Radio Studies of the Ionosphere

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IN view of the interest which is being shown by various investigators in the ionisation in the upper atmosphere, in particular with reference to the existence of several new regions which we pointed out in our communication of April 5 to NATURE (issue of June 3)[1], we have thought it desirable to record the results of some of the more recent observations which we have made in this field[2].

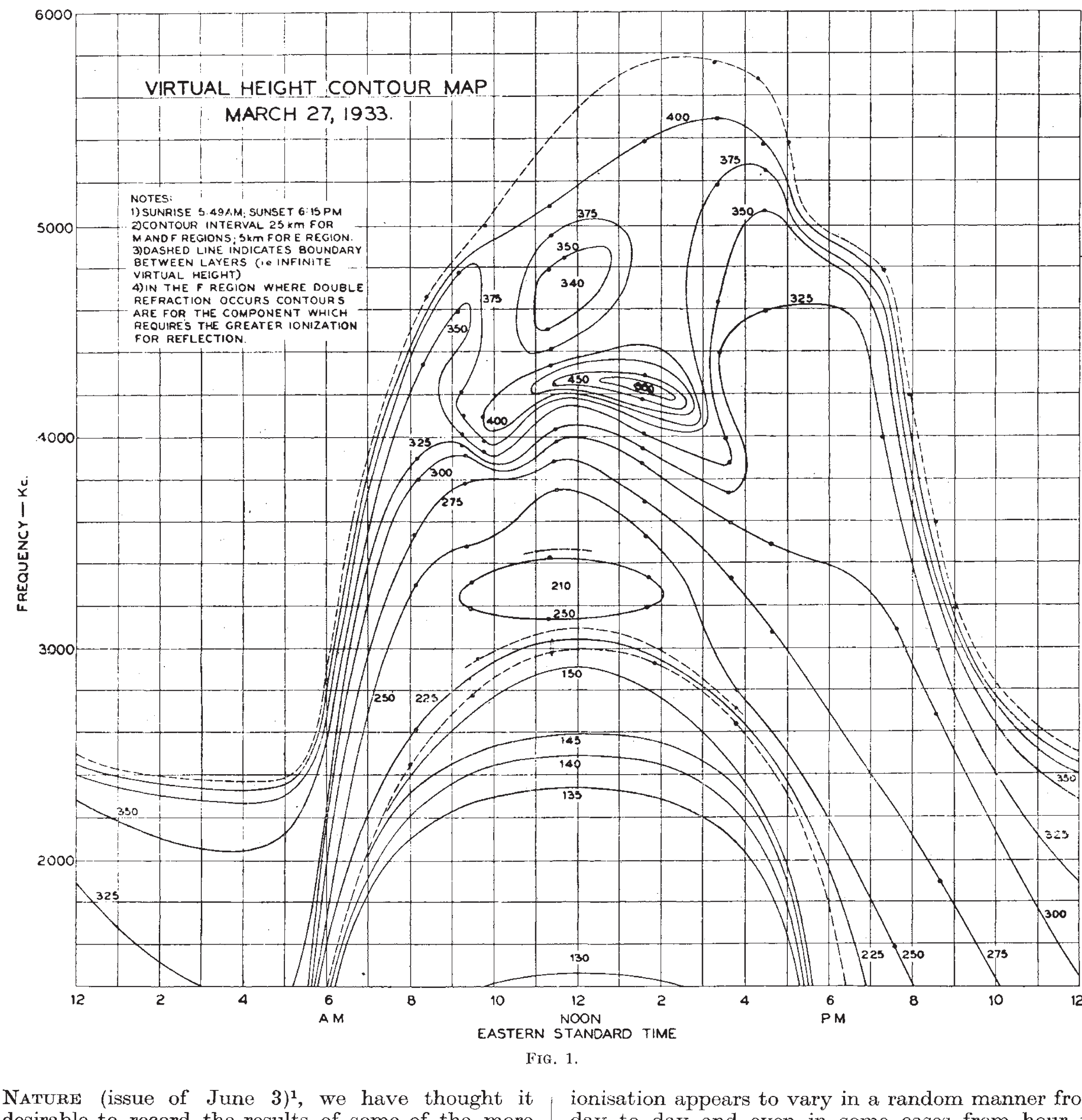

FIG. 1.

