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THE OZONE CRISIS

BY SALLIE BALIUNAS

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Executive Summary

Chlorofluorocarbons (CFCs) are said to begin a process that causes a net destruction of ozone in the upper atmosphere. Thus CFCs and related chemicals will be limited in production or cease to be manufactured beginning in 1994. These chemicals have uses in air conditioners, refrigerators, and fire-fighting. There are no inexpensive, safe replacements for the banned CFCs that can be "dropped in" to existing equipment. New equipment will have to be purchased.

Scientific findings do not support an immediate ban on CFCs. Both global and Arctic measurements point to natural factors as the main cause of recent ozone fluctuations. Ozone levels change primarily as a result of natural factors such as ultraviolet output of the sun, oscillation of upper stratosphere winds and El Niño conditions. It appears that ozone levels in the Arctic experienced wide variations before the buildup of CFCs in the atmosphere.

The phaseout of CFCs appears both scientifically unjustified and unnecessarily costly. A short-term cost of $2 trillion due to impending bans and related compounds has been cited. Some $135 billion of CFC-using equipment will have to be replaced. Unfortunately the Montreal Protocol, which bans CFCs over a period of time, contains no provision to slow phase-outs if new scientific information warrants.

THE OZONE CRISIS *

Sallie Baliunas

Dr. Baliunas: Manufactured chemicals such as Chlorofluorocarbons (CFCs) and related compounds are theorized to begin a process that causes a net destruction of ozone in the upper atmosphere. Over time, the erosion of ozone is predicted to allow ultraviolet rays of the sun to reach the ground. In turn, enhanced ultraviolet is expected to cause biological damage.

Based on that chain of reasoning, many CFCs and related chemicals[1] will be limited in production or no longer manufactured starting in 1994. CFCs such as Freon-11 and Freon-12 contain chlorine and are used in air-conditioners and refrigerators; related compounds such as Halon contain bromine and are used in fire suppression.

Does it matter that no inexpensive, safe, drop-in replacements exist for the banned CFCs in those applications? In addressing that question, three topics will be discussed: (1) the scientific measurements of changes in atmospheric ozone concentrations, and their possible causes, especially CFCs; (2) the economic cost of the ban of CFCs and related compounds; and (3) the implication in the scientific facts for the policy decisions.

Ozone and the Stratosphere. Ozone exists in the stratosphere, which is a layer of the earth's atmosphere beginning at 10 to 15 km and reaching up 50 km; the concentration of ozone peaks near 20-25 km. Ozone is a molecule formed when ultraviolet radiation (at wavelengths shorter than 240 nm) from the sun breaks up an oxygen molecule, O_2, into O atoms. One of the oxygen atoms then combines with an O_2 molecule to make O_3, ozone.

Ozone is thickest over the polar regions and thinnest over the equator. It is a trace gas, with a concentration of less than 10 parts per million by volume (ppmv). There are roughly 20,000 oxygen molecules for each ozone molecule in the region of the stratosphere where the ozone concentration is greatest.[2]

Since the 1970s there has been discussion of a possible trend toward ozone destruction in the stratosphere. In 1991, the Administrator of the Environmental Protection Agency, William Reilly, said the ozone decreases were "more serious than we

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* Edited informal remarks delivered by Dr. Baliunas at the May 17,1994 Washington Roundtable on Science and Public Policy.

believed" and deaths due to skin cancer would double in the next 40 years.[3] The reason for the decrease appeared to be that chlorine in the stratosphere, mainly from CFCs, interferes with the production of ozone. Since ozone blocks UV-B radiation (light at wavelengths of 280 to 320 nm, called the "UV-B" spectrum region) from the sun, a thinner ozone layer should mean more ultraviolet rays reaching the earth's surface and, therefore, more skin cancer. The EPA estimated in 1987 that the ban on production of CFCs introduced by the Montreal Protocol would save the U.S. $6.4 trillion by 2075 in reduced costs associated with skin cancer.[4]

The kind of measurements from which those ozone decreases are inferred are shown in Chart 1. The chart shows the ozone abundance measured by satellites, beginning in 1979.[5] The ozone abundances are averaged over the Northern and Southern Hemispheres, from 69°N latitude to 69°S latitude (i.e., excluding the polar regions for reasons discussed below). From 1979 to 1985, the linear trend is roughly a 3% decrease per decade, but note that after 1985 the trend reverses. That is, had the measurements begun in 1985,

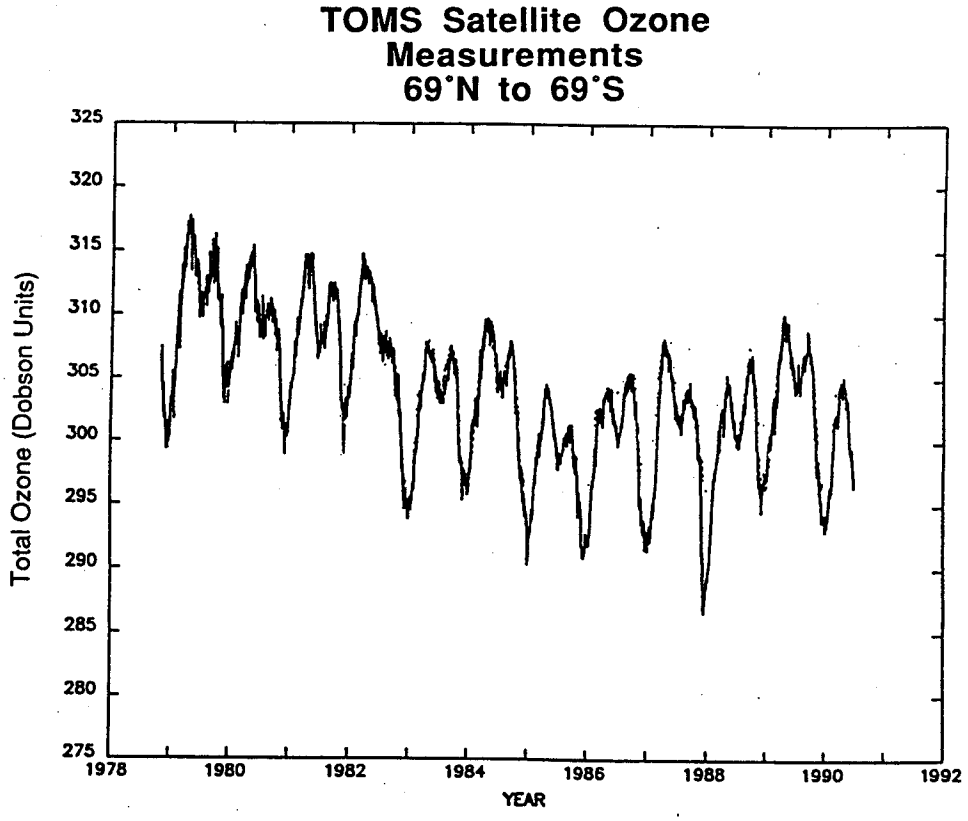


Chart 1

an increase in ozone would have been reported. Since anthropogenic causes are believed to lead only to a decrease in stratospheric ozone, this increase after 1985 must be the result of natural factors. Apparently, natural variations cause much of the ozone fluctuation rather than a secular, anthropogenic decrease.

Chart 2 shows the same data on a scale that is rarely seen — a scale that starts at zero ozone abundance. Chart 2 puts the changes of the 1980s in perspective. On the scale of Chart 2 the 3% per decade decrease in ozone concentration is unnoticeable. It is relevant to note that if you move from New York to Washington, D.C., the permanent decrease in ozone is 6% — twice the change which alarmed EPA Administrator Reilly — because the ozone layer thins toward the equator.

