The Ozone in the Earth's Atmosphere.

By Dr. D. N. HARRISON.

THE first accurate measurements of the amount of ozone in the atmosphere were made by Fabry and Buisson at Marseilles in 1920, and their method has been modified and developed by Dr. G. M. B. Dobson and others,[1] so that ozone observations are now made regularly at least once a day at about half a dozen places in different parts of the world. The results obtained up to the present from these series of observations are the subject of this article.

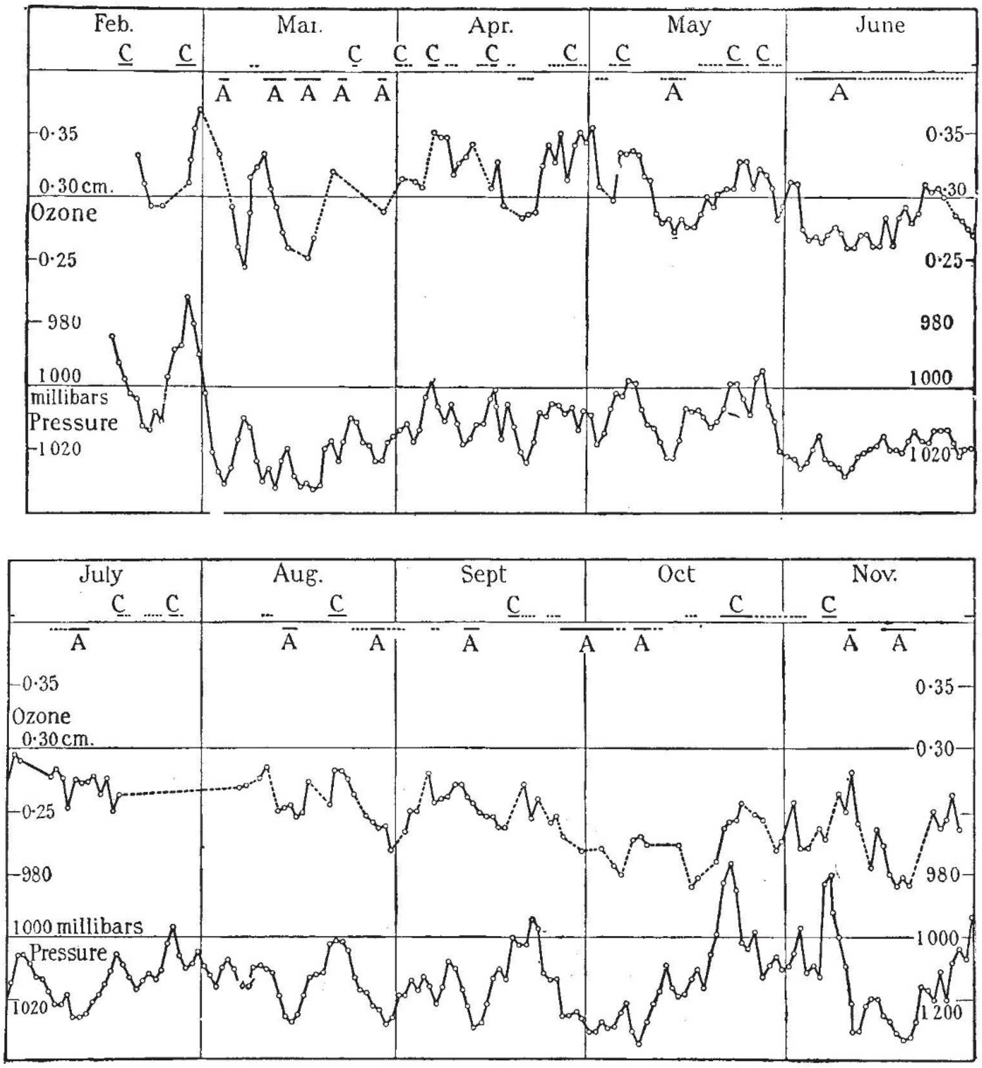


FIG. 1.

