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Daily patterns of dew-point temperature in a semiarid climate*

D.R. Butler

Resource Management Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502324, India

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ABSTRACT

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Hourly values of dew-point temperature (T_{dp}) recorded at ICRISAT, India, were examined on selected days between 1981 and 1985. The diurnal pattern changed seasonally, with a decrease in the mean T_{dp} during the dry season. Day-to-day variations of the mean T_{dp} and amplitude were large but, in general, values tended to remain fairly constant through the night, and started to decrease 1–2 h after sunrise to a minimum at 15:00–16:00 h. This pattern was simulated with a cosine function using two spot readings of humidity (at 07:15 and 14:15 h) from the meteorological site. The simulation gave reasonable agreement with measured values on days with widely contrasting patterns of T_{dp}.

INTRODUCTION

Crop production is affected by humidity in many ways. In most plant species, stomata close in response to an increase in vapour pressure deficit (VPD) (Hall et al., 1976) but, even when they do not, water use efficiency is almost inversely proportional to VPD (Bierhuizen and Slatyer, 1965; Tanner and Sinclair, 1983).

Indirect effects of humidity on crops are also important. Many diseases are strongly influenced by relative humidity (*RH*) and in epidemiological studies there is often a need to consider diurnal changes in *RH*. The concept of a threshold relative humidity is common in disease forecasting schemes (e.g. Kim et al., 1988); the number of hours each day that *RH* exceeds a critical

Correspondence to: D.R. Butler, Resource Management Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502324, India.
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value is used as a criterion to predict disease increase. Relative humidity may directly affect processes such as sporulation (Harrison and Lowe, 1989) and spore release (Gough and Lee, 1985), or it may be used as an indicator of surface wetness on vegetation (Hearn, 1961). Surface wetness in turn is a common requirement for spore germination and germ tube growth. Crop disease simulation models invariably include a measure of the diurnal change of *RH* (e.g. Savary et al., 1990) and may use hourly values of temperature and *RH* (e.g. Bourgeois, 1989).

When relative humidity measurements are not available, it may be necessary to obtain values by calculation. One approach is to use air and dew-point temperatures. Realistic estimates of hourly air temperature can be obtained from daily maximum and minimum values (Parton and Logan, 1981) and it is often assumed that the dew-point temperature (T_{dp}) is equal to the minimum air temperature and remains constant through the day (Dyer and Brown, 1977). This provides a fairly simple method to calculate hourly values of *RH*, where the accuracy of the estimate depends largely on the validity of the assumptions about T_{dp}. In temperate, humid climates T_{dp} tends to be conservative so, to a first approximation, it is reasonable to assume that it is constant throughout the day.

Monsoon climates are characterized by contrasting seasons; a dry season with little or no rainfall and a wet season with fairly predictable rainfall. There is a marked difference in the VPD between these seasons (Monteith, 1986), which is due, in part, to a difference in T_{dp}. To simulate diurnal patterns of relative humidity in semiarid regions, the assumption that T_{dp} is equal to the minimum temperature and remains constant through the day is often not correct. In the dry season there are commonly large diurnal changes in T_{dp} and patterns in the daily course of T_{dp} change with the time of year.

In this paper, diurnal changes in T_{dp} are examined at different times of the year, with a view to finding appropriate relationships to simulate relative humidity.

METHODS

An automatic weather station was operated at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Andhra Pradesh, India, between May 1981 and October 1985. This was a Didcot weather station (Didcot Instruments, Oxford, UK), where air temperature and humidity were measured using wet and dry bulb thermometers with platinum resistance sensors. These sensors were mounted in a Thermal Radiation Screen (type DTS/1, Didcot Instruments, Oxford, UK) at 1.3 m above the ground on the ICRISAT meteorological site. Readings were recorded every 5 min and hourly mean values computed.

Dew-point temperatures were calculated from unventilated wet and dry bulb temperatures, using a value of 0.1 kPa K^{-1} as the psychrometric constant for the Didcot screen (Huband et al., 1984). Recorded humidity was checked twice a day by comparison with manually read wet and dry bulb thermometers in a Stevenson screen (readings were taken at 07:15 h and 14:15 h local time). Hourly mean values (07:00–08:00 and 14:00–15:00 h) were compared with the manual readings.