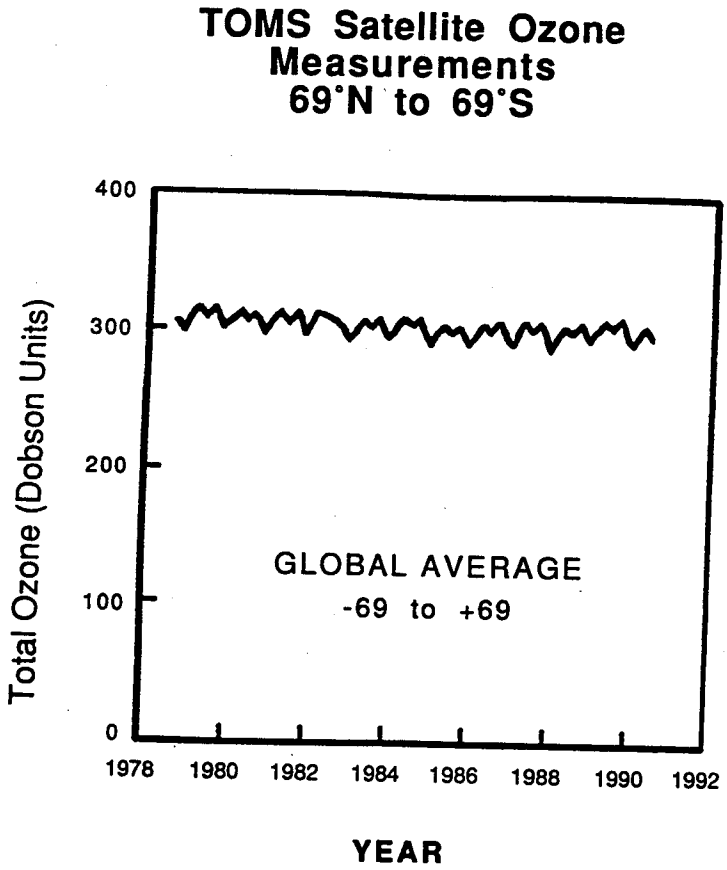


Chart 2

The three million skin cancer deaths by the year 2075 mentioned by the EPA refer to malignant melanoma, a rapidly metastasizing skin cancer that has been increasing ever since the 1930s, long before widespread use of CFCs, and is clearly unrelated to ozone depletion. In fact, epidemiological studies say that melanoma is not readily ex-

plained by long-term exposure to ultraviolet radiation; for example, it occurs on areas of the skin rarely exposed to the sun. In addition, recent studies suggest that melanoma risk is enhanced by long-wavelength light, i.e., UV-A or ordinary blue sunlight, and not by UV-B light.[6] This means that the ultraviolet (UV-B)-blocking properties of ozone can have little impact on the incidence of melanoma. Even apart from questions as to whether ozone is decreasing and UV-B fluxes at ground level are increasing, the EPA warning in 1991 on deaths to due melanoma appears to be without foundation.

Why are CFCs a problem? CFCs, which are chemically inert, diffuse upward to the stratosphere, where some kinds of CFC molecules break up, releasing chlorine atoms. According to the hypothesis of ozone depletion, the chlorine atom interferes with the process of making ozone by grabbing one of the oxygen atoms in the stratosphere. The oxygen atom, instead of combining with an O_2 atom to make O_3, instead reacts with Cl to make chlorine monoxide (ClO). Eventually, the chlorine atoms combine with hydrogen to make HCl and are rinsed out of the stratosphere, but this is thought to take many years.

Measurements show that the natural level of chlorine (Cl) in the stratosphere (0.6 ppbv) increased very roughly by a factor of six (3.6 ppbv) over natural levels, mostly as a result of increased CFC concentrations.[7] This is demonstrated, for example, by the measured increases in in the stratosphere of hydrofluoric acid (HF), probably entirely a by-product of CFCs, and hydrochloric acid (HCl). HCl, however, also has a substantial natural contribution that contributes to the uncertainty in estimating the amount of man-made chlorine in the stratosphere.

Evidence on Changes in the Ozone Layer. According to the theory of ozone depletion, the anthropogenic increase in chlorine in the stratosphere causes declines in ozone. However, the first problem in studying changes in ozone is that the effects of man-made chemicals in the atmosphere usually cannot be described accurately by theories or models of the atmosphere. The reason is that the atmospheric system is too complex to allow predictive power. For example, just the photochemistry of ozone in the stratosphere involves several hundred reactions, many of which are not understood. Hence, most of our knowledge rests on detailed measurements.

The second problem confronting the study of changing ozone levels is how to separate the manmade changes from the natural changes which have been occurring for eons. Unfortunately, there is little direct or indirect information on pre-industrial ozone levels or their natural fluctuations. Measurements of ozone in the upper atmosphere have been made since the early twentieth century, but earlier measurements, up to the 1950s, do

not have the desired accuracy or global coverage. Improved instrumentation produced better quality measurements starting in the late 1950s, although with uneven global coverage. The most accurate measurements, covering most of earth, come from satellite experiments, such as TOMS (Total Ozone Mapping Spectrometer) aboard Nimbus-7, and began in the late 1970s. Such accurate, systematic, nearly full-planet coverage measurements of ozone only span the last 15 years, and may not reveal the full possibility of natural changes over such a short interval of observation.

Consequently, in judging natural vs. anthropogenic change, we must rely on the accurate recent measurements available over a short period of time, or poorer measurements from an earlier era and from a limited number of regions, which may add large systematic errors to the comparison. Both options have risks.

What do the measurements say? In order to answer that question, stratospheric ozone will be divided into two geographical zones — the polar regions and the rest of the world — because the changes in ozone are different in the two regions. First "the rest of the world" will be considered, since this is where most of the human population lives.

Global Ozone, Excluding the Polar Areas. Again we turn to the measurements from satellites, which yield the most accurate and widespread monitoring. Chart 3 (p. 6) shows the geographical distribution of ozone in the stratosphere, looking down at the earth, from 1978 until 1993.[8] This chart is packed with information, since it contains daily measurements, averaged over zones of latitude. The first important result is that the coverage of the earth by the ozone layer is uneven. The ozone blanket at high latitudes is much thicker than at latitudes near the equator. The second result is that the thickness of ozone varies enormously over a year, based mainly on the season. Over Washington, D.C., for example, the seasonal change in ozone abundance is roughly 20%. Large seasonal variation is normal for the ozone layer.

Now look more closely at the record. One peak or trough in seasonal ozone abundance is different from the last. That is, there are large, year-to-year variations in addition to the seasonal changes within a given year. As a consequence, it is difficult to discern a smooth, decreasing trend in the ozone record.