Ozone has an absorption spectrum consisting of bands in the infra-red, a weak band in the visible, and a very strong band in the ultra-violet, which cuts off the solar spectrum completely at about 2900 A. Its equilibrium temperature in sunlight is therefore higher than that of the other constituents of the atmosphere, which have no ultra-violet absorption. Moreover, atmospheric ozone was known to be confined to a region many kilometres above the earth's surface. Thus variations in the amount of ozone would be expected to affect the temperature of the upper atmosphere, and it was thought that in this way it might play an important part in the various changes which the atmosphere undergoes.

Ozone, as is well known, is a form of oxygen having three atoms in the molecule. It is formed from oxygen by the action of ultra-violet light of shorter wave-length than that which ozone itself absorbs. The spontaneous decomposition in the absence of a catalyst is extremely slow, but by absorbing ultra-violet radiation ozone is transformed into oxygen, so that in the absence of other factors the amounts of oxygen and ozone would

[1] *Proc. Roy. Soc.*, A, vol. 110 (1926), p. 660; vol. 114 (1927), p. 521; vol. 122 (1929), p. 456.

tend toward equilibrium, depending on the distribution of intensity in the solar spectrum. It was thought at one time that solar radiation was one of the main sources of atmospheric ozone, but this is probably not the case, for reasons which will be explained later.

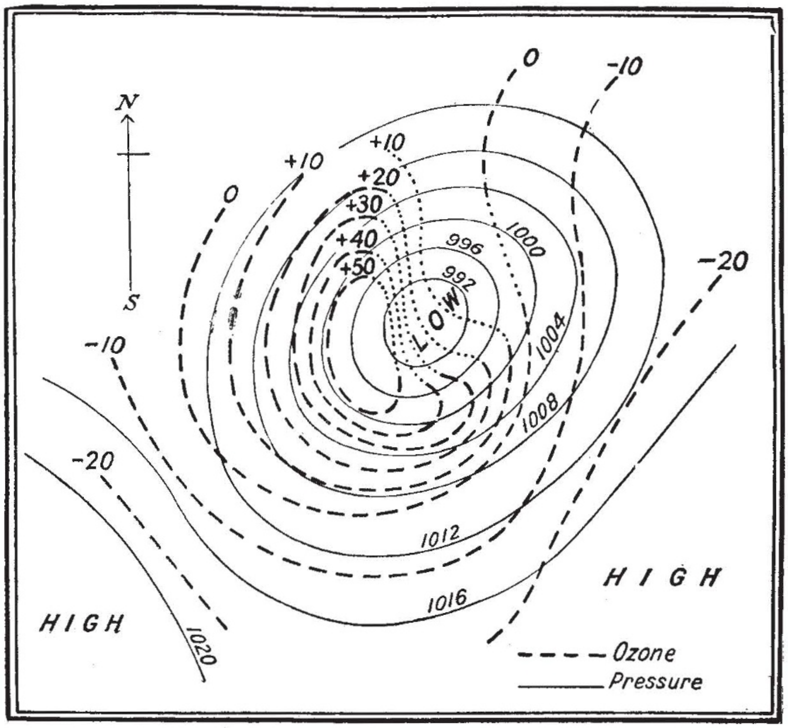


FIG. 2.

METHOD OF MEASUREMENT.

Briefly, and without technical details, the method by which ozone is measured is as follows. The method is spectroscopic; since ozone absorbs ultra-violet light of certain wave-lengths, the intensity of this light reaching the earth from the sun depends on the amount of ozone in the atmosphere; the intensity of the light is measured photographically, and consequently the amount of ozone through which it has travelled can be found. This is expressed as the thickness of a layer of the pure gas at N.T.P.; it varies about a mean value of roughly 3 mm. in Europe. In actual fact, of course, the ozone is spread through an unknown depth of the atmosphere, and this method of expression merely gives the number of molecules per horizontal square centimetre. The accuracy of the measurements is such that the results can usefully be expressed to three significant figures; the unit is usually taken as 0·001 cm., so that 321 would mean that the amount of ozone was equal to that in a layer 0·321 cm. thick at N.T.P.

