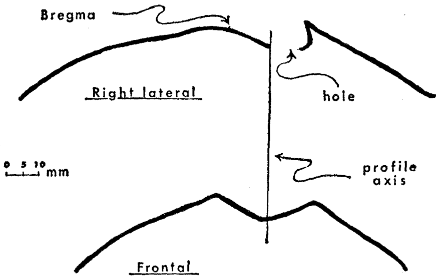


Fig. 3. Cranial profiles of B. 1 anomaly. (Top) Right lateral view. (Bottom) Frontal view.

that the anomaly might result from a long-standing lesion which prompted attempts to scrape or treat it.

What a trephined skull might mean at the Spruce Swamp site is unclear. Both generalized regional Archaic and Woodland levels have been postulated here (*1*), with only tenuous suggestion of exotic elements. These include an artifact of plasma (a stone material identified as originating in Georgia or Alabama) and an enigmatic incised paintstone (*10*), which may record Southern cult motifs.

The presumptive trephination may be an isolate, or it may relate to cultural practices or influences inadequately recorded in the literature. Certainly the unskilled and fragmentary recovery of most Indian burials in this region plus unrestricted "pothunting," may have destroyed much evidence.

BERNARD W. POWELL
Stonebridge Road,
Wilton, Connecticut 06897

References and Notes

1. B. Powell, *Amer. Antiquity* **30**, 460 (1965).
2. J. Daland, *Ann. Med. Hist.* **7**, 550 (1935).
3. T. Stewart, in *Smithsonian Institution Annual Report of 1957* (Government Printing Office, Washington, D.C., 1958), pp. 469–491.
4. J. Tello, *Prehistoric Trephining among the Yauyos of Peru* (Harrison, London, 191-), pp. 75–83.
5. W. Goldsmith, *Amer. Antiquity* **10**, 348 (1945).
6. C. Wells, *Bones, Bodies, and Disease* (Praeger, New York, 1964), plate 82.
7. R. Fletcher, in *Contributions to North American Ethnology* (Government Printing Office, Washington, D.C., 1882), pp. 5–30.
8. W. Hinsdale and E. Greenman, *Perforated Indian Crania in Michigan* (Univ. of Michigan Press, Ann Arbor, 1936), pp. 1–15.
9. M. Muniz and W. McGee, in *Sixteenth Annual Report of the Bureau of American Ethnology* (Government Printing Office, Washington, D.C., 1897), pp. 11–72.
10. B. Powell, *Amer. Antiquity* **30**, 98 (1964).
11. I thank T. Stewart, United States National Museum; M. Helpern, Chief Medical Examiner, and his staff, New York City; and H. Jaffee, Hospital for Joint Diseases, New York City, for their examinations of, and comments on, the cranium from B. 1. I also thank R. Colmers, Medical Examiner of Stamford, Connecticut, and J. Gifford of the Department of Anthropology, Temple University, for encouragement and other assistance in carrying out this project.

17 August 1970

Stratospheric Ozone with Added Water Vapor: Influence of High-Altitude Aircraft

Abstract. *Simple, steady-state models for ozone photochemistry, radiative heat balance, and eddy-diffusive mass transport can be combined to estimate water-induced changes in the stratospheric ozone concentrations and temperatures, the integrated ozone column, the solar power transmitted to the earth's surface, and the surface temperature. These changes have been computed parametrically for mixing fractions of water vapor between* 3×10^{-6} *and* 6.5×10^{-6}. *With added water from the exhausts of projected fleets of stratospheric aircraft, the ozone column may diminish by 3.8 percent, the transmitted solar power increase by 0.07 percent, and the surface temperature rise by 0.04°K in the Northern Hemisphere. Due to a cancellation of terms, temperatures in the lower stratosphere remain essentially unchanged. These results are sensitive to the form of the water profile and emphasize the potential role of convective transients near 30 kilometers.*

Several authors have expressed concern that exhausts from fleets of stratospheric aircraft may build up to levels sufficient to perturb weather both in the stratosphere and on the surface (*1–3*). Indeed, calculations indicate that the quantity of added water vapor may become comparable to that naturally present; projected fleets of high-altitude aircraft may add 0.6 part per million (ppm) to the mixing ratio of water above 15 km in the Northern Hemisphere, relative to the natural ratio of about 3 ppm (*4, 5*). Similarly, the added mixing ratio of carbon dioxide may be about 0.6 ppm in the presence of a natural ratio of 320 ppm.

