to get the same effect as all of the anthropogenic carbon dioxide in the atmosphere."

They also found that the environment in which the contrails occurred, such as other clouds in the atmosphere or Earth's surface itself, influenced a contrail's net radiative effect. "If planes fly through or over cirrus clouds that already exist naturally, you would minimize the radiative forcing from the contrails," Spangenberg said. Likewise, if contrails form in otherwise clear skies over a hot desert, or over warm low clouds, they will have a much greater radiative effect.

Yet while contrails may not increase atmospheric warming much on a global basis, the researchers discovered that contrails produced more significant regional warming. For instance, over the United States alone, more than 5,000 aircraft may be in the air at once. Many of these flights route through the large East Coast hubs, and generate a mesh of contrails that waft across the skies toward Europe. "We found that the North Atlantic tends to experience the greatest warming effect," Spangenberg said. "That's right along the corridors where planes are flying across the ocean." Another contrail hot spot includes central Europe, which also experiences heavy air traffic.

Bedka and Spangenberg caution that because they focused only on linear contrails, their results underestimate the total contrail effect on Earth's atmosphere. Spangenberg said, "We suspect there's at least a factor of three increase if we include the other types of contrails in our results, and their warming effect." Consequently, they are already conducting new studies that will include not just linear contrails but those that spread over time and become what are called contrail cirrus. "You really have to look at the evolution over time," Bedka said. "Because if the conditions in the atmosphere are right, contrails that start out linear can spread and merge with each other until they become large, relatively uniform areas of ice cloud."

And even though their research supplied a low estimate, it is still the first study that firmly quantifies the contrail effect using satellite data. "That's the unique part of it, that it's an observation-based approach," Spangenberg said. "Most of the other studies of contrails have been modeling-based approaches." Climate modelers finally have a specific set of results to help refine their estimates of contrail effects on the atmosphere. Likewise, researchers now have a basis to investigate the cloud forms that contrails may evolve into, and how that evolution contributes to warming or cooling in Earth's atmosphere. "With increasing air traffic, the effect of contrails has the potential to increase," he said.

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About the remote sensing data used

Satellite	Aqua
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data set	MODIS/Aqua Calibrated Radiances 5-Min L1B Swath 1km
Resolution	1 kilometer
Parameter	Clouds
Data center	NASA MODIS Level 1 and Atmosphere Archive and Distribution System (MODAPS LAADS)

About the scientists

Sarah Bedka is a senior research scientist at Science Systems and Applications, Incorporated (SSAI). She studies infrared satellite data to better understand cloud micro-physical and macro-physical properties, including optically thin cirrus clouds and contrails, clouds over snow-covered surfaces, and cloud retrievals at night. The Aviation Climate Change Research Initiative (ACCRI) and the Department of Transportation (DOT) supported her research. (Photograph courtesy S. Bedka)

Douglas Spangenberg is a research scientist at SSAI. He develops software to display and analyze satellite data and validates satellite retrievals of cloud properties. He also studies ice buildup on aircraft flying though clouds and the cloud radiative forcing of jet contrails. The Aviation Climate Change Research Initiative (ACCRI) and the DOT supported his research. (Photograph courtesy D. Spangenberg)

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For more information

NASA MODIS Level 1 and Atmosphere Archive and Distribution System (MODAPS LAADS)
http://laadsweb.nascom.nasa.gov

Moderate Resolution Imaging Spectroradiometer (MODIS)
http://modis.gsfc.nasa.gov

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