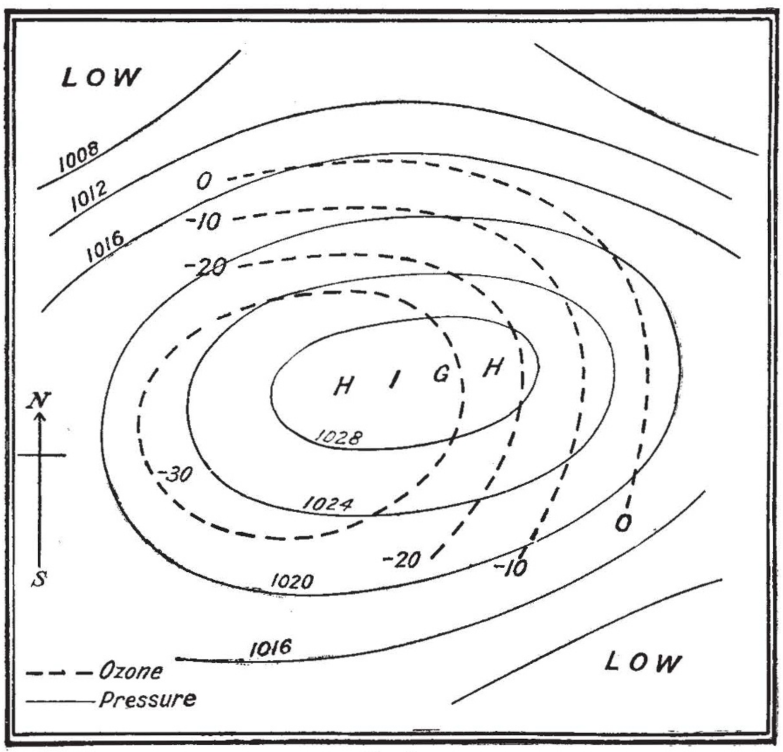


FIG. 3.

The height of the ozone layer can also be deduced. Several different workers agree in placing it at about 40-50 km.; this probably represents the 'centre of gravity' of the layer. The height appears to be greater when the amount of ozone is large than when it is small.

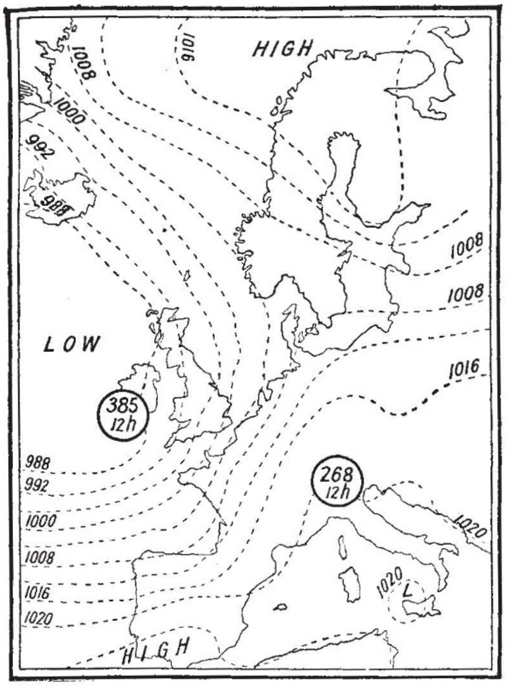
DIURNAL AND ANNUAL VARIATIONS.

It was discovered at Oxford in 1925: (1) that the amount of ozone can vary greatly from day to day, and indeed during one day; (2) that these variations have an inverse connexion with the barometric pressure; and (3) that there is a marked annual variation with a maximum of about 330 in April and a minimum of about 220 in October, taking a smooth curve through the year. Fig. 1[2] shows the ozone values for 1925, together with mean