Manabe and Wetherald (*2*) have examined the atmospheric radiative-convective balance and concluded that an increase of water vapor from 3 to 15 ppm, in *both* the stratosphere and troposphere, would produce temperature changes of + 2°K at the surface and about − 7°K at 20 km. As these authors pointed out, this large increase in the water column exceeds that anticipated from stratospheric aircraft.

Hampson (*3*) has suggested that water added from commercial supersonic transports may interact significantly with the photochemical cycle of ozone. This interaction might be expected to disturb both the stratospheric temperature gradients and the total solar power transmitted to the earth's surface. It is the purpose here to describe a quantification of Hampson's hypothesis, consistent with simple models of water distribution, ozone photochemistry, and radiative heat balance (*6*).

Leovy (*7*) has given a simplified treatment of the photochemical steady-state equations for stratospheric ozone concentrations. Leovy's model, with the assumption that the photochemical rate constants are slowly varying integral functions of ozone concentrations, implies that for small changes of water vapor:

$$\frac{\delta\,[O_3]}{[O_3]} \simeq -\frac{1}{3}\,\frac{\delta\,[H_2O]}{[H_2O]} \qquad (1)$$

The unperturbed stratospheric mixing ratio of water is approximately 3 ppm (*5*). Added water from projected fleets of high-altitude aircraft may assume a steady-state value of approximately 0.6 ppm (*8*). For these numbers $\delta\,[H_2O]/[H_2O]$ is approximately ⅕, and therefore Eq. 1 implies an aircraft-induced depression of the ozone column by about 7 percent. For a better estimate, it is necessary to solve the equations with explicitly altered water concentrations. This was done (*6*) with, for consistency with Leovy, the same solar fluxes, chemical rate constants, and photoabsorptive cross sections (*7*). Water mixing ratios were varied between 3 and 6.5 ppm by volume. The solar zenith angle was taken to be 45°. Ambient stratospheric temperatures were those of the 1962 standard atmosphere for all computations (*9*), but independent temperatures were also computed by a very approximate method of Lindzen and Goody (*10*):

$$T = \frac{\eta\phi + 9 \times 10^{-5}\ {}^{\circ}\mathrm{K\ sec^{-1}}}{5 \times 10^{-7}\ \mathrm{sec^{-1}}} \qquad (2)$$

where $\phi = [O_3]/[\text{total atmospheric concentration}]$. This equation follows from the assumptions that the only heating term, $\eta\phi$, is due to direct absorption of solar energy by ozone, and that the only cooling term is radiation in the 15-μ band of CO_2. For internal consistency, the heating coefficients η were computed for the work reported here with the same cross sections and solar fluxes as those used for the parent computation of perturbed ozone concentrations; however, the resulting coefficients differ inappreciably from the values calculated by Lindzen and Goody. The temperatures then resulting from Eq. 2 are systematically lower than those measured in the stratosphere at 20 km and higher than those at 30 km. This follows from the neglect at low altitudes of additional heating terms due to molecular absorption of infrared radiation emitted from the earth, and neglect at higher altitudes of additional cooling terms due to infrared radiation by water and ozone. Lindzen and Goody discussed the validity of Eq. 2 in the lower atmosphere, where the sense of the omitted heat-balance terms is to generate an overestimate of the relative perturbations due to added water vapor.

Surface temperatures were computed by means of the Stefan-Boltzmann equation, which for this problem takes the form:

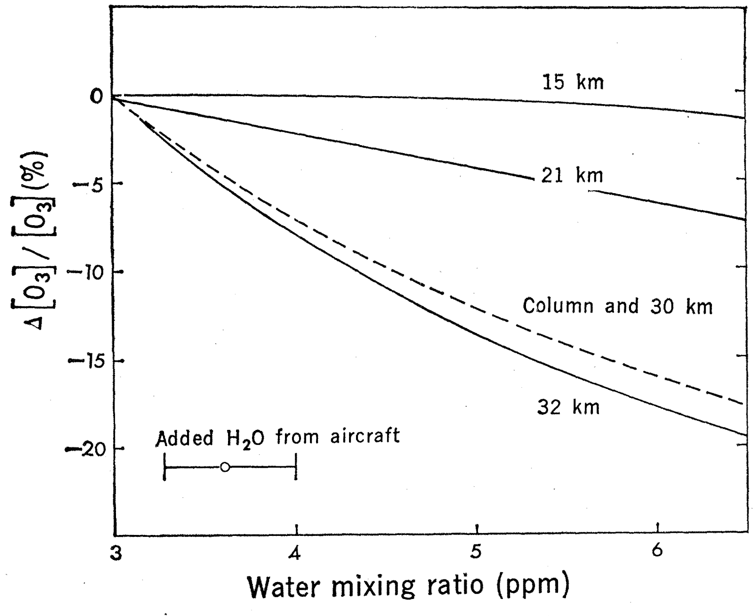
$$T_s = 533.57°\text{K} \times [(P_s + 0.012)\ \text{watt/cm}^2]^{1/4} \quad (3)$$

where P_s is the solar power transmitted to the surface. In Eq. 3 the constant within the bracket was empirically added to account for those infrared wavelengths beyond the absorption limits of O_3. This was done by equating the transmitted solar power for the undisturbed atmosphere (taken to be 3 ppm of H_2O) with the total solar constant at the surface, 0.085 watt/cm^2, as computed for 1.4 air masses (as is appropriate for zenith angles of 45°) by Moon (*11*), who included dust, H_2O, and CO_2 in his infrared transmission integral. The constant outside the bracket normalizes the undisturbed surface temperature to 288.1°K, the temperature of the U.S. 1962 standard atmosphere.

By this very rough method spatial variations in surface absorptivity and albedo, and important heat transfer terms due to surface winds, are absorbed into the proportionality constant to permit an estimate of an average global temperature change due to perturbed ozone.

The results of these computations are summarized in Figs. 1 and 2. It can be seen that, with currently projected fleets of high-altitude aircraft, this model predicts a change in the integrated ozone column of about − 3.8 percent, appreciably less than the first-order prediction of Eq. 1, and a surface temperature rise of about + 0.04°K in the Northern Hemisphere. It can also be seen that at cruise altitudes, about 20 km, the relative perturbations are less. This reduction follows from the near cancellation of two opposing influences: added local water tends to depress the local ozone concentration (Eq. 1), but a depletion of ozone at higher levels compensates by enhancing the low-altitude photochemical rates and the heating coefficient η. For H_2O mixing ratios between 3 and 6.5 ppm, the cancellation of the temperature rise is nearly complete in the lower stratosphere, and therefore one consequence of this model is that the tropopause is undisturbed.

Another feature of the model is its sensitivity to the assumed altitude profile of added water vapor. The distribution of constant mixing ratio, which has so far been assumed, is consistent with eddy-diffusive vertical transport in a gravity-stratified atmosphere, provided no other sources or sinks of water vapor are located closer than several scale heights above a narrow layer of aircraft cruise altitudes. It is also assumed that mixing fractions of water vapor are held constant at the tropopause by weather mechanisms not affected by high-altitude aircraft. As a test of sensitivity to the assumed water distribution, the model was recomputed with an extreme and probably unphysical distribution in which the added water was assumed to be of constant concentration, rather than constant mixing ratio, in a band one scale height thick and centered at about 20 km. In this case, again with added water corresponding to projected fleets of high-altitude aircraft, the changes in the ozone column (− 2.0 percent) and surface temperature (+ 0.02°K) are smaller than in the previous case, but the changes in local ozone concentrations (− 13 percent at 20 km) and temperature (− 0.4°K) are larger. This pattern is expected because the peak of



