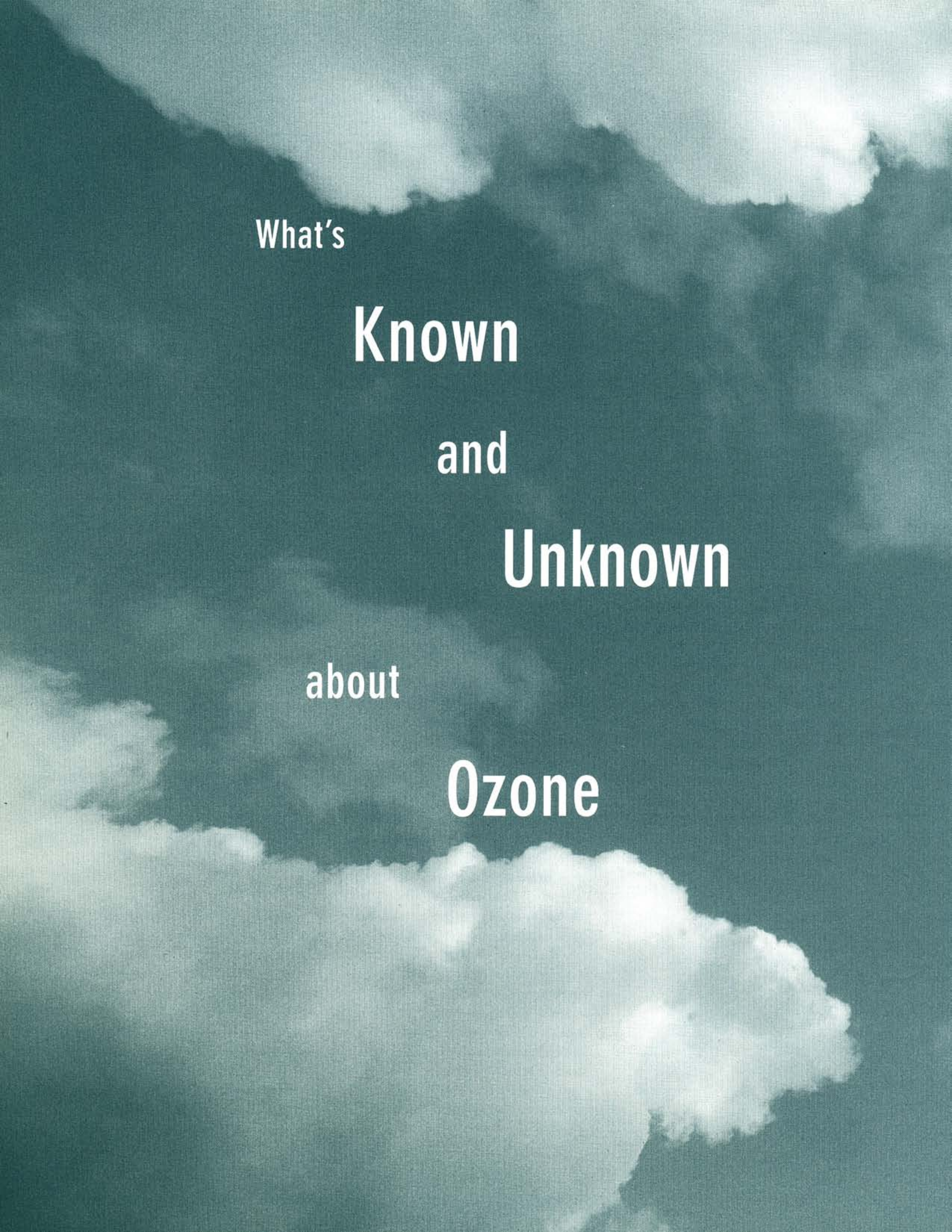


What's Known and Unknown about Ozone

The protective ozone layer over much of the world's populated areas has been gradually eroding since the 1970s. Measurements taken over the mid-latitudes indicate that the concentration of stratospheric ozone has been dropping by an average of two-to-four percent per decade.

To date, however, researchers have been unable to determine what effect this ozone decline has had on the amount of harmful ultraviolet-B radiation reaching the earth's surface. The biggest stumbling block in this quest has been the continually changing pattern of cloud cover, which, like ozone, screens out ultraviolet rays.

