the articles appearing in the Journal are of great importance and interest. Particular interest attaches to the results obtained in the cryogenic laboratory in Leyden, the measurements of intensities of spectral lines initiated by Ornstein and the X-ray studies of D. Coster and his pupils. In the issue before us we have accounts of X-ray studies from D. Coster's laboratory and of low temperature research carried out at Leyden. The Utrecht School is also represented. J. P. Schouten has an interesting note on a theorem in the operational calculus. We may confidently say that the high standard reached will be kept up in succeeding numbers. We wish the Journal a long and useful life.

## Frost Hazard in India.

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THE farmer knows how dependent his crops are on weather conditions. A good yield is dependent, amongst several factors, upon a sufficient quantity of rain, suitably distributed, during the growing season, as well as upon a favourable sequence of air temperature, humidity, soil temperature, etc. Experience tells us that there are optimum values for these factors and that excessive rain or drought, intensely hot or cold waves, extremes of humidity or dryness, are all equally dangerous to a growing crop. In the present note we shall confine our attention to the adverse effects* of cold waves in India and the frosts which occur during their incidence.

It may be pointed out that the phenomenon of frost is essentially a radiation† phenomenon during clear nights and occurs about the epoch of minimum temperature. In lower latitudes like ours the soil is usually warmer than the air layer above it so that the latter has to cool by radiation to the colder air masses in the upper atmosphere. If there is air movement at night the stratification due to radiative cooling is upset with the result that the air temperature will not fall as rapidly as when the air is stationary. During winter at most places the mean air temperature at sunset is too high for nocturnal cooling even during favourable nights to cause frost on the next morning. This is, however, possible on days when the temperature at sunset is sufficiently low, *e.g.*, when the country is invaded by a cold wave from the north.

The northern parts of India are visited by cold waves during winter. The cold waves usually come in the wake of the western depressions which enter India, at intervals of about a week across the north-west frontier and Baluchistan and move eastwards through the Indo-Gangetic plain towards the north-east frontier of India. The origin and structure of the winter depressions have been the subjects of many investigations, notable contributions having been made by Hemraj,[1] Walker and Kameswara Rao,[2] and recently by Banerji.[3] It is now an established fact that the winter depressions which invade India are associated with the family of depressions which originate at the partition in the Atlantic regions between the warm and moist equatorial air and the cold air of the higher latitudes.

The approach of a winter depression is heralded in North India by the appearance of high clouds, and the rise of air temperature associated with air movement from the south. Later, the clouds lower and drizzling weather ensues. So long as a place lies in this "warm" sector of a depression there is no likelihood of a conspicuous fall in temperature. The passage of the "warm" sector eastwards is followed, however, by the "cold wave" during which northerly

* For two interesting accounts of the damage to crops during frost please see Bulletin No. 165 of 1930 by K. V. Joshi, Department of Agriculture, Bombay, and an article on "The Effect of Frost on some crops at Pusa" by R. D. Bose, *Agriculture and Live-stock in India*, 1933, 3, 555.

† The loss of heat by radiation experienced by a layer of air during the night depends upon the amount and distribution of water vapour in the atmosphere. This problem is being discussed in a forthcoming paper.

[1] *Indian Meteorological Memoirs*, **21**, Part 7.
[2] *Ibid.*, **24**, Part 2.
[3] *Meteorology of the Persian Gulf and Mekran*, by B. N. Banerji; special brochure published by the Indian Meteorological Department.

