Proc. Fla. State Hort. Soc. 118:279-282. 2005.

A REFEREED PAPER

DIURNAL CHANGES IN DEWPOINT TEMPERATURE DURING THE FREEZE SEASON IN NORTH FLORIDA

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Additional index words. agricultural meteorology, frost, freeze protection, blueberries

Abstract. **Dewpoint temperature is the temperature to which a body of air at a constant pressure must be lowered to initiate the condensation of water vapor. Because air temperature never falls below dewpoint temperature and because dewpoint temperature varies far less over the 24-hour cycle than does air temperature, dewpoint temperature is useful in forecasting minimum temperatures in fruit and vegetable fields on nights with radiation freezes. Dewpoint temperature is also important because the difference between air temperature and dewpoint temperature strongly affects the rate of evaporation and the effectiveness of overhead irrigation in freeze protection of crops. This study was designed to determine whether there was a diurnal pattern that might be useful in predicting short-term changes in dewpoint at three agricultural locations in north Florida. Data were studied from nights during the winter half of the year that featured good radiation conditions and frost or dew formation. A well-defined diurnal rhythm was found, with 2 peaks and 2 valleys per 24-hour period. The cycle included a morning rise, a midday slump, an evening recovery, and a nighttime fall. For the Alachua station, which is typical of the three stations studied, the mean change in dewpoint over 47 nights was -3.7°C between 1 hour after sunset and 15 minutes before sunrise. Between 15 minutes before sunrise and 2 hours after sunrise the mean change in dewpoint at Alachua was 5.7°C. This morning rise is believed to be due to evaporation of water that was deposited during the night by frost, dew, distillation, and guttation. The midday slump results when turbulence mixes this new water vapor with drier air above. The evening recovery is due to declining wind speed, which allows the surface air to gain water vapor from evaporation and transpiration, and the nighttime decline is due to the removal of water vapor from the air at instrument level (2 m above the ground) as a result of dew or frost formation. Although the nighttime decline in dewpoint was a pronounced feature, not every night showed a decline, and the extent of decline varied considerably.**

Dewpoint temperature is the temperature to which a body of air must be lowered at a constant pressure to initiate condensation of water vapor. Dewpoint depends on the quantity of water vapor in the air, and thus is highly correlated with absolute humidity, expressed in grams of water vapor per cubic meter of air. Dewpoint temperature is a property of an air mass, and depends on the source region and history of the air mass. Within an air mass, dew point temperature typically decreases rapidly with elevation because relatively little water vapor can exist at the low temperatures that prevail at high altitudes.

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Dewpoint temperature is of great interest to fruit and vegetable growers attempting to protect their crops from freeze damage on cold nights. Because neither air temperature nor wet-bulb temperature can fall below the dew point temperature, information about current and future dewpoints can be of great value in predicting minimum temperatures. Dewpoint temperature is also useful in anticipating the effects of irrigating crops for freeze protection on cold nights (Harrison et al., 1972). Evaporation removes heat from the field. Under certain conditions, the heat lost due to evaporation can equal or exceed the heat gained by producing ice in the irrigated field. The rate of evaporation is strongly influenced by the difference between air temperature and dew point. When the dew point equals the air temperature, no net evaporation occurs; when the dew point temperature is far below the air temperature, evaporation can be rapid.

On much of the farmland in the southeastern United States, if conditions favor radiation (clear sky, light wind, and low relative humidity at mid-day), the temperature falls rapidly after sunset until it reaches a point about 1°C above the dew point. When conditions favor radiation freezes, objects such as grass and leaves become colder than the surrounding air. By the time the air temperature has fallen to about 1°C above its dew point, dew or frost begins to form. Condensation of water vapor transfers heat energy to the atmosphere and retards the temperature fall, but formation of dew and frost remove water vapor, lowering the dew point of the air near the ground. If there is little wind, the air near the ground becomes colder, drier, and denser than the air above. This stratification of cold air near the ground and warmer air above makes the atmosphere very stable. No vertical air currents mix air near the ground with the air above, and the dewpoint of air near the ground, to a height of several meters, may decrease considerably due to dew or frost formation.