Now, Dan Lubin, a research physicist in the California Space Institute at Scripps, has overcome that obstacle by developing a satellite mapping method that takes cloud variability into account.

BY JANET HOWARD

> **"Unfortunately, the scientific community has been really behind in monitoring UV radiation at the earth's surface."**

"Unfortunately, the scientific community has been really behind in monitoring UV radiation at the earth's surface," Lubin said. "It is kind of a strange thing that we've been worrying about ozone depletion as an environmental hazard, but efforts to monitor UV have been very, very sparse."

Only about a dozen high resolution instruments capable of measuring ultraviolet radiation at the earth's surface are currently deployed around the globe. In order to calculate how much ozone is penetrating the earth's atmosphere, Lubin and Elsa Jensen of SeaSpace Corp. in San Diego, combined NASA satellite measurements of trends in global ozone with satellite measurements of how much solar radiation was being reflected back into space by clouds.

The scientists analyzed data collected each July over the Northern Hemisphere and each January over the Southern Hemisphere. They then used the physics of radiation transport to map how much UV radiation propagates through both the ozone layer and clouds to reach the earth's surface.

Ozone is a bluish gas that is concentrated in a layer of the atmosphere some 10 to 15 miles above the surface of the earth. A form of oxygen that has three atoms instead of the usual two, it absorbs much of the sun's ultraviolet radiation.

Exposure to excessive levels of ultraviolet-B radiation is thought to play a role in causing skin cancer, eye damage, and immune system suppression. It is also thought to cause significant

Dan Lubin stands atop the roof of SeaSpace Corp. in San Diego. The antennae in the background are used to track orbiting polar satellites used by NASA to collect data on cloud reflectance and ozone.

damage to terrestrial and aquatic ecosystems.

Yet despite the risk increased levels of ultraviolet radiation pose, little is known about its seasonal and geographic distributions.

"The scientific community has basically assumed that any decrease in the ozone layer over temperate regions will automatically bring about an increase in UV radiation at the earth's surface that has some biological significance," Lubin said. "What the results of this study show is that whether or not there is a biological significance to the UV increase depends very much on where you are."

In areas with large swings in cloud cover, for example, ozone depletion may not be an environmental problem because any increase in ultraviolet radiation is still within the normal range under which the ecosystem has evolved, he said.

Lubin found that many regions are now being subjected to significant increases in ultraviolet radiation, including large parts of North America, most of central Europe, the Mediterranean, New Zealand, South Africa and the southern half of Australia, Argentina, and Chile. Areas of the United States experiencing increases in UV radiation are the Southwest (including southern California), the Midwest, part of the Northeast, and Hawaii.

Other areas of the world, however, are not expected to experience significant increases in UV radiation for decades. The British Isles and Ireland, for example, shouldn't see a change for 20 years. China, Japan, Korea, and parts of central Russia won't experience a significant difference for between 20 to 50 years.

Lubin and Elsa Jensen of SeaSpace Corp. examine a map indicating the amount of ultraviolet radiation reaching the earth's surface.

Perhaps the best region for studying the effects of increased ultraviolet radiation is the Antarctic, where an "ozone hole" appears each year between September and November. This appearance is partly a natural phenomenon.

This thinning of stratospheric ozone is caused by the release into the atmosphere of chlorofluorocarbons (CFCs) from such things as aerosol propellants and refrigerator coolants. Global atmospheric conditions cause the CFCs to accumulate in southern polar stratospheric clouds during the long, dark Antarctic winter. When the sun comes back above the horizon in September and the Antarctic spring begins, it triggers the CFCs to set off a massive destruction of ozone, reducing concentrations by as much as 80 percent. The hole sometimes grows as large as the size of the contiguous United States.

Osmund Holm-Hansen, a research biologist in the Scripps Marine Research Division, has spent much of the past decade traveling to Antarctica to study what effect increased ultraviolet

OZONE
Research Leads to Nobel Prize

Paul Crutzen, an adjunct professor at Scripps who co-founded the Center for Clouds, Chemistry and Climate at Scripps, has been awarded the 1995 Nobel Prize in Chemistry for his fundamental contributions to the understanding of the chemistry of the ozone layer.