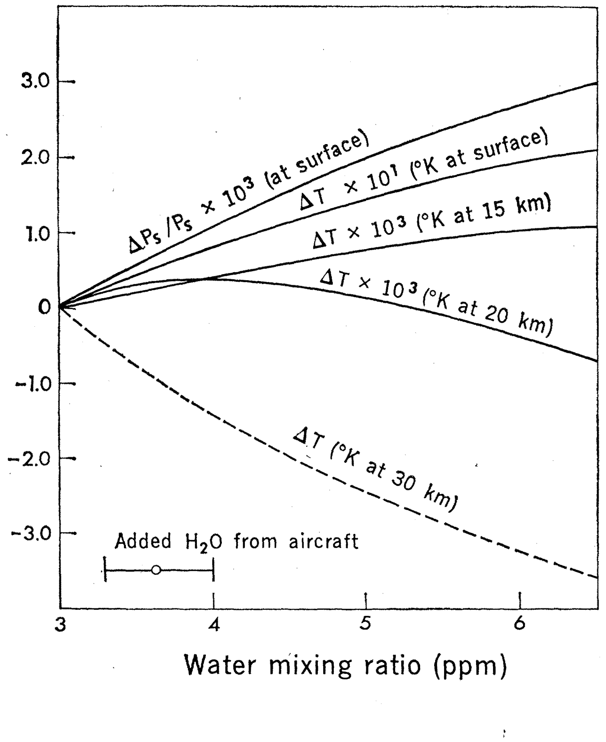


Fig. 1 (left). Computed perturbations of atmospheric ozone concentrations and integrated column as functions of the stratospheric mixing ratio of water vapor. Fig. 2 (right). Computed temperature perturbations as functions of the stratospheric mixing ratio of water vapor. See the text for cautionary remarks concerning the curve at 30 km.

ozone production occurs near 30 km; consequently, integrated effects such as the O_3 column and surface temperature will be most sensitive to water vapor that is transported upward from the flight altitudes. Brewer and Wilson (*12*) have emphasized the importance of ozone transport downward from the high stratosphere as, possibly, the rate-limiting process near the tropopause. The calculations presented here illustrate the potential role of transient injections of water vapor into altitudes near 30 km.

It should be remarked additionally that by vertical transport of ozone downward from the stratosphere into a region where, due to shielding from the solar flux, the ozone is relatively long-lived, the total ozone column is in fact enhanced appreciably above that resulting from this or other models of photochemical steady states. For this reason, relative perturbations of the ozone column, computed by steady-state models, are greater than those that will in fact occur.

With Leovy's collection of rate constants, cross sections, and fluxes, the fit between computed and observed ozone profiles is remarkably good, especially at altitudes near 30 km where the ozone concentration is greatest. To test the sensitivity of the present calculations to changes in input constants, the model was recomputed with the new rates described by Crutzen (*13*). On the basis of these rates, the ozone profile is altered appreciably by enhanced concentrations above 30 km. However, with one exception, the relative perturbations shown in Figs 1 and 2 are unchanged, within the uncertainties introduced in the estimates of added water. The exception occurs in Fig. 2 for the temperature changes at 30 km; in this case, the exalted ozone profile results in a temperature *rise* (+ 0.1°K at 3.6 ppm), instead of the fall which is shown. Obviously, this result should be treated cautiously. Indeed, natural variations in water, temperature, and ozone profiles will make all of the estimates of this study extraordinarily difficult to observe. Finally, it should be emphasized that the temperature changes in Eqs. 2 and 3, as applied in Fig. 2, represent rather ruthless spatial and temporal averages to obtain *global* perturbations.