Days were included in the analysis only if vapour pressures from the automatic weather station and manual readings agreed to better than 0.3 kPa in both the morning and afternoon. If rain occurred, the day of rain and the following day were excluded. On each remaining day, maximum and minimum air and dew-point temperatures were tabulated, as well as the difference between the minimum air temperature and the concurrent value of T_{dp}, referred to subsequently as the dew-point depression.

To provide a method to combine a number of days at a particular time of year, hourly temperatures (T_{air}) on each day were normalized by dividing ($T_{air} - T_{min}$) by ($T_{max} - T_{min}$) to give values between 0 and 1, where T_{max} and T_{min} are maximum and minimum air temperature, respectively. Dew-point temperatures were normalized similarly, using ($T_{dp} - T_{min}$) as the numerator, so that values less than the minimum air temperature were negative. Means and standard errors of hourly normalized temperatures were calculated for each month in each year.

RESULTS

Mean diurnal curves

Diurnal curves for selected months, averaged over the period 1981–1985 (Fig. 1), show a changing pattern through the year. In February T_{dp} remained fairly constant through the night (at about −0.3 on the scale) and decreased to a minimum value (−0.7) at 16:00 h. In April the pattern was similar, but the dew-point temperatures were much less (ranging from a night-time value of −0.6 to a minimum of −1.0). In June the amplitude was less, but night-time values remained at about −0.6. In August T_{dp} did not decrease during the day and the value remained more or less constant at −0.3. In October, the night-time value was closer to air temperature than at other times of year and there was a slight rise in T_{dp} after sunrise (about 06:00 h). This was followed by a marked decrease to a minimum value of about −0.5. In December the pattern was similar to October, but night-time dew-point values were more negative and the amplitude was less.

