

the strain was not discharged by the main shock. The general history of earthquakes is that after a severe shock aftershocks occur for a period of months or even years, after which there may be a period of relative quiescence of years. This means that the major portion of the strain has been released, and it is only if the cause which produced the original strains continues to operate causing further strains to accumulate, that another severe shock may

be ultimately expected. Unfortunately, geology has no means of predicting whether the occurrence of a big earthquake confers immunity upon the region where it has occurred for a long period of time, though this is the usual position. This means that in rebuilding in areas damaged by earthquakes, engineers should take account of the maximum acceleration hitherto recorded from that earthquake region and arrange accordingly in their buildings.

### Micro-Climatology.\*

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#### INTRODUCTION.

IN meteorology we have been concerned in the past with the prediction of weather over comparatively large tracts of country. The large-scale phenomena in the earth's atmosphere extend up to several kilometres above the ground and contribute to what may be called "macro-meteorology". It is usual to consider the surface of the ground and the adjacent air layers up to about 2 metres above ground as disturbing factors. When the meteorologist, however, turns his attention to problems relating to agriculture he finds that it is just this disturbance zone which assumes great importance.

Three years ago, the speaker, in collaboration with a few other workers, undertook a detailed investigation of phenomena taking place in the air layers near the ground.<sup>1, 2, 3</sup> With the creation of the Agricultural Meteorology Branch towards the close of 1932, our studies received a new orientation and the programme of work has included, among other items, also a study of the variation of the micro-climate in different environments, e.g., inside and outside different crops.

In Europe Schmidt, Geiger and others have been studying the micro-climate in temperate latitudes during the past few years and have made numerous important contributions to this new subject.<sup>4</sup>

The International Commission on Agricultural Meteorology at its last meeting at Munich<sup>5</sup>

\*Report of a lecture on "Micro-Climatology" at the Colloquium, Meteorological Office, Poona, on 10th April 1934.

<sup>1</sup> "Theory of extremely high lapse-rates of temperature very near the ground," by S. L. Malurkar and L. A. Ramdas, *Indian Journal of Physics*, VI, Part 6, p. 495.

<sup>2</sup> "Surface convection and variation of temperature near a hot surface," by L. A. Ramdas and S. L. Malurkar, *Indian Journal of Physics*, VII, Part 1, page 1.

<sup>3</sup> "The vertical distribution of air temperature near the ground during night," by L. A. Ramdas and S. Atmanathan, *Gerlands Beitrage Zur Geophysik*, 37, pages 116-17, 1932.

<sup>4</sup> *Handbuch der klimatologie*, Band I, Teil D, "Mikroklima und Pflanzenklima" Von Dr. Rudolph Geiger (1930). Contains an excellent

(September 1932) passed several important resolutions emphasising the importance of "micro-climatology" and its investigation in all countries. Similar resolutions were also passed at the Conference of Empire Meteorologists,<sup>6</sup> London, 1929.

The aims of "micro-climatology" are (1) to investigate the physical laws underlying the deviations of "micro-climate" from "macro-climate"; for, a knowledge of these laws is essential for getting a fresh insight into atmospheric phenomena, and (2) to apply the theoretical results to practical ends, e.g., a knowledge of the regular deviations would enable one to predict possible conditions in the hitherto unsurveyed regions with some confidence. In the tropics, owing to the intensive insolation, the "macro-climate" may be expected to be more profoundly modified by variations in the environment than in higher latitudes.

Some of the important aspects of this new subject may now be summarised very briefly. The influence of orography and crops, problems relating to experimental technique, "effective rainfall", etc., will be discussed on a future occasion.

#### ROLE OF SOLAR RADIATION.

Most variations of atmospheric conditions may be traced ultimately to (a) variations in the intensity of solar radiation received at the earth's surface, and (b) variations in the disposal of the thermal energy derived by the earth's surface from solar radiation. The first factor varies with season and latitude. The second factor depends on (i) the exchange of heat between the surface of the ground and the layers of the soil which are affected by the diurnal variation of temperature, i.e., the "conduction process", (ii) the exchange of heat between the surface of the ground and the air layers in contact with it or, in other words, the "convective process", (iii) the

bibliography of micro-climatological papers upto 1930.

<sup>5</sup> Proceedings of the Commission on Agricultural Meteorology; Munich Meeting, publication No. 14, "Secretariat de L'organisation Meteorologique, International."

<sup>6</sup> Resolution No. XIII of the Conference of Empire Meteorologists 1929, Agricultural Section, Report (p. 11, paras 29, 30, 31 and 32).



exchange of thermal energy between the ground surface and the atmosphere by radiation processes, which again are modified by the water vapour and carbon-dioxide content of the atmosphere, and (iv) the heat lost or gained by the earth's surface due to "evaporation" or "condensation" of water at the surface.