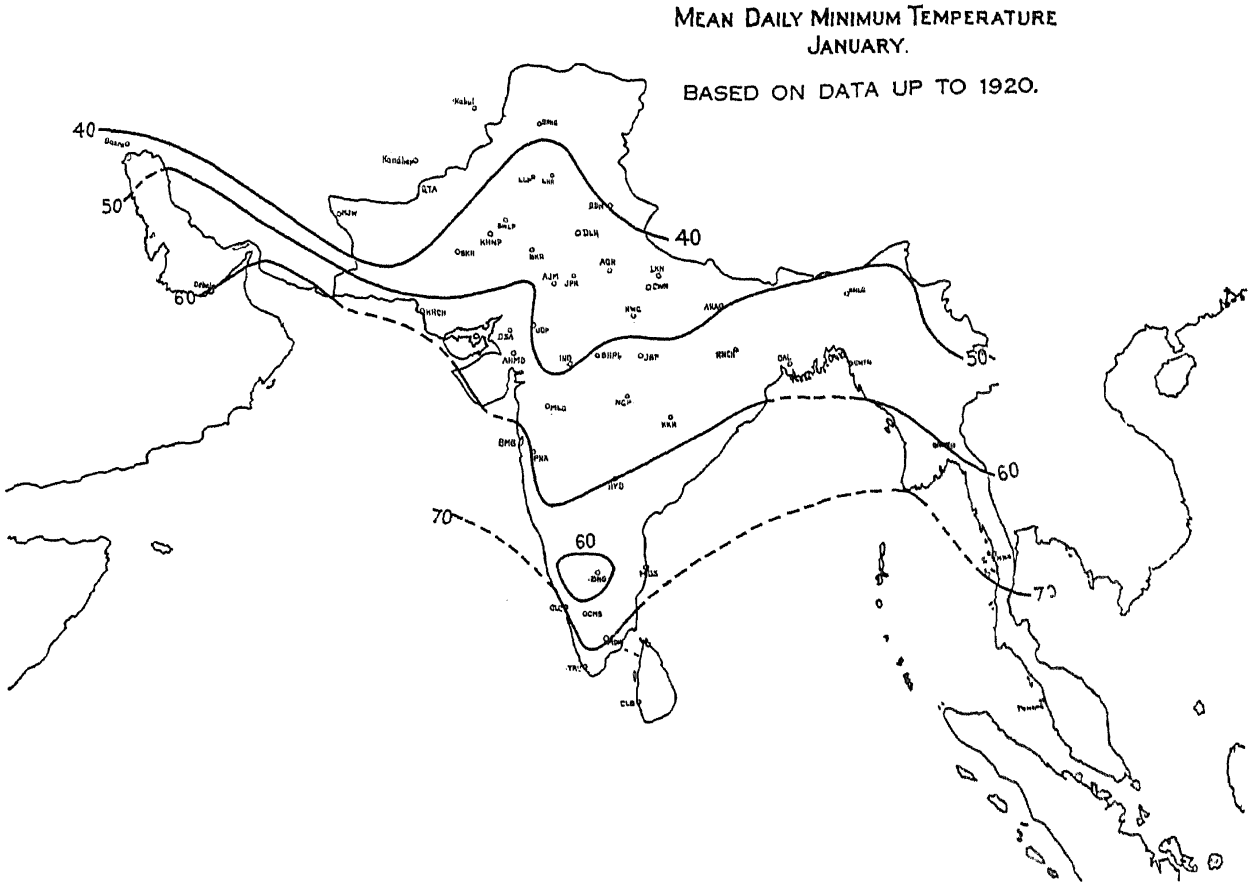


**Fig. 1.**

cold winds pour into the country. The cold wave in its turn extends or moves eastwards across the country, weakening in the meantime. As soon as another western depression approaches the north-west frontier the temperature begins to rise rapidly.

The intensity of a cold wave as well as the extent of the country which it affects depend upon a number of factors, *e.g.*, the intensity and area of the depression with which it is associated. Sometimes, the anticyclone over Tibet and Mongolia which is the main reservoir of cold air for Asia is itself shifted westwards towards Europe, and if at the same time a deep western depression passes through Persia and North-West India, a very severe cold wave sets in behind the depression. The phenomenal cold wave which visited India during the period 30-1-1929 to 3-2-1929 was of this type.

In most years the cold waves affect only north-west India and the adjoining parts of Sind, Rajputana, the United Provinces, Central India and Gujarat. During unusually intense cold waves even the Bombay Deccan is affected. The area to the south of latitude 18° N. is practically free from the adverse effects of the cold waves even on such occasions.

Fig. 1 shows the normal‡ daily minimum temperature over India during the month of January as recorded inside the standard screen or shed. The normal shade minimum temperature is 40° F. and above, practically over the whole of India excepting the mountainous tracts to the north.

Fig. 2 shows the lowest minimum temperature in the shade recorded up to 1920. This chart indicates that in the region lying to the north of latitude 18° N. the minimum temperatures may sometimes fall by 20° F. below the normal for January whereas to the south of this latitude the lowest minimum temperatures are only about 10° F. below the normal.

It must be remembered, however, that the temperature recorded by a minimum thermometer inside a screen at 4 ft. will be higher than the temperature recorded by a similar instrument exposed to the sky and

‡ Based on data up to 1920.