Variation in diurnal curves

The average diurnal temperature curves in Fig. 1 mask an enormous

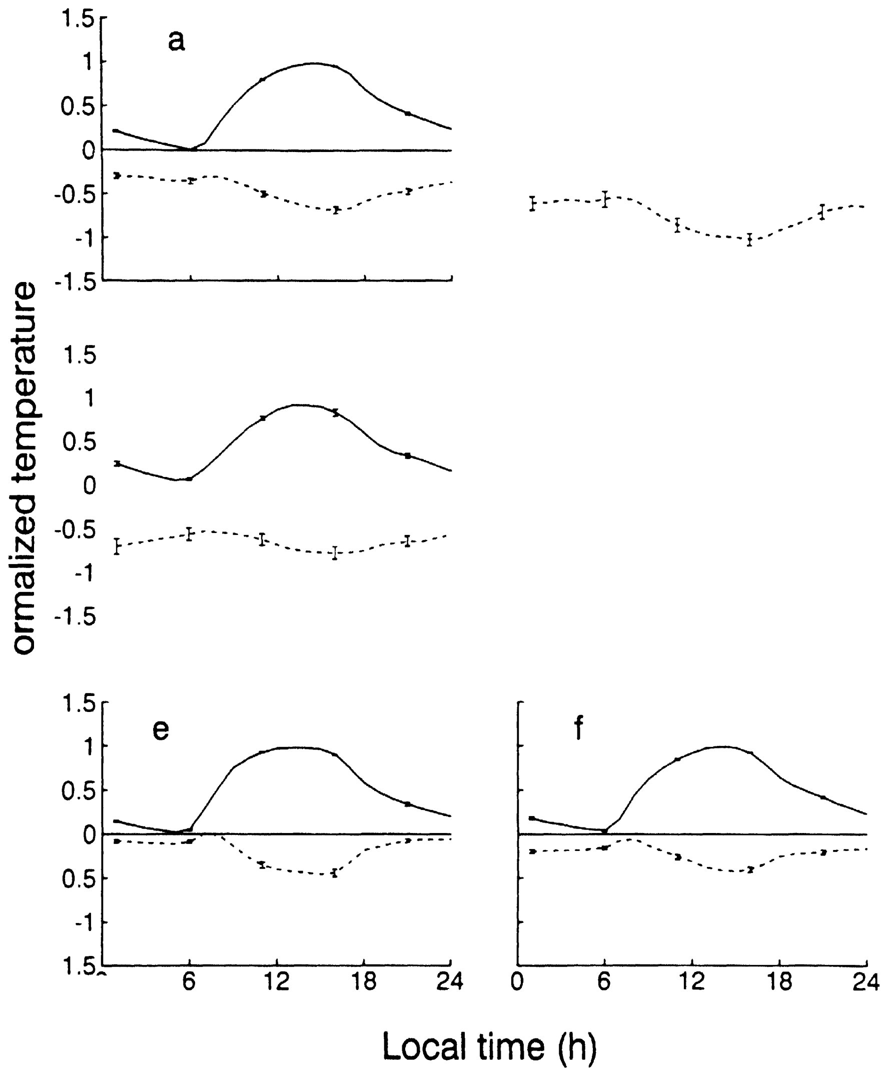

Fig. 1. Monthly mean diurnal curves of normalized air and dew-point temperature for all selected days between 1981 and 1985. Bars indicate standard errors. (a) February; (b) April; (c) June; (d) August; (e) October; (f) December. Key: ——, air temperature; — —, dew-point temperature.

day-to-day variation in T_{dp}. Some extreme examples have been selected (Fig. 2) to demonstrate range of absolute values, in the amplitude of T_{dp}, and in the size of dew-point depression (at the time of the minimum air temperature). On 6 September 1981 (Fig. 2(a)) T_{dp} was almost constant through the day and was close to the minimum air temperature. On 11 October 1981 (Fig. 2(b)) the atmosphere was almost saturated at the time of minimum air temperature and there was a marked increase in T_{dp} after sunrise. The amplitudes of air and dew-point temperatures were similar. On 12 October 1981 (Fig. 2(c)) there was a significant change from the previous day. There was no increase in T_{dp} after sunrise and the dew-point amplitude exceeded the air temperature

