This theme is not the vapourings of a visionary, but the outcome of practical necessity. That overworked doctors in the tropics, encumbered by so many practical difficulties and shortcomings, should collect and preserve specimens destined for institutions with which they themselves are not directly connected is to expect too much. We must now be prepared to exert our personal endeavours to obtain what is so essential for the teaching of tropical medicine. The harvest is indeed plenteous, but the labourers are few in the present disorganised state of the world. This is especially true of those Eastern countries recently released from the stringencies of war. Their medical services are now being rapidly reorganised and progress is becoming apparent. It should therefore be possible to put some of the suggestions outlined in this article into operation within the near future.

RADIO METEOROLOGY: INFLUENCE OF THE ATMOSPHERE ON THE PROPAGATION OF ULTRA-SHORT RADIO WAVES

WITH the introduction of radio waves a few metres in wave-length in the years before the Second World War, and of centimetric waves during the War, entirely new meteorological effects on propagation have come to light. The first of these is the variable, non-rectilinear propagation of metric and centimetric waves through the lower atmosphere, the range of such waves over the earth's surface often far exceeding the geometrical horizon of the transmitter. Ionospheric reflexion plays no part in this propagation, for in the wave-lengths concerned penetration of the ionosphere is almost or quite complete. The second major phenomenon is the strong reflexion and attenuation of the shorter of these waves by suspended water drops or snow crystals when present in sufficient density in or beneath a cloud. Much of the knowledge acquired on these phenomena during the War was described and discussed at a joint conference of the Royal Meteorological Society and the Physical Society held at the Royal Institution on April 8.

An introductory survey of the radio-meteorological field was made by Sir Edward Appleton. He recounted the history of the experimental and theoretical work from the pre-war results of England, Crawford and Mumford using 4 m. and 2 m. waves in the United States over land and sea to the later war-time results of the Services on centimetric radar sets. With cloudy weather and strong winds the range of a radio or radar transmitter over the earth's surface is a little more than the distance of the geometrical horizon of the transmitter aerial; but in certain other types of weather the range may be many times this value and occasionally it may be slightly less, the effect of the weather being in general greater the shorter the wave-length. Thus in July 1941, a 10 cm. radar set on the south coast of England was 'seeing' 170 miles across the Channel for several days on end in warm, settled weather, though the geometrical horizon was less than 40 miles. More striking is the performance of a 1·5-m. radar set near Bombay at a height of 80 m. above sea-level; during the monsoon season it was able to plot ships up to the expected range of 20 miles; during the hot season, however, it commonly reached shipping at 200 miles, once attained 700 miles, and not infrequently saw the coast of Arabia at 1,000–1,500 miles. Note that both examples refer to propagation over the sea, where the meteorological effects tend to be most pronounced. How are such observations, by no means unusual, to be correlated quantitatively with the meteorological conditions ?

If the atmosphere were absent the propagation of radio waves would be rectilinear and, small effects of diffraction apart, no signal would be received beneath the geometrical horizon of the transmitter. The atmosphere being present, a ray inclined to the vertical will be bent downwards if the refractive index of the air decreases with height, and conversely, downward bending producing an increased range and upward bending a shorter range along the curved surface of the earth. Such upward and downward bending has long been known for light rays, producing the so-called inferior and superior mirage respectively. But optical mirage is usually rather slight whereas radio mirage, particularly of the superior type, is quite common and, as the above examples show, large in amount as measured in range. The reason for the difference is the much greater refracting power of water vapour for radio waves than for light waves. The change in φ, the inclination of a ray to the earth's surface, with distance s along the surface is given by

$$\frac{d\varphi}{ds} = \frac{1}{R} + \frac{1}{\mu}\frac{d\mu}{dh},$$

where h is the height of the ray above ground, R the earth's radius and μ the refractive index of the air. Since μ is almost unity, this may be written