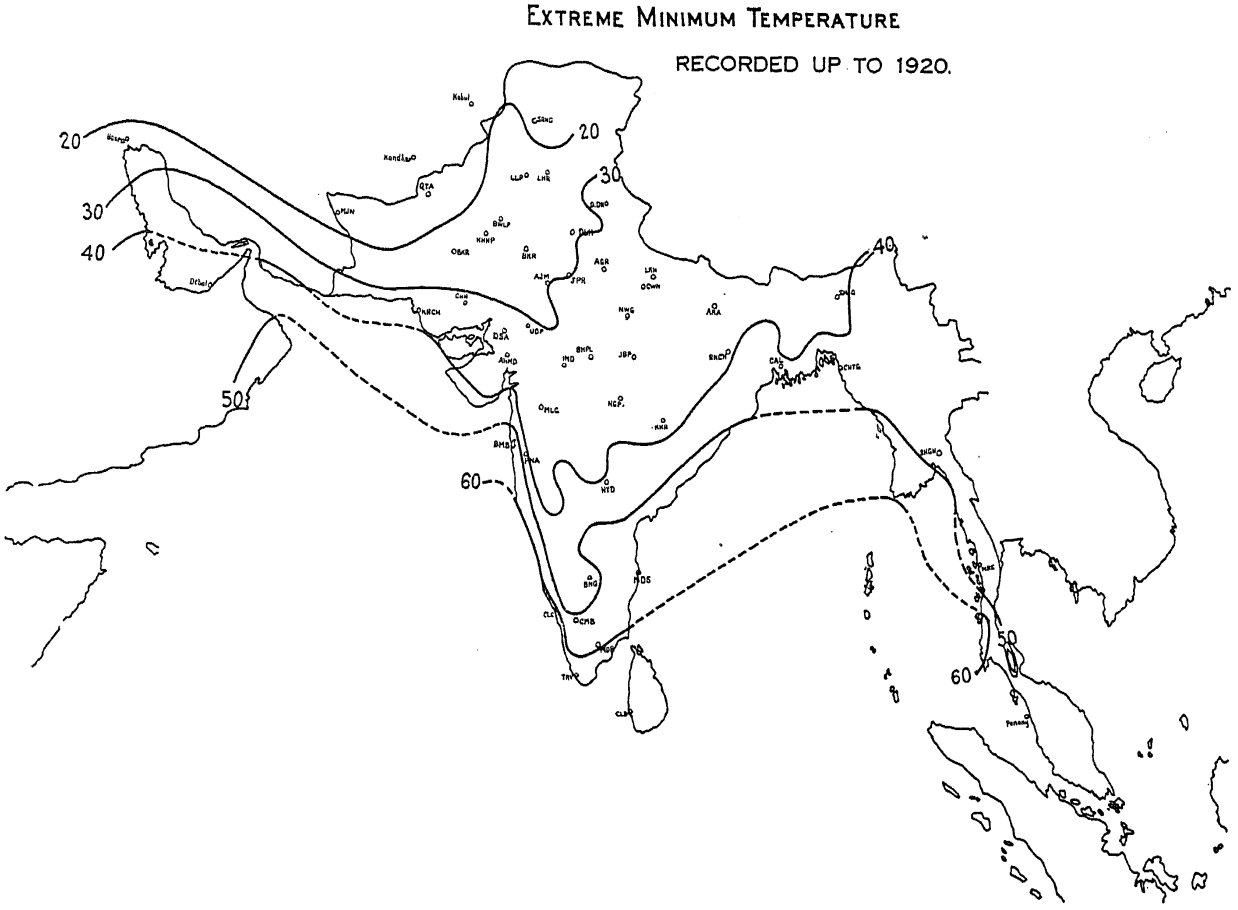


**Fig. 2.**

the ground surface. In studies on frost, we are concerned with the temperature attained during the night by objects near the ground which are exposed to the sky but which are thermally insulated from the soil. Such bodies usually radiate out more heat energy than they receive from the sky or the ground or by contact with the surrounding air.

A measure of the lowering of the minimum temperature in the open near the soil surface below the minimum temperature inside the screen at 4 ft. can be had from the nocturnal radiation temperature measurements made at a few selected stations in India for a few years. Table I gives the depression of monthly mean nocturnal radiation (minimum) temperatures below the mean minimum shade temperatures for the month of January.

On an average the depression is of the order of 10° F. in the month of January. Using similar data for other months Mr. Ananthapadmanabha Rao has prepared charts of India showing the frequency of occasions when the minimum temperature in the open fell below certain limiting values (*viz.*, below 34° F., 32° F., 30° F., 28° F.) during the period 1920 to 1929. Fig. 3 shows the total number of occasions during this period when the minimum temperature in the open fell below 30° F. in different parts of India. From this chart it may be seen that the number of days in January when the minimum temperature in the open may be expected to fall below 30° F. will be roughly as given in Table II.

TABLE I.

| Name of Station | Mean depression °F | Name of Station | Mean depression °F |
|---|---|---|---|
| Murree | 10·9 | Sibsagar | 5·2 |
| Lahore | 9·5 | Nagpur | 13·4 |
| Ludhiana | 10·1 | Deesa | 8·9 |
| Jeypore | 9·8 | Bombay | 10·1 |
| Mount Abu | 16·5 | Poona | 13·2 |
| Ranikhet | 13·6 | Vizagapatam | 11·8 |
| Lucknow | 8·7 | Madras | 3·9 |
| Allahabad | 11·4 | Wellington | 8·6 |
| Hazaribag | 9·9 | Rangoon | 7·4 |
| Calcutta | 9·2 | Leh | 11·8 |
| Saugar Island | 9·3 | Aden | 3·1 |
| Dhubri | 7·4 | | |

