The Antarctic Ozone Hole: Toward Closure on Ecological Impacts

Dan Lubin
Scripps Institution of Oceanography
UCSD, 9500 Gilman Drive
La Jolla, CA 92093-0221
telephone: (858) 534-6369
fax: (858) 534-7452
e-mail: dlubin@ucsd.edu

The International Polar Year presents an opportunity to determine precisely what ecological impacts have been generated by human influence on the ozone layer over Antarctica, as several fundamental aspects of both atmospheric science and Antarctic marine biology have now been established. The discovery of the springtime Antarctic ozone decrease (Farman et al., 1985) and the subsequent measurement of significantly enhanced solar ultraviolet radiation (UVR) increases at the Antarctic Earth surface (Lubin et al., 1989) motivated many studies into possible UV-B (280-315 nm) effects on Antarctic marine organisms (Weiler and Penhale, 1994). These studies considered physiological processes such as inhibition of photosynthesis in phytoplankton, protective pigmentation, and DNA damage and repair mechanisms. The overall concern was that UVR-induced damage to the base of the marine food web - during the season when organisms are released from the sea ice into the water column and are relatively vulnerable in a stratified upper water column - could have rapid and dramatic implications to may organisms higher on a relatively short food chain. However, to date there has been no discovery of a region-wide adverse ecological impact that can be directly attributed to the ozone "hole."

The closest discovery to such a detection was made by the ICECOLORS cruise (Smith et al., 1992), which was fortunate to carry out physiological experiments in the water column as the polar vortex advanced and receded over the Western Antarctic Peninsula (WAP) region. This oscillating "UV-B front" provided a naturally controlled experiment in which the researchers were able to estimate photoinhibition by UV-B. First-order extrapolation of their findings to the WAP region suggested a reduction in phytoplankton biomass, related to the ozone hole, in the range 6-12%. There are two limitations with this result: (1) it is based on extrapolating a limited series of point (shipboard) measurements to a large geographic area, and (2) primary production reductions of this size have not been reported since.

Detection of large-scale adverse impacts may be difficult for three reasons. First, there is a lack of a "baseline" in physiological understanding. Many of the detailed species composition studies, and assessments of reaction to excessive UV-B exposure among diverse species, were not done until the late 1980s, by which time the springtime ozone decrease had been occurring for several seasons. Thus, some of the more sensitive organisms might have suffered a high mortality that may never be known (Karentz, 1991). Second, Arrigo et al. (2003) have shown that actual exposure by marine organisms to enhanced UV-B is limited by (1) rapid attenuation of UVR within the upper few meters of the water column and (2) the largest ozone depletions being confined mainly over the Antarctic continent.

A third reason is only recently being revealed by satellite remote sensing: until now polar biologists have not been looking for adverse effects in the regions most likely to show them. A combination of surface UV-B retrievals based on NASA Total Ozone Mapping Spectrometer (TOMS) data and climatological surface phytoplankton biomass distributions based on Sea-viewing Wide Field of View Sensor (SeaWiFS) data shows that the Southern Ocean regions most subject to enhanced UV-B over spring algal blooms include the Weddell Sea, and the Indian Ocean sector of the Southern Ocean as far east as the Amery Ice Shelf (Lubin et al., 2004). Beginning in October 1983, the most frequent occurrences of enhanced UVR over phytoplankton-rich waters occurred in the Weddell Sea and Indian Ocean sectors of the Southern Ocean, and by the late 1990s the surface biomass fraction under enhanced UVR in these sectors regularly exceeded 60%. In contrast, most field work on this subject has been carried out in the Ross Sea and WAP regions, because of logistical considerations and the routine availability of research vessels.

During IPY, it would be worthwhile to launch an expedition to the most relevant regions indicated by the 20 years of NASA satellite data. The expedition might begin in the WAP region, where there is a baseline of data from the Palmer Long Term Ecological Research (LTER) program. The expedition would proceed into the Weddell Sea during the height of the springtime algal bloom season, and would proceed eastward as far as possible until stratospheric ozone has fully recovered during mid-late December. It may be necessary to use two research vessels to cover the necessary geography in the required timeframe: one starting from Palmer Station and one starting from Halley Bay. This research program would examine species composition, differential photoinhibition among major Antarctic phytoplankton species, repair mechanisms, other relevant biological processes, and would attempt to find a significant impact to the base of the marine food web with the same thoroughness as the ICECOLORS cruise of 1990. By intensively sampling the sectors of the Southern Ocean that have historically been most severely impacted by UV-B enhancements under the ozone "hole," the scientific community would be able to draw unambiguous conclusions about the ozone "hole's" true ecological impact. This would be a major accomplishment for the IPY, given that the Antarctic ozone "hole" provided the first undeniable evidence of humankind's ability to dramatically change the atmosphere (Solomon, 1999).

Arrigo, K. R., D. Lubin, G. L. van Dijken, O. Holm-Hansen, and E. Morrow, Impact of a deep ozone hole on Southern Ocean primary production, *Journal of Geophysical Research*, **108**, doi:10.1029/2001JC001226, 2003.

Farman, J. C., B. G. Gardiner, and J. D. Shanklin, Large losses of total ozone over Antarctica reveal seasonal ClO(x)/NO(x) interaction, *Nature*, **315**, 207-210, 1985.

Karentz, D., Ecological considerations of Antarctic ozone depletion, *Antarctic Science*, **3**, 3-11, 1991.

Lubin, D., J. E. Frederick, C. R. Booth, T. Lucas, and D. Neuschuler, Measurements of enhanced springtime ultraviolet radiation at Palmer Station, Antarctica, *Geophysical Research Letters*, **16**, 783-785, 1989.

Lubin, D., K. Arrigo, and G. L. van Dijken, Increased exposure of Southern Ocean phytoplankton to ultraviolet radiation. *Geophysical Research Letters*, in review, 2004.

Smith, R. C., et al., Ozone depletion: ultraviolet radiation and phytoplankton biology in Antarctic waters, *Science*, **255**, 952-959, 1992.

Solomon, S., Stratospheric ozone depletion: A review of concepts and history. *Reviews of Geophysics*, **37**, 275-316, 1999.

Weiler , C. S., and P. A. Penhale (editors), *Ultraviolet Radiation in Antarctica: Measurement and Biological Effects*, *American Geophysical Union Antarctic Research Series*, **62**, 257 pp., 1994.