Mercury raining

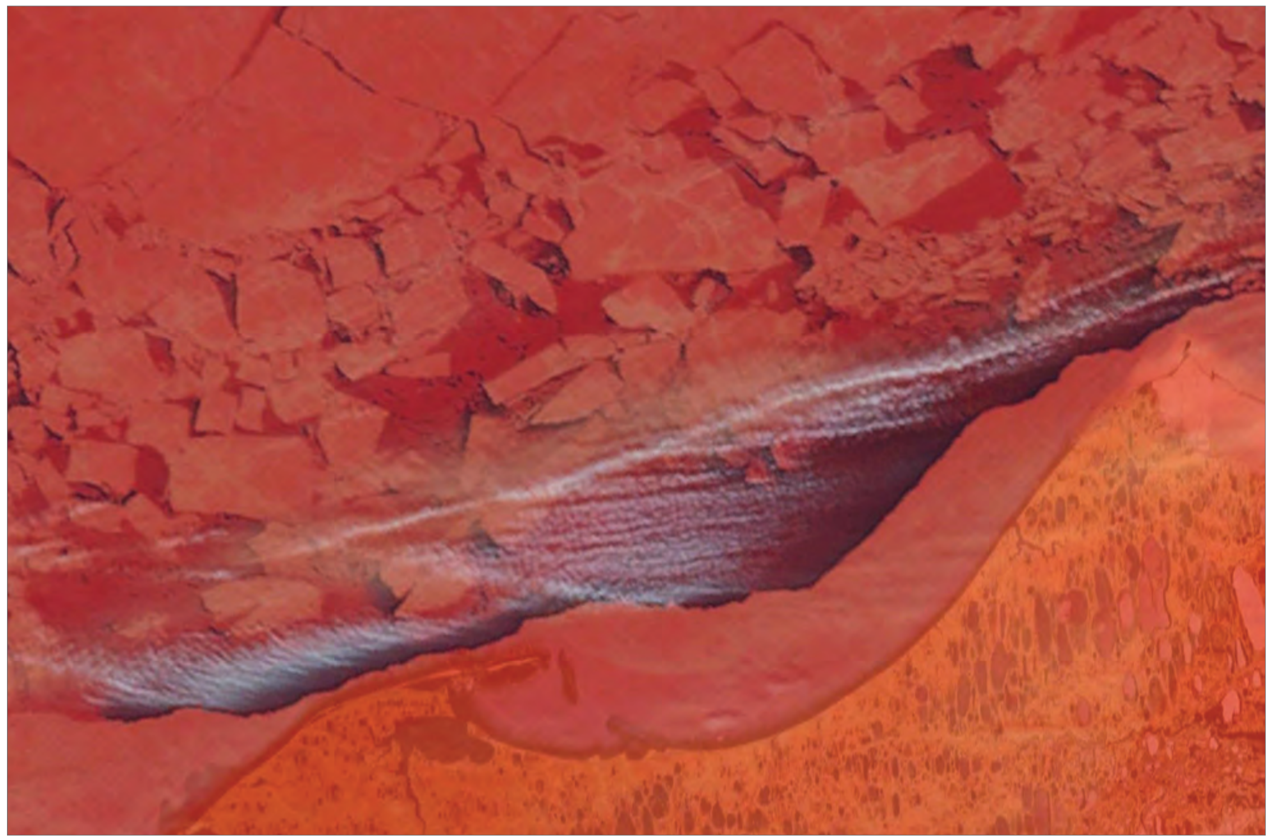
"If I told someone in a bar about this, they'd think I was crazy. You can't see it without these instruments and satellites, but it's there."

Matthew Sturm
University of Alaska Fairbanks

by Karla LeFevre

Air Force pilots flying over the Arctic in the 1950s first noticed a brown haze and wondered "What the heck is that?" said researcher Paul Shepson. It turns out an element called bromine was partly to blame for the dirty hue. Today atmospheric chemists like Shepson know it is actually part of the Arctic atmosphere doing its own spring cleaning. "Mother Nature got a really good idea," he said.

Every March in the Arctic, the atmosphere follows a certain cleaning regimen: combine upwelling bromine, plenty of cold air, and spring sunlight. When these ingredients mix,



This false-color satellite image shows sea ice in the Chukchi and Beaufort seas (red) near Barrow, Alaska. Dark areas indicate cracks, or leads, in the sea ice while gray streaks show vapor plumes upwelling from the leads. Red-orange shades indicate snow cover. The image was created with data acquired by the Terra MODIS satellite on March 24, 2012. (Courtesy NASA, Nghiem, et al. 2013) a chemical chain reaction ensues, and scrubs pollution out of the air. Scientists call this reaction a bromine explosion. The result? The atmosphere is much cleaner, but there is a catch. The cleaning process works so well that it causes a gaseous form of mercury to fall out of the sky.