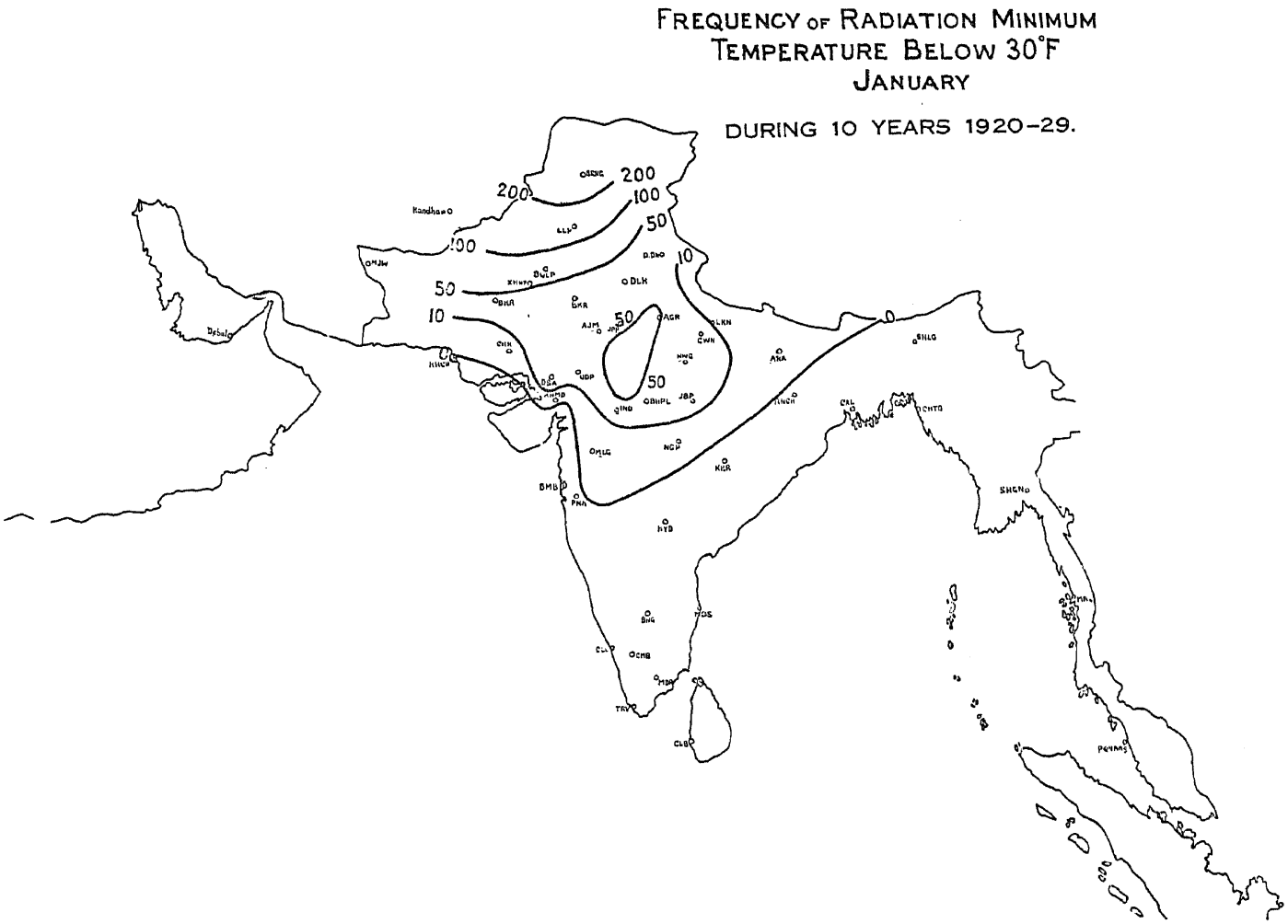


**Fig. 3.**

TABLE II.

| Area | Number of days in the month of January when radiation minimum temperature is likely to fall below 30°F. |
|---|---|
| 1. Kashmir and adjacent areas | 20 days |
| 2. Punjab (North) | 10 to 20 days |
| 3. Punjab (South) | 5 to 10 days |
| 4. Sind (excluding coastal tracts), Rajputana, Central India and West United Provinces. | 1 to 5 days |
| 5. Bombay Deccan, Northern portion of H.E.H. the Nizam's Dominions, East U.P., Bihar and a portion of North Bengal | 0 to 1 day |
| 6. Rest of Peninsula including the coastal districts of Sind, Kathiawar and the plains of Bengal | Nil |

So far we have been considering the radiation minimum temperature 2 or 3″ above the ground. The present writer and his associates[4,5] have found that even at the minimum temperature epoch in winter the temperature of the bare soil surface is higher than that of the air in contact with it and that the lowest air temperature occurs at some height above the ground. This level is usually about 6″ above the ground in the open and between 1 to 3 ft. above the ground inside crops, depending upon the plant population and height of the crop. The above results are obtained inside both irrigated and unirrigated crops. These temperature measurements were taken with the Assmann Psychrometer at the Agricultural Meteorological Observatory in the Agricultural College Farm, Poona, and refer to the air temperature. Radiation minimum temperatures taken with the help of "radiation minimum thermometers" exposed at various heights above the ground are found

[4] Ramdas, L. A., and Atmanathan, S., *Gerlands Beitrage Zur Geophysik.*, 1932, **37**, 116-117.

