Clouds Without a Silver Lining

Stratospheric clouds help pollutants poke holes in the ozone layer

By RICHARD MONASTERSKY

Twenty-thousand feet over the ocean, a propeller-driven plane plows through stygian skies somewhere between Greenland and the Arctic island of Spitsbergen. From the roof of the plane, laser pulses shoot upward into the winter stratosphere, searchlights seeking something called polar stratospheric clouds.

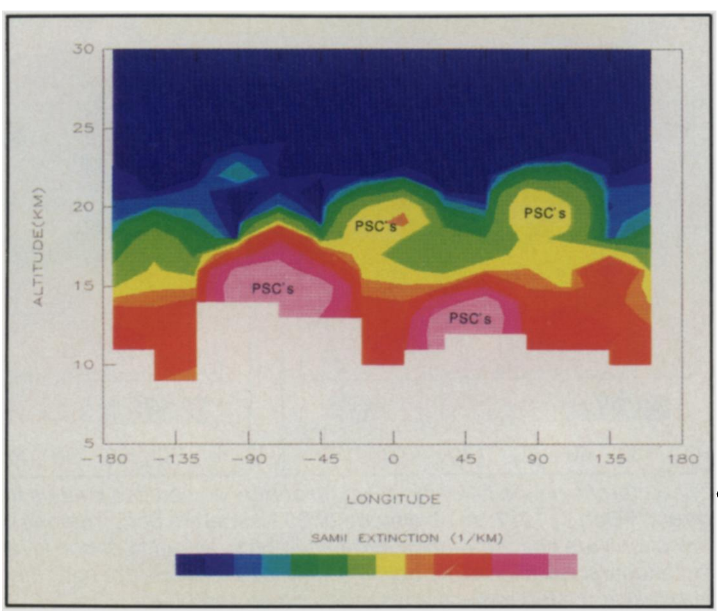
Despite their unassuming title, polar stratospheric clouds, or PSCs, have a dark side that is drawing the attention of dozens of atmospheric researchers. "I would say that right now, processes associated with PSCs are probably the most exciting area in stratospheric chemistry. That's where most of the research is going to be focused in the next couple of years," says Mark Schoeberl of the NASA Goddard Space Flight Center in Greenbelt, Md.

Experts are now convinced that these clouds in Earth's stratosphere play a fundamental role in the alarming disappearance of ozone from the skies over Antarctica — a phenomenon known to the world as the Antarctic ozone hole. Although human pollutants are clearly destroying stratospheric ozone near the South Pole, PSCs are collaborating in the dirty work. Moreover, new findings suggest PSCs may also be jeopardizing Arctic ozone.

PSCs are a relatively new addition to science. Before satellites started snapping revealing pictures of Earth, clouds in the extremely dry stratosphere were rarely sighted — mostly because they form near the poles only during winter and early spring, when darkness eclipses the sky and few spectators are around to take notice. M. Patrick McCormick from NASA Langley in Hampton, Va., coined the term PSC only recently, in a 1982 paper published in the JOURNAL OF ATMOSPHERIC SCIENCE.

PSCs first drew the attention of McCormick and his colleagues in the late 1970s, when measurements from a weather satellite revealed that the stratosphere held far more clouds than meteorologists had supposed. Aircraft with radar-like lasers that detect particles then confirmed the satellite measurements. Populating the coldest parts of the stratosphere over the poles, the clouds seemed to come in several varieties. Some were small and thickly opaque, while others spread like thin veils across the vast sky.

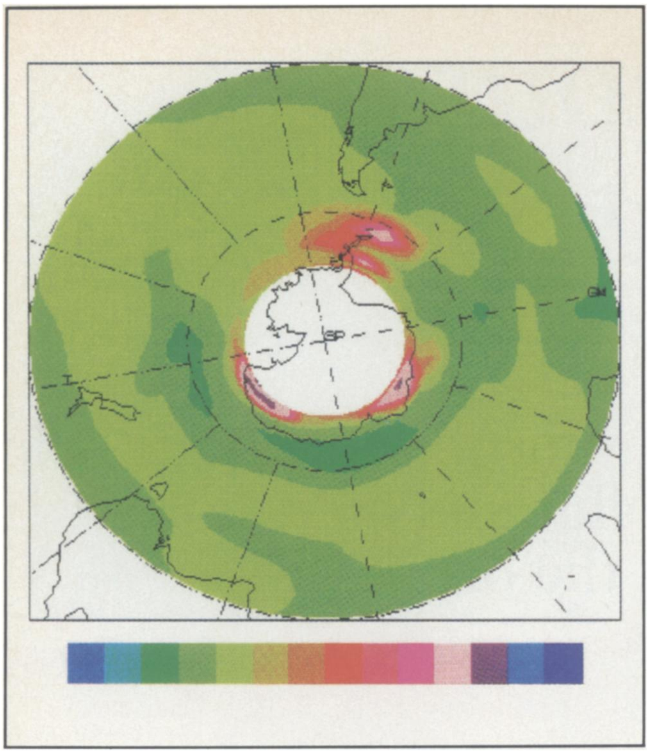
The discovery sparked no immediate fires in the scientific community. "At the time, it was pretty much academic interest," says McCormick. But PSCs did not remain in obscurity for long.