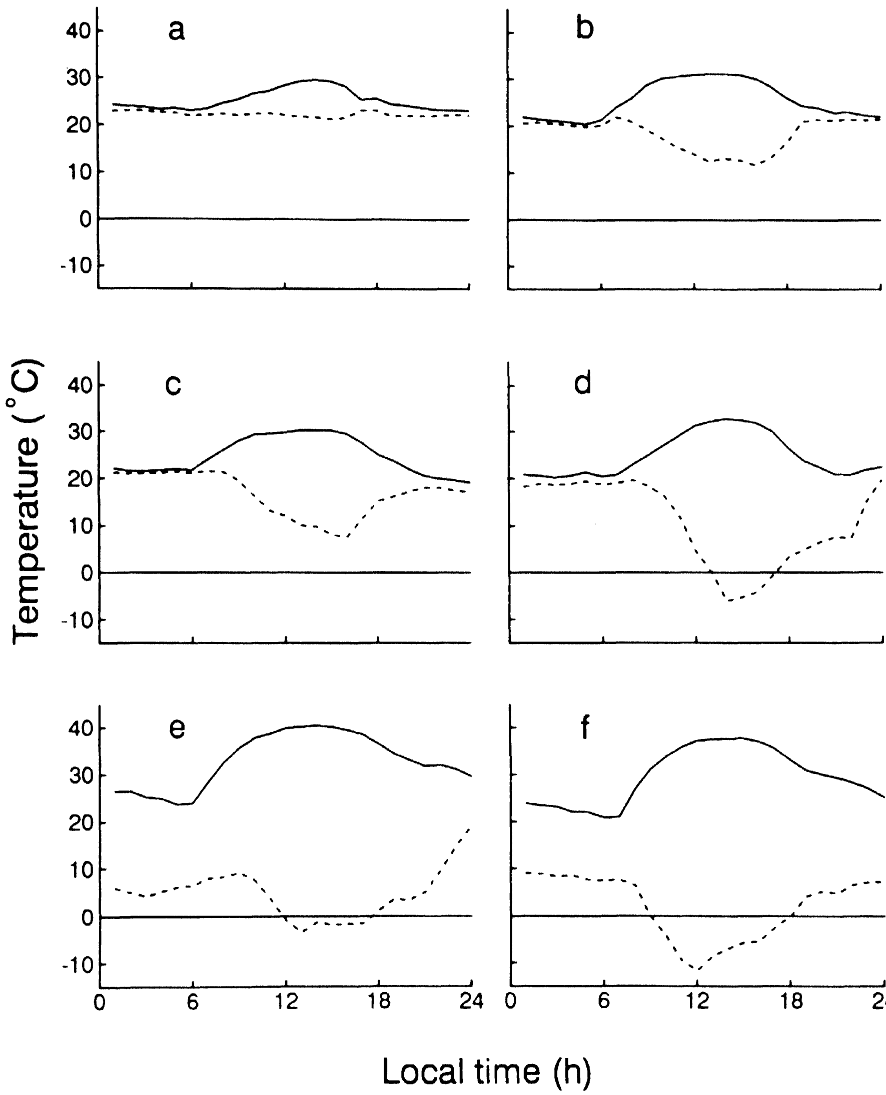

Fig. 2. Hourly mean measurements of air and dew-point temperature on selected days: (a) 6 September 1981; (b) 11 October 1981; (c) 12 October 1981; (d) 7 February 1983; (e) 2 May 1984; (f) 12 March 1985. Key: ——, air temperature; — —, dew-point temperature.

amplitude by about 3 K. On 7 February 1983 (Fig. 2(d)) a small dew-point depression was followed by a large decrease in T_{dp}. The minimum value was -6.1°C and the amplitude was 25.9 K. On 2 May 1984 (Fig. 2(e)) the dew-point depression was unusually large (17.5 K). On 12 March 1985 (Fig. 2(f)) the minimum T_{dp} reached -11.6°C. Prior to this, minimum values had been less than zero every day for 6 days. The dew-point depression was 13.3 K and the amplitude was 20.7 K.

Dew-point depression and amplitude

Day-to-day variabilities of the dew-point depression and amplitude were

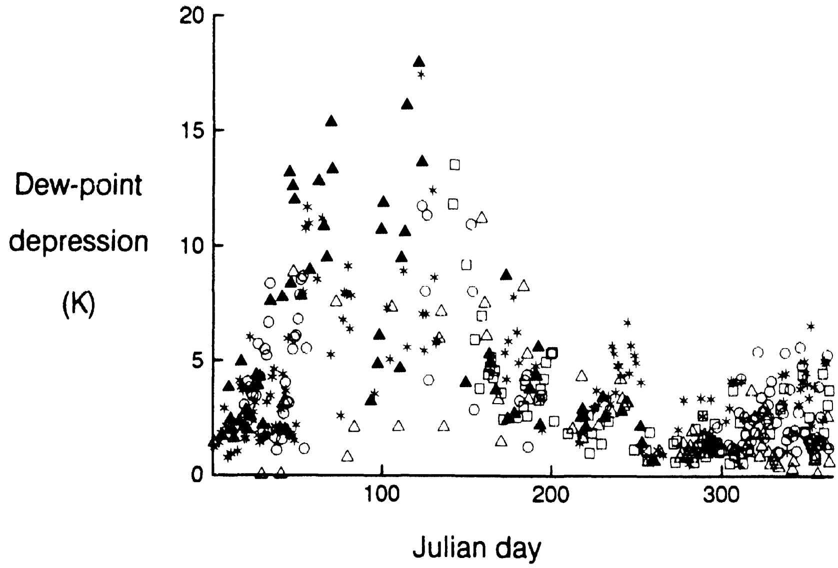

Fig. 3. Dew-point depression at the time of minimum air temperature plotted against Julian day. Key: □, 1981; △, 1982; ○, 1983; *, 1984; ▲, 1985.

very large, but there were marked seasonal patterns (Figs. 3 and 4). These were, in general, consistent from year to year.