[5] Ramdas, L. A., Kalamkar, R. J., and Gadre, K. M., *Indian Journal of Agricultural Science*, 1934, **4**, 451-467.

to be lower than the Assmann readings but they also behave similarly, *i.e.*, the lowest temperature is recorded by the instrument kept a few inches above the ground and not the one nearest to the ground. Table III gives the mean values of the soil surface temperature (minimum) and the air temperatures (taken with an Assmann Psychrometer at the minimum temperature epoch) as well as the radiation minimum temperatures at different heights above ground for the month of January 1934.

TABLE III.

| Height above ground | Air Temperature °F. | Radiation Minimum Temperature °F. |
|---|---|---|
| 0 (soil surface) | 51·2 | 51·2 |
| 0·4″ | 48·0 | .. |
| 1″ | 47·1 | 44·2 |
| 3″ | 46·8 | 43·5 |
| 6″ | 46·8 | 43·9 |
| 1 ft. | 46·9 | 44·1 |
| 3 ft. | 48·6 | 44·5 |
| | | The radiation minimum temperature over a grass plot, at a height of about 2″ above the soil surface was only 41·8 °F. |

In the calculation of the means in the above table for the month of January 1934, a few cloudy days have also been included. On especially clear and calm nights the temperature contrast between the layer of coldest air and the air layers above and below it is much more pronounced. A few such instances are given in Table IV.

TABLE IV.

| Height above ground | Air temperature in °F. at the minimum temperature epoch taken with an Assmann Psychrometer in January 1934 on | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 13 | 14 | 17 | 20 | 31 |
| 0·4″ | 44·8 | 36·0 | 33·8 | 40·1 | 46·0 | 37·0 |
| 1″ | 43·3 | 34·7 | 32·9 | 37·9 | 44·6 | 34·0 |
| 3″ | 43·0 | 34·0 | *32·0* | 37·2 | 43·7 | 33·8 |
| 6″ | 42·6 | *34·0* | 32·9 | *37·0* | *42·8* | 38·8 |
| 1 ft. | *42·4* | 34·0 | 32·9 | 37·4 | 44·6 | *33·8* |
| 2 ft. | 44·1 | 35·2 | 32·9 | 37·8 | 45·7 | 35·4 |
| 3 ft. | 45·0 | 35·6 | 33·8 | 40·5 | 46·4 | 37·4 |
| 4 ft. | 45·5 | 35·8 Frost observed. | 35·2 | 41·7 | 47·7 | 37·4 |

## COLD WAVE WARNINGS AND PROTECTIVE MEASURES.

From the daily weather charts it is generally possible to give prior warnings for the incidence of cold waves. Such warnings were issued by the Forecasting Section of the Meteorological Office at Poona, to Mr. K. V. Joshi, Deputy Director of Agriculture, Nasik, well in advance of the cold waves which affected his area both during January 1934 and 1935. Mr. Joshi had made arrangements to disseminate the warnings promptly. The grape-growers of this district are reported to have appreciated these warnings as they could attempt to take some precautions to safeguard their crops.

The series of charts in Fig. 4 show the departure of the mean temperature of day from normal for the period 13th to 20th January 1935. The passage of the cold wave through the country (this was associated as usually with a western depression) is well illustrated by these diagrams. It will be noticed that the departures from the normal were up to 16° F. after the wave entered India.

Besides disseminating the warnings it is also important to tell the cultivator how best he may take advantage of them. Although suggestions for protective measures had been made it was found that the measures taken by the grape-growers were very inadequate to resist the damaging effects of the cold wave this year. Some farmers had a few dull and smoky fires lit up at the fringes of the garden and these had very little effect even in their immediate neighbourhood on account of the wind. The effect of irrigation has not been found to be significantly beneficial this year. Wind breaks of jowar stalks were found to be of no use. One or two grape gardens which escaped with light damage had apparently the natural advantage of road-side avenues (which served as wind breaks) or of higher elevation or of slopes where cold air will not stagnate.

The whole problem of frost prevention inside crops is one which awaits further experimental work so far as its practical aspects under Indian conditions are concerned. At present we have no working knowledge of the measures that may be economically adopted for the prevention of frost-damage in India.

The main steps in any attempts to conserve heat inside gardens are :—

(1) Prevention of air movement: during intense cold waves in winter there is fairly strong air movement near the ground, especially during the initial period; protective measures like fires will not be effective unless the air movement is checked by an adequate system of wind breaks.

(2) Burning *bright* fires in adequate numbers: they should be uniformly distributed inside the garden; to afford protection to marginal plants there should be an extra line of fires at the outskirts of the garden.

The experience in the United States of America, where a very large amount of work on protective measures against frost has been done is that other methods like irrigation or placing covers may afford temporary relief under mild and short spells of frost but are of little use during intense

Charts showing departure of mean temperature of day from normal from 13-1-1935 to 20-1-1935.