Because dew point temperature is an important factor in the freeze threat to crops, forecasting dewpoint changes is also important. Changes in dewpoint as measured by a ground station can result from the replacement of one air mass by another, from subsidence within an air mass, by mixing of air from different altitudes within an airmass, and from changes in water vapor content of the air mass due to evaporation, transpiration, condensation, or precipitation. The purpose of this study was to describe the pattern of diurnal variation in dewpoint temperatures as measured 2 m above the ground at three stations in the northern Florida peninsula for nights on which there was frost or dew during the winter half of the year. The goal was to help fruit and vegetable growers improve their use of dewpoint information in anticipating and reacting to freeze threats.

Materials and Methods

The weather data used in this study were obtained from the archives of the Florida Automated Weather Network (FAWN) stations maintained by the Institute of Food and

Agricultural Sciences, University of Florida (http://fawn.ifas.ufl.edu). Data from three stations were used: Alachua, Citra, and Brooksville. The Citra station is about half way between Gainesville and Ocala. The Alachua station is 60 km northwest and the Brooksville station 100 km southwest of the Citra station. All sites are rural, well inland of major bodies of water, and have elevations less than 100 m.

The first survey determined the dew point and air temperature 2 m above the ground for each of the 24 h averaged over the 62 d from 1 Dec. 2002 to 31 Jan. 2003 for the Alachua station. This period was chosen arbitrarily to represent winter months. Based on this survey, four features of the diurnal cycle were recognized: the morning rise, the afternoon slump, the evening recovery, and the nighttime fall (Fig. 1, Table 1). Each of these four features was studied further using days that met certain criteria that were chosen to include only cool nights with good radiation conditions.

The morning rise and the nighttime fall were studied for all three stations using all days between 15 Oct. 2002 and 15 Apr. 2003 that met all of the Group 1 criteria: 1) the minimum temperature occurred at or near sunrise and was 7°C or lower; 2) the relative humidity was 94% or higher at sunrise or for at least one reporting period within 3 h before sunrise; 3) the sky was clear or mostly clear the following day as indicated by solar radiation recorded each hour through noon. The 94% minimum relative humidity requirement was included to eliminate nights with neither dew nor frost. Data were analyzed separately for each station. For each station, for each night that met Group 1 criteria, the dewpoint temperatures were recorded at three times: 1 h after sunset, 15 min before the following sunrise, and 2 h after sunrise. These hours were chosen because they were near the times of minima and maxima in the preliminary study reported in Fig. 1. Because data were available only as 15-min averages, the following rules were followed to decide which reading to use when sunrise and sunset fell between readings: the reading designated 1 h after sunset was the reading that was available between 1 h and 1 h plus 14 min after sunset; the reading designated 15 min before sunrise was the reading that was available for the period between 15 min and 29 min before sunrise. The reading designated 2 h after sunrise was the one available between 2 h and 2 h plus 14 min after sunrise. The hours were Eastern Standard local time. For each qualifying day, the change in dew point between the reading 1 h after sunset and the reading 15 min before the following sunrise was recorded. Means and standard deviations for the changes (signs taken into account) were calculated and a t-test was used to test the hypothesis that the mean change was not statistically different from zero. Similarly, means and standard deviations were calculated for each of the three stations for the changes associated with the morning rise.

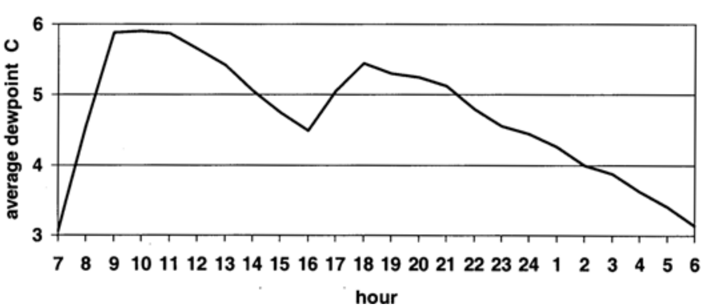

Fig. 1. Mean dewpoint (°C) for each hour for the period 1 Dec. 2002 to 31 Jan. 2003 at Alachua, Florida.

Table 1. Means and standard deviations for temperature and dewpoint for each hour at Alachua, Florida for the 62 days from 1 Dec. 2002 to 31 Jan. 2003.

