B. HOFFMAN

Summer in Svalbard

Scientists at one of the world's most remote research outposts are tracking the air masses that swirl through the Arctic atmosphere in an attempt to understand why the ozone layer continues to thin. Quirin Schiermeier visits the Koldewey research station.

"Ozonesondes, at last!" Relief shows in the face of Jens Kube as his ozone-measuring devices arrive. A small, propeller-driven Dornier aircraft has just touched down on the bumpy airstrip of Ny-Ålesund, Spitsbergen, part of the Norwegian archipelago of Svalbard. The cargo hatch opens, revealing equipment that Kube and others need to continue their research.

The delivery is one of two that arrives each week at the Koldewey station, Germany's Arctic research outpost. Each arrival brings spare parts, mail, visitors from the Norwegian mainland and excitement for the scientists who work at the isolated Arctic base, the world's northernmost permanently inhabited village, just 1,000 kilometres from the North Pole.

Temperatures are well above zero on this sunny July day. Thick inland ice covers 60% of the region's land mass, but there is open water in Spitsbergen's majestic King's Fjord, and nearby on the Barents Sea. Flowers shoot up in the green meadows surrounding the scattered wooden stations and dormitories. Outside the yellow building, where the Norwegian arctic explorer Roald Amundsen once waited in 1926 for a dirigible that would take him on a trip to the North Pole, small groups of researchers are having drinks in the bright midnight sun.

In six months' time, things will be very different at Koldewey. During the long winter the region is an inhospitable, freezing Arctic desert, and despite the aerial grandeur of the *aurora borealis*, or Northern Lights, the station is swathed in permanent darkness. It is then that Kube's ozone-measuring equipment will begin to track a worrying problem — the continued seasonal thinning of the Arctic ozone layer. Although ozone may no longer be a political hot potato, the future status of the stratospheric ozone layer above the North Pole, and the effects of its depletion on the polar environment, is uncertain. Atmospheric scientists believe that ozone levels will remain resilient in coming decades, but they warn that we should not ignore an alarming possibility: that holes could form in the Arctic ozone layer, just as they do over the South Pole.

Clear conditions

The Koldewey station, which is headed by Kube and run by the Alfred Wegener Institute (AWI) for Polar and Marine Research's facility in Potsdam, Germany, provides a perfect arena for research. The untouched environment is free of air pollution, and the station is relatively accessible at any time of year. Germany, for example, is never more than 36 hours away; Antarctic research stations, by contrast, can be almost impossible to enter or leave during winter months. As the tail end of the Gulf Stream adds to the station's summer warmth, Italian, French, British, Japanese and Korean researchers, spanning disciplines from ornithology to glaciology, visit other nearby research stations.

Sunny outlook: Jens Kube enjoys the summer while working at his remote Arctic research base.

There are drawbacks — Spitsbergen is polar bear country, so researchers have to carry a gun every time they leave the protection of the centre. But there are also good reasons for keeping the station open throughout the dark winter. Every day, Koldewey researchers use ground-based equipment to measure levels of ozone and aerosols in the atmosphere above the station. Balloon-borne atmospheric measurements, carried out since 1989, add extra information. Any gaps in the data would diminish their usefulness — one reason why Kube gets nervous when he runs short of measurement equipment.

Ozone measurements make up one of Koldewey's critical data sets. After all, fears over the thinning of the ozone layer have not gone away, among scientists at least. Chlorofluorocarbons (CFCs), the compounds responsible for ozone depletion, were phased out under the 1987 Montreal Protocol, but those already in the atmosphere are likely to continue to attack the ozone layer until the middle of this century.

When CFCs reach the stratosphere, the layer of the atmosphere that stretches from about 13–50 kilometres above ground, they are exposed to solar ultraviolet (UV) radiation. This causes them to decompose, producing highly reactive chlorine atoms that break up the three oxygen atoms that form an ozone molecule. Such destruction should lessen as CFC levels fall, but this success is being tempered by another environmental threat to the ozone — the build-up of atmospheric carbon dioxide that is causing climate change.

Most of the chlorine atoms created when CFCs decompose quickly form relatively harmless compounds such as hydrochloric acid. But under certain circumstances, these compounds can re-release chlorine atoms. This reverse reaction occurs on the surface of polar stratospheric clouds (PSCs), wisps that form only in the low temperatures, around −80 °C, reached during the winter in the polar stratosphere.