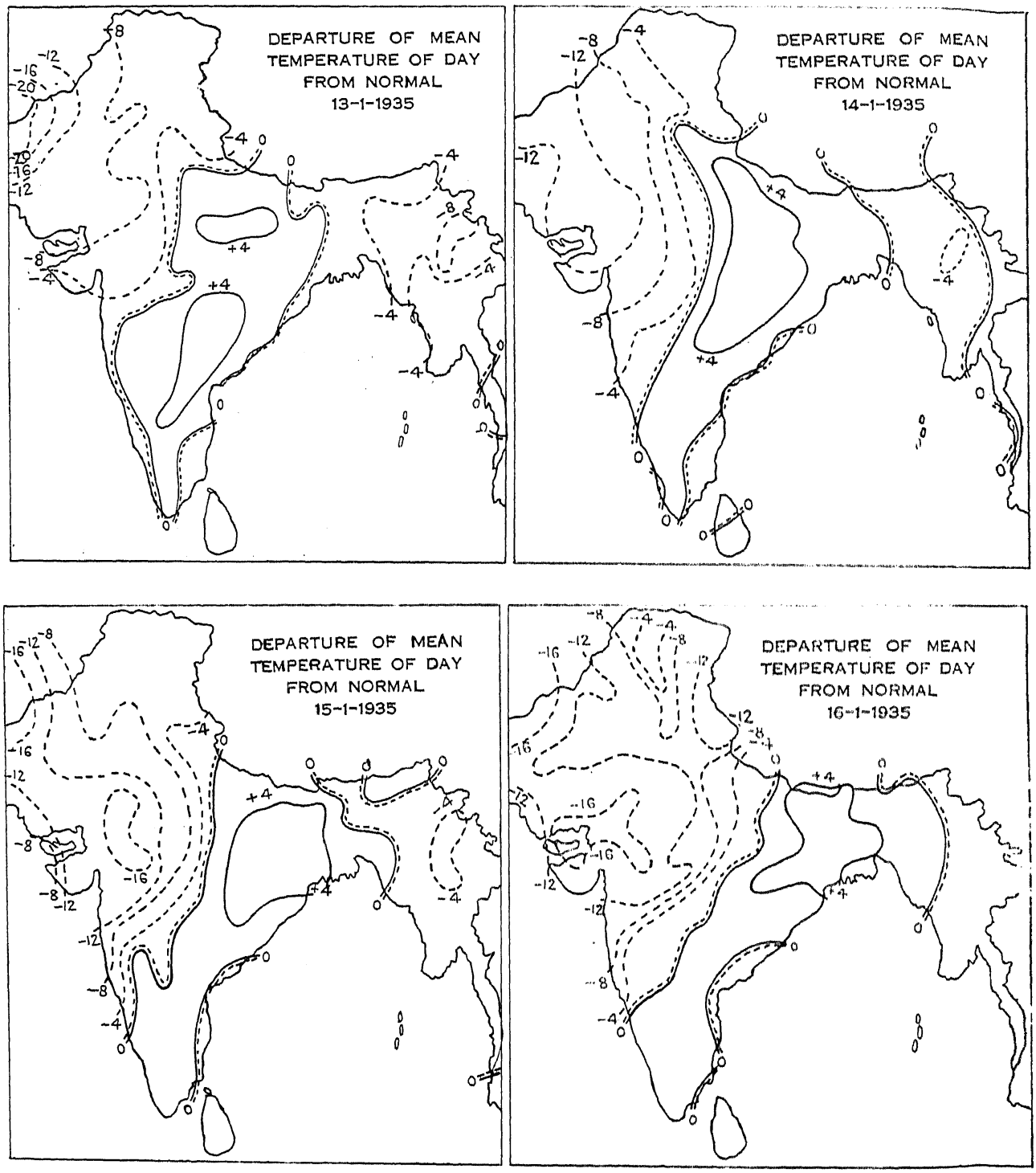


**Fig. 4.**

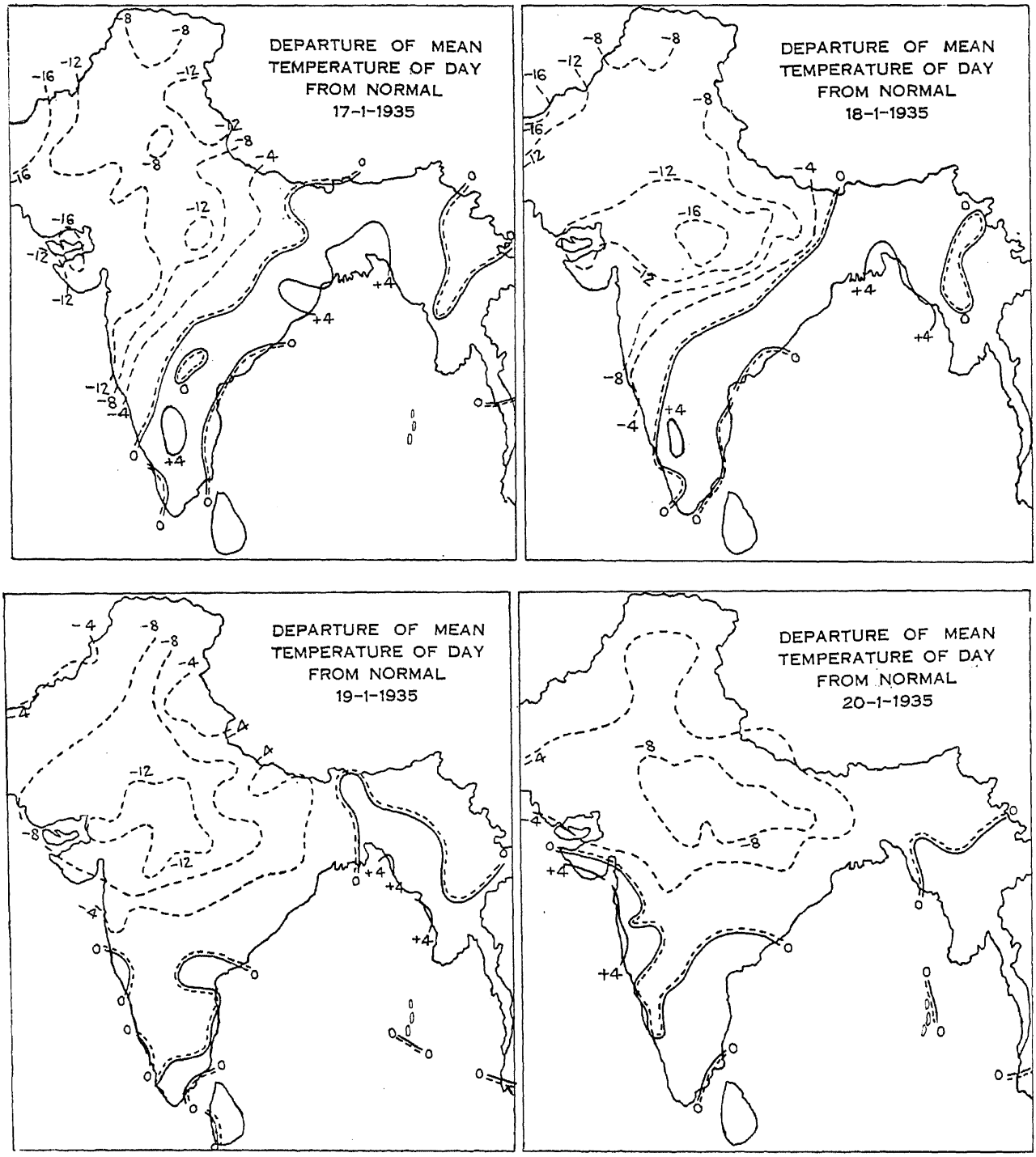


**Fig. 4.**—(*Contd.*)

frosts lasting for a few days, like the one which was experienced recently in many parts of North-West India, Gujarat and the Bombay Deccan.

The actual extent and distribution of the damage to different crops are being ascertained and the writer hopes to discuss the effects of this year's cold wave in greater detail in collaboration with Mr. K. V. Joshi and others.

A few photographs taken this year during the cold wave may be of interest. Figs. 5 (*a*) and (*b*) show an undamaged and a damaged guava plant; Figs. 5 (*c*) and (*d*) show an undamaged and a damaged bush of vine. Figs. 6 (*a*) and (*b*) show the meteorological instruments kept inside the vine-garden of Mr. Phadatre (Nasik), and a wind break of dry jowar which proved ineffective respectively.

The camp observatory (see Fig. 6*a*) consisted of one set of instruments inside a garden and a similar set exposed in an open space near by.

The observatory was set up at Nasik early in January by the Agricultural Meteorology Branch with the co-operation of Mr. K. V. Joshi, Deputy Director of Agriculture.

**Fig. 5**(*a*).
Healthy guava plant.

**Fig. 5**(*b*).
Guava plant affected by frost.

**Fig. 5**(*c*).
A healthy vine.

**Fig. 5**(*d*).
Vine affected by frost.

**Fig. 6**(*a*).
Camp Observatory inside vine-yard.

**Fig. 6**(*b*).
Jowar wind-breaks.

Figs. 7 (*a*) and (*b*) show the hourly march of the percentage humidity and the air temperature respectively from 0800 hours of the 15th to 0800 hours of the 16th January when the cold wave was most intense. The records were obtained from hygro-graphs and thermo-graphs kept inside two Stevenson screens which were placed on the ground. The dotted curves refer to conditions inside the vine-garden while the full lines refer to conditions outside in the open. It will be noticed that the air inside the garden was

