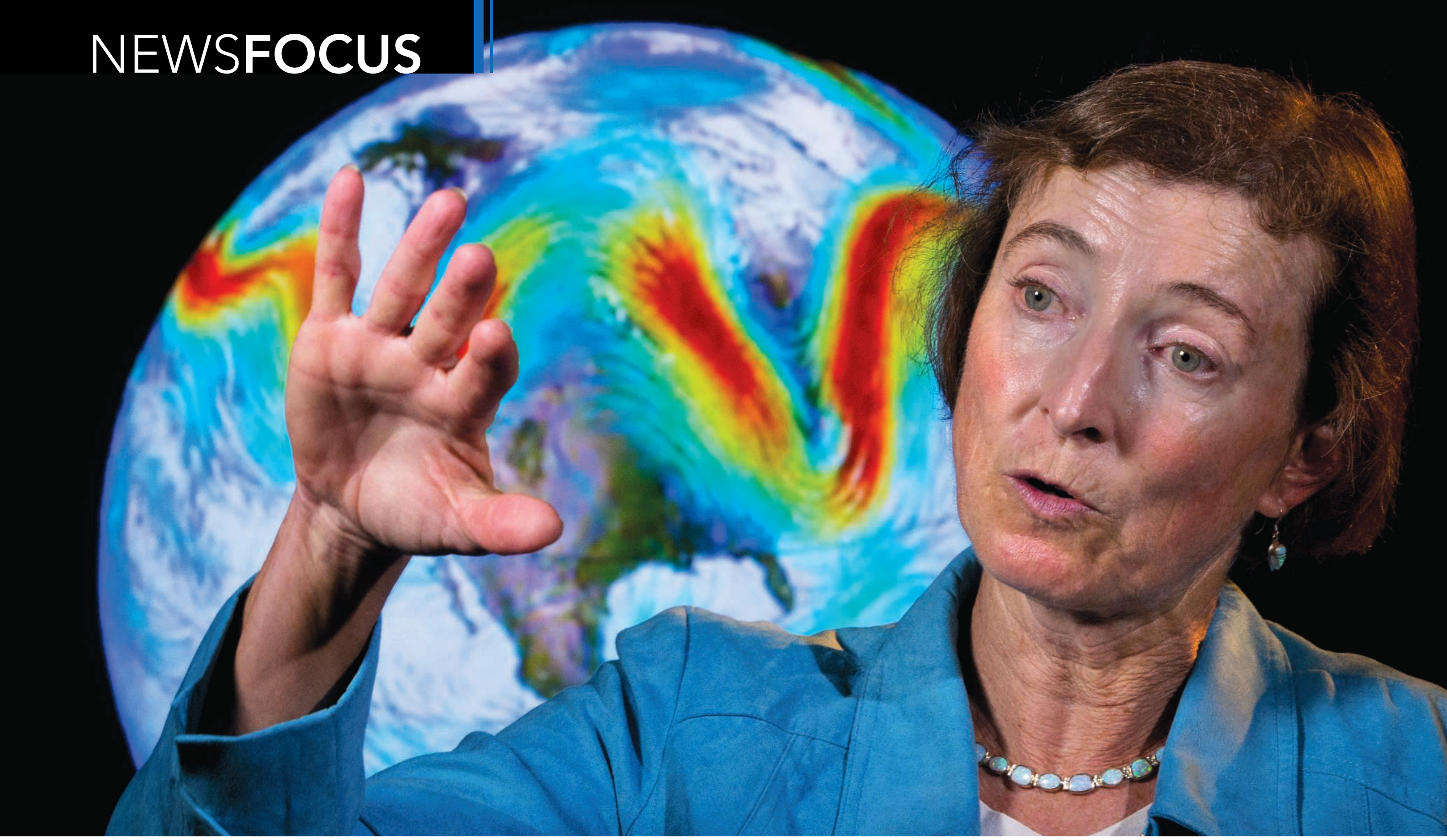

Into the Maelstrom

Jennifer Francis has made waves linking the melting Arctic to extreme weather around the world. But a storm of criticism has forced the climate scientist to defend her hypothesis

When 40 climate experts huddled in a small conference room near Washington, D.C., last September, all eyes were on an atmospheric scientist named Jennifer Francis. Three years ago, Francis proposed that the warming Arctic is changing weather patterns in temperate latitudes by altering the behavior of the northern polar jet stream, the high, fast-moving river of air that snakes around the top of the world. The idea neatly linked climate change to weather, and it has resonated with the press, the public, and powerful policymakers. But that day, Francis knew that many of her colleagues—including some in that room—were deeply skeptical of the idea, and irritated by its high profile.