For dew-point depression (Fig. 3), the largest values occurred between February and June at the hottest time of year. In this period, however, the day-to-day variability was also large so the probability of finding a small or large dew-point depression was similar. From July to December most values fell between 0 and 5 K.

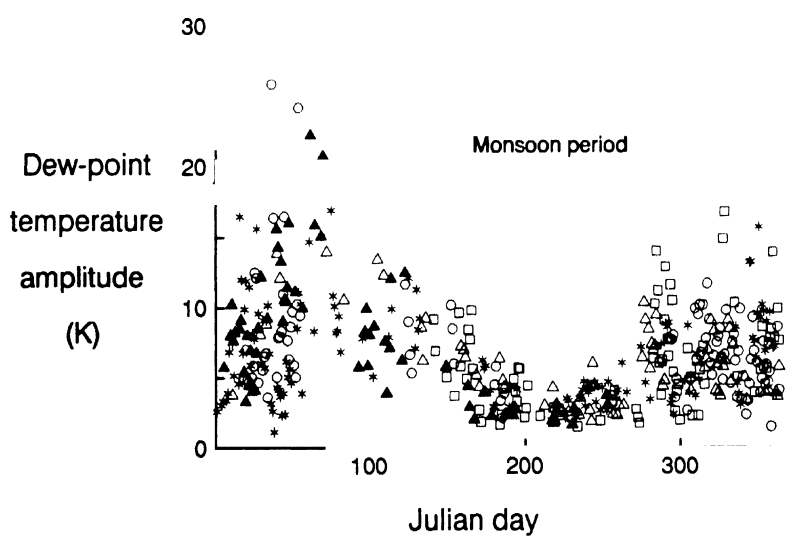

Fig. 4. Daily dew-point temperature amplitude plotted against Julian day. Key: □, 1981; △, 1982; ○, 1983; *, 1984; ▲, 1985.

The daily amplitude of T_{dp} (Fig. 4) showed a somewhat similar pattern to the depression. However, smallest values were restricted to the rainy season (July–September), with a clear increase from October and peak values from January to April. As before there was large day-to-day variability, especially during the same period that peak values occurred.

Simulation of diurnal temperatures

In general, T_{dp} tends to remain fairly constant through the night, but may decrease markedly during the day (Figs. 1 and 2). Values start to decrease about 1 h after the time of the minimum air temperature, and the minimum T_{dp} usually occurs at about 15:00–16:00 h. To simulate this pattern, it is convenient to use a cosine function

$$T_{dp} = T_{dpn} + 0.5(T_{dpx} - T_{dpn})[\cos(\pi\tau) + 1] \quad (0 < \tau < 2) \tag{1}$$

where

$$\tau = (t - S - c)/(Y/2 + d)$$

and

$$T_{dp} = T_{dpx} \quad (\tau < 0 \text{ or } \tau > 2)$$

T_{dp} is the dew-point temperature at time t, T_{dpn} is the daily minimum dew-point temperature, T_{dpx} is the daily maximum dew-point temperature, S is the time of sunrise, and Y is the day length. The parameter c ($c = 1.5$ h) is the delay between sunrise and the time that values start to decrease and d ($d = 2.5$ h) determines the time of the minimum dew-point temperature. The value of τ is zero at the time of T_{dpx}, and $\tau = 1$ at the time of T_{dpn}.

The time of sunrise and day length can be obtained from the latitude, longitude and day of the year (List, 1984). Minimum and maximum dew-point temperatures are not normally recorded manually on meteorological sites, but it is common to take humidity records twice each day. On agrometeorological sites in India, wet and dry bulb temperatures are observed at 07:15 and 14:15 h. These are approximately the times when the maximum and minimum dew-point temperatures are expected, so good relationships between the spot readings and maximum and minimum values are likely to exist. Linear relationships were found between T_{dpx} and T_{dp} at 07:15 h, and between T_{dpn} and T_{dp} at 14:15 h (Fig. 5). T_{dpx} is often greater than T_{dp} at 07:15 h and the scatter in Fig. 5(a) shows that quite large errors are possible (up to 10 K), although most points lie within 2 K of the regression line. There is less scatter in Fig. 5(b), so it appears that T_{dp} at 14:15 h can give quite a good indication of T_{dpn}.