$$\frac{d\varphi}{ds} = \frac{1}{R} - \alpha,$$

where $\alpha = -d\mu/dh$ is the lapse-rate of refractive index. Now in the study of ray paths, it is convenient to regard the earth as flat, and the quantity $d\varphi/ds$ is then the curvature of the ray relative to the earth's surface. In the absence of an atmosphere ($\alpha = 0$) the relative curvature is $1/R$, and with the atmosphere present $1/R - \alpha$ ($= 1/R'$ say). The vertical gradient of refractive index is usually negative (α positive) so that R', the effective radius of the earth, is usually greater than R. If α reaches the critical value of $0{\cdot}15 \times 10^{-6}$ per metre, R' becomes infinite and the earth effectively flat, while for greater values of α than this R' becomes negative, the earth effectively concave, and radio vision around the curvature of the earth becomes possible. In a well-mixed atmosphere α is positive but less than the critical value, with R' equal to about $\frac{4}{3}R$. Such a value of R' implies a measure of downward bending, while a condition of super-refraction is said to exist if R' is greater than $\frac{4}{3}R$.

The gradient of refractive index is determined by the gradient of density of dry air (in terms of observables, of pressure and temperature) and of the associated water vapour. Pressure decreases with height at an almost constant rate near the earth's surface and contributes therefore a more or less constant positive amount to the lapse of density and therefore to α, namely, $0{\cdot}03 \times 10^{-6}$ m.$^{-1}$. If now the temperature decreases with height (lapse of temperature) the air density and therefore the refractive index fall off with height less rapidly than in an isothermal atmosphere, whereas if the temperature increases with height (inversion of temperature) the lapse of density and of refractive index is enhanced above isothermal values, a gradient of $\pm$ 1° C./10 m. contributing about $\pm 0{\cdot}16 \times 10^{-6}$ m.$^{-1}$ to α. An inversion of 1° C./10 m. provides, therefore, rather more than the critical value of α for the earth to be treated as flat. Finally, a lapse of vapour pressure makes a positive contribution to α, and conversely, $\pm$ 1 mb./30 m. producing $\mp 0{\cdot}13 \times 10^{-6}$ m.$^{-1}$ in α. Thus an inversion of temperature associated with a lapse of vapour pressure is the most favourable combination for a super-refracting atmosphere.

Prof. P. A. Sheppard discussed the physical processes determining the vertical gradients of temperature and humidity in the bottom kilometre of the atmosphere and assembled observational data on their magnitudes. One or more of the following factors, (*a*) the net radiation inflow (positive or negative) at, and the physical properties of, the earth's surface, (*b*) the horizontal gradient, in the direction of the wind, of temperature and vapour pressure at the earth's surface, (*c*) the rate and pattern of subsidence in the free atmosphere, combine with the intensity of the mixing process in the vertical to determine the magnitude of the gradients concerned. When neither of the factors (*a*), (*b*) and (*c*) is large in the meteorological sense, the lapse-rate of temperature near the surface in a well-mixed atmosphere is very near the so-called dry adiabatic value of 1° C./100 m., a value too small to produce any material control on the curvature of radio rays, and the gradient of humidity will also be negligible so far as its effect on α is concerned. Under strong insolation, the lapse-rate of temperature over the land may amount to 1° or 2° C. per 10 m. in the bottom 20 m., decreasing with increase in height up to about 100 m., while on a clear night with light wind the net outflow of infra-red radiation from the surface may produce an inversion of temperature about twice as great numerically as the day-time lapse and extending to an increasing height with time during the night up to about 300 m. Thus, so far as the temperature is concerned, sunny days on land are inimical to super-refraction, while calm, clear nights are favourable. Over the open sea such diurnal effects are absent, because of the much higher effective thermometric conductivity of water than of land. The gradient of vapour pressure over the land follows much the same diurnal course as the gradient of temperature provided the surface is not dry or the vegetation withered, the boundary value of vapour pressure following approximately the change in surface temperature along the saturation vapour-pressure curve. There is, however, generally a lag of an hour or two in the onset of an inversion of humidity on a clear evening behind the onset of the temperature inversion. The observed day-time lapse of vapour pressure may amount to 1 or 2 mb. per 10 m. over the lower 10–20 m. during very hot weather, and the night inversion to rather smaller numerical values, both decreasing numerically with height. Thus the diurnal effect of humidity gradient on refractive index is comparable with, and opposed to, that of temperature gradient except in the early evening. Again, diurnal effects on vapour pressure are absent over the sea.