Sometimes, Francis is anxious before high-pressure talks and wakes before dawn. Not this time, even though the National Academy of Sciences had assembled the group essentially to scrutinize her hypothesis. "I wasn't nervous," she recently recalled. "I was prepared for the pushback."

It came fast and hard. Just one slide into her talk, before she could show a single data point, a colleague named Martin Hoerling raised a challenge. "I'll answer that with my next figure," Francis calmly responded, her bright blue eyes wide open. Two minutes later, Hoerling interrupted again, calling a figure "arbitrary." Francis, unruffled, parried—only to have Hoerling jab again.

Francis presented the evidence for her hypothesis as an orderly chain of events. "I challenged every link in the chain," recalls Hoerling, an atmospheric dynamicist at the National Oceanic and Atmospheric Administration's (NOAA's) Earth System Research Laboratory in Boulder, Colorado. Eventually, the workshop's organizer had to intervene. No more questions "so the dissertation defense can go on," nervously joked David Robinson, a climatologist at Rutgers University in New Brunswick, New Jersey, where Francis also works.

Later, some attendees praised Francis's performance. "The way [Hoerling] aggressively interrupted was unusual," says Arctic scientist Walt Meier of NASA's Goddard Space Flight Center in Greenbelt, Maryland. "But she handled it very well, with grace."

Hoerling's assessment? "She was unpersuasive," he says. "The hypothesis is pretty much dead in the water."

A stiff headwind

Francis's hypothesis has divided colleagues ever since she first proposed it in 2011, and the divisions have only deepened as Francis became a go-to climate scientist for reporters, a marquee speaker at major conferences, and an informal consultant to John Holdren, President Barack Obama's science adviser. "It's become a shooting match over her work," says atmospheric dynamicist Walter Robinson of North Carolina State University in Raleigh. "Which side are you on?"

More than scientific bragging rights are at stake. If a warming Arctic is already affecting weather in the midlatitudes, then climate change "no longer becomes something that's remote, affecting polar bears," Meier says. Instead, it's a day-to-day reality affecting billions of people—and a challenge to policymakers responsible for assessing and reducing the risks.

CREDIT: JACQUELYN MARTIN/AP PHOTO

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Jet setter. Jennifer Francis has proposed that Arctic warming is altering the polar jet stream.

Yet to many Francis critics, the attention she has received is premature, a product of unusual weather in the United States and Francis's cheerfully outgoing and insistent style. Hoerling, for one, says Francis is driving "a campaign. … This single person has been able to promulgate a conjecture into an apparent explanation of everything."

"I can't help it if the media and public are interested in my research," Francis responds. But she readily admits that all the evidence is not in and concedes that the public interest has inverted the normal life cycle of a scientific controversy. "Usually a hypothesis gets tested … the conclusions are solid and then it becomes news," she says. But in this case, says Stephen Vavrus, a climate modeler at the University of Wisconsin, Madison, who collaborates with Francis, "Jennifer and I have been forced into the uncomfortable position of defending—or at least explaining—our position before the scientific process has run its course."

Clouds on the horizon

Seeking out adversity is part of Francis's character. In 1980, after her junior year in college, she and her to-be husband Peter overhauled a 14-meter sailboat named *Nunaga* and sailed around the globe, logging almost 100,000 kilometers over 5 years. They used a sextant to navigate and drew crude weather maps on acetate, using naval data broadcast over the radio in Morse code. Many circumnavigators make the "milk run," sticking to the relatively bucolic tropics. The pair instead pushed the limits, enduring punishing winds to round Cape Horn, dipping into the "Roaring Forties" off New Zealand, and dodging ice floes some 900 kilometers from the North Pole. At one point they struggled to fix a broken rudder during a fierce winter storm in the Tasman Sea. "We regularly placed our lives in the other's hands," Peter later wrote in a self-published volume. His wife, meanwhile, "matured from a young woman to an adult."

