Degree-day concepts

Users interested in the historical development of the degree-day concept should consult Baskerville & Emin (1969), Andrewartha & Birch (1973), Allen (1976), Zalom et al. (1983), and Wilson & Barnett (1983). The last page of this chapter lists full references for these publications.

Developmental thresholds: Upper and lower developmental thresholds have been determined for some organisms through carefully controlled laboratory and field experiments. Thresholds vary with different organisms. For example, the lower developmental threshold is 51°F and the upper developmental threshold is 90°F for the San Jose scale (Quadraspidiotus pernicious).

The lower developmental threshold for an organism is the temperature at and below which development stops. The lower threshold is determined by the organism's physiology. It is independent of the method used to calculate degree-days.

The upper developmental threshold is the temperature at and above which the rate of growth or development begins to decrease or stop as determined by the cutoff method. A degree-day model approximates the physiology of an organism. The physiological interpretation of the upper threshold is dependent on the cutoff method. Refer to "Cutoff methods" in this chapter for more information.

Degree-days: The total amount of heat required, between the lower and upper thresholds, for an organism to develop from one point to another in its life cycle is calculated in units called degree-days (°D). Sometimes called heat units, degree-days are the accumulated product of time and temperature between the developmental thresholds for each day. Figure 3.1 illustrates the relationship between time and temperature, and the accumulation of degree-days. One degree-day is one day (24 hours) with the temperature above the lower developmental threshold by one degree. For instance, if the lower developmental threshold for an organism is 51°F and the temperature remains 52°F (or 1° above the lower developmental threshold) for 24 hours, one degree-day is accumulated.

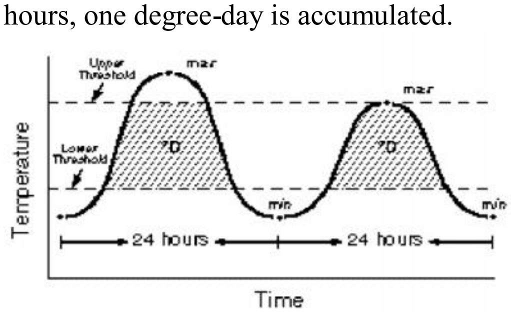

Figure 3.1. Thresholds and accumulated degree-days

A Celsius degree-day is not the same as a Fahrenheit degree-day because a Fahrenheit degree is smaller than a Celsius degree. It takes nine Fahrenheit degree-days to make five Celsius degree-days. Figure 3.2 shows that the areas under the curve represented in Fahrenheit and Celsius units are equal, but the units differ. Each model in the DDU phenology database gives degree-days for both scales. If you use other references, be sure to use the same scale as that used in the research.

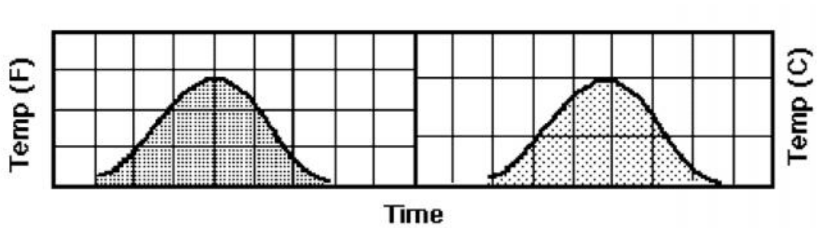

Figure 3.2. Accumulated degree-days represented in Fahrenheit and Celsius units

Accumulated degree-days. Each developmental stage of an organism has its own total heat requirement. Development can be estimated by accumulating degree-days between the temperature thresholds throughout the season. Each species requires a defined number of degree-days to complete its development. The accumulated degree-days from a starting point can help predict when a developmental stage will be reached. The date to begin accumulating degree-days, known as the biofix date, varies with the species. Biofix dates are usually based on specific biological events such as planting dates, first trap catch, or first occurrence of a pest.

Accumulation of degree-days should be done regularly, especially when a control action decision is near.

The DDU Action Menu provides several options for accumulating degree-days.

DDU degree-day calculation methods

Although it is simple to calculate the degree-days accumulated at a constant temperature in the laboratory, calculating degree-days for the daily temperature fluctuations that occur in nature is more difficult. Several methods are used to estimate degree-days through the use of daily minimum and maximum temperatures. All are approximations of the actual number of degree-days accumulated for a given set of daily temperatures and developmental thresholds, and therefore do not provide the exact degree-day values. However, most are adequate considering the accuracy of weather instruments used and the precision required for crop management decisions. (Some developmental relationships that require use of degree-hours have been determined. Accurate calculation of degree-hours requires a record of hourly temperatures rather than daily minimum and maximum temperatures. You can approximate degree-hours by multiplying the number of degree-days by 24.)

The degree-day calculation methods differ somewhat in complexity. Season and climatic region also cause these methods to vary in how accurately they reflect actual degree-days. Whichever method is used, it is important to use the same method as that used in developing the organism's biological growth relationships. If the method is unknown, UC IPM recommends using the single sine method with a horizontal cutoff at the upper threshold, since it has been the most common method for many years and is the standard method used by the UCIPM IMPACT program.

All but one of the DDU methods are named for the way the program simulates a temperature curve for a 24-hour period. Degree-day calculations and accumulations are based on the area under the curve and between the thresholds. These are single sine, double sine, single triangle, and double triangle. Huber's method is a modification of the single sine method with a horizontal cutoff. From the simplest to the most mathematically complex, these are: single triangle, double triangle, single sine, double sine, and Huber's. All of these are linear methods because the rate of development is presumed to be a straight line directly related to temperature. There are nonlinear methods as well, but they are primarily used in research at this time. Figure 3.7 illustrates six possible relationships between the daily temperature cycle and the upper and lower thresholds.