	Dewpoint temperature (°C)		Air temperature (°C)	
Hour	Mean	SD	Mean	SD
700	3.1	7.1	4.3	6.6
800	4.5	6.7	5.7	5.8
900	5.9	7.3	8.6	5.1
1000	5.9	7.7	11.0	5.1
1100	5.9	8.0	12.8	5.2
1200	5.7	8.2	14.1	5.1
1300	5.4	8.4	15.0	5.0
1400	5.1	8.3	15.5	4.9
1500	4.8	8.2	15.8	4.8
1600	4.5	8.3	15.5	4.7
1700	5.1	7.9	14.2	4.5
1800	5.4	7.2	11.1	4.8
1900	5.3	6.9	9.3	5.3
2000	5.2	6.7	8.5	5.5
2100	5.1	6.7	7.9	5.5
2200	4.8	6.5	7.3	5.5
2300	4.6	6.6	6.9	5.7
2400	4.4	6.8	6.4	5.9
100	4.3	6.9	6.1	6.2
200	4.0	7.0	5.7	6.3
300	3.9	7.1	5.5	6.5
400	3.6	7.1	5.1	6.5
500	3.4	7.2	4.8	6.6
600	3.1	7.2	4.5	6.6

The afternoon slump and the evening recovery were studied for the Alachua station using a more restrictive criteria list (Group 2 criteria), and included all days that met the criteria during 2 periods: (1) from 15 Oct. 2001 to 15 Apr. 2002 and (2) from 15 Oct. 2002 to 15 Apr. 2003. The more restrictive Group 2 criteria were used because it was considered important that both the night preceding and the night following the daytime period studied be a dew or frost night with minimum temperature below 7°C, relative humidity at or near sunrise of 94% or higher for at least one reporting time, and sky with no or little cloud. To quantify the afternoon slump, the change in dew point (sign considered) was determined for each qualifying day between 2 h after sunrise and 1600 the next afternoon. The mean and standard deviation of these values were determined and a t-test was used to test the hypothesis that the average change was not statistically different from zero.

The evening recovery was calculated based on all days meeting Group 2 criteria by recording the change in dew point (sign included) between 1600 and 1 h after sunset. Mean, standard deviation, and t-test were obtained to test the hypothesis that the mean of this change did not differ from zero.

Results and Discussion

The mean dewpoint for each hour averaged over the 62 consecutive days from 1 Dec. 2002 to 31 Jan. 2003, showed much less diurnal variation (highest hour minus lowest hour = 2.8°C) than air temperature at 2 m height (highest h minus lowest h = 11.5°C) (Table 1). Whereas mean air temperature had one peak and one valley per 24 h, dewpoint temperatures had two peaks and two valleys. One peak occurred about 2 h after sunrise and the second about 1800 in the afternoon. The valleys were near sunrise and at about 1600 in the afternoon. The change in dewpoint during the morning rise averaged 2.8°C for these 62 d, the afternoon slump -1.4°C, the evening recovery 0.9°C, and the nighttime fall -2.3°C.

When the 2 diurnal rises and 2 diurnal declines in dew point temperature were studied using 24-h periods selected for good radiation conditions, a t-test showed that all four diurnal changes were significant at all locations (Table 2). This indicates that the four changes were real and not due to sampling error. When the morning rise was studied for dew/frost mornings following nights with strong radiation (Group 1 criteria), the morning rise averaged 5.7, 6.8 and 6.8°C for Alachua, Brooksville, and Citra, respectively (Table 2). The probable cause of the morning rise in dew point is rapid evaporation of dew/frost during the 2 h following sunrise. This increases the water vapor content of the air near the ground at a time when the nocturnal temperature inversion is still strong enough to prevent the mixing of surface air with drier air aloft. The higher values for the morning rise in Table 2 compared to Table 1 are probably due to the fact that Table 2 data are from days chosen to have frost/dew conditions, whereas the 62 d in Table 1 included all types of days.

The mid-day slump and the evening recovery were approximately equal in magnitude but opposite in direction (Table 2). The mid-day slump probably results from the mixing of surface air with air aloft due to turbulence caused by solar heating of the ground. This turbulence disperses water vapor produced by evaporation of the dew and introduces drier air from above. The evening recovery probably results from a reduction in turbulence as the ground cools. Evaporation of water from the surface and transpiration from plants can then increase the water vapor content of the air near the ground. The evening recovery ends and the nighttime fall begins when dew or frost begin to form.