Peering at the sun as it rises over the Earth's horizon, sensors aboard the Nimbus 7 satellite detect clouds in the stratosphere that block out sunlight. Yellow, orange and magenta shades represent clouds observed along the latitude 74.2°S on Aug. 26, 1987.

Images: McCormick

In 1985, members of the British Antarctic Survey brought the ozone hole to the world's attention. Measurements from Halley Bay showed that for more than five years, vast quantities of ozone had disappeared from the Antarctic stratosphere each spring — alarming news that mobilized researchers from all segments



Clouds in the ozone hole: About 17 kilometers over Antarctica, air is cold enough to form frozen cloud particles in the stratosphere. These can help chlorine break apart ozone. Clouds show up as orange, magenta and purple on a composite satellite image from two weeks of observations in September and October 1987. Clouds over the Palmer peninsula, which stretches toward South America, are a form created by mountains and are not directly related to ozone destruction. White area in center represents blind spot of the satellite instrument.

of the atmospheric sciences. Chemists, wind experts, solar scientists, cloud researchers and others entered the search for an explanation, each branch suggesting theories to explain ozone's annual disappearance and reappearance.

Stratospheric ozone in the Antarctic is part of a global ozone layer that surrounds Earth and absorbs ultraviolet solar radiation harmful to animals and plants (SN: 10/10/87, p.230). The stratosphere is one of the middle layers of the atmosphere that starts some 15 kilometers above Earth's surface and extends to a height of about 50 kilometers.

While the journals began to fill with theories soon after news of the ozone hole reached the world, several research groups immediately focused their attention on chlorine, which turns out to be the real culprit responsible for most of the ozone loss. (Bromine, a chemical cousin to chlorine, is believed to cause 15 to 20 percent of the depletions.) Since the mid-1970s, scientists have warned that a class of widely used chemicals known as chlorofluorocarbons could transport chlorine to the stratosphere, where it would catalytically break apart ozone around the globe. But at the time, investigators thought ozone would remain safe for several decades. They theorized that when chlorine reached the stratosphere, most chlorine molecules would form relatively inactive compounds that do not break down ozone.

Unfortunately, PSCs have invalidated this scenario near the poles. Several research campaigns to the Antarctic in 1986 and 1987 have convinced scientists that clouds in the polar stratosphere radically alter the chemical reactions involving chlorine. "Without PSCs, I don't think you would have the ozone hole," McCormick says.

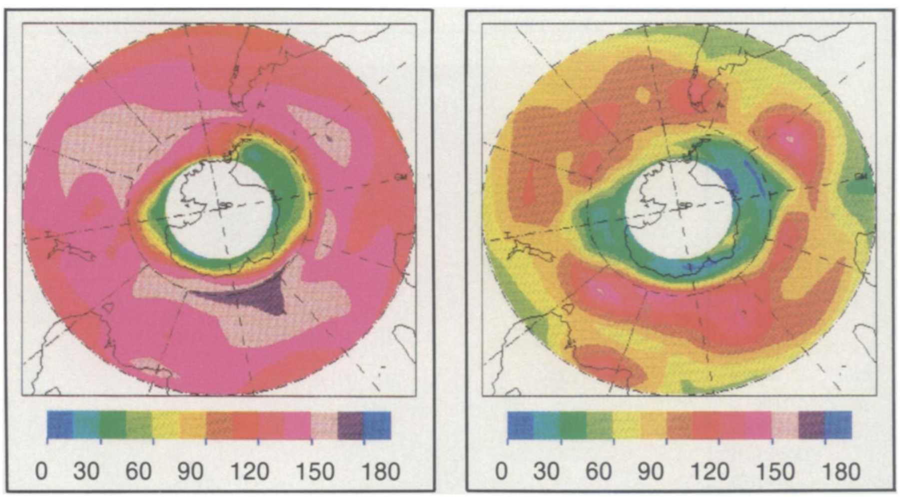
Earlier this year, researchers meeting at the Polar Ozone Workshop in Snowmass, Colo., devoted two half-day sessions to work on PSCs. News from that meeting and reports of other research appear in a special section of the August Geophysical Research Letters, which contains a half-dozen articles concerning PSCs and their effect on ozone loss. What is emerging is a complex portrait of PSCs. The evidence indicates that these cloud particles contribute to the ozone problem in several different ways.