The difference between one peak or trough and the next has several causes: changes in global weather patterns at intervals of 2 or 3 years, the occurrence of El Niño events every 3 to 4 years, the eruption of volcanos such as El Chichon in 1982 and Mt. Pinatubo in 1991, and changes in the ultraviolet output of the sun on roughly a 10- to 11-

TOMS Satellite Ozone Measurements 1979 - 1993

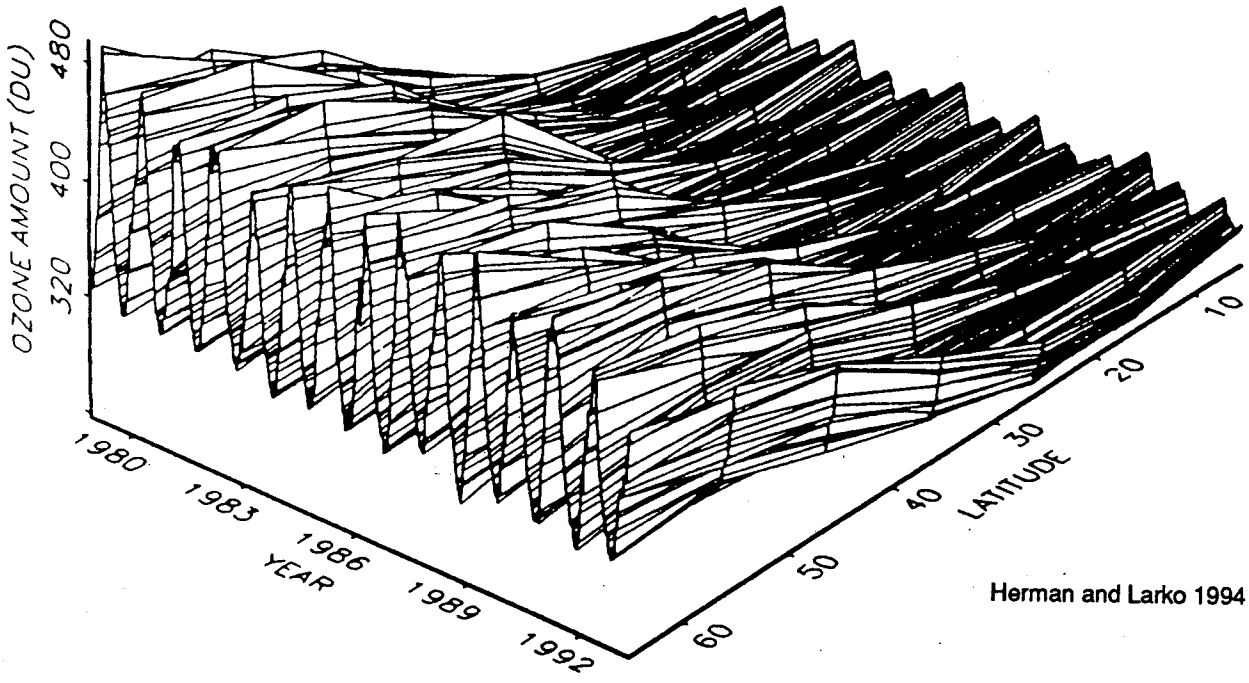


Chart 3

year interval. It is important to emphasize that ozone is produced by solar ultraviolet radiation: if there were no solar UV, there would be no ozone. Since solar UV flux rises and falls with the 11-year cycle of sunspots, ozone concentration should do likewise. Indeed it does.[9] (Chart 4, p.7).

Also important to address is the effect produced by volcanos causing temporary ozone declines, which has been debated for years. Mt. Pinatubo, with its massive, June 1991 eruption, indeed caused a decrease in ozone levels worldwide of 2-4%.[10] Earlier debate often had focused on chlorine (derived from HCl) from volcanos as a possible source of ozone loss, and whether enough volcanic HCl is injected into the stratosphere to cause significant depletion. However, it appears that sulphur dioxide may be more important in volcano-caused ozone depletion. Whatever the cause, study of the ozone abundance after the Mt. Pinatubo eruption demonstrates that volcanos do temporarily lower ozone levels. But a few years after the eruption, the effect of a volcanic eruption in lowering ozone should disappear.

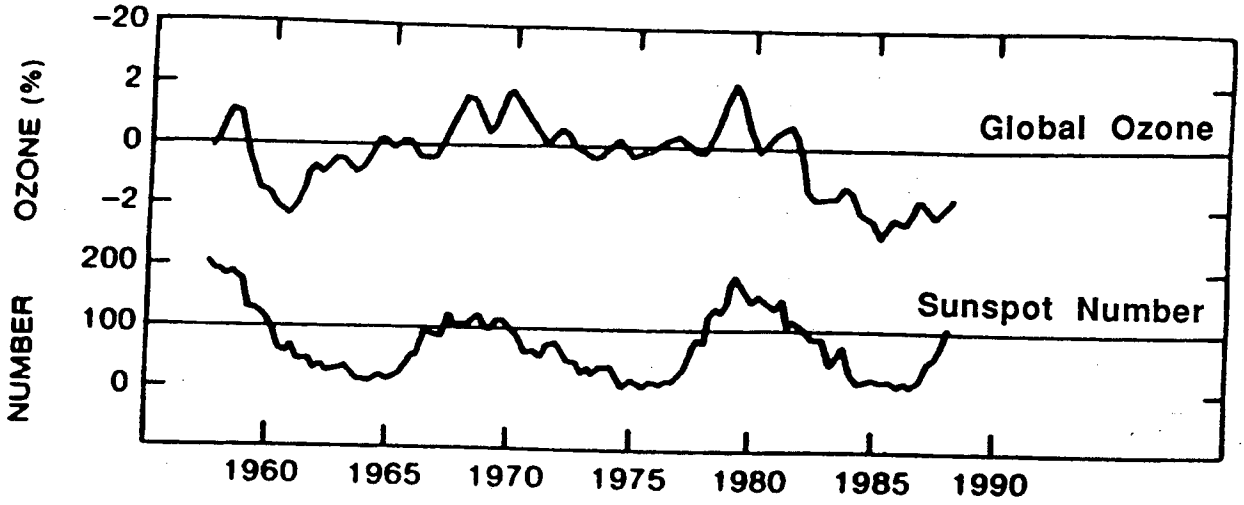


Chart 4

All those known natural effects must be removed in order to judge the manmade trend that is left. But it is doubtful that they can be removed accurately, since they vary by unknown and unpredictable amounts from year to year. The decline of ozone concentration excluding the polar regions has been estimated to be 3% per decade.[11] This figure was arrived at on the basis of satellite measurements. This is essentially the same as the trend quoted by the EPA. But the trend obtained from the data strongly depends on the years chosen as the beginning and endpoints of the analysis, and so is not, statistically speaking, robust.[12] As noted, the correction for natural fluctuations is subject to large, systematic error of the subtracting process. Essentially, zero manmade trend is possible, given the large magnitude of the natural fluctuations in the data. The problem is the subtraction of all natural causes of change, which cannot be done to a useful degree of accuracy. In fact, the World Meteorological Organization concluded in 1991, "There is not a full accounting of the observed downward trends in global ozone." [13]

The problem of natural fluctuations in the ozone layer can be underscored by looking at the earlier records that extend the time interval beyond one solar cycle. (Chart 4) Especially note in Chart 4 the very low levels of ozone in the early 1960s, as low as current levels. At that time, the impact of manmade chlorine from CFCs was trivial, so the drop must be due to natural causes, as yet unidentified.[14] Some scientists suggest long-term changes of the UV output of the sun, which is theoretically plausible. But no direct measurements exist to test the possibility of solar UV changes over 30 years.