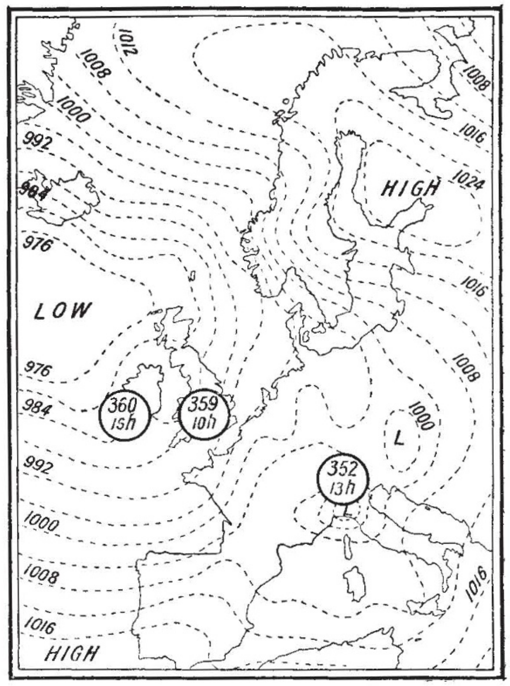
[2] The illustrations are reproduced by kind permission from the *Proceedings of the Royal Society*.

pressure for each day at Oxford. The short horizontal lines A and C above the curves mark the occurrence of cyclones and anticyclones.

are accompanied by definite and characteristic changes in the quantity of ozone in the atmosphere above any given place. Measurements



March 23, 1927. 7 A.M.



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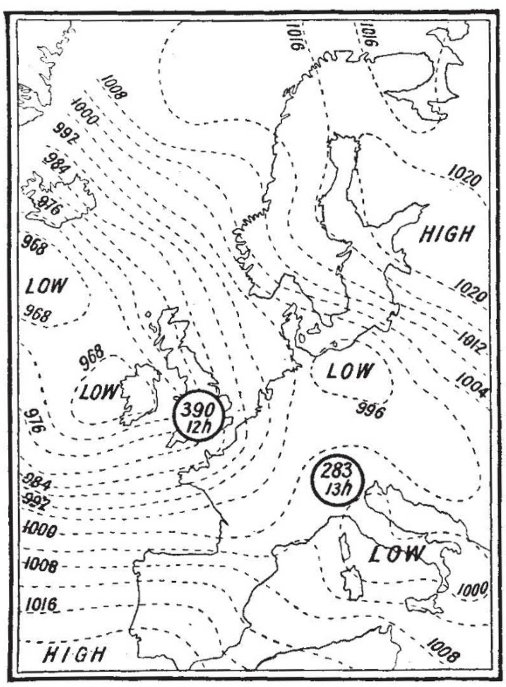

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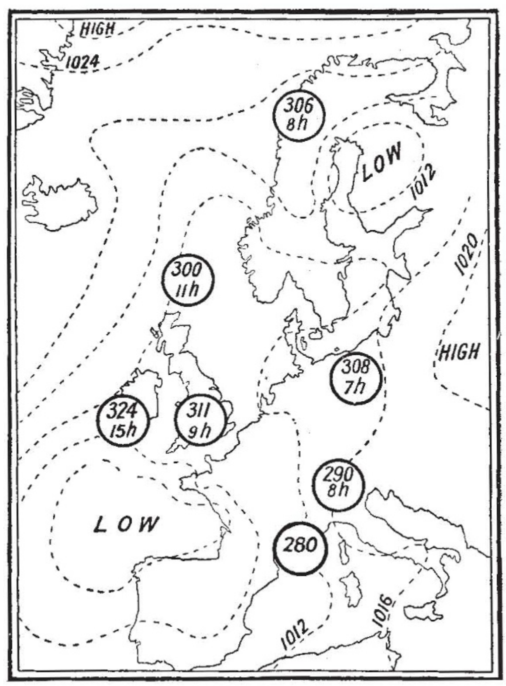

May 30, 1927. 7 A.M.

FIG. 4.

Subsequent observations at other places confirmed and amplified these conclusions, and it is now certain that the various sequences of weather

were made at Oxford, Lerwick (Shetland), Valentia (south-west Ireland), Abisko (Norway), Lindenberg (near Berlin), Arosa (in the Alps), and Marseilles during 1926 and 1927, with the view of discovering the distribution of ozone at different times, in the same sort of way as that in which weather maps are plotted by the aid of a network of reporting stations.

OZONE AND WEATHER.

The general conclusion so far reached is that there is a very close connexion between the ozone and the origin of the great air-currents the interplay of which gives us our 'weather'; the connexion is closest when the air considered is that not at the surface, but in the stratosphere (the isothermal region) which begins at a height of roughly 10 km. These currents are named by meteorologists 'polar' and 'tropical'; polar air is associated with high ozone values and tropical air with low ozone values. When studied in connexion with a weather map, the changes of ozone with the fluctuations of these air masses are most striking. There are difficulties, however, in the way of assuming that the varying quantities of ozone are actually brought by the air-currents.