Estimates of T_{dpx} and T_{dpn}, obtained from the linear relationships in Fig. 5, were used in eqn. (1) to calculate hourly values of T_{dp}. From 01:00 h to the time of minimum dew-point ($\tau = 1$), T_{dpx} for the day in question was

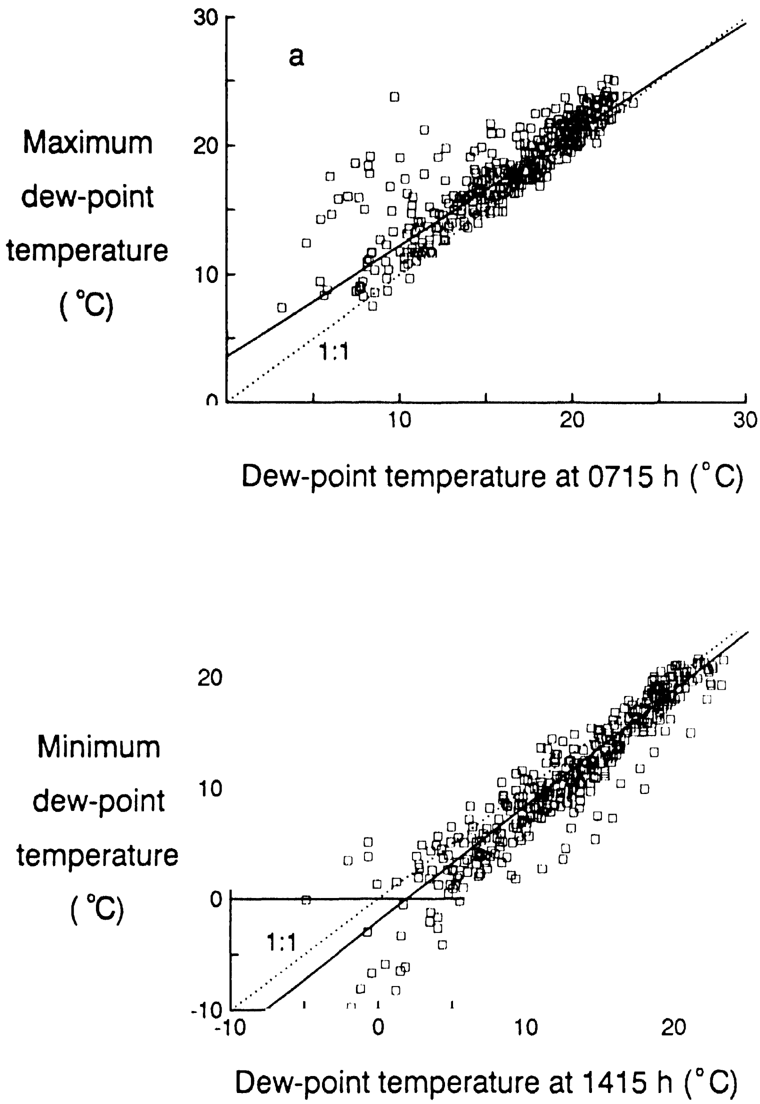

Fig. 5. (a) Daily maximum dew-point temperature from the automatic weather station (hourly average) plotted against manually observed spot readings at 07:15 h. The regression line is $y = 0.79x + 5.11$ ($r = 0.88$). (b) Daily minimum dew-point temperature from the automatic weather station (hourly average) plotted against manually observed spot readings at 14:15 h. The regression line is $y = 1.06x - 2.60$ ($r = 0.94$).

used, and from $\tau = 1$ to 24:00 h, T_{dpx} for the following day was used. Hourly air temperature was also calculated from manually observed maximum and minimum values, using the equations of Parton and Logan (1981).