Perhaps foremost, particles are thought to provide a surface for certain chemical reactions necessary for the destruction of ozone. The scenario goes as follows: Normally, stratospheric chlorine becomes trapped in what scientists call reservoir compounds, such as hydrogen chloride (HCl) and chlorine nitrate ($ClONO_2$), which do not destroy ozone on their own. However, when temperatures drop to the point where frozen cloud particles form in the stratosphere, the reservoir compounds can suddenly react chemically on the particle surfaces. These reactions release active chlorine that can then attack ozone.

The damage from PSCs doesn't end with the surface reactions. When PSCs form, they pull nitrogen out of the atmosphere because certain classes of cloud particles contain frozen nitric acid. With less nitrogen gas in the atmosphere, there are fewer nitrogen molecules to protect ozone by locking chlorine into the reservoir species, chlorine nitrate.

For all their work in recent years, scientists are still sorting out the details of PSC formation. Originally researchers assumed that all clouds in the stratosphere were made of pure water-ice particles. In the extremely dry stratosphere, where the air is 10 to 20 times thinner than at the planet's surface, water vapor will condense and form ice only when temperatures drop below the frost point, which is around −85°C. Yet PSCs develop at temperatures well above the frost point, indicating the particles contain something other than pure water.

The link between nitric acid and PSCs emerged in 1986 as two independent groups of researchers attempted to ex-



The Antarctic ozone hole shows up on combined satellite images from Sept. 25 through Oct. 7, 1987. At an altitude of 23 kilometers (left), regions with extremely low ozone are shaded orange, green and blue, keyed to ozone levels as measured in nanobars. Six kilometers below (right), ozone levels are naturally lower and abnormally depleted regions are shaded green and blue.

plain the severity of the Antarctic ozone destruction. Gaseous nitrogen compounds were known to hinder chlorine's attack on ozone, so several scientists thought something in the stratosphere must be taking nitrogen molecules out of the picture. Suggesting that PSCs contain nitrogen seemed to be a good solution, says Owen B. Toon from NASA's Ames Research Center in Mountain View, Calif., one of the researchers who first raised this theory. Toon says airborne measurements over the last year now prove that some stratospheric clouds contain nitric acid particles.

Researchers have taken to distinguishing among several types of PSCs. Type I are diaphanous sheets containing small particles with a diameter on the order of 1 micron, or one-millionth of a meter. The denser Type II clouds have particles five to 100 times larger than Type I particles.

Present theories on the growth of PSCs suggest that Type I clouds develop first, when the stratospheric temperatures reach −80°C. They are thought to contain nitric acid trihydrate – a crystal made of three molecules of water for every one molecule of nitric acid.

Type II clouds appear when the stratosphere cools several more degrees and pure water can freeze out of the atmosphere. While the exact composition of Type II particles remains unknown, researchers suggest that they are mostly pure ice with a trace amount of nitric acid. Some Type II particles may simply be Type I particles wearing a thick coat of ice, McCormick says.

For ozone destruction, the difference in particle size between the two cloud types is crucial. Type I particles are light and fall slowly, while Type II particles are massive enough to drop several kilometers in a matter of weeks. Both pull nitrogen from the atmosphere, but Type I particles are thought to evaporate and release the bound nitrogen before they can fall far. Conversely, evidence suggests Type II particles remove nitrogen permanently, by falling several kilometers below the region where chlorine destroys ozone, before they evaporate.

A computer model by Ross Salawitch and colleagues at Harvard University reveals that ozone destruction is quite sensitive to the amount of nitrogen permanently removed from the atmosphere, suggesting that Type II particles are necessary for acute ozone destruction. Another important factor in ozone loss is how long PSCs last before they evaporate in the springtime.