Passing from diurnal effects, when a light or moderate wind blows over a surface the temperature of which changes, either abruptly or continuously, in the direction of the wind, appreciable departures from the adiabatic lapse of temperature may be produced in the lowest few hundred metres, and humidity gradients corresponding to the air mass and surface humidities will also arise. This so-called advection condition is most marked in the lower atmosphere when the surface temperature falls in the direction of the wind, for the vertical stability associated with the inversion of temperature then formed confines the effect of the changing boundary condition to a relatively shallow layer of air. Further, if in this case the air mass is initially very dry and moves over the sea, the evaporation at the surface will produce an appreciable lapse of vapour pressure in the lower atmosphere, so that temperature and humidity profiles combine towards super-refraction. Such a condition arises when anticyclonic air moves out from a continent over the sea in summer, and is responsible for a majority of the long radar ranges observed over the sea.

The air in an anticyclone and certain other situations subsides from aloft and spreads out horizontally at low levels, the adiabatic heating of the air during descent generally resulting in an inversion of temperature at the base of the subsiding layer to be found between 0·5 km. and about 2 km. height. Such subsiding air, having moved from levels of low temperature, is also generally very dry, whereas the air beneath the subsiding column is likely to be damp due to surface evaporation. Thus the inversion of temperature is likely to be associated with a strong lapse of vapour pressure. Only recently has the fine structure of such subsidence inversions been observed, gradients of as much as + 3° C. in 7 m. or 6° C. in about 30 m., and in vapour pressure of -2 mb. in 7 m. or $-3{\cdot}5$ mb. in 30 m., having been found over Britain. Again a super-refracting atmosphere results, though how important such raised inversions are likely to be in radio propagation has yet to be determined completely.

Dr. R. L. Smith-Rose presented data on the effect of weather conditions upon the propagation of 9-cm. and 3-cm. waves over the land and over the sea which, in part at least, fit well with the above considerations. In the sea trials, meteorological soundings of pressure, temperature and humidity were made so as to provide values of the refractive index up to about 500 m. over the radio links, and encouraging correlations were found with field strength at the receivers. Exceptionally high accuracy is required in the meteorological observations in order to provide trustworthy profiles of refractive index, so that some scatter in the correlation was not surprising. This apart, there were indications that a simple refraction theory was adequate to explain the observed fields except for low-level links, for which the field strength was systematically greater than simple theory would suggest.

Surface observations only of weather were available on the land-link trials, in which high signal strengths were frequently observed at the receivers on clear nights and, perhaps surprisingly, during the advection fogs of autumn and winter ; whereas almost complete fade-outs occurred during radiation fog at night. The passage of a cold front across the link generally produced markedly variable signals, a feature also in evidence in the absence of any marked weather phenomenon and probably to be accounted for by the inhomogeneity of the atmosphere in temperature and vapour pressure.

The ray-tracing treatment in studies of propagation takes no account of the wave-length whereas this is an important factor, and Dr. H. G. Booker described to the conference a wave-treatment in which the principles of wave guides was extended to an atmosphere with a given profile of refractive index. Certain observed forms of profile in the lower atmosphere provide a wave guide, or radio duct as it is called, either at the surface or in a slightly elevated layer, in which the energy of shorter waves is almost or completely trapped, and propagation around the curvature of the earth follows. But the leakage from such ducts increases with the wave-length, with the consequence that decametre and longer waves take no notice, as it were, of the fine-grained structure of the lower atmosphere. Prof. D. R. Hartree added to this branch of the subject by describing some ingenious mathematical devices which have been developed for tackling propagation studies for certain classes of profile.

In the discussion on the above aspects of radio propagation, Mr. F. Hoyle, to whom the concept of a radio duct is partly due, considered that, given the meteorological observations, field strengths could be calculated with satisfactory accuracy with more or less of labour, and that the important practical problem to-day is that the meteorologist should be able to forecast successfully the propagation conditions for some time ahead—no small problem in regions such as the temperate latitudes experiencing much 'weather' but little 'climate'. Mr. E. G. S. Megaw was not, however, quite so satisfied with present theory, and considered that the assumption so far made that the earth's surface is a perfect reflector and conductor needs re-examination.