The Arctic foray deeply affected Francis, now 56. "I just sort of fell in love with the light up there," she says. She had been studying to be a dentist, but she switched to meteorology after returning to school, focusing subsequent graduate work on Arctic forecasting. Later, as a research professor at Rutgers, she published respected analyses of the Arctic climate with a focus on sea ice, which has lost roughly 75% of its fall volume since 1980.

It was a second circumnavigation of the globe, beginning in 2009, that inspired what one might call the Francis hypothesis. (This time the crew included her 12-year-old son and 14-year-old daughter.) "Gazing out at the waves, you have a lot of time to think out there," she says. Francis had been studying how a changing climate was affecting the Arctic. At sea, she flipped the equation: "I started to wonder how much the Arctic was affecting the system."

Upon return, she e-mailed Vavrus in January 2011 with a "thought I have been noodling." The Arctic is warming faster than the midlatitudes, she noted, a phenomenon known as Arctic amplification. Could that amplification—2°C more warming than the rest of the globe over the past 2 decades—be changing the behavior of the polar jet stream, with global consequences?

> "I can't help it if the media and public are interested in my research."
>
> **JENNIFER FRANCIS, RUTGERS UNIVERSITY**

Studies dating back to the 1970s had hinted at the idea, which turns some conventional wisdom about climate change on its head. Traditionally, researchers have attributed the rapid Arctic warming to local drivers such as the loss of ice and snow. In other words, the Arctic is generally seen as the victim, not the perpetrator.

Francis had doubts, however, based on her observations of the northern polar jet stream. First recognized by scientists in the 1890s, this meandering torrent, which can be up to 200 kilometers across, flows west to east some 7 to 12 km above Earth's surface at speeds of up to 400 km per hour. It forms a wavy ring around the North Pole, and typically marks the border between colder, low-pressure polar air masses inside the ring (called the polar vortex), and warmer, higher pressure air to the south.

By the time Francis and Vavrus began talking, she already suspected the jet stream was changing. In 2009, she and colleagues published a paper suggesting that its west-to-east winds were weakening, or slowing, especially after Arctic summers with less sea ice. Francis blamed Arctic warming. By reducing the air pressure gradient between the Arctic and the midlatitudes, she argued, amplification might be robbing the jet stream of the engine that drives its flow (see graphic, p. 252).

If so, Arctic amplification could be shaping weather farther south. Researchers have come to understand that shifts in the path and speed of the jet stream exert a powerful influence over weather in the Northern Hemisphere. When the jet meanders far to the south over North America in winter, for instance, the result is cold snaps; when it meanders far to the north, temperatures can warm well above normal.

Building on that work, Francis and Vavrus began examining changes in the amplitude of jet stream meanders, or how far the crests of its bends reach north and south. Combing through atmospheric data, they found that the amplitudes in the fall and winter had increased by roughly 150 kilometers over the past 30 years, as the Arctic warmed. The northern peaks (called ridges by meteorologists) tended to stretch farther toward the Arctic, they found. The southern dips, known as troughs, were apparently affected less, but overall the jet stream seemed to be becoming more sinuous.

Like the weakening of the winds themselves, that increased "waviness," as some researchers call it, would tend to slow the eastward movement of weather patterns. The result: Weather conditions of all sorts—dry periods and warm spells, or storms and cold snaps—would persist. In North America, for example, large pools of Arctic air would linger longer over the continent, as they did during this past winter.

The end result of all that slower motion, Francis believes, is more persistent weather that could be more extreme—and she said as much at a meeting of the American Geophysical Union in San Francisco in late 2011. As examples, she pointed to weather events of the previous 2 years—long, snowy winters in the eastern United States and Europe, a lengthy Texas heat wave, and a record-breaking rainy spell in the U.S. Northeast. All were "consistent" with her analysis, Francis said.