Whatever the downward trend in ozone concentration is, the increase in UV-B light that is supposed to accompany it has not been observed. (Chart 5, p. 8) Ultraviolet B either *decreased* or *did not change* at ground level in the continental U.S. between 1974

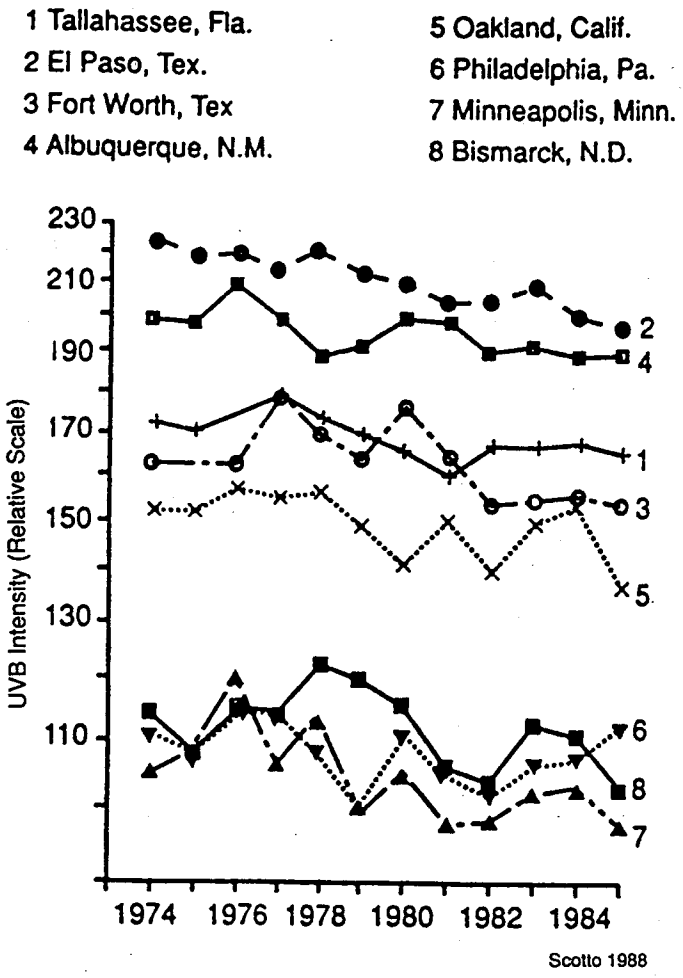


Chart 5

and 1985,[15] after which the measurements were dropped for lack of funding. And while the UV was falling, the ozone levels showed a decline in the same interval. Some argue that ground-level pollutants have blocked the supposedly increasing UV caused by declining ozone levels. However, since the Clean Air Act of 1970, U.S. pollutants, especially sulfates and aerosols, have also been *declining* and so cannot explain the decline in UV-B at ground level.

One of the only other systematic UV-B studies is from Toronto.[16] Although the UV-B observations are of excellent quality, they cover only a very short interval, 1989 - 1993. The conclusion from the Toronto data of an increasing trend in UV-B, coincident with declining ozone over the interval, has been criticized because the interval is too short to provide a reliable trend.[17] When the analysis is correctly done, the four years of data show no significant increase in UV-B in Toronto.

Apparently, ozone changes in the inhabited portions of the world are primarily the result of large natural fluctuations caused both by the changing ultraviolet output of the sun, and by meteorological conditions mostly related to the quasi-biennial oscillation of upper stratosphere winds and El Niño conditions. As yet, no convincing evidence suggests an anthropogenic crisis in declining ozone or increasing UV-B radiation over most of the world. Unfortunately, little systematic monitoring of UV-B fluxes, whose increase is alleged to be the danger of declining ozone, is underway.[18]

Antarctic and Arctic Regions. On February 2, 1992, NASA held a press conference to announce that an ozone hole was about to open up over North America's populated areas, or as the press reported, over the President's family summer home in Kennebunkport. At the time, high levels of ClO, a molecule that forms in abundance as a precursor associated with the sharp ozone decline in spring in Antarctica, had been found by NASA near the Arctic. However, the ozone hole never developed.[19] Some scientists have speculated that NASA scientists knew that another condition necessary in creating the antarctic ozone depletion, namely, sustained cold air in the stratosphere, was not present at that time, and that ozone depletion was therefore impossible. When the hole didn't develop, NASA on April 30 quietly retracted its earlier press release, but not before new restrictions on CFCs has been adopted by Congress. Interestingly, the first press conference occurred during the time Congress was considering NASA's budget.

Let's review the situation in the antarctic.

The ozone record is quite different in Antarctica than in the rest of the world. In 1985, scientists announced that ozone in the lower portion of the stratosphere had dropped to low levels every spring since the mid-1970s. The popular and scientific name, "the ozone hole," is hyperbole. The ozone does drop to extraordinarily low levels at some altitudes nearly every spring, with a trend that seems to have leveled off in recent years (with the exception of Mt. Pinatubo's additional suppression of 1991 - 1993 values), but the total ozone never disappears completely (Chart 6, p. 10) and recovers to its previous historic levels within a month or so.

The dramatic antarctic ozone declines so noticeable through the 1980s are a temporary annual event.

The cause of the antarctic phenomenon seems best explained by the extreme cold of the antarctic winter, inside the frigid, sunless isolation of the stratosphere's polar vortex. The prolonged cold "activates" chlorine into its ozone-depleting form, and allows ice clouds to form and remain. As the sun rises in late September, it provides the UV

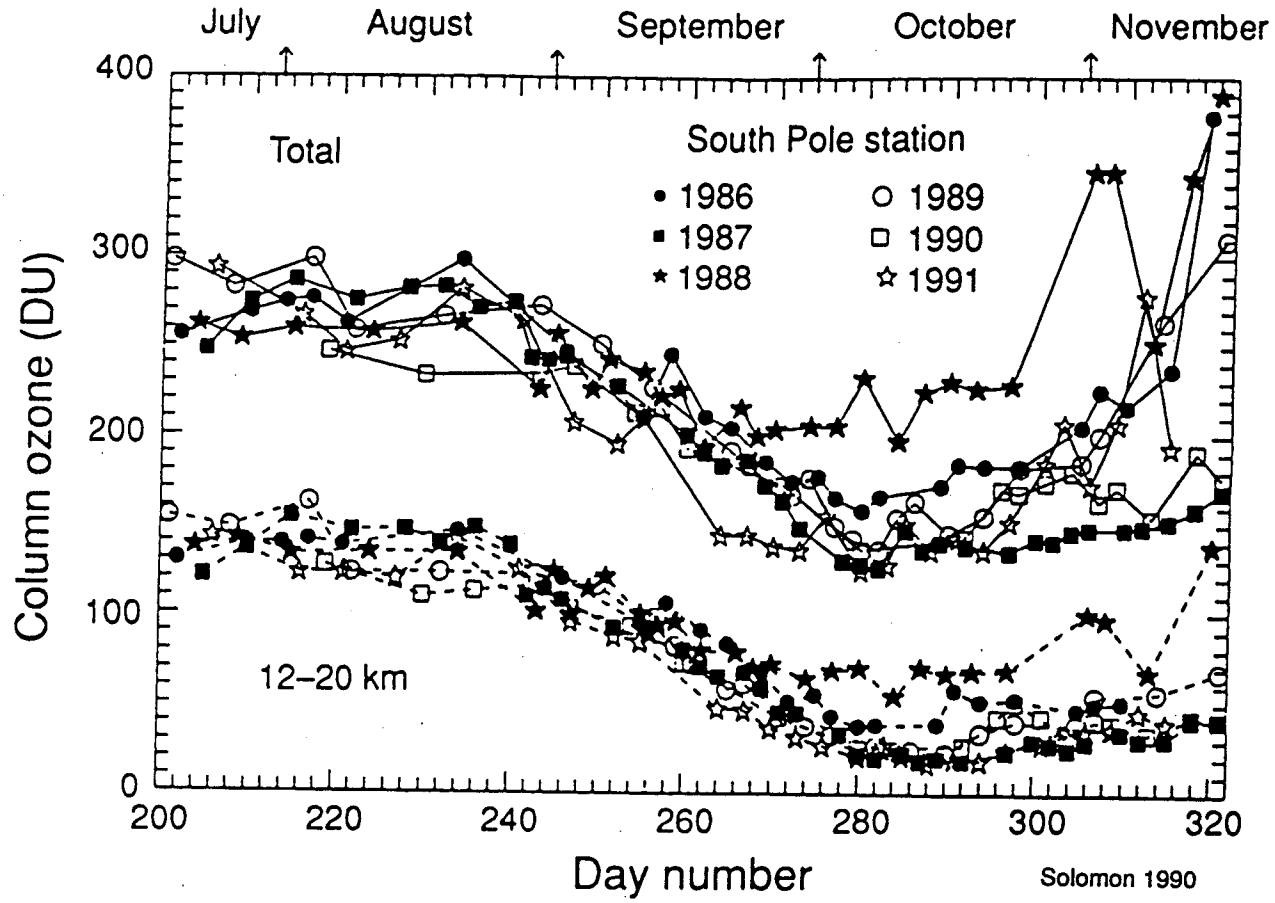


Chart 6.