In both respects, the Arctic cannot compete with the Antarctic. In each area during the winter, a vortex of winds circles the polar regions and cools the stratosphere by blocking out warmer air currents from more temperate zones. The northern vortex, however, is much less stable than its southern counterpart. During the winter, invading winds break through into the Arctic stratosphere and keep temperatures from falling quite as far as they do in the South. Therefore, Type II particles are rarer in the North, observations reveal. As well, the northern vortex collapses much sooner, which means the Arctic stratosphere warms earlier in the springtime.

While this type of unruly air motion helps protect ozone in the Arctic, it also hinders research aimed at determining whether chlorine and bromine are actually eating Arctic ozone.

"The nice thing about trying to look at these kinds of problems in Antarctica is that you have the world's most stable part of the atmosphere to deal with. It's just rock steady," says Susan Solomon from the National Oceanic and Atmospheric Administration (NOAA) Aeronomy Laboratory in Boulder, Colo. "You go down there every year and you know exactly what to expect and where it's going to be and how cold it's going to be, to within a few degrees anyway. In the Arctic, you just don't have that luxury. [Stratospheric] temperatures can fluctuate by tens of degrees, and where the coldest temperatures are can move around from Siberia to western Canada."

Ozone levels all over the globe swing naturally from year to year, making it difficult to detect any unusual drop in concentration, unless the change is dramatic. Through extensive study of satellite and ground measurements, an international panel of experts detected hints earlier this year of a drop in wintertime Arctic ozone levels over the last decade. Scientists are now trying to determine how much of that drop, if any, was caused by chlorine chemistry – the same type of reactions depleting ozone in the Antarctic. Since ozone loss in the Arctic could affect major population centers in the North, answers are eagerly awaited.

In January and February of this year, Solomon and her colleagues spent two weeks in northern Greenland probing the Arctic stratosphere with ground-based spectrographs. These machines measure atmospheric chemicals by analyzing light from the sun and moon that must pass through the atmosphere on its way to the Earth's surface. The group detected elevated levels of chlorine dioxide and depressed concentrations of nitrogen dioxide, a suggestion that surface reactions might be occurring on PSC particles (SN: 6/11/88, p.383).

Scientists have only a snapshot of what happens in the Arctic stratosphere. To help fill in the details of the picture, NASA, NOAA and a handful of other agencies and universities are planning a six-week-long Arctic aircraft campaign, similar to last year's Antarctic Airborne Ozone Expedition. Next January, more than 100 international researchers and support crew will descend on Stravenger, Norway. The expedition will use two planes: a converted spy plane, the ER-2, that takes measurements within the stratosphere; and a DC-8 that skirts the bottom of the stratosphere carrying scientific investigators and their research equipment.

One of the major quests of the aircraft project will be assessing how clouds affect ozone in the Arctic. "In fact, the focus of the next ER-2 mission in the Arctic is really going to be PSC chasing," says NASA's Schoeberl. "The idea is to fly the aircraft into PSCs and air that's gone through PSCs."

As implied by the popularity of the term PSC, researchers have thought that stratospheric clouds are limited to Earth's polar regions. Most believe that the skies covering the rest of the world are too warm to form frozen particles. However, a new study challenges this belief. Patrick Hamill from San Jose (Calif.) State University and Giorgio Fiocco of the University of Rome report in the October GEOPHYSICAL RESEARCH LETTERS that, at least theoretically, the stratosphere over the equator is occasionally cold enough for frozen particles of nitric acid to form.

"That does not mean that they *are* forming," Hamill told SCIENCE NEWS. He adds that even if tropical stratospheric clouds do exist, they might have little effect on ozone since the tropics, with their heavy supply of sunlight, are continually producing ozone.

Some researchers, however, think ozone outside the poles may face another form of threat. Tiny droplets of sulfuric acid are found in the stratosphere all around the globe, and recent laboratory experiments indicate they can support surface reactions involving chlorine reservoir compounds – the same reactions causing problems in Anaatarctica (SN: 9/3/88, p.148).

Earlier this year, scientists announced that Earth's average ozone levels have dropped 2.5 percent over the last decade as a result of both natural effects and reactions with chlorine and bromine (SN: 3/19/88, p.183). Some experts suggest reactions on the sulfuric acid droplets may be causing part of this decline by speeding chlorine's normally slow destruction of the global ozone layer. "That's a topic of intense research right now – to find out exactly how effective these reactions are at lower latitudes," says atmospheric chemist José Rodriguez from Atmospheric and Environmental Research, Inc., in Cambridge, Mass. "Chances are they're not going to be as effective as in the Antarctic. But the question is how much less effective will they be, and what are their implications. That is definitely something people are concerned about." □