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Senator Albert Gore, Chairman

HEARINGS ON STRATOSPHERIC OZONE DEPLETION, April 16, 1991

Total Ozone Loss in the Northern Hemisphere

The new ozone data from the TOMS instrument on the Nimbus-7 satellite, as reported by Dr. Richard Stolarski and his colleagues, provide no grounds for optimism about the global status of stratospheric ozone depletion, nor about the situation directly over the United States. Their measurements and analysis cover the period of operation of the satellite instrument, from November 1978 through May 1990, and decisively confirm and extend the conclusions announced in March 1988 by the NASA Ozone Trends Panel that:

(1) significant ozone loss has been observed over the United States and other countries in the latitude bands northward of 30°N; and

(2) this northern hemisphere ozone depletion is greater during the winter than in the summer.

However, the quantitative information from the new data goes well beyond the analyses reported in 1988 and indicates that extensive southern hemispheric ozone losses have occurred not only in the polar regions with its well-known Antarctic "ozone hole", but also at all latitudes south of 30°S.

While the new satellite data are both startling and ominous in their own right, they do not represent the total ozone depletion which has occurred over the past decades, but only that part of the loss which has taken place since commencement of the satellite measurements in November 1978. The 1988 ozone depletion estimates of the NASA Ozone Trends Panel were based upon the observations taken from the global network of ground-based stations using Dobson spectrophotometers for ozone measurement. Their statistical analysis utilized only ground stations which had continuous records for 22 years or longer, at least from January 1965 through December 1990, and reported significant ozone depletion over the United States during the 17-year period from 1969 to 1986, and that roughly half of these losses had already happened by 1980. The December through March wintertime ozone depletion between 1969 and 1986 averaged 6.2% for the latitude band from 53°N-64°N, 4.7% between 40°N-52°N, and 2.3% in the band from 30°N-39°N. The recorded ozone losses during the other eight months were smaller, but the ozone depletion averaged over all twelve months was still -2.3% for 53°N-64°N, -3.0% for 40°N-52°N, and -1.7% for 30°N-39°N. If half of these ozone losses had already been recorded by the time Nimbus-7 was launched, then the best estimate for total ozone depletion over the past two decades requires recognition that the satellite measurements were not in place when ozone loss commenced. Correction for these earlier losses will add about 2% to 3% to the satellite-recorded data for the winter months from 40°N-65°N. An approximate estimate for the total wintertime loss since 1969 over Canada and the northern half of the United States is therefore about 10%.