Crutzen, director of the department of atmospheric chemistry at the Max Planck Institute for Chemistry in Mainz, Germany, shared the $1 million prize with F. Sherwood Rowland of UC Irvine and Mario Molina of the Massachusetts Institute of Technology.

Crutzen in his office in Mainz, Germany

The three scientists were cited for their pioneering contributions to explaining how ozone forms and decomposes through chemical processes in the atmosphere. Their work demonstrated how sensitive the ozone layer is to emissions of certain manmade compounds.

"The thin ozone layer has proven to be an Achilles heel that may be seriously injured by apparently moderate changes in the composition of the atmosphere," said the Royal Swedish Academy of Sciences in Stockholm, which awards the prize. "By explaining the chemical mechanisms that affect the thickness of the ozone layer, the three researchers have contributed to our salvation from a global environmental problem that could have had catastrophic consequences."

Crutzen was born in Amsterdam in 1933 and received a Ph.D. in meteorology from Stockholm University in 1968. Each year, he spends two months at Scripps teaching a course in atmospheric chemistry. He also travels to the institution in the summer to collaborate on research with Veerabhadran Ramanathan, director of the Center for Clouds, Chemistry and Climate. He has been affiliated with Scripps since 1991.

Crutzen was the first to discover that nitrogen oxide radicals contribute to the decomposition of ozone. He also showed how nitrous oxide (N_2O) from soils rises unchanged through the lower atmosphere to the stratosphere, where it is decomposed by ultraviolet radiation. A small amount of the N_2O is converted to the nitrogen oxides that destroy ozone catalytically (without themselves being consumed).

A few years later, Rowland and Molina demonstrated that a similar mechanism occurs with chlorofluorocarbon (CFC) gases used in refrigerator coolants, aerosol cans, and plastic foams. The two scientists found that CFCs survive intact until they enter the stratosphere, where ultraviolet radiation causes them to break up and release free chlorine atoms that destroy ozone.

The results of their research led to the establishment, in the late 1970s and early 1980s, of restrictions on the release of CFCs. In 1985, scientists noted a dramatic depletion of the springtime abundance of ozone over the Antarctic, which was far greater than expected from earlier calculations of the CFC effect.

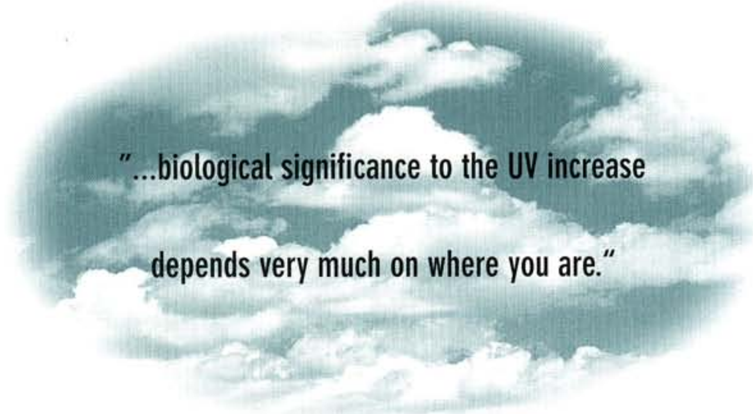
Today's scientific understanding of the ozone problem, largely due to the combined research efforts of Crutzen, Rowland, and Molina, has resulted in far-reaching decisions on prohibiting the release of gases that destroy ozone. An international agreement on the protection of the ozone layer was negotiated under the auspices of the United Nations and signed in Montreal in 1987. Under the latest amendments to the Montreal Protocol, the most

Following the Nobel banquet, the Crutzens (right) together with the Royal Family of Sweden

dangerous gases will be totally banned this year. Because it takes some time for the ozone-destroying gases to reach the ozone layer, it is expected that the depletion, not only over Antarctica but also over lower latitudes of both hemispheres, will worsen for some years to come. Given compliance with the prohibitions, the ozone layer should gradually begin to heal after the turn of the century.

radiation caused by the ozone hole may have on phytoplankton. These tiny, free-floating plants are of extreme importance because they form the base of the marine food web.

Holm-Hansen is interested in learning the extent to which primary production, or the rate of photosynthesis in the upper water column, is decreased by enhanced levels of UV-B radiation (280-320 nm) resulting from ozone depletion.