as the final ingredient needed to temporarily remove ozone. However, in late spring the temperature rises, removing the unusual chemical and meteorological conditions needed for dramatic ozone loss. Ozone then recovers.[20]

As for the biological effects of increased UV-B in Antarctica due to the ozone decline, no measurements exist over any appreciable interval, so the increase in UV-B must be based on *theoretical calculations*. Although the October ozone loss is large, the sun is barely above the horizon, so the slanting rays of sunlight are weakened as they pass nearly horizontally through a thick layer of air. According to the calculations, even at the depth of the October ozone loss, the UV-B dose is barely 1/15 that experienced at the equator.[21]

The lesson from the Antarctic and the Arctic is that the cold conditions within the polar vortex necessary for the temporary ozone decline do not occur in the Arctic. That is, the phenomenon of the antarctic ozone hole will not occur in the Arctic.

As in the case of global ozone, the length of the record in the Arctic is critical in establishing the existence and amount of anthropogenic decline against the backdrop of natural change. For example, measurements of ozone from Trømso, Norway (70°N

latitude) have been made since 1935.[22] The Trømso record agrees with other measurements of ozone in high Northern latitudes where there is overlap. The agreement suggests that the Trømso measurements provide a record of springtime ozone valid for the Arctic. Two important results from an analysis of that record are large changes from year to year and the lack of any significant, recent decline. Fluctuations from the mean include a 15% ozone depletion in the early 1950s, long before the buildup of CFCs in the stratosphere; a sudden increase of 15% in the early 1940s. Those fluctuations must have been produced naturally. And indeed, last winter's arctic ozone actually *increased*, instead of undergoing its usual seasonal thinning.

Economics. The preamble of the 1987 Montreal Protocol states that "... measures taken to protect the ozone layer from depletion should be based on relevant scientific knowledge, taking into account technical and economic considerations ..."

The production of Freon will soon cease (end of 1995), and remaining stores will be available for use, although at a highly taxed cost. Yet the substitutes promised by the Protocol's advocates, with attributes of "drop-in, safe and inexpensive," do not exist. The drop-in replacement for Freon-12 in automobile air-conditioners does not exist. SUVA (HFC 134a) must be placed in a new system, or one thoroughly purged of Freon-12. It is more expensive than the pre-tax cost of Freon-12, less efficient, and reportedly quite corrosive, so that a new compressor will be needed every 2-3 years. It is neither a drop-in nor a cheap replacement. As for safety, the EPA claims SUVA is safe, although it is flammable at high temperatures. Conversions of cars reportedly range in cost up to $1,000, but the parts are unavailable for older cars. To complicate the economic impact further, HFCs like SUVA are chlorine free, but are strong greenhouse gases, and may be phased out for global climate change considerations.

Freon in refrigerators is the same story; no drop-in replacement exists, so new equipment must be purchased. A new type of German refrigerator uses propane and butane; another uses pentane. The old standbys ammonia, sulphur dioxide and ether vapor are also available for refrigeration. But each is toxic, flammable or explosive, and U.S. manufacturers may decide not to use those replacements because of liability risk.

Bromine is another chemical now implicated with chlorine in ozone depletion. Methyl bromide has a large ozone-depleting potential, but a short lifetime in the atmosphere. Nevertheless, production levels will be frozen by 1995. Methyl bromide is widely used as a crop fumigant and is critically important to agriculture.

Production of Halons, a family of bromine chemicals, was banned earlier

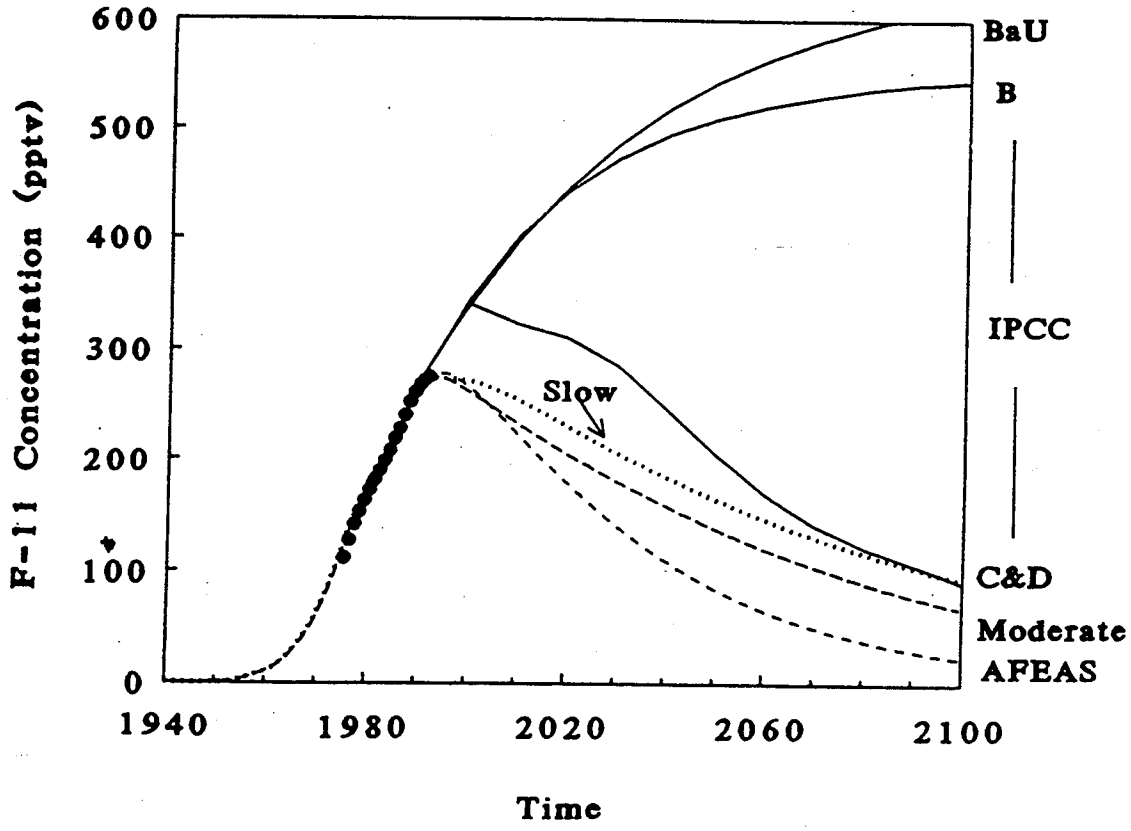
this year. The halons are important in firefighting, especially in smothering a fireball and leaving equipment undamaged, e.g., fighting vehicles, rockets, aircraft, ships, and utility plants. Halon has many virtues. It is nontoxic, lightweight, highly compressible, noncorrosive, nonconductive, chemically stable, and non-destructive to electronic and mechanical equipment. We are now working with stockpiled halon; there is no comparable replacement.