$$T_{air} = T_{min} + (T_{max} - T_{min}) \sin [\pi m/(Y + 2a)] \quad (2)$$

and

$$T_{air} = T_{min} + (T_s - T_{min}) \exp - (bn/Z) \quad (3)$$

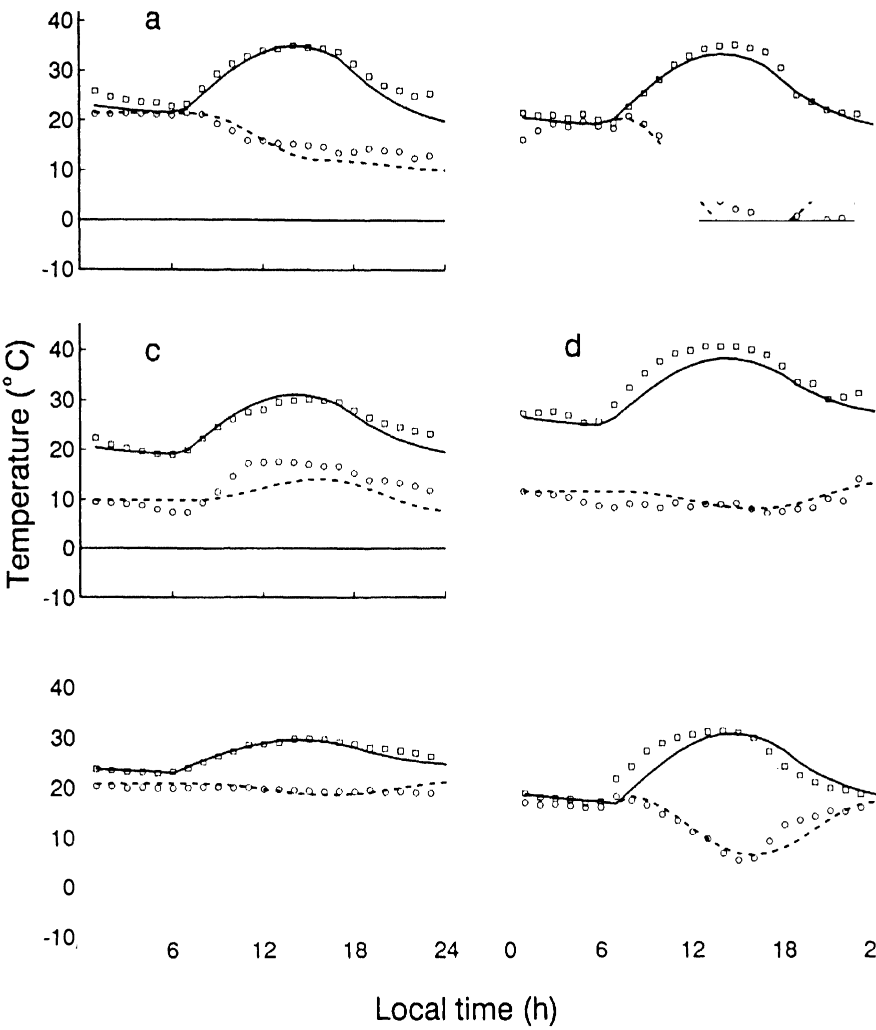

Fig. 6. Hourly measurements of air (□) and dew-point (○) temperatures with simulated values (——, air temperature; - - -, dew-point temperature) on 6 contrasting days. Simulated values were obtained using eqn. (1) with T_{dpx} and T_{dpn} derived from spot readings at 07 : 15 and 14 : 15 h: (a) 14 February 1985; (b) 24 February 1983; (c) 25 February 1985; (d) 25 April 1985; (e) 3 July 1981; (f) 18 October 1981.

where m is the number of hours after the time of the minimum temperature, a (a = 1.86 h) is a lag coefficient for the maximum temperature, b (b = 2.8) is a night-time temperature coefficient, n is the number of hours after sunset until the time of the minimum temperature, Z is the night length, and T_s is the temperature at sunset. The time of T_{min} was taken as 0.8 h after sunrise. These calculations were done on all the days selected for analysis from 1981 to 1985, and if the calculated dew-point temperature exceeded the calculated air temperature, T_{dp} was made equal to T_{air}. Examples of the results on contrasting days are given in Fig. 6.