Checking the barometer

After that talk, "I was mobbed," Francis recalls. A few months later, in March 2012, Francis and Vavrus formally outlined their idea in *Geophysical Research Letters* (*GRL*). The timing was uncanny: Temperatures in the United States were skyrocketing again. Within weeks, *The New York Times* ran a front-page story on the "surreal heat wave" and a subsequent frigid cold snap. Francis was the first scientist quoted. "The question really is not whether the loss of the sea ice can be affecting the atmospheric circulation on a large scale," she said. "The question is, how can it not be?"

"And then my life changed," Francis says. Before the *GRL* paper appeared, she estimates she spent just one-quarter of her time working on outreach and communication. Soon after, that fraction rose to 80%. Since 2011, she has logged more than 150 media mentions and speaking engagements. She's an articulate scientist, after all, with a surprising take on a topic that everyone loves to talk about: the weather.

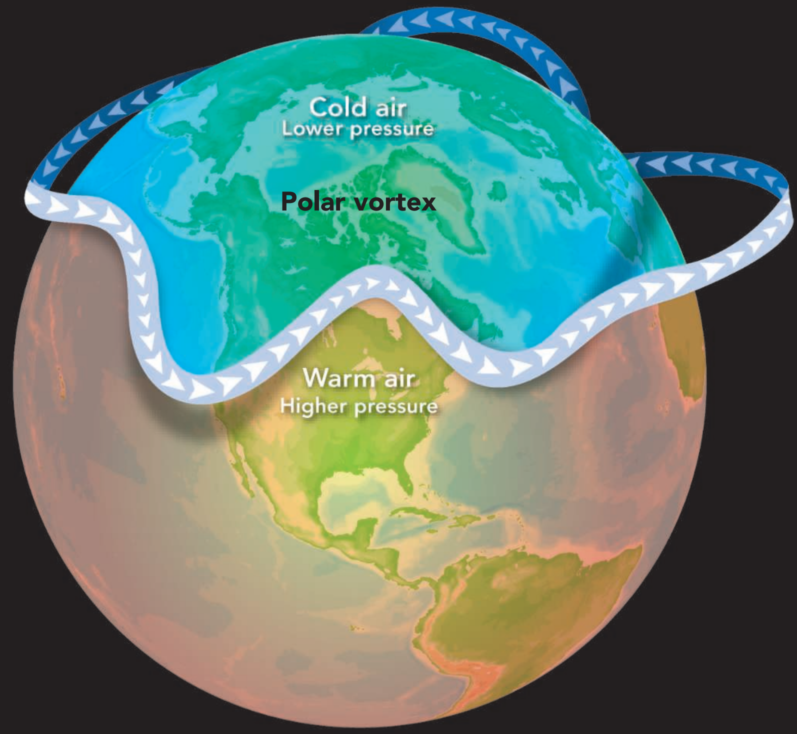
40-knot winds

As Francis has accumulated media appearances, however, opposition to the hypothesis has grown steadily among researchers. In early 2011, for instance, she and Vavrus submitted a proposal to analyze data and model the phenomenon to the National Science Foundation's (NSF's) climate dynamics division. It got generally positive reviews, although it didn't make the funding cut. A year later, however, despite revisions "the reviews of our second attempt were much worse," Francis says. "That's when we realized there was a backlash." (NSF's Arctic science program ultimately funded the work.)

Criticism is coming from three directions. First, scientists have challenged the pair's analysis of historical data, questioning whether it really shows that the polar jet stream's west-to-east winds are slowing and its meanders stretching. Last year in *GRL*, for example, climate modeler James Screen of the University of Exeter in the United Kingdom and a colleague reported that they had measured the meanders and found few statistically significant changes. "It could easily just be natural variability," Screen says. The pair did find a reduction in the size of the jet stream's vertical waves, which rise and fall perpendicular to Earth's surface. But that is inconsistent with the Francis hypothesis, they say, because it would translate into fewer temperature extremes at any specific latitude. Last year, climate dynamicist Elizabeth Barnes of Colorado State University, Fort Collins, also analyzed the data, and concluded that the Francis and Vavrus findings were an "artifact of [their] methodology."