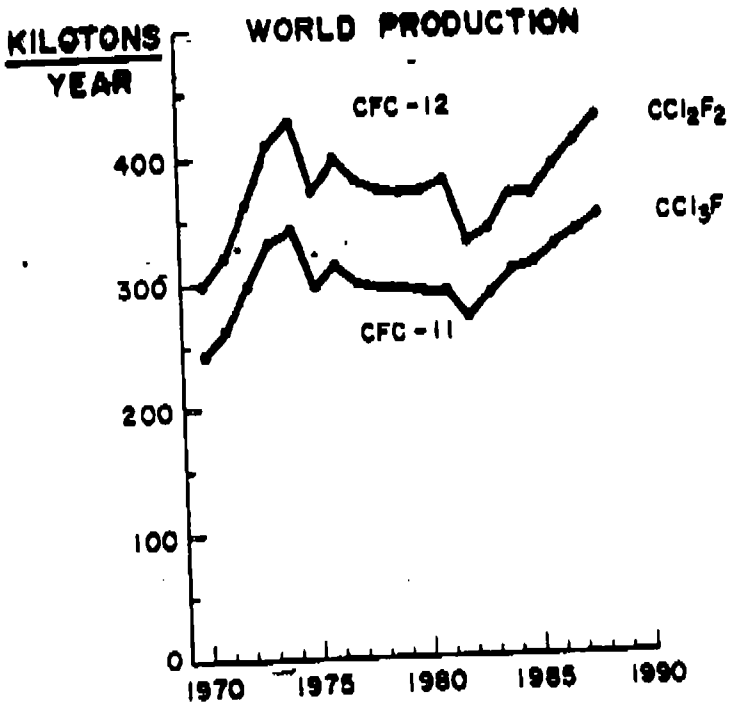
total depletion over the past 20 yrs

Similar comments also apply for the "ozone hole" which reappears every austral springtime over Antarctica. The familiar TOMS "before and after" pictures of the daily ozone distributions for the southern hemisphere begin with the observations from October 1979, the earliest October in the Nimbus-7 ozone record, and end with the most recent data, those from October 1990. While these ozone maps graphically illustrate that very much less ozone existed over Antarctica in October 1990 than 11 years earlier, they substantially underestimate the actual ozone depletion for the south polar region. The original Dobson data of Joseph Farman and his colleagues from the British Antarctic Survey's Halley Bay station showed for 1979 an October ozone average of only 260 Dobson units as compared to an average of about 317 D.U. for the first ten years (1957-1966) of their October observations. Ozone depletion of about 18% had already taken place over Halley Bay, and presumably much of Antarctica, before the satellite measurements even began!

Perhaps the most disconcerting aspects of the new ozone data analysis are that (1) the rates of ozone depletion appear to be accelerating; and (2) the depletion seems to be spreading into the summer months over the north temperate zone of latitudes. The peak rate of ozone loss between 1979-1990 in the satellite data is about 0.8% per year in February/March for latitudes around 50°N, almost double the maximum ozone loss rate found in the ground-based data for the years 1969 through 1986. The earlier analysis by the NASA Ozone Trends Panel had given indications that spring and summer ozone losses (April through August) had crept in and intensified during the 1980s. Ozone depletion has now been observed in the satellite data throughout the year at all latitudes from 30°N-65°N.

Continued Increase in Atmospheric Concentrations of Chlorofluorocarbons

The United Nations conference in Montreal in September 1987 has deservedly received widespread publicity because of the cooperative agreement, now known as the Montreal Protocol, which emerged from that meeting to reduce the yearly emissions of chlorofluorocarbon (CFC) compounds to the atmosphere. The original 1987 pact called for a 20% reduction in emissions by 1994, with a further 30% cut in 1999, both based on CFC emissions to the atmosphere in 1986. A lesser known aspect of these CFC emission scenarios was the continued increase in global emissions during 1987 and 1988 above this base level of 1986. The best estimate of CFC emissions during 1988 (Figure 1) is that they exceeded the 1986 level by almost 16%, with much of the increase caused by the still-growing use of CFC-113 (CCl_2FCClF_2) for cleaning of electronic components. As shown in Figure 1, the "chlorofluorocarbon-stratospheric ozone" problem of the mid-1970s when CFC regulations were first introduced into the global picture was essentially concerned with CFC-11 (CCl_3F) and CFC-12 (CCl_2F_2). By 1991, however, the regulatory problem has expanded to three CFCs, with the yearly emissions of CFC-113 now almost as important as those of CFC-11 and CFC-12. The revision of the Montreal Protocol in London in June 1990 now calls for an essentially complete phaseout of the use of CFCs in the countries of the first world by the year 2000.



* ↑ production of CFC's !!