J. KUBE

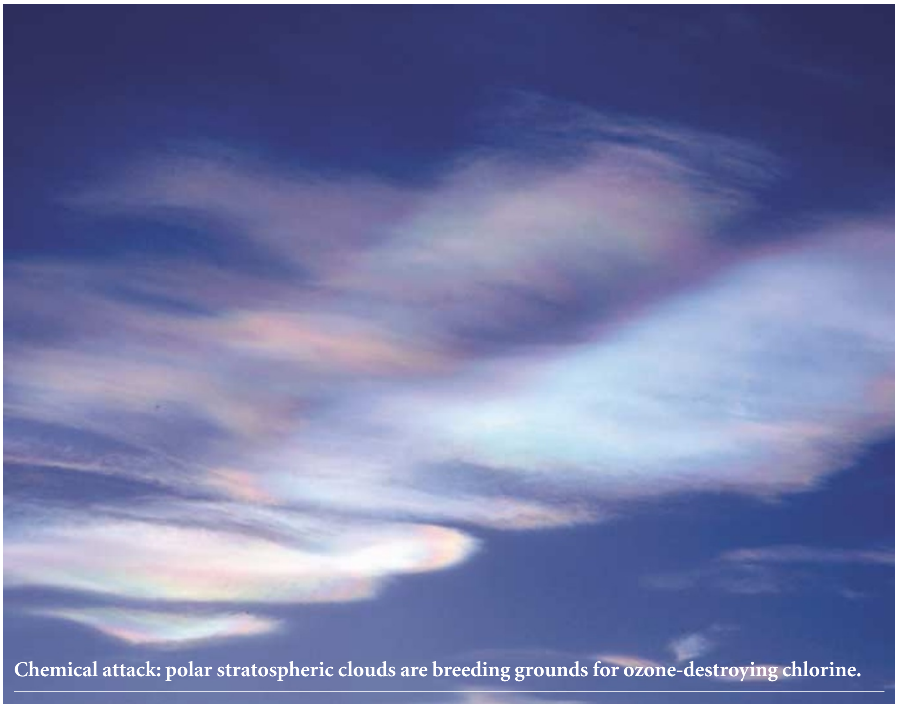
Touch base: besides mail and visitors, Koldewey's twice-weekly air deliveries bring crucial equipment.

Layer effect

Although carbon dioxide heats the lower atmosphere, it has the opposite effect on the stratosphere. Carbon dioxide in the stratosphere reflects the UV radiation that warms the air when it is absorbed by the ozone layer. Carbon dioxide in the layer between the stratosphere and the ground also locks heat into the atmosphere at lower altitudes, preventing it from reaching higher ones. Stratospheric temperatures have fallen by around 0.5 °C per decade since the 1950s, causing more PSCs to form and enhancing the rate at which ozone is destroyed. Moreover, if cold conditions last longer in spring, when sunlight arrives and accelerates ozone-depleting reactions, future ozone losses in the northern hemisphere may become even worse.

In the Antarctic, where local winter weather conditions isolate the stratosphere from lower, warmer parts of the atmosphere, PSCs have always been more common, and are one reason why ozone losses there have been more dramatic. Since holes in the ozone layer above the South Pole were first detected in the 1980s (ref. 1), the Arctic ozone layer has thinned every winter, but holes have not appeared.

Exactly what will happen to the Arctic ozone layer remains unclear. "We still don't know enough about the correlation between climate change and ozone depletion. It is an open question as to whether future Arctic ozone losses will get worse," says Paul Crutzen, an atmospheric chemist at the Max Planck Institute of Chemistry in Mainz, Germany, who shared the 1995 Nobel Prize in Chemistry for his work on the formation and decomposition of ozone. "Different models arrive at very different predictions. The answer must therefore be found by *in situ* measurements."



M. REX/AWI

Chemical attack: polar stratospheric clouds are breeding grounds for ozone-destroying chlorine.

As part of the international Network for Detection of Stratospheric Change, a global network of observation points that monitor physical and chemical conditions in the stratosphere, the Koldewey station is trying to provide those measurements. Researchers there are collaborating with colleagues at around 40 other research stations to run experiments using the Match technique, which attempts to track ozone losses in specific packets of air, about 500 km across, as they circulate around the pole. Meteorological readings and weather models are used to predict the movement of tens of thousands air parcels. Then, over a period of days, balloons are launched from participating stations under the paths of packets that were probed by previous measurements. First used in 1992, the technique allows researchers to focus on CFC-triggered ozone losses in individual packets, which are relatively isolated from the surrounding atmosphere.

Ballooning workload

As well as balloon-borne measurements, the atmosphere is probed each day — weather permitting — with light detection and ranging (LIDAR) devices, which send out pulses of laser light. The reflections of the LIDAR's vertical signals provide detailed information about PSCs and other components of the atmosphere's different layers. All raw data are checked for plausibility — a bird may have crossed the laser's path — and then transmitted to Potsdam for further analysis.

Such techniques have provided evidence that, during particularly cold Arctic winters, CFCs destroyed up to 30% of ozone in Arctic regions[2]. Although no hole has so far appeared, such an occurrence would be a more serious problem in the Northern Hemisphere than it is in the almost uninhabited Antarctic. Weather patterns in the north shift air masses over large distances and could push a hole over populated areas of Scandinavia, North America or Russia. And for every 1% decrease in stratospheric ozone, the amount of UV-B radiation — with wavelengths between 290 and 320 nanometres — reaching the ground increases by 2%, raising the risk of skin cancer by around 4% for a typical inhabitant of the affected areas[3].