Detailed measurements of these complex factors which control what may be called the "thermal balance" at the earth's surface are necessary for a proper understanding of the phenomena taking place in the air layers near the ground and in the first few feet of the soil below. Investigations on these lines are in progress at Poona.

#### SURFACE CONDITIONS.

The colour of the soil determines the absorbing and the radiating power of the surface. A black surface absorbs most of the incident solar radiation whereas a white surface reflects a considerable fraction of it and is a poor absorber. Recent experiments at Poona show that a very thin coating of chalk over the black cotton soil depresses the maximum temperature by about 15°C. at the surface, 5°C. at a depth of 5 cms., and 3°C. at a depth of 10 cms. At depths of 5 and 10 cms. the minimum temperature also is lowered by about 2°C. These effects penetrate further downwards with rapidly decreasing intensity. The changes take a few days to be fully developed; on removing the chalk the normal conditions are restored gradually and the temperatures become similar to those under the untreated soil only after a few days.

Similarly, even a very thin coating of wet soil at the surface decreases the amount of heat conducted downwards because part of the solar energy received by day is utilized for evaporation. The effects of soil covers of different colours, of a crop cover, and of wetting the surface of the ground, on soil temperatures at various depths are being investigated at Poona.

#### SOIL CONDUCTIVITY.

The thermal conductivity of the soil is an important factor in controlling the distribution of temperature in the soil as well as in the air above. It varies with different soils and, in the same soil, with the water content. As more and more water replaces the soil air (air is a poor conductor of heat) the conductivity increases; but the specific heat as well as the apparent density also increase so that, beyond a critical stage, the effect of further increasing the moisture content is to depress the thermal diffusivity.

In general, during the day hours a well-conducting soil transmits more heat into the interior, the surface remaining comparatively cool; at night the heat so stored up is returned rapidly to the surface to compensate the radiation loss. In such soils, the diurnal variation of temperature has a small amplitude. In badly conducting soils the heat energy gained by day mostly remains at the surface which becomes very hot and, at night, owing to the radiation loss not being compensated for by heat conducted from below, the surface attains a low temperature. This results in a large diurnal range of temperature in a shallow layer at the surface. The importance of the heat conductivity of the soil in relation to conditions during winter may easily be anticipated. Experiments show that a compact undisturbed soil has a warmer surface at night than one in which the soil has been turned up and loosened at the surface.

Reports received from different places on damage to crops due to frost during the cold waves of January last show that crops irrigated prior to the onset of frost were less affected. A study of the thermal conductivity of different soils in varying degrees of packing and of moisture content is therefore of importance.

#### CONVECTION PROCESS AND RADIATION FROM THE EARTH'S SURFACE AND ADJACENT AIR LAYERS.

During a clear day, the ground surface becomes very warm owing to the absorption of solar radiation; the air in contact with it is warmed up in its turn and is in unstable equilibrium with the denser and cooler air higher up. Consequently, there is a considerable vertical exchange of air mass in the shape of warm ascending currents of air and cool descending currents. This gives rise to the well-known "shimmering". The thermal structure of the "shimmering" layer has been investigated by Geiger<sup>7</sup> and recently ourselves by taking temperature observations with a sensitive thermo-couple set at quick intervals. The vertical interchange of air masses or what may be called "Surface Turbulence" is confined to the first few feet above ground. Above it, is the horizontal flow with its associated turbulence on a larger scale. The effective upward transfer of heat due to both the surface and the free air turbulence is minimum near the ground and, therefore, the ground and the air layers immediately in contact with it attain higher temperatures during afternoons than the air layers higher up.\* Owing to the same reason the ground and the air layers near it cool more rapidly by night than the layers higher up. This results in a large diurnal range of temperature near the ground, the range rapidly decreasing with height. As may be expected in the higher latitudes, the frequency of frost is found to decrease with height. In tropical countries, however, owing to the fact that even during the night the ground is warmer than the cooling air above,<sup>8</sup> it may be expected that the height of maximum frost frequency will be a few inches above the ground. This is also supported by recent frost reports.

The conditions that prevail at night are equally interesting. Soon after sunset the ground and the air layers above it begin to cool rapidly by radiation. The air layers begin to stratify, *e.g.*, at Poona it is observed that the cooling of the air by radiation in winter is of the order of 10°C. per hour during the first half hour after sunset, the fall of temperature being large near the ground and decreasing with altitude. Occasionally, winds of local origin set in for short periods during the night; then the stratification is disturbed temporarily, the air layers get mixed up and there is a rise of temperature as a result. Towards the end of winter, the sea breeze sets in in the evenings and continues for a few hours during the night.