Figure 1. Global Production of Chlorofluorocarbons 11 and 12

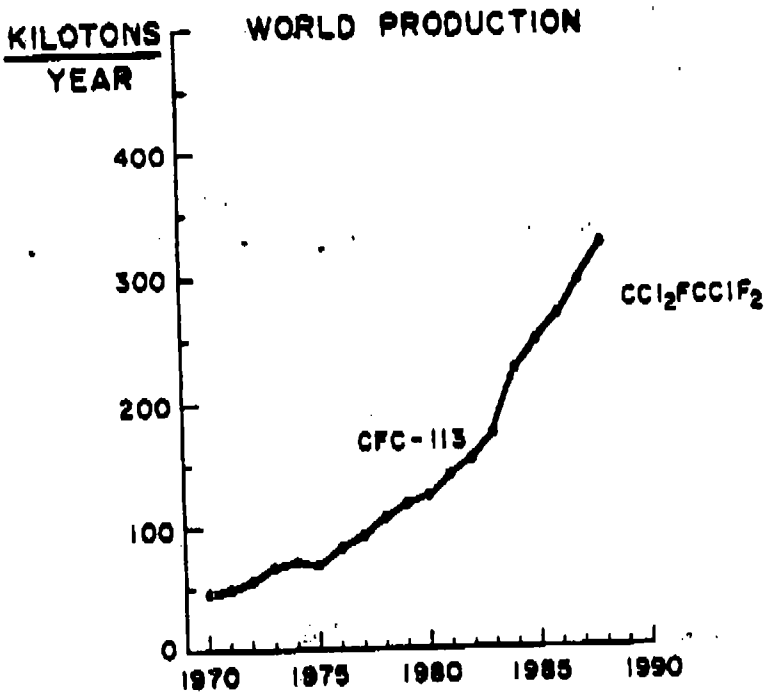


Figure 2. Trend in Global Production of Chlorofluorocarbon-113

In the atmosphere itself, the concentrations of CFC-11 and CFC-12 have been increasing at a steady rate for more than a decade, reflecting the nearly constant emission level for each coupled with their atmospheric lifetimes of many decades to a century or more. The concentration of CFC-113 has been growing very rapidly, as more and more of this compound is used every year on a global basis (Figure 2) with most of it ending up in the atmosphere. The total emission of CFCs to the atmosphere during the five year period 1985-1989, the most recent period for which data are available, is larger than for any other five year period in the past. Although an international agreement now exists for control of the emissions of CFCs, the process of slowing down their use is taking a long, long time, and the total amounts of man-made chlorine in the atmosphere are continuing to grow. The total organochlorine concentration in the atmosphere is now almost 4.0 parts per billion by volume (ppbv), in comparison to about 1.8 ppbv in 1974, 0.8 ppbv in 1950, and 0.6 ppbv at the beginning of the 20th century. While the atmospheric chlorine concentrations have multiplied by a factor of 2 over the last 15 years, and a factor of 5 in the past 40 years, the decline in concentration after the Montreal Protocol is fully in effect a decade from now will be much slower because of the long atmospheric lifetimes for all three of these CFC compounds.

Substitutes for the CFCs are now appearing in almost all of their technological uses, but the process of substitution is a slow one. Often decision-makers are very reluctant to substitute an untested new apparatus for an old-CFC based one which is known to be successful for the local need, even though they are well aware that the CFC will eventually contribute to the depletion of stratospheric ozone. Government regulatory activities such as the current tax on CFCs may need to be strengthened in order to accomplish total replacement of CFCs as soon as possible.

Stratospheric Chlorine Chemistry

The chlorofluorocarbon compounds are quite inert in the lower atmosphere (although very effective as greenhouse gases in while in this unchanged state), but are decomposed in the middle stratosphere by solar ultraviolet radiation from which they are shielded by the ozone layer itself. Once decomposed, the individual chlorine atoms released from the CFC molecule react very rapidly and continually with ozone through a long free radical chain which can remove thousands of ozone molecules without getting rid of the chlorine itself. Two different classes of chlorine chain reactions have been identified in the laboratory and in the atmosphere. In the first, which occurs in the upper stratosphere above the temperate and tropic latitudes, the chlorine chain proceeds in fits and starts, with the chain interrupted after a few hours by alternative reactions with NO_2 to form chlorine nitrate ($ClONO_2$), or with methane to form HCl. While chlorine is chemically located in these reservoir molecules, the chlorine chain is temporarily not operating and no ozone is being lost. However, subsequent chemical reactions release the atomic chlorine, and the chain removal of ozone begins all over again. These alternating processes continue until eventually the chlorine atom, in some chemical form, works its way through the ozone layer into the lower atmosphere, and is rained out as hydrochloric acid.

