

LETTERS TO NATURE

PHYSICAL SCIENCES

Atmospheric Total Ozone Increase during the 1960s

NAMIAS¹ has postulated that sea-air interactions on a regional basis, and not necessarily air pollution, volcanic activity, or solar intensity variations, may have caused the cooling trend that was observed in numerous areas of the world during the past decade^{2,3}. In particular, he attributed the United States temperature anomaly, that is, lower than normal winter temperatures in the eastern two-thirds of the country, and higher than normal winter temperatures in the west, to intensification of the Rossby wave at the 700 mbar level. This intensification strengthens the ridge over western North America and deepens the trough to the east, thus increasing the frequency of deployment of Arctic air masses into the eastern United States. Namias attributed the change in the character of the Rossby wave to abnormal cyclonic activity that occurred in the winter atmospheric circulation over the North Pacific, the surface waters of which were unusually warm during the 1960s.

Because the effects of a deepened 700 mbar trough over the eastern United States might reasonably be expected to extend to higher altitudes, we considered the possibility that the increased southward flow of air in the troposphere and low stratosphere led to an average increase in total ozone amount over central and eastern North America during the 1960s. Ozone is transported poleward from the equatorial stratosphere source region in the winter hemisphere, before it descends to lower levels⁴. To determine whether an increase in total ozone occurred, we analysed data obtained during the decade 1961 to 1970 at Edmonton, Goose Bay, and Toronto, in Canada, and at Boulder, Bismarck, Green Bay, Caribou, Bedford, Nashville, and Tallahassee, in the United States. The periods of record ranged from 7 to 10 years for all stations except Tallahassee, where observations were made for only 5 yr. At eight of the ten stations, we found statistically significant increases in ozone that varied between 4.4% per decade at Goose Bay, to 8.8% per decade at Nashville, with an average increase for the eight stations of 5.6% per decade. At Green Bay and Toronto, although the calculated trends in ozone were not found to be statistically significant, they produced small positive values, 2.0% and 3.5% per decade, respectively.

To ascertain whether the trough deepening described by Namias extended into the low stratosphere, the geopotential heights of the 200, 100, and 50 mbar pressure surfaces at two stations—Caribou and Nashville—were investigated for the period January 1961 to August 1970. The results of the analysis suggest to us that trough intensification occurred at both stations, particularly during February and March and to a lesser extent in September, October, and November. During other months of the 10 year period, progressive weakening of the trough occurred.

Our total ozone data analyses also yielded statistically significant ozone increases during the 1960s at Dobson spectrophotometer stations distant from the North American continent. At Mauna Loa Observatory in Hawaii, the upward trend was 2.5% per decade, while at Huancayo, Peru, the trend was 6.0%. Subsequent analyses of data from several foreign stations

(Fig. 1) confirmed that increases in ozone were not confined to the North American region, but were also characteristic of other areas of the world.

Fig. 1 shows mean monthly total ozone deviations from monthly normals, based on the periods of record indicated, for seven stations in the northern and southern hemispheres. The ozone monthly means were calculated, in most instances, from observations during 25 or more days per month; in isolated cases, however, the means were determined from as few as 10 days of observations. The ozone trend lines were fitted to the data by the least squares method. Table 1 summarizes the results.

Note that the calculated rates of ozone increase range from $2.4 \pm 0.6\%$ per decade at Mauna Loa Observatory in Hawaii, to $10.0 \pm 0.4\%$ per decade at Kodaikanal in India. Errors given with the trend figures are computed probable errors. In calculating the trends we have assumed that the calibration levels of the spectrophotometers, operated at the stations listed in Table 1, remained constant in time. Using the criterion that the sign of the ozone trend is significant, provided that it does not change within the range of ± 3 probable errors, the

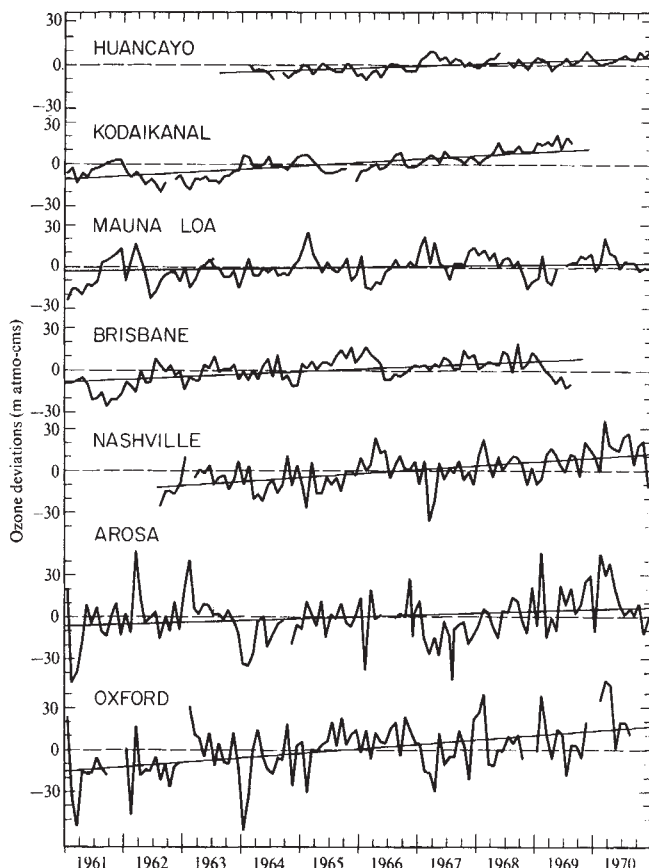


Fig. 1 Plots of mean monthly total ozone deviations from monthly normals for selected stations. Linear trend lines have been fitted to the data.

data clearly indicate that statistically significant increases in total ozone amount were detected at the stations listed in Table 1.