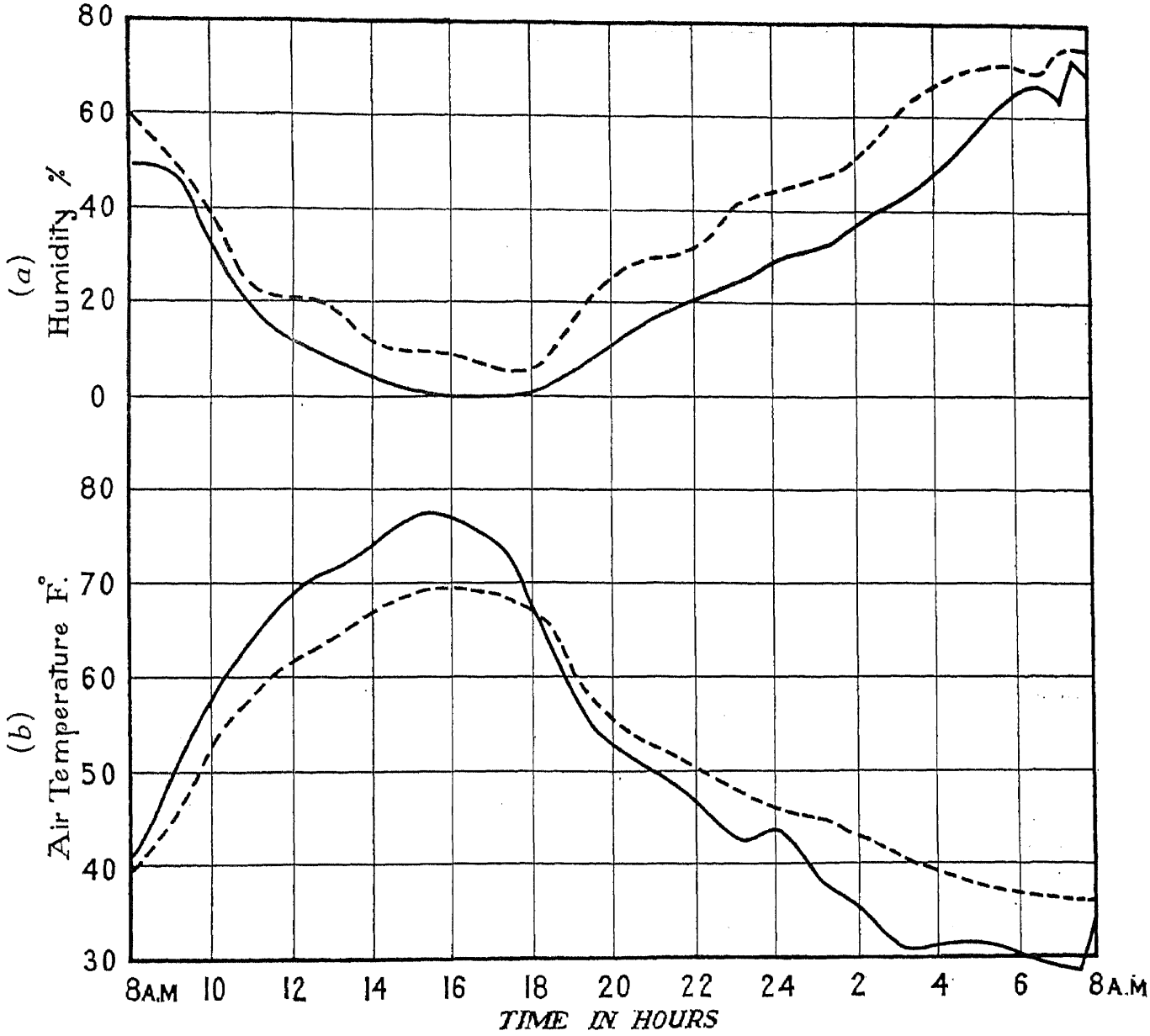


**Fig. 7.**

Hourly variations of humidity and temperature from 8 A.M. of 15-1-1935 to 8 A.M. of 16-1-1935 at Nasik
Full lines refer to conditions inside a screen kept at ground level in the open. Dotted lines refer to conditions inside a grape garden in a similar screen at ground level.

more humid than outside at all hours and that the temperature was lower inside the garden than in the open during the day hours but higher during the night. The air temperature near the soil in the open was below 32° F. for nearly five hours on the 16th morning (0245 to 0745). Another noticeable feature is the extreme dryness of the air, *e.g.*, the percentage humidity was practically zero on the afternoon of the 15th. The data collected at Nasik will be discussed in greater detail elsewhere.

It is hoped that in the years to come the joint efforts of the Agricultural and the Meteorological Departments will help to solve the problem of frost prevention. The prevention of frost damage inside gardens will be more practicable economically than in the more extensive field crops; a beginning may be made at Nasik where the grape interests are concentrated over a small area. Adequate funds for detailed experiments on the efficacy of fires, wind-breaks, topography, etc., will be required for undertaking such joint investigations.