Trace Gases Could Double Climate Warming

The climate warming due to increasing atmospheric carbon dioxide will be augmented by increasing concentrations of other gases

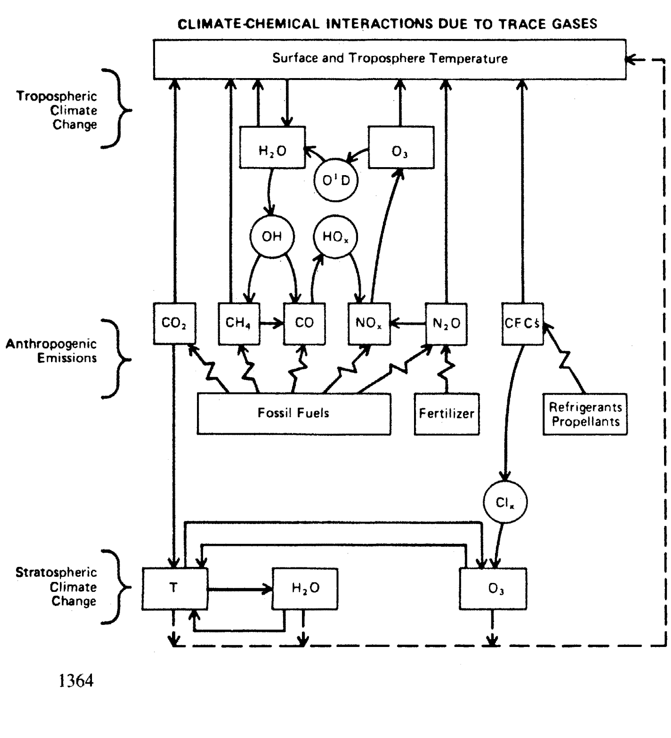
What is the connection between old refrigerators and a global climate warming in the next century? Or between the bacteria in the gut of a cow or in the muck of a rice paddy and the drying out of the American grain belt? The connection in each case is made by gases whose atmospheric concentrations are measured in parts per billion but whose effects on climate could rival those of the 1000 times more abundant carbon dioxide.

The atmospheric concentrations of several trace gases capable of changing climate, such as the refrigerant Freon of ozone-layer fame and the methane of cows, are increasing. The increases have not yet been sufficient to produce a detectable climate change, but the realization that carbon dioxide from the burning of fossil fuel may not be alone in enhancing the greenhouse effect and warming the atmosphere has greatly complicated the task of identifying the causes of future climate change.

Researchers are concerned about the trace gases despite their minuscule concentrations because they are such efficient absorbers of far-infrared radiation. Carbon dioxide at its present concentration of 340 parts per million, water vapor, clouds, and ozone absorb long-wavelength infrared radiation, which could otherwise escape to space, and reradiate it toward the surface, raising the average surface temperature by about 30°C. Because of the burning of fossil fuels and the clearing of forests, the atmospheric concentration of carbon dioxide has increased about 45 parts per million during this century and is expected to double within the next century, raising the mean global temperature 1.5° to 4.5°C.

Increases in gases measured in only parts per billion could create an equally worrisome warming. A World Meteorological Organization (WMO) panel of experts* has concluded that, remaining uncertainties not withstanding, "the available studies strongly suggest that the combined climatic effects . . . of potential future alterations in minor trace gases . . . can be as large as those estimated due to a carbon dioxide increase."

Trace gases can compensate for their extreme dilution in several ways. The trace gases that concern climatologists, such as methane (1600 parts per billion), nitrous oxide (300 parts per billion), and the chlorofluorocarbons or CFC's (less than 1 part per billion), absorb outgoing infrared radiation in the "atmospheric window," wavelengths where the more abundant water vapor is not competing with them. Trace gases can be extremely strong absorbers—the absorption in one wavelength band of CFC-11 is eight times as strong as the absorption of one of the principal bands of carbon dioxide. Because trace gases are so dilute, their absorption is linearly related to concentration—a doubling of concentration doubles absorption. Doubling the carbon dioxide concentration falls far short of doubling its absorption. And then there is the advantage of adding the effects of many different gases. In the WMO's compilation of climate effects, a doubling of carbon dioxide to 600 parts per million would produce a 2.0°C warming. The doubling of the concentrations of methane and nitrous oxide, plus increases in CFC-11 and CFC-12 from 0 to 1 part per billion, would warm the atmosphere by a total of 0.9°C.



Trace gas interactions

This diagram includes some of the sources, sinks, and interactions of the trace gases that can alter climate. Natural sources of trace gases can also be altered by human activities. Some researchers suspect that the production of methane from wetlands (such as rice paddies), the digestive tracts of cows, or termites may have been influenced by human activities. [Source: V. Ramanathan, in Interactions of Energy and Climate *(Reidel, Dordrecht, 1980)]*

The atmospheric concentrations of these four potent trace gases are definitely increasing, according to James Peterson, director in Boulder of the National Oceanic and Atmospheric Administration's (NOAA) Geophysical Monitoring for Climate Change program. The fastest rate of increase is currently about 6 percent per year for both CFC-11 and CFC-12, according to NOAA monitoring and other analyses. The worldwide production of CFC's for use as solvents, refrigerants, and spray-can propellants peaked in 1974 and has been declining slightly since. Nitrous oxide in the atmosphere, produced by fossil fuel combustion, has been increasing by about 0.2 percent per year.