Researchers at Ny-Ålesund are studying the potential effects of a collapse or thinning of the ozone layer. Humans can protect themselves using suncream; marine Arctic ecosystems also have a safety barrier — an ice sheet — but this melts when spring arrives. At Koldewey's biology lab, scientists are investigating how marine algae react when the ice melts and increased UV radiation hits the water. Divers collect algae from King's Fjord at depths of 3–10 metres, and subject them to varying levels of artificial UV radiation in the lab.

Previous work has shown that mature algae cells can adjust to increased UV levels by expressing compounds that absorb the radiation, thus protecting their DNA and photosynthesizing apparatus from damage[4]. "Presently measured UV levels are not likely to seriously affect adult algae," says Christian Wiencke, a marine botanist and group leader of the AWI's solar UV radiation project group, who has students working at Koldewey. "But it is unclear how enhanced UV radiation might affect algae in their early developmental stages."

To address such issues, Wiencke studies single-cell zoospores, the earliest stage in the life cycle of algae. In unpublished experiments, conducted at the AWI's headquarters in Bremerhaven, Germany, he found that the spores died within 16 hours of being exposed to UV levels similar to those that penetrate the uppermost metre of Arctic seas. But he has also found that zoospores can produce tannic acids — these substances had, until now, only been found in algae at the multicelled stage, where they are thought to have the potential to produce other compounds that protect cells from UV radiation.

M. REX/AWI

Snow place like home: the research station at Koldewey is the world's northernmost year-round town.

M. REX/AWI

Bear with it: researchers who venture out into Spitsbergen's wastes must be wary of the locals.

In the long term, Wiencke and others want to develop a detailed understanding of how all types of algae will react to increases in UV radiation, and what the knock-on effects on the marine ecosystem will be. "We are beginning to understand how photosynthesis, growth and reproduction of algae respond to sudden UV stress in spring," he says. "The next step is to turn to the community level to see how algal ecosystems might be affected."

Defensive strategy

Back at the AWI in Potsdam, researchers are trying to work out whether defensive measures will have to be taken to protect Arctic ecosystems. Atmospheric physicist Markus Rex has extrapolated future Arctic ozone losses from the temperature records, trends in PSC occurrence and other data. According to his unpublished analysis, ozone losses may increase until 2010–20, and decrease only slightly by 2030. "A total collapse of the arctic ozone layer is unlikely," he says, but it is a worst-case scenario that we should not ignore."

There are great uncertainties involved in the analysis, however. Some significant processes that affect the arctic ozone layer, such as the supply of ozone from lower latitudes, and the formation of PSCs, are not yet well understood, says Rex. Because existing models fail to account for the observed large ozone losses that occurred during several cold Arctic Januaries over the past decade, he suggests that there must be a currently unknown mechanism by which ozone can be destroyed[5].

One theory is that ozone reacts naturally on the surfaces of PSCs, even in the absence of CFCs. Another, perhaps more likely, answer is that the chemical reactions that link CFCs to ozone destruction are stronger or faster than experiments have shown. Rex hopes that future Match campaigns, such as one currently under way in the Antarctic, will help to resolve these issues.

Back at Koldewey, the drinks continue to flow in the summer sun. Researchers there know that their geographical location gives them an advantage over their more isolated colleagues working in the Antarctic. When they finish their day's work, they can look forward to a richer social life and, in summer at least, many outdoor activities. The possibility of taking a kayak tour and encountering a polar bear, rather than a penguin, is a thrill they just have to accept. ■

Quirin Schiermeier is *Nature*'s European correspondent.

1. Farman, J. C., Gardiner, B. G. & Shanklin, J. D. *Nature* **315,** 207–210 (1985).
2. Rex, M. *et al. Nature* **389,** 835–838 (1997).
3. Van der Leun, J. C., Tang, X. & Tevini, M. (eds) *Environmental Effects of Ozone Depletion: 1998 Assessment* (UN Environ. Prog., Nairobi, 1998).
4. Bischof, K., Hanelt, D. & Wiencke, C. in *UV Radiation and Arctic Ecosystems. Ecological Studies Series* Vol. 153 (ed. Hessen, D.) 227–244 (Springer, Berlin, 2001).
5. Rex, M. *et al. Geophys. Res. Lett.* doi:10.1029/2002GL016008 (2003).

Koldewey station
▸ **www.awi-potsdam.de/www-pot/koldewey/kolnav.html**
Network for Detection of Stratospheric Change
▸ **www.ndsc.ncep.noaa.gov**
Global Atmosphere Watch
▸ **www.wmo.ch/web/arep/gaw/gaw_home.html**