The other chlorine chain reaction takes place with the assistance of articles in the atmosphere, especially with the surfaces of the polar stratospheric clouds, or PSCs. When the stratospheric temperature drops down as low as -110°F to -115°F (about -80°C), droplets of nitric acid trihydrate (NAT) form, and these in turn serve as the nucleus for the condensation of water ice to form larger drops. These very low stratospheric temperatures are usually associated with polar winter conditions, especially during the long Antarctic darkness, and the PSCs furnish reactive surfaces on which the chemical nature of the gases can be transformed. The nitrogen oxides are almost entirely converted to nitric acid and then incorporated in the cloud particles as NAT. The temporary chlorine reservoirs HCl and chlorine nitrate can react on the surfaces to create molecular chlorine, Cl_2, which is released into the gas phase, and nitric acid which is tied up as NAT. These chemical changes can proceed even in the darkness of polar winter, and leave a system primed to react whenever sunlight penetrates again. With the arrival of solar radiation, the molecular chlorine is destroyed with the release of atomic chlorine which then initiates the polar chlorine chain reaction. In the absence of NO_2, sequestered as nitric acid in the clouds, the chlorine chain removes ozone very rapidly until the PSCs evaporate. In the Antarctic, the very strong stratospheric polar vortex prevents mixing of warmer air from the temperate zone for many weeks, and massive ozone depletion is observed during September and early October. In the Arctic, the polar vortex is not as strong, and the very rapid chain reaction can only go forward for a week or two before the PSCs are dissipated at lower latitudes. However, a succession of air masses can pass through the Arctic polar region, form PSCs, lose some ozone, and move southward. The scientific measurements of the chemistry of the the Arctic stratosphere have clearly shown that the same reactions important in the Antarctic ozone hole are also occurring in the northern polar air.

The strong polar emphasis of the ozone depletion recorded by the TOMS instrument for the northern hemisphere suggests that an appreciable fraction of this ozone loss has originated through the polar chlorine chain, presumably facilitated by PSC formation in the Arctic stratosphere. While the PSCs are certainly implicated in polar ozone depletion, the normal stratosphere in the temperate and tropical zones also contains fine particles of sulfuric acid, and the question is then raised whether these droplets can also serve to initiate the chemical transformations known to occur on PSC surfaces. Laboratory experiments suggest that at least some of these reactions can take place on sulfuric acid particles, making rather probable some reactions of this nature in the temperate zone stratosphere.

Predictions of future ozone depletion can be attempted if all of the pertinent chemical and physical data are available for incorporation into the atmospheric models. The gas phase reactions of the temperate and tropic stratospheric chlorine chain can indeed be rather well described by the atmospheric models, and the ozone loss in the upper stratosphere predicted in a manner consistent with the various measurements. However, the PSC-driven heterogeneous reactions characteristic of the Antarctic and Arctic winter stratospheres cannot be quantitatively described from laboratory data with sufficient precision to permit successful

extrapolation into the future. The apparent acceleration in the rate of zone depletion which is suggested by the new satellite data is particularly noteworthy, because an ozone loss of 5%-6% in a single decade is well beyond the expectations from the temperate chlorine chain alone. Production of chlorofluorocarbons and related molecules is scheduled to continue under the revised Montreal Protocol until the year 2000, and further time delays of a decade or more can be expected for final release of the CFCs into the atmosphere from their various uses, and for transport to the stratosphere. For these reasons, stratospheric ozone depletion is likely to worsen beyond its present levels for another 20 to 25 years before gradually lessening throughout the remainder of the 21st century, and into the 22nd century. Nothing significant can now be done for the CFCs already released to the atmosphere, but efforts need to be intensified to minimize further release of these CFCs to the atmosphere.

Consequences of Stratospheric Ozone Depletion

The absorption of solar ultraviolet radiation by stratospheric ozone has two important physical consequences in the atmosphere: much less solar ultraviolet-B radiation reaches the surface of the earth, and the absorbed ultraviolet energy eventually emerges as a high altitude heat source. This conversion of UV radiation into heat actually creates the stratosphere--the atmospheric region between about 6-10 miles and 30 miles in which the temperature rises with increasing altitude because the ozone heat source exists at its top. With less ozone in the stratosphere, especially in its upper levels, the altitude of the heat source will be lowered, and the temperature gradient of the stratosphere altered. Already, satellite data have indicated a temperature decrease at the top of the stratosphere of 3.1±1.3°F (1.7±1.0°C), consistent with the combined change expected from ozone depletion in the upper stratosphere and from the greenhouse effect of CO_2. (The greenhouse effect is expected to warm the lower atmosphere, but to cool the upper stratosphere.)