<sup>7</sup> Page D. 26 of publication (4) above.

\*Temperature and humidity observations taken at several heights above ground, both above bare soil as well as inside a few representative crops at the epochs of maximum and minimum temperatures, are being discussed by the writer and others in a series of papers. Each crop is found to develop its own peculiar local climate, the deviations of which from the "open" depend upon the season and the growth of the crops.

<sup>8</sup> Ramdas and Atmanathan, *loc. cit.*



During such nights the convection and the radiation processes act simultaneously and bring about a more gradual and less accentuated fall of temperature than during calm winter nights.

#### WIND MOVEMENTS.

The complex thermal structure referred to in the above section has also its counterpart in the wind movements in the air layers near the ground. Simultaneous observations of wind velocity taken at various heights show considerable variations, the larger variations being associated with greater turbulence. It is found that there are three zones *viz.*, (a) one near the ground in which the surface disturbances predominate, (b) an intermediate layer in which the air is relatively quiet, and (c) the regions above where air movement is more or less horizontal and where the large-scale turbulence investigated by G. I. Taylor and others prevail. Schmidt's<sup>9</sup> observations also show that the surface turbulence increases with the roughness of the surface, *e.g.*, over a turnip field the variations in the wind movements are larger than over a bare plot.

#### LIMITS OF SURFACE CLIMATE.

The change from the surface to the climate of open space is not quite gradual. R. Geiger<sup>10</sup> quotes evidence to show that there is a level of transition at about 1½ to 2 metres above ground which would probably coincide with the quiet zone referred to in the previous section. In tropical regions it may be expected that, owing to the more intense insolation, the horizontal partition between the zone of vertical exchange and the zone of horizontal flow may be slightly higher up. Recent observations appear to show that this upper limit of the surface climate undergoes variation during the day, attaining a maximum height in the afternoon and coming down towards the ground in the evening and later during the night. Observations of the temperature distribution at short intervals of height and time after sunset indicate the rapid fall of this level which may be expected to coincide also with the level at which the nocturnal inversion of temperature begins. In short, the surface turbulence will not completely die away in the tropics even during winter nights owing to the greater warmth near the ground. In higher latitudes, owing to the weaker solar insolation, the surface turbulence will cease after sunset and the inversion of temperature may start at the ground surface itself.

#### THE WATER VAPOUR CONTENT IN THE ATMOSPHERE.

During all seasons of the year there is a considerable amount of evaporation of water from the soil surface. During the wet seasons it may

be expected that the specific humidity in the air would be more or less constant with height above ground, with a tendency to be a maximum near the ground during periods of sunshine. At Poona, the above state of affairs prevail during the monsoon season, *i.e.*, June to September. During autumn, the upper layers of the soil rapidly desiccate and, by the time winter sets in, the loss by evaporation during day becomes smaller. It is still found that the usual decrease of vapour pressure with height persists even during this period. A surprising observation is that during night the above situation is reversed, *i.e.*, water vapour is minimum near the ground and rapidly increases with height. It was somewhat difficult to explain this at first sight, but, measurements of the loss of water from samples of soil exposed under natural conditions at the surface of the ground during the day showed that the loss is actually compensated by the absorption of moisture from the air by the same samples during the night. In other words, the soil which is intensively desiccated during the day acts as an absorber during the night thereby producing a minimum of vapour pressure near the ground. These results will be discussed more fully elsewhere.

#### EVAPORATION.

The evaporating power of the atmosphere is measured by the loss of water in small reservoirs with suitable measuring devices. As a meteorological element evaporation expresses the combined influence of temperature, humidity, sunshine, etc., as a single factor. Recent observations at Poona with a series of Piche's evaporimeters at various heights show that upto 4 ft. the evaporation increases with height even during the afternoon when the ground surface has the highest temperature. The effect of wind is thus seen to be more pronounced than that of the high temperatures near the ground. The study of the variations of evaporation in different environments at the same place, as well as the standardization of different types of evaporimeters are in progress.

#### DEW FALL.

When objects thermally insulated from the ground lose more heat than they gain from the air in their neighbourhood, their surfaces attain a lower temperature than the air. This results in condensation of water vapour if the lowering of temperature is sufficiently large. In many parts of India dew deposition during the night is very pronounced during clear weather. Exact measurements of dew deposition are not available at present, but qualitative observations at Poona made with collectors with bright surfaces exposed at various heights during last winter show that dew deposition starts from a height of 6" to 1 ft. above bare ground and increases with height.

<sup>9</sup> Page D. 28 of (4).

<sup>10</sup> Page D. 31-34 of (4).