Table 1 Summary of the Data Analyses presented in Fig. 1

Station	Lat., long.	Mean O ₃ in m atmo- cms †	% O ₃ increase per decade *
Huancayo, Peru	12° 03' S, 75° 19' W	262	6.0 ± 0.4
Kodaikanal, India	10° 14' N, 77° 28' E	257	10.0 ± 0.4
Mauna Loa, Hawaii	19° 32' N, 155° 35' W	276	2.4 ± 0.6
Brisbane, Australia	27° 28' S, 153° 02' E	289	6.6 ± 0.6
Nashville, USA	36° 15' N, 86° 34' W	332	8.8 ± 0.7
Arosa, Switzerland	46° 46' N, 09° 40' E	333	4.1 ± 1.0
Oxford, England	51° 45' N, 01° 11' W	354	8.9 ± 1.0

* Extrapolated from the periods of record shown in Fig. 1.

† The unit "m atmo-cms" or "milli-atmo-cms" is used to denote the total amount of ozone in a vertical column of the atmosphere, expressed as the thickness of the ozone layer at STP, assuming that the ozone is separated from the rest of the air.

Although additional data analyses yielded increases in ozone at most stations investigated, the results were not always statistically significant. For example, a small but statistically insignificant increase in ozone of $1.1 \pm 0.9\%$ per decade was calculated for Aspendale, Australia (38° 02' S, 145° 06' E). We also analysed data obtained at Tateno in Japan (36° 03' N, 140° 08' E), and Vladivostok in Siberia (45° 07' N, 131° 54' E). Both these stations lie near a region that, according to Namias, experienced a deepening of the 700 mbar trough during the past decade similar to the trough intensification that occurred over eastern North America. Although a positive trend in total ozone of $6.2 \pm 3.3\%$ per decade was computed for Vladivostok, we cannot classify this as significant under the criterion that it did not change sign within the range of ± 3 probable errors. For Tateno, on the other hand, a downward trend in ozone was calculated, also statistically insignificant, and of magnitude $-3.4 \pm 1.3\%$ per decade.

The tentative linear analyses of the North American total ozone data, as well as the analyses of the data from foreign stations shown in Fig. 1, suggest that an increase in total ozone occurred in many areas of the world during the past decade. This increase cannot be interpreted as an apparent ozone increase that has arisen because of errors in measurement associated with changing atmospheric turbidity. The fundamental method of measuring ozone with Dobson ozone spectrophotometers⁵, using wavelength pairs $A(3055 \text{ \AA}, 3254 \text{ \AA})$ and $D(3176 \text{ \AA}, 3398 \text{ \AA})$, is highly insensitive to scattering of solar radiation by particulate matter because, through the subtraction of two nearly equal terms, the scattering term that appears in the equation from which total ozone amounts are calculated is rendered negligibly small. The possibility that the computed rates of ozone increase are due to long term drift in spectrophotometer calibrations should, however, not be discounted. We recently compared the calibration level of our Caribou spectrophotometer with that of a standard spectrophotometer maintained at Boulder, Colorado, and found a drift in the calibration of the Caribou instrument. The magnitude and direction of the drift are such as to account for about one-half of the 5.9% calculated rate of ozone increase per decade at Caribou. In June 1970, on the other hand, the Nashville spectrophotometer was brought to Boulder and compared with our standard instrument. The intercomparison tests showed that the calibration level of the Nashville spectrophotometer did not change by more than 2% during 8 years of opera-

tion. Thus, the deduced 8.8% per decade increase in ozone at Nashville cannot be attributed, in large measure, to drift in instrument calibration.

A more comprehensive analysis than that presented here is needed to determine whether a global increase in atmospheric total ozone occurred during the past decade, or whether ozone increases in certain areas of the world were compensated by decreases in other areas. Such an analysis should not only involve data from the worldwide network of total ozone observatories, but should also take into account the calibration histories of the instruments with which observations were made. We are currently recalibrating our Dobson ozone spectrophotometers in an effort to determine the influence of drift in instrument calibrations on the accuracy of the North American ozone measurements.

The Huancayo station is operated in cooperation with the Instituto Geofisico del Peru.

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Do Neutron Stars have an Ocean Surface?

This article draws attention to one of the more important unsolved problems concerning the qualitative nature of the outer layers of a neutron star. We refer to the likelihood of there being a vapour-liquid type phase transition, involving a major density discontinuity by a factor that could be as high as three or more, between the crust (in which starquakes are thought to take place) and the neutron superfluid below. The idea that such a phase discontinuity might exist is not new¹, but the question does not seem to have been taken seriously in recent years. This is due to the absence of discontinuities not only in the highly simplified but historically important equations of state of Harrison and Wheeler² and of Tsuruta and Cameron³ which played such an important role in discussions of neutron star structure in the period extending up to the mid sixties, but also in the much more sophisticated equations of state which have been published in recent years, such as those of Langer, Rosen, Cohen and Cameron⁴, Bethe, Borner and Sato⁵, and Wang, Rose and Schlenker⁶.

We wish to make clear that the issue is still far from closed and that the existence of a major discontinuity is not only possible but even probable. The general problem of vapour-liquid type phase transitions in many fermion systems has recently been the subject of a reappraisal by Baker and Kahane⁷. They give naive but cogent reasons for expecting the existence of a discontinuous phase transition in any system of fermions where the interparticle forces are predominantly attractive at medium ranges but repulsive at short ranges: conditions which are believed to hold in a real neutron gas. This simple reasoning cannot, of course, be conclusive (the