Where T_{dpx} exceeded T_{min} (Figs. 6(b) and (f)), a transient rise occurred in the simulated dew-point temperature, similar to that observed in the hourly measurements. Quite realistic simulations were possible on days with a large dew-point range (e.g. Fig. 6(b)) and days with virtually constant T_{dp} (e.g. Figs. 6(e) and (d)). On one occasion (Fig. 6(c)), the dew-point at 07 : 15 h was less than the dew-point at 14 : 15 h, but simulation was still fairly good. When the dew-point maxima on sequential days are very different (e.g. Fig. 6(a)), the shape of the curve may become quite unlike a cosine function.

DISCUSSION

An overall decrease in dew-point temperature between October and April coincided with the dry season when there was very little rain. As the source of water for evaporation became progressively more scarce, the air became drier. The rainy season is normally from June to October, during which time there was a progressive increase in mean daily T_{dp}. Between October and December dew normally occurs and the increase in T_{dp} after sunrise coincided with the time when dew was evaporating.

The decrease in T_{dp} during the day is likely to be the result of the entrainment of very dry air at the top of the Planetary Boundary Layer. Mahrt (1991) associated entrainment-drying boundary layers with dry, unstable conditions typical of sunny days with weak surface evaporation and weak winds. These conditions are very common between January and April, when the maximum values of T_{dp} amplitude occur (Julian days 1–120, Fig. 4). During this period surface evaporation is severely restricted as soil water becomes exhausted, much of the natural vegetation dries, and the majority of agricultural land lies fallow. Between 1981 and 1985, the average values of wind speed (at 3 m) and bright sunshine between January and April were 2.4 m s^{-1} and 9.7 h day^{-1}, respectively.

Maximum wind speeds occur in June and from 1981 to 1985 the (monthly) average value at 3 m was 5.4 m s^{-1}. Strong winds with cloud cover are common in July and August and the increase in atmospheric stability would reduce entrainment-drying. Monsoon rains and a flush of vegetative growth during this period increase surface evaporation. In these conditions, the amplitude of T_{dp} is small (Julian days 180–250, Fig. 4).

At the end of the rainy season (October), clear skies and calm conditions are common. Strong inversions occur at night and in the day, strong surface evaporation results in a moist unstable atmosphere. After an initial increase in T_{dp}, there is commonly a marked decrease in T_{dp} during the day. Similar effects were observed by Coulman (1978a, b) and Mahrt (1991), where moistening regimes were associated with nocturnal inversions, and drying regimes with daytime instability.

Although monthly mean diurnal curves (Fig. 1) show a changing pattern through the year, day-to-day variation is so large (Figs. 2 and 6) that individual days often do not match the mean curves. The largely unpredictable values of dew-point amplitude and dew-point depression underline the need to measure humidity rather than make assumptions about it. Hourly dew-point values are rarely constant through the day and there is normally a substantial dew-point depression at the time of the minimum air temperature. The examples in Fig. 2 include several days when the amplitude of dew-point temperature exceeded that of the air temperature. This occurred on 6% of the days included in the analysis.

The equation for simulating hourly dew-point values from the daily maximum and minimum dew-point temperature (eqn. (1)) is simple and gives realistic results (Fig. 6). Although not obvious from the examples in Fig. 6, there is a tendency for night-time values to be overestimated. This is because the maximum dew-point temperature commonly occurs 1–2 h after sunrise and the simulation assumes that T_{dp} is constant (and equal to T_{dpx}) through the night. Very often night-time values are less than T_{dpx}. The size of the error may not be large, but it could have a significant effect on the period that a threshold relative humidity is exceeded.

Mean values of VPD for the dry season in India are typically about 2 kPa (Monteith, 1990). Day-to-day variation in humidity is large, however, and the curves in Fig. 2 indicate that daily mean values may reach about 4 kPa. Peak hourly values may be between 6 and 7 kPa on extreme days (e.g. Fig. 2(f)). Such large values of VPD will result in proportionately small values of water use efficiency for irrigated crops in the dry season.

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