Another group of alternative compounds, HCFCs, have less ozone-depletion potential than CFCs and are used in many home and building air-conditioners. However, because the HCFCs still contain chlorine, they will be banned from manufacture by 2020.[23]

Most of the nation's food supply and many medicines require refrigeration and so depend on CFCs. Some $135 billion of equipment in the U.S. which uses CFCs will soon need to be replaced.[24] Last year, House Resolution 547 cited a short-term cost of $2 trillion dollars to Americans because of impending bans on CFCs and related compounds. A thorough study of the cost of the ban of chlorine and bromine chemicals is difficult to find. Part of the reason may be that the industrialists, environmentalists and regulators behind the Montreal Protocol and related instruments have produced a cartel for the production of CFCs and their replacements, and none has an interest in revealing the cost of the ban.[25]

Policy. Serious consideration should be and is being paid to the state of the ozone layer by detailed satellite, ground and *in situ* measurements of the stratosphere. If declining ozone means increased biological danger from increased UV-B, then serious systematic study of the ground-level amounts of UV-B must also be undertaken.

Unfortunately, the example of the policy planners' response to Mt. Pinatubo's temporary effect on ozone is not encouraging. At the Montreal Protocol's follow-up meeting in Copenhagen in November, 1992, the temporary decrease in ozone which was caused by a volcano was given as an argument to ban production of additional chemicals and speeding phase-out of previously targeted chemicals, because "... as in many years throughout the history of the ozone layer issue, scientific findings sparked the political process." [25] This is a reference to the "flexibility" of the Montreal Protocol in responding to new scientific information. But that flexibility is apparently in only one direction. The Protocol contains no provision to *slow* phase-outs if new scientific information warrants. For example, one study finds that Freon-11 will, sooner than expected, be declining in atmospheric concentration.[26] (Chart 7, p. 13) But there has been no initiative at the policy level, to my knowledge, to modify the Protocol with respect to Freon.



Kahlil and Rasmussen 1994

Chart 7

The policy decisions that have been made in regard to the ozone layer are portrayed as overly cautious in order to err on the side of "safety." Such policy logic is called the Precautionary Principle, which, roughly translated, is a dictum to do no harm in the absence of knowledge about certain safety.

If the economic burdens associated with environmental action were trivial, then policy decisions made in accordance with the Precautionary Principle would be easy. But the costs of decisions can be very great. And the policy decisions, once made, are apparently irreversible.

The Precautionary Principle introduces a notion that destroys the scientific basis of policy debate. The Precautionary Principle says no human action will be allowed unless it is *certain* that it will cause no harm. This is antithetical to science, in which full certainty can never be achieved. A successful outcome for the test of a scientific theory is achieving *less uncertainty*, but never reaching the mythical nirvana of full certainty. This is the irreducible nature of science. Demanding full certainty is anti-scientific because certainty is impossible in the real world. So the Precautionary Principle, as a basis for the formula-

tion of environmental policy, is the denial of science.

The inseparable obverse of the Precautionary Principle is: given any theoretical possibility of harm, no matter how great the uncertainty in the theoretical estimate, we must take action to prevent that harm. Therefore, full and open discussion of the uncertainties of a theory must be censored because such debate may provide an excuse for policymakers to delay action while accurate information is obtained. That means that even if a policy of "wait and see" is based on the best available *scientific* information, and is the best *economic* policy, it is not an appropriate *environmental* decision. Thus, policy made in accordance with the Precautionary Principle is conveniently divorced both from the scientific facts and from the economic consequences of environmental action. The following comment sums up this "new-age science."

> "...[A] governing authority is not obliged, before regulating a particular substance, to prove conclusively either that it modifies the stratosphere or that the consequences are dangerous to health and the environment. All that is required is a standard of *reasonable expectation*." (R.E. Benedick 1991, p. 24)

Note the hypocritical treatment of scientific uncertainty in the Precautionary Principle's approach to policy. The conclusions of a theory, no matter how unreliable, can initiate policy action. However, the hallmark of science — the critical testing and determination of a theory's uncertainty — is forbidden. And some of this environmental "always do something" urge has now been codified in attendant legislation to the Montreal Protocol. For example, *The New York Times* recently reported the EPA's first successful prosecution under the ozone protection law: a car mechanic in St. Louis let Freon-12 leak into the air.[27] The mechanic can be fined up to $250,000 and sentenced to up to 5 years in prison. The mechanic was turned in by a former employee. Not reported in the *Times* is that the EPA offers a $10,000 bounty to any "concerned citizen" who reports an alleged violation of freon releases from car air-conditioning which is successfully prosecuted.

The economic costs and benefits of the phaseout of CFCs are rarely weighed and never seriously considered, although lip service is paid to them. For example, according to a recent study, [27] only 1.5% of Freon-11 is in refrigerators compared to that already in the atmosphere, so the costly program of recycling Freon-11 from refrigerators will not benefit the ozone layer.

In summary, there is no observed change in global ozone concentrations that is outside the bounds of natural variability. There is no scientific merit to the claim of an ozone crisis or UV catastrophe. Building on a case without scientific justification, poli-

cymakers have put in place restrictions on CFCs that are bound to be extremely costly in lives and dollars.

Discussion

Q: Although NASA seems to be using ozone and atmospheric measurements from the shuttle flights, will this data eventually be made available to people who are qualified to interpret it, or will it be sequestered and then statistically jiggered around to support the ozone depletion theory?

Dr. Baliunas: NASA eventually published its data showing there was no ozone hole over Kennebunkport in 1992. It appeared in *Nature* (See Endnote #19). The article did not mention the press conference results which they had retracted quietly April 30th, 1992. NASA publishes data from satellites in the peer-reviewed literature. They also make them available over the information superhighway — we all can download them and work on them.

Q: I'm wondering about the lack of funding to measure UV. It reminds me of EPA's current stance toward asbestos. EPA says you shouldn't measure the levels of asbestos in schools. You should just remove the asbestos. When people did measure it, they found nil. Now, I'm wondering whether ozone isn't a similar issue.

Dr. Baliunas: I don't know why the program was cancelled, except the official word was lack of funding. Some of the important questions we need to ask are: What is the intensity of UV-B at the ground level? What are the biological effects? Is this the worst problem facing humanity; or is it not that bad a problem? Where should we put our limited resources?

Q: What is the current situation in replacing CFCs in car air-conditioning systems?

Dr. Baliunas: In Massachusetts, many gas stations can still service car air-conditioners. The mechanic must be certified by the EPA, must be retrained at intervals, and have EPA-certified equipment, which the EPA tests periodically. My mechanic said the equipment cost him $4,000. The mechanic hooks up your car's air-conditioning system to the EPA-certified equipment, which vacuums in any loose freon molecules in order to reuse them and prevent their escape to the atmosphere. The mechanic is licensed to buy only a certain amount of freon, an amount which the EPA checks. My 1978 car over the years has devel-

oped pinhole leaks in the hoses and in the seals, and is therefore not 100% certifiably leak-free. On legal advice, my mechanic cannot recharge my car, because he is afraid he will be accused of improperly servicing the air-conditioner, which is punishable by large fines. Thus, he must certify that a car is leak-free before filling its air-conditioning system.

Freon 12 costs approximately 50¢ per pound to manufacture and now is taxed at something like $9.50 per pound. So, the cost is $15 a pound, retail. Auto parts stores used to sell a can of freon for $1.98. A visit to the mechanic is now upwards of $100, just to have the system checked. Freon, parts and labor are additional.