Climate modelers also have offered heckles, saying their computer simulations have mostly failed to confirm the hypothesis. In their models, they've dialed up future greenhouse warming or reduced Arctic sea ice—both factors that should amp up Arctic amplification—but failed to produce a slower, more meandering jet stream. And models that simply reproduce existing conditions, Screen says, have to run for the equivalent of more than "60 years before I start to see anything" similar to Francis's observations.

A Changing Jet Stream? The Francis Hypothesis



The northern polar jet stream, which can be up to 200 kilometers across, flows west to east at speeds of up to 400 km/hr, some 7 to 12 kilometers above Earth's surface. It delineates colder and warmer air masses.

The most vociferous critiques, however, have come from researchers who study atmospheric dynamics, or the many mechanisms that jostle and shape air masses. Given the Arctic's relatively puny influence over the planet's atmospheric energy flows, the notion that it can alter the jet stream "is just plain wrong," says dynamicist Kevin Trenberth of the National Center for Atmospheric Research in Boulder. The more likely culprit, he says, is natural variability driven by the tropics, where Earth gets its largest input of solar energy.

Such variability, Trenberth says, could explain the jet stream's giant curvy shape this past January, which brought record chill to the southeastern United States, warm temperatures to Alaska, and made "polar vortex" a household term. At the time, a massive amount of so-called latent heat was accumulating in the tropical Pacific, Trenberth notes, in an incipient El Niño event. Parcels of warm air from the tropics may have forced the jet stream northward in one place, causing it to meander southward farther east. "It may not be that Arctic amplification is causing a wavier jet stream, it may be that a wavier jet stream is causing Arctic amplification," he says.

"I understand that people would be skeptical," Francis says. "It's a new paradigm." But she counsels patience. She notes that evidence of Arctic amplification itself has emerged from the statistical noise only in the last 15 or so years, so it may take time for the changes to the jet stream to become statistically significant. And she believes the modeling experiments that fail to simulate a more meandering jet stream are biased, because they don't include sufficiently robust Arctic amplification.

Such arguments have persuaded some colleagues to at least wait and see. Oceanographer James Overland of NOAA's Pacific Marine Environmental Laboratory in Seattle, Washington, for example, says, "I find the tropical explanation for the recent behavior of the jet stream no less implausible than the Arctic one." And he suspects that, as data accumulate, the dynamicists will come to gain a greater appreciation for the Arctic's role.

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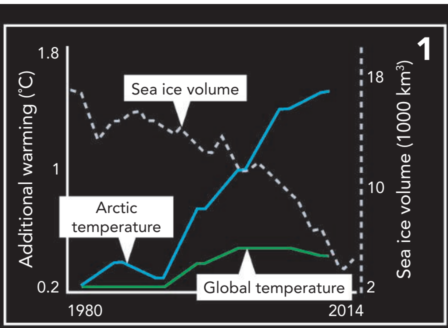
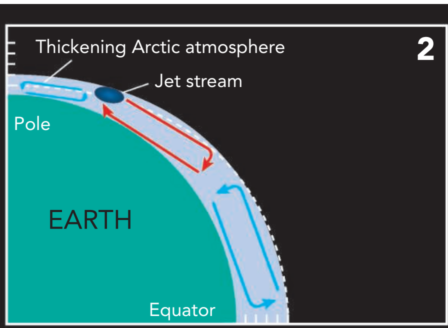
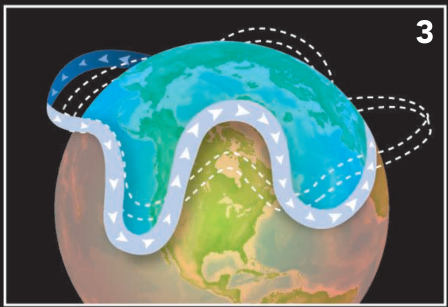


Declines in sea ice cover and other factors are driving "Arctic amplification," or the more rapid warming of the Arctic than warming of the globe as a whole.



Jennifer Francis believes Arctic warming is altering the jet stream's behavior, in particular by reducing the pressure gradient between the colder, thinner polar atmosphere and the warmer, thicker atmosphere to the south.