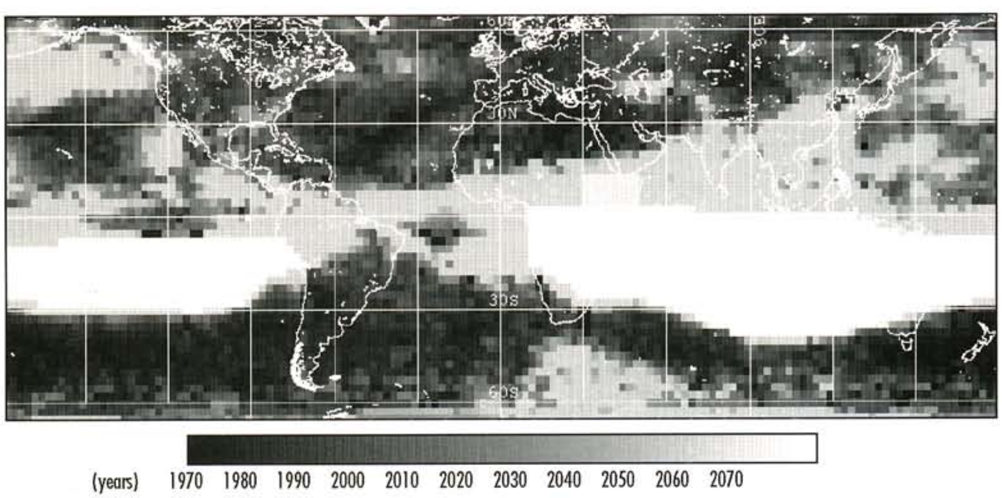


"Ecologically, the rate of primary production is probably the most important reaction that we can study as it represents the rate at which organic food is being made," he said. "It supports all other organisms on Earth."

Because ultraviolet light decreases in intensity with ocean depth, Holm-Hansen collects samples of phytoplankton from different depths, seals them in quartz flasks that contain radioactive carbon dioxide, and then returns each flask to the depth from which it was taken. Some of the flasks are shielded by various types of filters to block out different spectral regions of UV-B or UV-A (320-400 nm) radiation. The flasks are recovered later and the amount of radioactive carbon dioxide assimilated by the phytoplankton is measured to determine the plants' level of photosynthetic activity. When the differences between shielded samples and unshielded samples at the same depth are compared with measurements of spectral irradiance at that depth, Holm-Hansen can relate any change in rate of photosynthesis to the total UV dose to which the phytoplankton samples were exposed.

His experiments indicate that increased ultraviolet-B radiation seen in Antarctica on a clear day at the maximum development of the ozone hole causes about a four percent decrease in the productivity of phytoplankton, which could have a significant impact on the marine food web.

He cautions, however, that this figure tends to be misleading because such conditions are present only a fraction of the year.



This map indicates when various parts of the globe will experience significant increases in ultraviolet radiation.

"Over the United States and Europe, the increases in ultraviolet due to ozone depletion we've documented are comparable to moving a hundred miles closer to the equator."

"That is the absolute worst case scenario," he said. "It does not take into account clouds, the fact that the ozone hole is present for two months or less out of the year, and that most of the Southern Ocean is covered by ice when the ozone hole is at its maximum, and ice attenuates UV very quickly."

Once the figure is extrapolated to include changing conditions throughout the entire year, the reduction in phytoplankton productivity is less than 0.2 percent, he said.

"The annual loss due to enhanced UV-B radiation is so small that it is insignificant when compared to changes in primary productivity rates caused by variation in cloudiness, ice cover, water temperature, and grazing impacts," Holm-Hansen said. "Phytoplankton in San Diego are exposed to a lot more UV almost the entire year than they would ever experience during an average day in ice-free Antarctic waters under an extreme ozone hole."