Researchers agree that the methane concentration has been increasing during the past few years by about 1.5 percent per year, but the cause or causes remain controversial. Suggested sources of the increase include microbial activity in the digestive systems of cattle (herds are growing) and termites (forest clearing is increasing) and in rice paddies (acreage is increasing). Whether the methane increase will continue or is actually part of natural variations is unknown. Peterson

*Report of the Meeting of Experts on Potential Climatic Effects of Ozone and Other Minor Trace Gases, held 13–17 September 1982 in Boulder, Colorado; available from Rumen D. Bojkov, Chief, Atmospheric Sciences Division, World Meteorological Organization, Case Postale No. 5, CH-1211 Geneva 20, Switzerland.

also sees evidence of global increases in CFC-22, methylchloroform, and carbon tetrachloride, all less radiatively active, man-made chemicals.

Additions of radiatively active trace gases to the atmosphere are only part of the trace gas problem. A web of subtle and often poorly understood processes links radiatively active trace gases, inactive trace gases, atmospheric temperature, and the biosphere so that a disturbance in one part of the web will be felt in the others. For example, fossil fuel burning produces carbon monoxide and nitric oxide, neither of which is radiatively active but both of which can react through the classic smog reactions to produce ozone, which is radiatively active. CFC's and nitrous oxide can produce the opposite effect by destroying ozone in the stratosphere. A greenhouse-related warming could increase the rates of chemical reactions that destroy methane in the atmosphere (another participant in the smog reactions), while it could accelerate the biological processes that produce methane.

The effort to account for the trace gases' bewildering array of direct and indirect climate effects is still in its infancy. Most calculations are in the form of simple, one-dimensional climate models, which include only atmospheric processes acting along a vertical column. To produce some of the latest results, Wei-Chyung Wang of Atmospheric and Environmental Research in Cambridge, Massachusetts, included in his model 20 gases, 48 reacting chemical species, 100 chemical reactions induced by solar radiation, and some effects of atmospheric aerosols and clouds. For the purposes of the model, he assumed increases after 1980 in carbon dioxide (0.5 percent per year), methane (1.2 percent per year), and nitrous oxide (0.2 percent per year). Emissions of CFC's and other nitrogen oxides remained unchanged.

Wang's model predicts equal roles for carbon dioxide and trace gases in raising the average global surface temperature 0.8°C by 2010. (This model predicts a 2.0°C warming for a doubling of carbon dioxide.) By the turn of the century, the climate would be warmer than it has been in several centuries or even the past 1000 years. The warming due to increased carbon dioxide would be 48 percent of the total, and that due to the direct radiative effects of the trace gases other than ozone would be 26 percent of the total. The total amount of ozone would not change, but its redistribution, especially around the sensitive altitudes of the tropopause, would contribute the remaining 26 percent of the warming.

Although models have differed widely in the assumed trace gas changes, chemical reaction rates, and other crucial details, all the models indicate a significant role for trace gases. In a model constructed by Andrew Lacis and his colleagues at the Goddard Institute for Space Sciences, New York, doubling carbon dioxide produced a 2.9°C warming, and assumed changes in trace gas concentrations that might occur over the next century produced a 1.0°C warming. At the National Center for Atmospheric Research in Boulder, V. Ramanathan's model indicates a 2.0°C temperature increase in response to the doubling of carbon dioxide and an additional 1.6°C warming when changes in trace gases are included. The actual uncertainties in such calculations are probably greater than these broadly consistent results might suggest, but researchers want very much to reduce those uncertainties. When policy-makers ask what is causing an apparent global warming, researchers want to have some answers.

—RICHARD A. KERR

The Infrared Astronomy Satellite (I)

Our tale begins with the engineers who got an enormously complex mission into orbit—working perfectly; next, IRAS science

The Infrared Astronomy Satellite (IRAS) was launched into polar orbit from Vandenberg Air Force Base, California, at precisely 6:17.375 p.m. PST on 25 January 1983. Lift-off was right on schedule—or 2 years late, depending on how one looked at it. In fact, getting IRAS to that point had been one of the most frustrating and difficult space projects ever attempted. Yet on 25 January that hardly mattered. Because when IRAS was finally in orbit, it performed almost perfectly.

The scientists were ecstatic. "[IRAS] marks the beginning of a new era in infrared astronomy," proclaimed the exultant science and engineering team in a recent review article.* The $180-million IRAS, a joint endeavor of the United States, the Netherlands, and the United Kingdom, is making the first comprehensive survey of the sky at infrared wavelengths between 8 and 119 micrometers. This particular band contains some of the most important emissions from planets, asteroids, comets, interstellar molecules, and the cold gas and dust of the galaxy's star-forming regions. Moreover, infrared photons are able to penetrate the interstellar clouds that obscure so much of the galaxy from optical astronomers. (These same photons are strongly absorbed in the atmosphere of the earth, unfortunately, which is why the all-sky survey had to wait for a satellite.) IRAS's early discoveries include, for example, two new comets and a ring of dust around the Andromeda galaxy.

IRAS is a milestone in an engineering sense as well. The telescope has to be cooled with superfluid helium lest its own thermal emissions overwhelm the signal it is looking for. Thus, IRAS contains by far the largest cryogenic system ever flown in space (475 liters of liquid helium). Moreover, the system is working even better than expected: helium is boiling off inexorably, but so slowly that the estimated lifetime of IRAS is now 340 days instead of the prelaunch estimate of 220 days. IRAS's success has encouraged NASA headquarters to move forward on such long-delayed cryogenic projects as the Cosmic Background Explorer, which will look for subtle, cosmologically significant variations in the 2.7 K microwave radiation; and the Shuttle Infrared Telescope Facility (SIRTF), a more powerful successor to IRAS that will be operated from the shuttle payload bay.

For all of that, the smiles are still a bit strained at times. The institutional scars left by the IRAS development effort are only just now beginning to heal. Indeed, the IRAS story is strikingly reminiscent of the managerial confusion and technical hang-ups that have recently come to light on the Space Telescope project (*Science*, 8 April, p. 172).

Nature, (London)* **303, 287 (1983).