When the freon supply runs out, you will not be able to do even this. On the other hand, black-market freon is selling illegally for about $9 per pound in New Jersey.

One can think about retrofitting a car to use SUVA, but I've not yet found anybody who can do that for my 1978 car. SUVA is less efficient than Freon, and mechanics warn that a SUVA system will not chill as well. A SUVA air-conditioner runs at a higher pressure than Freon, and at the very least, all hoses, fittings and gaskets must be upgraded to prevent explosion. In fact, I have found no mechanic who is unconfused enough to do the changeover. One will have to do without air-conditioning or buy a new car with a SUVA system already built in. I'm told the expense of keeping up an air-conditioner charged with SUVA will be a lot higher than we're used to, because this new replacement chews up the compressor every couple of years.

Q: Did Dobson discover an ozone hole in 1958? Could you explain this controversy, and whether or not it has any significance?

Dr. Baliunas: Dobson measured some low values, although not as low as what we would call the ozone hole today. One of his colleagues, Nicolet, claims that when Dobson saw extraordinarily low levels from Halley Bay, he threw them out. But that claim has so far not been substantiated. Other very low readings made by the French in 1958, and recently reported, have been questioned. So, there is no evidence that there was an ozone hole back then. But there is no evidence that there wasn't. The measurements really are uncertain.

Q: I am troubled about the natural sources of chlorine- and bromine-bearing compounds. Marine sources are huge, and volcanoes contribute as well.

Dr. Baliunas: The natural levels do appear to be about 0.6 parts per million by volume with some indeterminacy of chlorine in the stratosphere. You can look at the increase in chemicals like HCl and HF in the stratosphere in concert with the buildup of CFCs in the

lower atmosphere. That would suggest that a manmade component is showing up in measurements of HCl. The evidence does point to chlorine in the stratosphere, mostly from CFC sources. Anybody want to add to that?

Q: As far as I know, there's no evidence at all for bromine increases in the stratosphere. It is very difficult to measure, which suggests that there is so little that we shouldn't have to worry about it.

Q: With respect to methyl bromide, EPA published some data in the *Federal Register*, which, if we accept it, indicates that methyl bromide is not a problem. In essence, they say that the natural sources are much larger than the manmade sources. The *Federal Register* article also stated that the lifetime of methyl bromide is only two years. CFCs have a lifetime on the order of 100 years, which allows them to stay long enough in the atmosphere to leak into the stratosphere. With a lifetime of two years, only a very small amount of bromide may get into the stratosphere. And if the lifetime really is only two years, and methyl bromide turns out to be a problem, one can immediately take action, and in two years the stuff is gone. You're not committing your children and grandchildren to a methyl bromide future, as we are being told about CFCs.

Q: I wanted to ask you if there is any organized attempt to refute or rebut that first NASA news conference about the ozone hole, and I'd like to know if you're aware of any effort to do so the next time this thing comes up.

Dr. Baliunas: It's difficult to rebut a press conference, because one is told that the results are not in the peer-reviewed literature. It's up to the media to seek out sources to discuss the other side of this issue.

Q: Is it possible that the credibility of the environmental movement is so tied up in the ozone issue that no matter what data you come up with, they're not going to accept the results? Michael Oppenheimer said recently on *Nightline* that if the public is led to believe they can't believe us on ozone, then they're not going to be able to believe us on anything. After Alar and acid rain, and some other things ...

Dr. Baliunas: There are statements by scientists like Professor Schneider at Stanford University, that scientists have to draw a line between being effective and being right. That's pretty scary. I don't think there's a line at all for scientists in that regard; one must be effective *and* right. As for environmentalists losing their credibility, it's the public who ultimately supports them with contributions and it's the public who ought to be educated about what it means to support them in these matters.

Q: If I'm understanding you correctly, current ozone policy has been based completely on data that has been either retracted or shown to be false, and the only thing driving or keeping the current policy is the unwillingness to go back and reform policy based on current scientific information?

Dr. Baliunas: Part of your statement, that the data have been proved false, is not accurate. The recent data are real and they are reliable. The question is the interpretation of those data. If you look at Charts 1 and 2, which show the same data but on two different scales, one gets two very different impressions. If you look at Chart 1, as the EPA did, you might say, oh, my goodness, look at that large decline in ozone. Yet, say they had started their monitoring program in 1985 — you'd say, there's not too much to be worried about because ozone *increased*. On the other hand, Chart 2 is not alarming at all. It's the interpretation that is critical, but the data are good.

There is no *scientific* reason for the current policy. And there is no economic reason to have policy that is inflexible and irreversible.

The other part of your statement involves what I call momentum to revisit these questions. For example, Dupont has no interest in remanufacturing a chemical for which they no longer have a patent, that's incredibly cheap and is not profitable for them to recreate.

Q: Also the people who manufacture the refrigerators, the air-conditioning equipment and so forth.

Dr. Baliunas: That's right, and these equipment manufacturers have to make these decisions on a timescale of 10-20 years. They don't want to make something and then have to discard their manufacturing plant in 5 years.

The CFC phaseout is all small change compared to carbon dioxide limits or a carbon tax for global warming problems. But CFC policy is looked at as the model of how to make policy. The Montreal Protocol was used as a model for the Rio treaty and looked at as a model of how to convince policymakers to act on environmental hypotheses.

The Rio Treaty, which the U.S. and 50 other countries signed, and is now in effect, says that we are going to limit not greenhouse gas emissions, but *concentrations* in the atmosphere. What the Rio Treaty defines as "concentrations" includes both natural and manmade, even though manmade is a very small component. But "we are trying to stabilize those concentrations" means that we must cut our *emissions* by 80%.

Q: HCFC-123 has not been omitted although it causes, or has caused in tests, benign tumors in male rats. But EPA says people are not rats.

Dr. Baliunas: Which is contrary to what they say for any other test. In this case, people will be guinea pigs, but not rats.

Q: What does your study of the sun tell you about the future of the ozone layer? In other words, the argument is that, because of the ban on CFCs, we will see an increase in the ozone level, and then any increase in the ozone level will appear to be a result of the ban, not natural forces. In fact, President Clinton, in a message to the Senate recently, said scientists discovered in late '92 and early '93 that global levels of protective ozone reached the lowest concentrations ever observed. They also could foresee an end to the decline in the ozone layer, that "... reduced use of ozone destroying chloroflurocarbons would allow ozone quantities to increase again about the year 2000, and gradually return to 'normal' ."

Dr. Baliunas: Ozone does go in step with the solar cycle. This is not the only component of change, as I pointed out. If the stratosphere were to warm up, I think, we would see less depletion in the antarctic. What could cause the temperature changes — who knows?

I can't predict what the sun's output will be. It may, in fact, go to historically very low levels of ultraviolet in the next 50 years. That is, in fact, my best prediction, based on looking at longer records of the sun's activity back through time, and that may mean less ozone even than now, from natural causes. But predicting the behavior of the sun a week ahead is just about on as good a footing as predicting the weather in Boston a week ahead of time.

Q: Regarding Mt. Pinatubo: most recent estimates of HCl from that eruption run about 2 million tons and 20 million tons of SO_2. The HCl has not been talked about much.

Q: And the usual argument is that the HCl doesn't reach the stratosphere because it's water-soluble and therefore scrubs out in rainwater. They also use the same argument to discredit inorganic chlorides as the source of the chlorine up there — they claim they get scrubbed out in the rain.

Q: Viewed in the perspective of the geologic past, the Pinatubo eruption is small change. We've had eruptions 100 times as large, which must have released tremendous amounts of chemicals into the stratosphere.