The result, she hypothesizes, is a slower, more sinuous jet stream with tips that stretch farther north.

The "wavier" jet stream causes longer lasting weather patterns, such as the southward bend that brought record cold to much of eastern North America this past winter.

Batten the hatches

Scientists may debate the reasons for this past January's cold spell in the eastern United States, but one clear effect was to direct more attention to the Francis hypothesis. In early January, Francis was at home in Marion, Massachusetts, responding to a blizzard of e-mails from reporters, her cat Kessie on her lap. Then came a message from an unexpected address. "I have been following with interest your work," wrote White House science adviser Holdren.

"I fell off my chair first, and started breathing again," Francis recalls.

Holdren wanted to learn more about her research, he wrote, and any relevant unpublished work. "I work for a very smart President," he explained in a follow-up message. "I don't go near him with any chart I can't completely explain!" Francis says she "fell off my chair again."

That same day, 8 January, Holdren appeared in a YouTube video produced by the White House in which he essentially endorsed her hypothesis. "There will be continuing debate," he said over clips of stark Arctic ice and blowing snowdrifts. "But I believe the odds are that we can expect, as a result of global warming, to see more of this pattern of extreme cold in the midlatitudes."

"I was blown away that he was so convinced," Francis says. She was hardly alone. When dynamicist John Wallace of the University of Washington, Seattle, saw the video, he was appalled. He quickly recruited four colleagues to pen an op-ed challenging Holdren's message. "Normally, I don't have time to write letters to newspapers," says Wallace, who didn't mention Holdren by name in the piece. The Francis hypothesis "deserves a fair hearing," the quintet wrote in a letter that eventually appeared in *Science* (14 February, p. 729). "But to make it the centerpiece of the public discourse on global warming is inappropriate." Later, in another article, Wallace warned: "When the public becomes confused, the carefully considered scientific consensus [on climate] becomes vulnerable to attack."

"That really hurt," Francis says. But she won't back down from speaking out. The discussion "in the media has really galvanized some people to realize climate change is happening right now," she says. An oceanographer who collaborates with Francis, Charles Greene of Cornell University, agrees. "When we see something happening," he says, "we should put it out there."

Francis has taken to that mission with zeal. She sends reporters long e-mails answering their questions, carefully tracks her media hits, and continually rehones and rehearses her presentations. After a recent talk at the annual meeting of AAAS (which publishes *Science*), she was approached by Lewis Branscomb, 87, a U.S. science policy luminary with lengthy experience in Washington. "That was the best general audience lecture I have ever heard," Branscomb told her.

She's also learned from some mistakes. In an incident this past January, Francis asserted that the "intent" of one of her critics—Colorado State's Barnes—"seems less than objective." That personal assault was included in a long technical e-mail to a weather blogger, and the comments drew a public scolding from prominent climate blogger Judith Curry of the Georgia Institute of Technology in Atlanta. Francis promptly apologized. "That e-mail was written at 5 o'clock in the morning while I was on a college tour with my daughter," Francis says. "Usually I like to let things simmer."

She has conceded some scientific points, too. She largely dropped one part of her hypothesis—that a curvier jet stream is leading to more atmospheric "blocking"—after Barnes published an analysis challenging the idea.

Francis predicts that "within a few years, as Arctic amplification continues, we will have enough data to know whether or not we're right." In the meantime, she is as comfortable as ever weathering the squalls. "I've developed a thicker skin," she says. At a recent meteorology conference, she suggested that curvier jet streams would steer more future Atlantic hurricanes west, along the path taken by Superstorm Sandy in October 2012. That contention drew fire from critics, including modelers whose work suggests the opposite. Her reaction? "That was kind of fun because people were irately skeptical," she says.

To put it all in perspective, Francis thinks back to the more serious dangers she faced at age 22 aboard the *Nunaga*. "Maybe this acceptance of higher risk was something I was more comfortable with than most, and maybe it translated to my research as having more confidence in myself—my judgment and my ability," she writes in an e-mail. The title of the book, which documents that life-changing journey, seems apt these days in more ways than one: *A Path to Extremes*.

–ELI KINTISCH

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