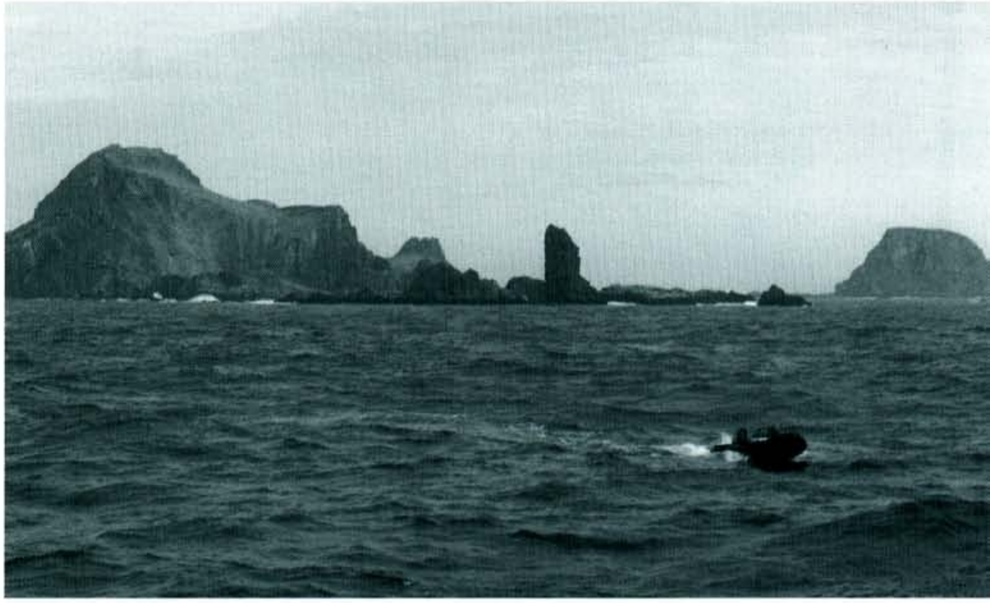
Studies by other scientists indicate a greater decline in phytoplankton productivity, leading to continued debate among scientists.

Holm-Hansen believes that the amount of increased ultraviolet radiation documented by Lubin in such areas as the United States and central Europe would have essentially no impact on phytoplankton production. Increased UV radiation, however, may favor the growth of some types of phytoplankton over others, which might result in changing the cell size or the species composition of the phytoplankton, he said.

Holm-Hansen and Russ Vetter, of the National Marine Fisheries Service's Southwest Fisheries Science Center in La Jolla, also raise the possibility that increased UV radiation may present a threat to some types of fish larvae. Unlike phytoplankton, which are continually being mixed

Osmund Holm-Hansen sits among some of his sampling equipment aboard R/V *Polar Duke*, a Norwegian ship leased by the National Science Foundation. Holm-Hansen uses these floatation devices, called spar buoys to incubate samples at various depths between the ocean surface and about 325 feet in order to study the effects of ultraviolet radiation on phytoplankton productivity.

Located on Anvers Island in Antarctica, Palmer station serves as home to Holm-Hansen and his colleagues from September to December each year. Below, Holm-Hansen uses a small inflatable, such as the one pictured here off Seal Island, to collect phytoplankton samples. Seal Island is a rocky outpost located near the tip of the Antarctic Peninsula.



throughout the depth of the upper mixed layer (generally about the upper 165 feet in Antarctic waters), larval fish often remain close to the surface, where UV radiation is very high. The early larval stages of many fish species thus may represent a critical stage where solar radiation could cause high mortality.

In general, however, Holm-Hansen believes that the danger posed by the depletion of the ozone layer has been exaggerated. He also points out that, in contrast to atmospheric and modeling research, few studies have been devoted to the ecological impact of solar UV radiation on terrestrial or aquatic ecosystems. Thus, the data base is very small and limited. "I don't think it is a very serious problem for either aquatic environments or for terrestrial vegetation," he said. "In regard to humans, however, it must be realized that exposure to increased UV radiation may result in life-threatening damage to skin or eye tissues. However, any such damage may be mitigated by the use of appropriate clothing and sunglasses in addition to the use of lotions that block UV radiation."

Lubin agreed that there is no need for the public to become alarmed. "The biggest factor that influences how fast you get sunburned or how susceptible you are to skin cancer is where you are in latitude," he said. "Over the United States and Europe, the increases in ultraviolet due to ozone depletion we've documented are comparable to moving a hundred miles closer to the equator."

The level of chlorine in the stratosphere is expected to peak around the end of the century and gradually return to pre-1980 levels over the next 50 years if the international community complies with regulations on the release of CFCs set out in an agreement called the Montreal Protocol.