Even though a nighttime decline in dewpoint was a marked feature of the 24-h pattern, not every night showed a decline (Table 3). Even among nights pre-selected to have good radiation conditions, some nights showed increases in dewpoint rather than decreases. On nights when the dewpoint fell, the size of the fall varied considerably. The reasons for these variations are not known, but various factors are probably involved. One factor could be the water vapor content of the air mass at various altitudes above the ground, sometimes reported as the precipitatable water potential (PWP) of the air mass. The PWP indicates how much rain would fall if all the water vapor in a column of air from the ground to the top of the atmosphere suddenly fell as rain. Values range from less than 0.20 inches to more than 2.00 inches. The greatest declines in dew point during the night would be expected when the air mass is very dry at all altitudes.

Because dewpoint temperature tends to change much less during the 12 h before a radiation freeze than does the air temperature, it is a valuable tool in forecasting minimum temperatures. However, to maximize the use of this tool, further study is needed to understand why the dew point falls much more on some nights than on others, and why, on some nights, it even rises.

Not all of the water that accumulates on plants during the night is from water vapor that was present in the air at sunset. Up to 0.07 $mm \cdot h^{-1}$ can be deposited on plants by distillation (Tanner, 1974). In this process, which occurs on frost/dew nights, particularly if the ground is moist, water evaporates from the relatively warm ground, rises, and condenses on the cold leaves and stems of the plants. In saturated, well-mixed air, heat energy transfer during condensation of water vapor already present in the air combined with heat transferred from the soil by distillation is about 40 to 70% of the net radiation loss in the field (Tanner, 1974). Evaporation of water from the ground at night also tends to reduce the rate of decline in dewpoint. It has long been known by fruit growers that maintaining bare, moist, packed row middles and irrigating fields the afternoon before an expected freeze provides some freeze protection. Blueberry growers in north Florida have noticed that temperatures on radiation-freeze nights tend to fall much farther on farms where the surrounding soils are dry (Lyrene and Williamson, 2000).

The three stations studied were located on land that was nearly level. It would be interesting to study nocturnal changes in dewpoint on orchard sites with steep slopes. It might be expected that on such sites, the mixing of air that results when cold air flows down the hill might prevent or reduce the nocturnal decline in dewpoint.

Many of the freezes that damage blueberry flowers and fruit in Florida occur on nights when the dewpoint temperature at sunset is above the critical air temperature of -2 to -3°C required to cause damage. These freezes are easy to combat

Table 2. Means, medians, and ranges for changes in dew point temperature during 4 periods of the diurnal cycle based on frost/dew days at 3 locations in north Florida.

	Morning rise (°C)[z]			Midday slump	Evening recovery	Nighttime fall (°C)[w]		
	Alachua	Brooksville	Citra	Alachua[y]	Alachua[x]	Alachua	Brooksville	Citra
n[v]	47	54	36	41	41	47	54	36
$\bar{x}$	5.7	6.8	6.8	-1.6	1.3	-3.7	-3.0	-2.6
S.D.	3.18	3.61	3.49	3.47	1.96	2.91	3.91	2.70
t	12.2***	13.8***	11.7***	3.0**	4.1***	8.8***	5.6***	5.7***
Median	5.3	7.2	6.8	-2.0	1.1	-3.4	-3.4	-2.2
Min.	-2.1	-5.4	-4.1	-10.8	-2.6	-9.7	-11.6	-8.2
Max.	11.2	14.2	12.5	6.2	5.6	4.3	5.5	3.2

[z]Period starting 15 min before sunrise, ending 2 h after sunrise for qualifying days between 15 Oct. 2002 and 15 Apr. 2003.
[y]Period starting 2 h after sunrise, ending 1600 in afternoon for qualifying days between 15 Oct. and 15 Apr. for winters 2001-2002 and 2002-2003.
[x]Period starting 1600, ending 1 h after sunset for qualifying days between 15 Oct. and 15 Apr. for winters 2001-2002 and 2002-2003.
[w]Period starting 1 h after sunset, ending 15 min. before sunrise for qualifying days between 15 Oct. 2002 and 15 Apr. 2003.
[v]Number of days used in calculation. Varied among stations according to the number of days that met the criteria described in Materials and Methods.
,*Mean difference was significantly different from zero at p = 0.01 and 0.001, respectively.