Fig. 2 shows the average distribution of ozone in a cyclone. It was obtained by drawing the isobars for a typical or idealised cyclone, and plotting for each individual case the ozone value in its appropriate position; in order to eliminate the annual variation, the ozone values are expressed as differences from the mean for the time of year, so that the figure shows in units of 0·001 cm. the changes which, on the average, take place during the passage of a cyclone. (The figure should be imagined to move from left to right, that is, from west to east.) It will be seen that the ozone begins to fall at some distance in front of the depression, when tropical air is arriving at high altitudes, remains low during the passage of the 'warm sector' (roughly the south-east quadrant of the cyclone), and rises rapidly just behind the centre; this sequence of changes in a cyclone is found practically without exception, and even a small secondary (judged from the weather-map) may be followed by a large and abrupt rise of ozone. The highest ozone values found are those at the rear of depressions.

Fig. 3 shows the average distribution of ozone in an anticyclone; here we see that ozone tends to be low and that the minimum comes after the maximum of pressure.

The highest value hitherto found is 420 and the lowest 172.

Typical 7 A.M. weather maps, with ozone-values and hours of observation, are reproduced in Fig. 4. In the first three maps the passage of a secondary depression over Arosa is accompanied by a large but temporary rise of ozone; in the fourth map comparatively uniform conditions are illustrated.

The correlation co-efficients between the amount of ozone and upper air conditions are among the highest found in meteorology. The correlation with surface pressure is high, but those with the pressure at heights of 9-14 km. are much higher, and very high values are found for temperature in the troposphere and for the height of the base of the stratosphere; these are all negative, as would be expected from what has been said, while that for the temperature at 14 km. (in the stratosphere) is positive.

So far we have considered the distribution in Europe, about the latitude of Great Britain. We now turn to the world-wide distribution, so far as it is known. Observations at Montezuma (Chile) and at other places within the tropics give remarkably uniform and constant values of about 200 to 220, which is about the value found for tropical air in Europe in the summer. At Montezuma there seems to be a small annual variation, with a maximum in the southern spring.

Observations in high latitudes are scanty, but it seems probable from the Abisko figures that there is a maximum of perhaps 400 in the spring, after which the amount of ozone falls rapidly through the summer and autumn. In this connexion Prof. Rosseland's letter in NATURE, Feb. 9, is of interest. As was predicted by Dr. Dobson, photographs of the spectra of stars taken within the Arctic circle in December were cut off at 3000 A. by ozone.

A few observations from New Zealand indicate that there the amount and variations of ozone are similar to those in Europe.

ORIGIN OF OZONE IN THE ATMOSPHERE.

These results are of great interest from their bearing on the probable origin of atmospheric ozone. The ozone is at a minimum in the tropics; it is at a maximum in Arctic regions after the winter night, and decreases rapidly as the sunlight becomes stronger. Therefore we must conclude that the amount of ozone in equilibrium in sunlight is relatively small (perhaps about 2 mm.) and there must be some other source of supply. The rate of decomposition in sunlight must be slow, since observations near sunrise and sunset indicate no regular decrease during the day.

The origin may possibly be found in the aurora, or some associated phenomenon of which we know nothing. The amount of ozone is related to magnetic conditions in the sense that high ozone values tend to occur at times of magnetic disturbance, and a marked auroral display is always accompanied by a magnetic storm. Nevertheless, the aurora is situated at a height of 100-500 km., far above that found for the ozone layer. Further evidence of the presence of ozone at about 50 km. is given by temperatures found near this level. Dobson's and Lindemann's observations of meteors gave a high temperature above 55 km., and observations of sound-waves indicate a temperature at about 40 km. as high as that at the earth's surface.

Although no simple relation between ozone and weather has been found, the results here outlined show that the problem is full of interest; and in any case no one would expect, with such a complicated machine as the earth, its atmosphere, and the sun together form, to disentangle one complete thread of cause and effect.