Dr. Baliunas: No matter what the effect, look at the ozone concentration after a volcanic eruption. You can see ozone did change, so you know volcanos do have a signature, no matter what the mechanism.

Dr. Salmon: If there are no other questions, I'd like to thank Dr. Baliunas for this very interesting, stimulating talk.

ENDNOTES

1. Contrary to assertions in the popular literature and classroom material, the use of CFCs as propellants in consumer products such as hair spray has been banned since 1978, and Styrofoam® coffee cups contain no CFCs.
2. See *Exploring the Atmosphere* by G.M.B. Dobson (Oxford: Clarendon Press, 1968), Chapter 6, "Ozone in the Atmosphere."
3. *The Washington Post*, October 23, 1991, p. A3. See also R.E. Benedick, *Ozone Diplomacy* (Cambridge, MA: Harvard University Press, 1991), p. 21.
4. *Assessing the risks of trace gases that can modify the Stratosphere* (Washington, D.C.: EPA, 1987), 7 Volumes; and *Regulatory Impact Analysis: Protection of Stratospheric Ozone* (Washington, D.C.: EPA, 1987), 3 volumes.
5. Herman, J.R., R. McPeters and R. Stolarski, *J. Geophys. Res.* **96**, 17,297 (1991).
6. Studies of mice show that sunscreens blocking UV-B radiation do not decrease the risk of melanoma (Wolf, P., C.K. Donawho and M.L. Kripke, *J. Nat. Canc. Inst.* **86**, 99 [1994], "Effect of Sunscreens on UV Radiation-Induced Enhancement of Melanoma Growth in Mice"). Studies of fish indicate that melanoma is induced by wavelengths longer than UV-B light (from UV-A [at wavelengths 320-400 nm] to 436 nm [blue light in the visible]) (Setlow, R.B., E. Grist, K. Thompson and A.D. Woodhead, *Proc. Nat. Acad. Sci. USA* **90**, 6,666 [1993], "Wavelengths Effective in Induction of Malignant Melanoma").
7. Waters, J.W., *Engineering & Science* **Summer 1993**, 3 (1993), "The Chlorine Threat to Stratospheric Ozone."
8. Herman, J.R. and D. Larko, *J. Geophys. Res* **99, D2**, 3,483 (1994), "Low Ozone Amounts During 1992-1993 from Nimbus-7 and Meteor-3 Total Ozone Mapping Spectrometers."
9. Angell, J.K., *J. Climate* **2**, 1,404 (1989), "On the Relation Between Atmospheric Ozone and Sunspot Number."
10. Prather, M., *J. Geophys. Res.* **97**, 10,187 (1992), "Catastrophic loss of stratospheric ozone in dense volcanic clouds;" Gleason, J.F. et al., *Science* **260**, 523 (1993), "Record Low Global Ozone in 1992;" Hofmann, D.J. and S.J. Oltmans, *J. Geophys. Res.* **98, D10**, 18,555 (1994), "Anomalous Antarctic Ozone During 1992: Evidence for Pinatubo Volcanic Aerosol Effects."
11. See, for example, Herman, J.R., et al., *J. Geophys. Res.* **96**, 7,531 (1991), "A new self-calibration method applied to TOMS/SBUV backscattered ultraviolet data to determine long-term global ozone change;" Zerefos, C.S., A.F. Bias and I.C. Ziomas, *J. Geophys. Res.* **97, D9**, 10,135 (1992), "On the relative importance of Quasi-Biennial Oscillation and El Niño/Southern Oscillation in the Revised Dobson Total Ozone Records;" Callis, L.B., et al., *J. Geophys. Res.*, **96, D2**, 2,921 (1991), "Ozone Depletion in the High Latitude Lower Stratosphere: 1979-1990." The ozone trend is not significantly different from zero (at a level of two standard deviations) for latitudes between ± 40°, and for high northerly latitudes for most of the year in the interval from 1978-1990 (Stolarski, R.S., P. Bloomfield, R.D. McPeters and J.R. Herman, *Geophys. Res. Lett.* **18**, 1,015 (1991), "Total Ozone Trends Deduced from Nimbus-7 TOMS Data."
12. Singer, S.F., "What Could Be Causing Global Ozone Depletion?" in *Climate Impact of Solar Variability*, ed. K.H. Schalten and A. Arking, NASA Publication 3086. (Washington, D.C.: NASA, 1990.)

13. *Scientific Assessment of Ozone Depletion: 1991*, World Meteorological Organization, Global Ozone Research and Monitoring Project, Report No. 25, p. xiii.

14. Brasseur, G., *Annales Geophisique* **34**, 301 (1978), "Long term effect on the ozone layer of nitrogen oxides produced by thermonuclear explosions in the atmosphere."

15. Scotto, J., et al., *Science* **239**, 762 (1988), "Biologically Effective Ultraviolet Radiation: Surface Measurements in the United States, 1974 to 1985;" Scotto, J., *Science* **239**, 1,111 (1988), "Global Stratospheric Ozone and UV-B Radiation;" Larsen, S.H. and K. Stamnes, *Photochemistry and Photobiology* **49**, 621 (1989), "Biological UV Doses and the Effect of an Ozone Layer Depletion;" Penkett, S.A., *Nature* **341**, 283 (1989), "Ultraviolet Levels Down, Not Up."

16. Kerr, J.B. and C.T. McElroy, *Science* **262**, 1,032 (1993), "Evidence for Large Upward Trends of Ultraviolet-B Radiation Linked to Ozone Depletion."

17. Michaels, P.J., S.F. Singer and P.C. Knappenberger, *Science* **264**, 1,341 (1994), "Analyzing Ultraviolet-B Radiation: Is There a Trend?"

18. Dr. William Happer, the Department of Energy's Research Director, was probably fired in 1993 because he stated that the UV-B levels are decreasing (*Science* **260**, 743 [1993]). *The Boston Globe* (May 27, 1994, p. 1) reports that NOAA has proposed *predicting* UV radiation based in part on the amount of ozone. The predictions can now be seen in daily weather reports on television and in newspapers. This is no substitute for *measurements* of UV-B dosage.

19. Waters, J.W., et al., *Nature* **362**, 597 (1993), "Stratospheric ClO and Ozone from the Microwave Limb Sounds on the Upper Atmosphere Research Satellite."

20. See e.g., Kanzawa, H. and S. Kawaguchi, *Geophys. Res. Lett.* **17**, 77 (1990), "Large Stratospheric Sudden Warming in Antarctic Late Winter and Shallow Ozone Hole in 1988."

21. Crutzen, P.J., *Nature* **356**, 104 (1992), "Ultraviolet on the increase."

22. Larsen, S.H.H. and T. Henricksen, *Nature* **343**, 124 (1990), "Persistent Arctic Ozone Layer;" *The Boston Globe* (May 27, 1994, p. 1), "Warnings Could Cast Gloom Over Sunny Days."

23. EPA Press Release, undated.

24. McInnis, D.F., *Environmental Politics: Public Costs, Private Rewards*, ed. M.S. Greve and F.L. Smith, Jr., (New York: Praeger, 1992) pp. 129-154.

25. Rowlands, J.H., *Environment* **35**, 25 (1993), "The Fourth Meeting of the Parties to the Montreal Protocol: Report and Reflection."

26. Kahlil, M.A.K. and R.A. Rasmussen, *J. Geophys. Res.* **98, D12**, 23,091 (1994), "The Environmental History and Probable Future of Flourocarbon 11."

27. *New York Times* (May 13, 1994, p. A12), "First Prosecution Under Ozone-Protection Law."