Table 3. Number of nights when dewpoint temperature changed by various amounts at 3 stations on qualifying frost/dew nights 15 Oct. 2002 to 15 Apr. 2003.

Change °C	Alachua	Brooksville	Citra
5.00 to 5.99		2	
4.00 to 4.99	1	2	
3.00 to 3.99	1	2	1
2.00 to 2.99	1	2	1
1.00 to 1.99	0	0	1
0.00 to 0.99	1	3	3
-1.00 to -0.01	3	4	5
-2.00 to -1.01	3	5	5
-3.00 to -2.01	10	6	6
-4.00 to -3.01	5	4	2
-5.00 to -4.01	4	7	6
-6.00 to -5.01	9	4	3
-7.00 to -6.01	5	6	0
-8.00 to -7.01	1	4	2
-9.00 to -8.01	2	1	1
-10.00 to -9.01	1	0	
-11.00 to -10.01		1	
-12.00 to -11.02		1	

[z]Changes were measured between the starting time 1 h after sunset and the ending time 15 minutes before sunrise.

with overhead irrigation, and even microsprinkler irrigation may prevent the decline in dewpoint that allows the temperature to fall to critical levels. However, if dew point temperature is below -3°C at sunset or if the air temperature falls below -3°C with wind, high-volume overhead irrigation is usually required to prevent freeze damage (Lyrene, 1996).

Information is not available on diurnal variations in dew point under conditions of good noctural radiation in other parts of the country, but patterns may vary from those measured at the Florida stations. With the possible exception of hilltops, it is rare in Florida to have radiation freezes (no wind, clear skies) in which the temperature at night does not fall close enough to the dew point to produce dew or frost. In areas with very dry air, where frost and dew are less common, the dew point may show less circadian variation. During the summer in the southeastern U.S., when dewpoint temperatures are high, the nocturnal fall in dewpoint may be less than in winter because of the large amount of water vapor that must be condensed to lower the dewpoint by 1°C. The heat from this large amount of condensation greatly inhibits further temperature falls.

The following observations may be useful to growers using dewpoint temperatures at sunset to anticipate minimum temperatures the following morning. It must be remembered, however, that every night is unique. These rules apply only to nights with clear skies and light winds. (1) The lower the dewpoint temperature at sunset, the greater will be the temperature fall during the night. After the day's maximum temperature, the temperature will fall rapidly until it is about 1°C above the dewpoint. Thereafter, the temperature and the dewpoint will slowly fall together. (2) So-called "dry fronts" may pass during the night, accompanied by few or no clouds and little or no wind at the surface. While these are not common, neither are they rare. Dry fronts may cause rapid drops in dew point. They are not readily apparent to an observer in the field who is not specifically monitoring humidity. One pronounced dry front passed through northeast Florida during the night of 1-2 Mar. 2005. With clear sky and light wind, the dewpoint temperature at the Alachua FAWN station fell from 4.4°C at 2100 on 1 Mar. to -6.1°C 4 h later. On the same night, at the Citra FAWN station, the dewpoint was 5.7°C at 2200 but had fallen to -4.0°C only 3 h later. The only way to anticipate such changes is to know that a dry front will be passing through the region. (3) Counties or parts of counties that have numerous lakes, cypress swamps, bayheads, and other sources of surface water normally suffer less drop in dewpoint during the night than areas with dry sandy soil. Although growers in dry, sandy areas with little surface water might saturate the soil of a 100-acre field with overhead irrigation the afternoon before a radiation freeze in hopes of reducing dewpoint falls during the night, even an imperceptible wind of 0.5 mph would carry dry air from the surrounding countryside across the entire field in half an hour. Blueberry growers on moist flatwood soils in eastern Alachua County Florida and in Clinch County in southeast Georgia frequently see dewpoints fall only slightly during nights when dewpoints fall 4 to 7°C on farms in western Alachua county, where soils are well-drained and vegetation is typical of sandhills or scrub.

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