As a result of daily measurements made near noon as well as a number of all-day tests which have been made from time to time, it appears that in the lower part of the *E* region and the lower part of the *F* region the ionisation in each is found to be substantially the same from day to day. Moreover, the ionisation in these regions attains a maximum shortly after noon and, in general, varies slowly with time in the manner that would be expected if the ionising agency which is effective in these regions, were constant in magnitude and originated at the sun. Tests made by us during the solar eclipse of August 31, 1932, indicate strongly that in *both* these regions this ionising agency is ultra-violet light.

As regards the three or more other regions, the ionisation appears to vary in a random manner from day to day and even in some cases from hour to hour. There appears to be no correlation between variations in one of these regions with those in another. The exact cause of these variations is not known but it seems likely that they are due to corresponding variations in the ionising agencies, or to changes in the atmosphere (for example, of density or of mass motion), or to both. Because of these variations it is not always possible to find all these regions at the same time, since the ionic density of a higher region must exceed that of a lower region in order to be detected by radio measurements.

Probably the most important of these variable regions, from the point of view of radio communication, is the upper part of the *F* region. This region can usually be found throughout the day, but there are periods of three or four hours near noon on some summer days when the ionic density of this region is less than that of the lower *F* region and at such times, therefore, this region cannot be detected. It has also been found that sometimes in the middle of the day in summer, such reflections as are returned from the upper *F* region are so highly absorbed that it is difficult if not impossible to find the critical ionisation frequency for this region[3]. The rapid variations of ionic density in this region which were mentioned in our previous communication have been found less frequently during the present summer than in the past winter. On the other hand, the day-to-day variations have been more pronounced.

Another striking characteristic of the variation of maximum ionic density, is that the maximum occurred at about *noon in winter* but *near sunset in summer*. The winter noontime value appears to be greater than the summer noontime value. The maximum near noon in winter and the maximum near sunset in summer were approximately the same value until about June 21, but since that time the value of the summer maximum has apparently decreased.

During the past winter the upper and lower parts of the *F* region were not usually separated by actual ionisation minima. During the late spring and summer, however, an actual minimum was apparently formed near noon on most days. (Deal, N.J., 1932–33, latitude 40° N.)

Another of the variable regions is that which we have previously designated as the *M* region. During last winter, reflections from this region were found only in the forenoon, but during the late spring and summer, reflections from this region have on occasion been found throughout the daylight hours.

A third reflecting region of the variable type is frequently found to occur at a height slightly above the normal *E* region. On a number of occasions, both day and night, the ionisation in this region was found to increase to such an extent that it completely shielded all regions above it. It is often very difficult to differentiate between the parts of the *E* region because of the fact that the virtual heights measured are of practically the same value. The division between the parts is usually evidenced by a rise and fall in the curve of virtual height vs. frequency, although at times an actual discontinuity has been found.

All the data available suggest that conditions in the general *E* region of the ionosphere are particularly suitable for ionisation and that there are many different agencies or mechanisms which can cause ionisation in this region. It appears that ultraviolet light is responsible for the more or less steady daytime ionisation in this region. As regards the large increases in ionisation in this region which are often found (both day and night) to last from several seconds to several hours, several ionising mechanisms have been suggested. Among these agencies are the following: Meteors and meteoric matter (both radio[4] and visual[5] observations); charged particles or agency causing auroræ[6]; thunderstorms[7]; and changes in the composition of the atmosphere[8]. With such a wide range of possibilities and with the relatively limited data available it is difficult at this time to evaluate the relative importance of the different mechanisms.