The conference then passed to the absorption and scattering of radio waves in the atmosphere, on which subject Mr. J. W. Ryde gave the results of an intensive theoretical study which has received wide observational support. The attenuation and scattering of 2 cm. and longer waves is negligible for atmospheric gases but may be appreciable for suspended matter such as water drops, ice crystals and dust. For the small water droplets found in fogs and most non-precipitating clouds (diameter d of order 10μ) the attenuation and back scattering is proportional to d^3, and therefore to the total mass of liquid present irrespective of the drop-size distribution. The total mass of such water in a centimetric radar beam is, however, usually far too small to produce measurable echoes, though the attenuation in a kilometre of fog or cloud may be appreciable. For larger drops, for example, drizzle and rain, the Rayleigh law of scattering proportional to $(d/\lambda)^4$ applies, and considerable attenuation and echo intensity may result from clouds and the precipitation beneath them, particularly at the shorter wave-lengths. From the observed drop-size distribution for given rates of rainfall, Ryde deduces an attenuation up to 1 db. per km. on 3 cm. waves in Britain, and up to 6 db. per km. in the tropics where the heaviest rain occurs, the ratio of attenuation on 10 cm., 3 cm. and 1 cm. waves being roughly as 1 : 100 : 700. The echo intensity on 10 cm. radar from a cloud at 50 km. distance producing rain at the moderate rate of 7 mm./hr. is about the same as that for a small aircraft at the same distance, but on 3 cm. radar the echo intensity from the same cloud increases a hundred-fold. The increased sensitivity of the shorter wave-lengths is, however, offset by attenuation if precipitating cloud lies in the line of sight to the farther cloud. Precipitation usually begins as snow above the 0° C. isotherm, and Ryde has shown that, while a snow crystal is a less effective resonator than a raindrop of equal mass, the snow will produce an echo equal in intensity to that from the rain resulting from the snow, provided the snow crystals are not less than 1–2 mgm. in mass, a quite usual value, and will produce a much greater echo if the crystal aggregate is greater than about 5 mm. diameter. This results from the greater mass of water substance per unit volume of air in the snow region, the snowflakes having a lower terminal velocity of fall than the corresponding raindrops. Also arising from this interplay is the enhanced echo from a thin layer of cloud near the 0° C. isotherm, where the snowflakes melt and become better resonators but do not immediately reach their higher terminal velocities.

Lieut.-Commander F. L. Westwater followed with an account of the use to which radar echoes from storm clouds may be put by the synoptic meteorologist. As forecast by Ryde, the major echoes arise from instability showers, either scattered or such as occur along an active cold front, with or without thunder, the rate of precipitation in these cases being generally high. Such storms can be picked up sufficiently far off, and their path of travel and their development or decay followed so as to provide useful additional observations, particularly at sea or at a coastal station. Of special interest to aircraft and ships, and more generally, is the radar vision of tornadoes or other tropical storms and the plotting of their often variable tracks.

In discussion, Lieut. R. G. Ross referred to echoes occasionally obtained from unexpected meteorological quarters, for example, haze layers and strato-cumulus clouds, and when using metre-waves, so that much remains to be investigated before the significance of a particular echo will always be clear.

Mr. C. S. Durst read a paper on "Radio-Climatology", relating mainly to abnormal propagation. He has considered the likely general form of the temperature and humidity profiles in characteristic weather situations and areas of the world, and amalgamated them to provide tentative world charts of what may be called 'radio climate'. Such charts are at present more reliable for the oceans than for the land, since the meteorological phenomena are simpler over the oceans and less dependent therefore on long series of detailed observations not yet in existence or even begun.

Sir Nelson Johnson rounded off the conference by considering future developments in radio meteorology. In relation to abnormal propagation, many more observations are required of the humidity profile in order that an adequate theory of matter-exchange may be formulated and integrated with the theory of heat- and momentum-interchange in the vertical. Further, our knowledge of the subsidence mechanism in anticyclonic conditions and its relations with the temperature and humidity gradients at the subsidence inversion need elucidation for their own sake and in relation to radio-propagation. The problems associated with radar echoes from clouds are exceptionally important—and difficult. One is concerned with the vertical velocities in clouds, with the size-distribution of cloud elements and the transformation of ice to water and vice versa, matters of great concern in aviation as well as to the more academic meteorologist. All these problems are being tackled, in Britain and in other parts of the British Commonwealth, and there is little doubt that the union between radio and meteorology so happily begun under Sir Edward Appleton's chairmanship during the War has many mutual benefits to confer in the coming years.

P. A. Sheppard