HALSTEAD HARRISON
Boeing Scientific Research Laboratories, Seattle, Washington

References and Notes

1. F. G. Finger and R. M. McInturff, *Science* **167**, 16 (1970); R. E. Newell, *Nature* **226**, 70 (1970).
2. S. Manabe and R. T. Wetherald, *J. Atmos. Sci.* **24**, 241 (1967).
3. J. Hampson, *Can. Air Res. Def. Estab. Tech. Note 1738* (1966).
4. In this work, all mixing ratios are by volume.
5. H. J. Mastenbrook, *J. Atmos. Sci.* **25**, 299 (1968). Additional recent measurements are described by H. J. Mastenbrook in *Nav. Res. Lab. Rep. 6891* (1969) and *Nav. Res. Lab. Rep. 6974* (1969).
6. The Fortran IV programs employed in the preparation of this report are documented in H. Harrison, *Boeing Sci. Res. Lab. Tech. Note 002* (*Revised*) (1970).
7. C. B. Leovy, *J. Geophys. Res.* **74**, 417 (1969), equation 7 and succeeding arguments; solar fluxes are taken from C. B. Leovy, *J. Atmos. Sci.* **21**, 238 (1964).
8. The literature is confused by widely varying estimates of stratospheric water perturbations. In this work I assumed: 500 U.S. and 350 non-U.S. supersonic transports consuming 13.4 and 9 kg of fuel per second at cruise speed, respectively; 25 percent aircraft utilization at cruise altitudes; 80 percent of the traffic in the Northern Hemisphere; 1.5-year residence times for material added to the stratosphere; and uniform steady-state mixing fractions above 15 km. These assumptions are discussed at greater length in (*6*).
9. S. L. Valley, Ed., *Handbook of Geophysics and Space Environments* (McGraw-Hill, New York, 1966), pp. 2–19.
10. R. Lindzen and R. Goody, *J. Atmos. Sci.* **22**, 341 (1965).
11. P. Moon, *J. Franklin Inst.* **230**, 583 (1940).
12. A. W. Brewer and A. W. Wilson, *Quart. J. Roy. Meteorol. Soc.* **94**, 249 (1968).
13. P. Crutzen, *Ann. Geophys.* **25**, 275 (1969).

6 August 1970; revised 18 September 1970 ■

Mercury Compounds Reduce Photosynthesis by Plankton

Abstract. *Concentrations of organomercurial fungicides as low as 0.1 part per billion in water reduced photosynthesis and growth in laboratory cultures of one species of marine diatom and several natural phytoplankton communities from Florida lakes. The acute toxicity of mercury compounds to phytoplankton is dependent on the chemical nature of the mercury compound and on cell concentrations.*

Mercury pollution is presently a serious problem in many parts of the world. Humans have died as a result of eating fish from mercury-contaminated coastal areas of Japan, high concentrations of mercury in fish and birds have been traced to industrial and agricultural discharges in Scandinavia, and at least 17 states in the United States have banned fishing in contaminated waters or warned against eating fish and shellfish contaminated with mercury. The sources and environmental pathways of mercury in the affected areas of Japan and Scandinavia have been studied (*1*). Investigations of mercury pollution in the United States are beginning.

An almost total lack of information on the biologic effects of mercury prevents the establishment of adequate water-quality standards. The Bureau of Water Hygiene, United States Public Health Service, and the Soviet Union have tentatively adopted a standard of

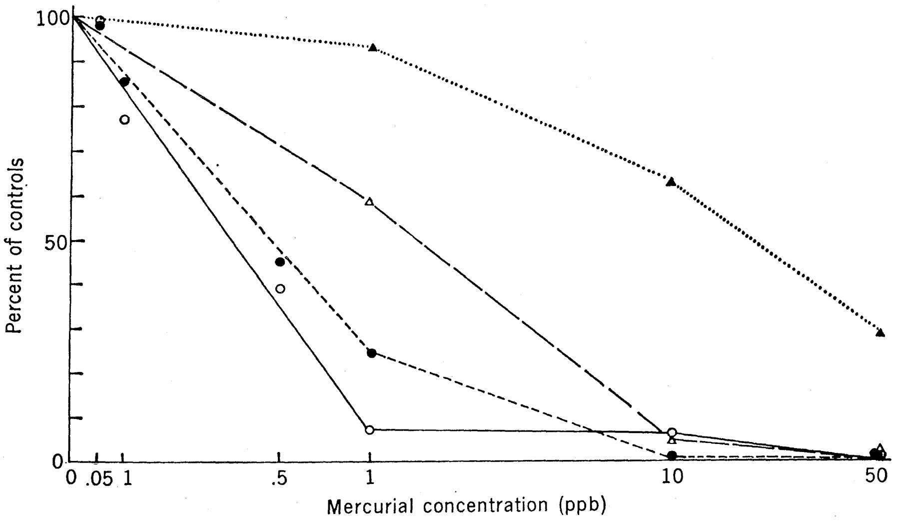


Fig. 1. Photosynthesis by *Nitzschia delicatissima*, a marine diatom, measured by uptake of carbon-14 relative to uptake by controls, after 24 hours of exposure to the following mercurials: Filled triangles, diphenylmercury; open triangles, phenylmercuric acetate; filled circles, methylmercury dicyandiamide; open circles, MEMMI.