So what happens to all that mercury? Does it get released back to the atmosphere, or does it stick around? That question led Shepson and colleagues to understand more about bromine explosions as the Arctic continues to warm and change.

In search of salt

Barrow, Alaska is an ideal place to get a closer look at bromine explosions. At the northernmost tip of the U.S., this small town looks like an arrow pointing toward the Arctic Ocean. To the left and right are the Chukchi and Beaufort seas. In several ways, this makes Barrow a salty place, and sea salt contains bromine.

Frost flowers also contain it. These delicate, crystalline structures sprout on top of fresh sea ice when the air is calm and colder than the ice below. As if by magic, sea salt is pulled to the surface of the ice and forms a tiny root-like opening. Saturated water vapor then threads more salt up the opening into the freezing air until it builds on itself, eventually appearing as frost in full bloom. “Scientists are human like everyone else, and we’re attracted to bright, shiny things,” explained Shepson. But the flowers are more than beautiful. Frost flowers contain about three times as much salt as any other type of frost or surface, and possibly a lot of bromine.

Another potent source of bromine, they reasoned, might be the fresh sea ice. When ocean water freezes, salt accumulates into droplets called brine that can get trapped in watery pockets between ice crystals. If the ice is frozen long enough, say one to ten years, the brine eventually drains out. So an ideal place to measure bromine was over both new and old sea ice, over salty conditions and not-so-salty conditions. Huge cracks in the sea ice, called leads, were just the place.

One of local fame is the Barrow Lead. The Inupiaq people stand at the edge of this wide “whale road” every spring to hunt bowhead whales. Subsistence whale hunters like the Inupiaq can normally walk right from the shore on sturdy landfast ice, the ice attached to land, and set up their camps on heavy multiyear ice. But as recently as spring 2013, scientists at the University of Alaska Fairbanks reported finding zero multiyear ice in the Beaufort Sea. As Arctic sea ice conditions continue to change, scientists are grappling with how these changes will shape future conditions. Shepson said, “If we sample the air above all these surfaces that represent the old world, like the multiyear ice, and above lots of fresh, new ice like we have now, and over what represents the future—meaning open water—we can predict how climate change will impact the Arctic’s ability to clean itself.”

Son Nghiem, lead scientist for the bromine investigation, wondered if such change has led to more bromine explosions, and possibly more mercury ending up on the land or ocean. On the other hand, since bromine reactions require frigid temperatures, they might eventually stop altogether with a warmer Arctic. There was also the mercury. Does it change back into a gas and return to the atmosphere, or does it wind up in the food chain?

A field of frost flowers in full bloom catches the springtime sunlight. These freshwater frost flowers are similar in appearance to their salty, arctic counterparts. (Courtesy B. Berwyn/Summit County Citizens Voice)

Searching high and low

These complex questions called for a complex approach. Nghiem said, “From the ground, to the air, to space, we measured it all.” Nearly thirty researchers conducted the Bromine, Ozone, and Mercury Experiment, or BROMEX, in spring 2012. They used half a dozen satellites to gather data over Barrow and the Chukchi and Beaufort seas for bromine, mercury, and other atmospheric markers like ozone. With an eye out for polar bears, they also set up instruments at field sites and combed the area for snow, ocean, and air samples.

Other measurements were riskier to gather. They needed to place instruments in the Barrow Lead just before the spring melt began breaking up the ice. Physical scientist Matthew Sturm knew the challenges firsthand from his days with the U.S. Coast Guard and U.S. Army. “It’s sort of like the winter world you’re used to,” he said, “except it’s things breaking up, and sliding around, and

From left to right, researchers Bill Simpson, Matthew Sturm, and Carl Kippe venture out into an open sea ice lead to collect water samples and measure upwelling vapor for its bromine content. (Courtesy D. Perovich/Cold Regions Research and Engineering Laboratory)

getting crunched up." His task was to somehow get two instrument-laden buoys to hitch a ride on chunks of ice as they floated down either side of the lead. "The goal was to put each instrument out far enough to see the bromine explosions, but not so far so that it couldn't talk back to us, and not so far that it would get swept away," he said. Adding to the challenge was the small window they would have. It had taken the team months to design and outfit the expensive instruments, but they would have just a few minutes to deploy them from a helicopter. Nghiem said, "Matthew knows Alaska like the back of his hand. It worked perfectly, and that is tremendous."

They also needed to gather air samples over remote areas with small aircraft. Fortunately, atmospheric chemist Shepson was also a skilled pilot. Spotting frost flowers during one flight, he banked to fly downwind from them for the best bromine measurements, always mindful of where to land his small plane in case of engine failure. "It's incredibly beautiful up there," he said. "Sometimes scary though. We flew over pretty unpopulated areas. Really unpopulated areas."

Unexpected leads

As the researchers suspected, the data confirmed that more bromine explosions are occurring now than at any other time in the past twenty years—but not near frost flowers. "We were looking for a smoking gun," said Bill Simpson, a chemist at the University of Alaska Fairbanks. "We were expecting to see a huge amount of bromine coming from them, but it just wasn't there." Instead, it was the air above the tundra slightly inland that was steeped in bromine.