With less total ozone in the whole atmospheric column, more UV-B radiation will reach the surface of the earth. This relationship of "less ozone, more UV-B" is so strong and well-established that the ozone data taken with the Dobson spectrophotometer are actually direct measurements of ultraviolet radiation and not of ozone. The Dobson instrument records the ratio of radiation intensity received directly from the sun at two ultraviolet wavelengths. One of these wavelengths is chosen from the UV-A range, and passes through the atmosphere and the stratospheric ozone layer with only minor diminution on its path to the detector. The other wavelength is chosen in the UV-B range, and is substantially reduced in intensity in passage through the ozone layer; the more ozone, the greater the reduction in intensity at this UV-B wavelength, and the smaller the ratio of UV-B/UV-A intensities recorded by the Dobson spectrophotometer. The answer to the frequently asked question, "Has any increase in UV-B been observed to accompany the measured ozone depletion?" is that the increase in direct solar UV-B radiation is actually what was observed. In actual practice, of course, the observation is of the ratio of UV-B to UV-A, but an increase in this ratio without any change in UV-A radiation--most of which always reaches the surface--necessarily means an increase in UV-B.

Some measurements of UV-B intensities at the surface have also been made with a quite different detector, the Robertson-Berger meter. This apparatus measures the total UV-B radiation coming from all directions, and not just directly from the sun. As anyone knows who has managed to receive a tan despite protection against direct sunlight by a beach umbrella, appreciable amounts of UV-B radiation--the cause of human sunburn--reach the skin by an indirect route. Unlike the Dobson spectrophotometer which measures only the radiation received on a direct line from the sun, the Robertson-Berger meter responds to the sum of the direct and indirect solar UV-B radiation. When the R-B meter has been operated in a relatively remote location, as in Australia and in the Swiss Alps, increases in UV-B over the past decade have also been recorded. When operated in urban locations, as has frequently been the case in the United States, the amounts of indirect UV-B radiation received by the instrument can be reduced over a decade if local pollution, including ground-level ozone, has increased over that time. Under such circumstances, the sum of an increased direct UV-B radiation because of stratospheric ozone depletion, and decreased indirect UV-B radiation because of local pollution, can result in little change in the total.

The major impacts of additional UV-B radiation upon humans are located in those parts of the body directly exposed to the sun--an increase in skin cancer, an increase in eye cataracts, and perhaps in changes in the immune system. It should be noted that the UV-B radiation exposure of humans is dependent on the sun's angle, with greater exposure near solar noon, and at latitudes nearer the equator. With the larger ozone losses of the northern hemisphere concentrated toward the winter, the larger <u>percentage</u> increases in UV-B exposure--a 2% increase in UV-B for each 1% decrease in total ozone--will occur at seasons of the year when UV-B exposure in the northern United States is much less than the maximum received during June and July. Humans already have some systems for protection against UV-B, as in the process of tanning in the sun, and these are immediately available if the UV-B exposure is increased substantially during a season when such would not normally take place.

Of course, mankind is not the only biological species at the surface of the earth, and many of these species have been shown by field experiments to be sensitive to UV-B radiation. With significant ozone loss extending into the northern hemisphere springtime, special concern needs to be directed toward biological species which evolve rapidly during a one or two month period in March or April, with larval forms as a possible example. With normal ozone levels and the sun far from directly overhead, such transitional biological forms would not need much protection against UV-B radiation because such exposure could not normally occur. In this situation, the larger percentage increases in UV-B accompanying springtime ozone depletion might cause substantial disruption even though the absolute amount of UV-B radiation is no larger than would be found in the same location in mid-summer. In any event, the biological exposures to UV-B radiation can also be expected to intensify for another 20 or 25 years into the future as ozone depletion reaches its maximum.