In addition to the three variable regions mentioned above, it has been found on a number of occasions that the lower part of the *F* region is further subdivided into two distinct parts.

In Fig. 1 the virtual height, for March 27, 1933, is given as a function both of time of day and of frequency. It is in effect a 'topographical map' in which virtual height is substituted for altitude above sea-level, time of day and frequency for east-west, north-south dimensions. A map of this sort is obtained from a series of virtual height frequency curves similar to the one shown as Fig. 1 of Prof. Appleton's letter.[1] This contour drawing illustrates the variation of virtual height throughout a typical spring day. The dashed lines represent discontinuities in the virtual height curves and mark the boundaries between the various regions or layers. Beginning at the bottom of the figure at noon the dashed lines represent in order the separation between the various parts of the *E*, *M* and *F* regions, which were found on that day. On this particular day there was no actual discontinuity between the lower and upper *F* region but the separation is marked by the peak in the virtual height contours at about 4200 kc.

Finally as regards nomenclature, Prof. Appleton has suggested that the intermediate region which we have designated as the *M* region, be called the "E^{11}" region. Aside from the objection that an ionisation maximum half-way between the *E* and *F* regions has probably no more relation to the one than to the other, we prefer to use the letter *M* since we have found that an upper part of the *E* region exists which is distinct from the *M* region and should in our opinion be designated as the E^{11} or E_2 region if this type of nomenclature were adopted. It seems preferable to us to avoid giving special designations to the various layers until we know more about the number of regions with which we have to deal.

[1] Two interesting letters in the June 17 issue of NATURE, one by Prof. E. V. Appleton, and the other by Messrs. J. A. Ratcliffe and E. L. C. White, commented on this announcement and discussed similar or related results obtained in Great Britain. The results obtained by investigators at the Bureau of Standards have led them to conclusions similar to ours. Abstracts of their papers were published in the June issue of the *Proceedings of the Institute of Radio Engineers*.

[2] The material previously communicated was obtained during the winter months of 1932–1933. It was submitted in March of this year for presentation at the Fifth Pacific Science Congress and will soon be published in the *Proceedings* of that body.

[3] This is in conformity with T. L. Eckersley's discussion on absorption in the *F* region as given in *J. Inst. Elec. Eng.*, Vol. 71, September, 1932.

[4] That meteors are an ionising agency in the ionosphere was suggested by A. M. Skellett, *Proc. I.R.E.*, December 1932. Pulse experiments which give evidence of an ionising effect in the *E* region due to meteors have been conducted by J. P. Schafer and W. M. Goodall, *Proc. I.R.E.*, December 1932 and *Science*, November 25, 1932.

[5] Visual evidence that meteors sometimes leave glowing trains, presumably due to ionisation of gases, and that these trains are definitely restricted to the general level of the *E* region (70-100 km.) has been given by C. C. Trowbridge, *Astrophysical Journal*, 1907.

[6] Further evidence that the general *E* region is particularly sensitive to external ionising agencies is given by Størmer, who has shown that there is a pronounced maximum in the number of visible auroræ at heights of the order of 90-100 km. *Terrestrial Magnetism and Atmospheric Electricity*, Vol. 35, No. 4, December 1930.

[7] An effect of thunderstorms on the ionisation in the *E* region has been suggested by C. T. R. Wilson, *Proc. Phys. Soc.*, **37**, 32D; 1925. Appleton and Naismith, *Proc. Phys. Soc.*, 5, **45**, pp. 389, May 1933, and Ratcliffe and White, *Proc. Phys. Soc.*, pp. 399, May 1933, have published data tending to support the thunderstorm theory.

[8] Ivo Ranzi, NATURE, **130**, 368, Sept. 3, 1932, and R. C. Colwell, *Proc. I.R.E.*, May 1933, have found evidence of *E* region ionisation increases with corresponding changes in barometric pressure in the lower atmosphere.