Simpson and his colleagues believe snow might be a factor in at least two ways. First, blowing snow carries sea salt from the top of the ice further inland than it otherwise might travel. Once on land, the snow blows across the surface and piles up in drifts. In this way, a small volume of salt gets spread over large distances, effectively covering the surface.

Samples also revealed that the snow cover is more acidic than other surfaces. And that acidity helps initiate the reaction by chemically unlocking the bromide in the salt, which is bromine in its nonreactive form, and releasing it to the atmosphere where it becomes reactive. "It's an amazing, invisible process," Sturm said. "If I told someone in a bar about this, they'd think I was crazy. You can't see it without these instruments and satellites, but it's there."

Whatever role snow plays, however, remains to be solved in the next round of studies. But the

Scientist Ignatius Rigor lies at the edge of a frozen sea ice lead to photograph frost flowers. In the background, a vapor plume can be seen along the horizon as it wafts up from an open crack further down the lead. (Courtesy C. Linder/chrislinder.com)

About the remote sensing data used

Satellites	Terra	Terra, Aqua	Aura	Quick Scatterometer (QuikSCAT)	Defense Meteorological Satellite Program (DMSP) F17	Aqua
Sensors	Moderate Resolution Imaging Spectroradiometer (MODIS)	MODIS	Ozone Monitoring Instrument (OMI)	SeaWinds	Special Sensor Microwave Imager/ Sounder (SSMIS)	Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E)
Data sets	MODIS Level 2 Aerosol	MODIS Level-3 Sea Ice Extent, and Ice Surface Temperature	OMI Level 3 Backscatter	QuikSCAT Ku-band Backscatter	Near-Real-Time Brightness Temperatures	AMSR-E/Aqua Brightness Temperatures, Sea Ice Concentration, & Snow Depth
Resolution	10 kilometer	4 kilometer	725 kilometer	25 kilometer	25 kilometer	6.25–25 kilometer
Parameters	Aerosol optical depth	Sea ice extent, sea ice surface temperature	Bromine, aerosol optical depth	Sea ice extent, sea ice class distribution, melt on sea ice	Brightness temperatures	Brightness temperatures, sea ice concentration, snow depth
Data centers	NASA MODIS Level 1 and Atmosphere Archive and Distribution System (MODAPS LAADS)	NASA Land Atmosphere Near-real-time Capability for EOS (LANCE)	NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)	NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC)	NASA National Snow and Ice Data Center (NSIDC) DAAC	NASA NSIDC DAAC

team confirmed that mercury dropped on the surface does not go away; it accumulates. And since plankton and fish cannot digest it, it can get passed along the food chain to whales and of course people. Sturm said, "Mercury deposited in the Arctic could be coming from a power plant in Florida or from a volcano. But the Arctic can plate it out better than any other place."

As long as there are intermittent cold spells, and some sea ice, it appears the Arctic atmosphere will continue cleaning itself of mercury and other pollutants. According to Nghiem, although the average temperature of the Arctic is indeed rising, unseasonal cold spells have become more common over the last decade, and they are sufficient for beginning the bromine chain reaction. Yet he remains optimistic that their research can help convince governments to limit mercury pollution where possible. Nghiem said, "With the scientific foundation to show this is happening, I hope it will be the basis for making the right decisions, and even help to expedite the right decisions."

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2013/mercury-raining

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For more information

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About the scientists

Son V. Nghiem is a senior research scientist at the NASA Jet Propulsion Laboratory. His research focuses on polarimetric scatterometry and scientific applications of scatterometry in land, ice, and snow processes. NASA supported his research. Read more at http://radar.jpl.nasa.gov/people/index.cfm?FuseAction=ShowPerson&pplID=12. (Photograph courtesy of S. V. Nghiem)

Paul Shepson is a professor of chemistry at Purdue University. His research focuses on the exchange of gases between the surface and the atmosphere in the Arctic and in mid-latitude forests. NASA supported his research. Read more at http://www.chem.purdue.edu/people/faculty/faculty.asp?itemID=59. (Photograph courtesy of P. Shepson)

Bill Simpson is a professor of physical chemistry at the University of Alaska Fairbanks. His research focuses on high latitude oxidation chemistry and snowpack photochemistry, and the development of instrumentation for detecting reactive radicals. NASA supported his research. Read more at http://www.gi.alaska.edu/profile/william-simpson. (Photograph courtesy B. Simpson)

Matthew Sturm is a professor of geophysics at the University of Alaska Fairbanks. His research focuses on snow and sea ice physics, and snow in high latitudes the world over, from the Arctic to Antarctica. NASA supported his research. Read more at http://polar.crrel.usace.army.mil/people/personnel_sid/sturm.matthew.html. (Photograph courtesy M. Sturm)