Note: Figures 3.3 through 3.6 illustrate the estimated accumulation of degree-days for a 3-day period. In the first half of the day, degree-days tend to be underestimated by an amount equal to area b. In the second half of the day, degree-days tend to be overestimated by an amount equal to area a. Over a 24-hour period, the overestimated area a helps to compensate for the underestimated area b.

Triangle methods. Figure 3.3 illustrates the single triangle method. The method draws a straight line between a day's minimum temperature and maximum temperature, assumes the next day's minimum temperature is the same, and draws another line to that point, forming two sides of a triangle. This method assumes the temperature curve is symmetrical around the maximum temperature. Degree-days are estimated by calculating the area within the triangle and between the thresholds.

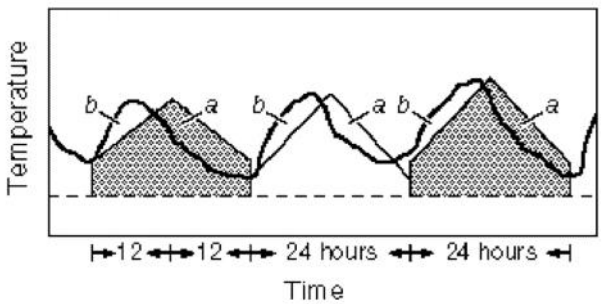

Figure 3.3. The single triangle method of accumulating °D

The double triangle method is illustrated in Figure 3.4. Using two 12-hour or half-day calculations, the double triangle method draws a straight line between a daily minimum and maximum temperature, and another line vertically through the maximum temperature, forming two sides of a triangle. Degree-days are estimated by calculating the area within the triangle and between the thresholds. The second 12-hour period uses the same configuration with the minimum temperature of the following day. Degree-days for the day are the sum of the two half-days. See Note above.

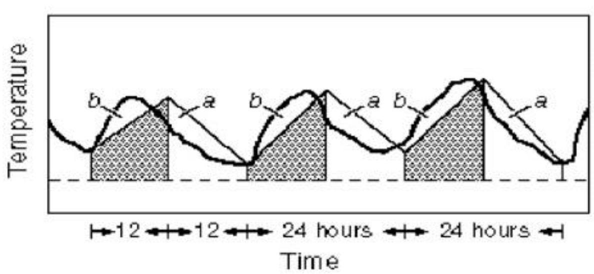

Figure 3.4. The double triangle method of accumulating °D

Sine methods. Figure 3.5 illustrates the single sine method. This technique uses a day's minimum and maximum temperatures to produce a sine curve over a 24-hour period, and then estimates degree-days for that day by calculating the area above the threshold and below the curve. This method assumes the temperature curve is symmetrical around the maximum temperature. See Note above.

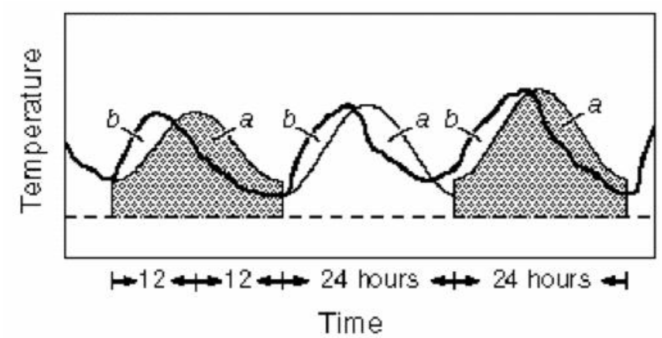

Figure 3.5. The single sine method of accumulating °D

Figure 3.6 illustrates the double sine method. This method fits a sine curve from the minimum temperature of the day to the maximum temperature of the day and then fits a separate sine curve from the maximum temperature of the day to the minimum temperature of the next day. Degree-days for the day are the sum of the two half-days. See Note above.

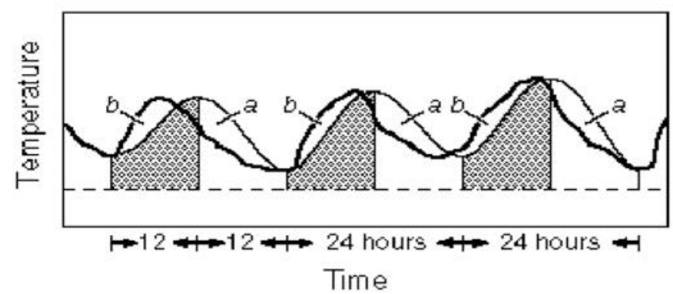

Figure 3.6. The double sine method of accumulating °D

Cutoff methods: The DDU cutoff method refers to the manner in which the degree-day calculation area will be modified in relation to the upper threshold. DDU refers to the modification as a "method for cutoff at upper threshold." Other literature may refer to the upper developmental threshold cutoff, the upper cutoff, the upper developmental cutoff, or cutoff.

DDU provides a choice of three cutoff methods — horizontal, vertical, and intermediate — to be used in conjunction with the sine and triangle calculation methods. (Huber's method automatically incorporates a horizontal cutoff method.) Figure 3.7 illustrates the modifications by each cutoff method to the single sine method of calculation.

Horizontal: The horizontal cutoff method assumes that development continues at a constant rate at temperatures in excess of the upper threshold. Mathematically, the area above the upper threshold is subtracted from the area above the lower threshold.

Intermediate: The intermediate cutoff assumes that development slows, but does not stop, at temperatures above the upper threshold. Mathematically, the area above the upper threshold is subtracted twice from the area above the lower threshold.

Vertical: The vertical cutoff method assumes that no development occurs when a temperature is above the upper threshold.

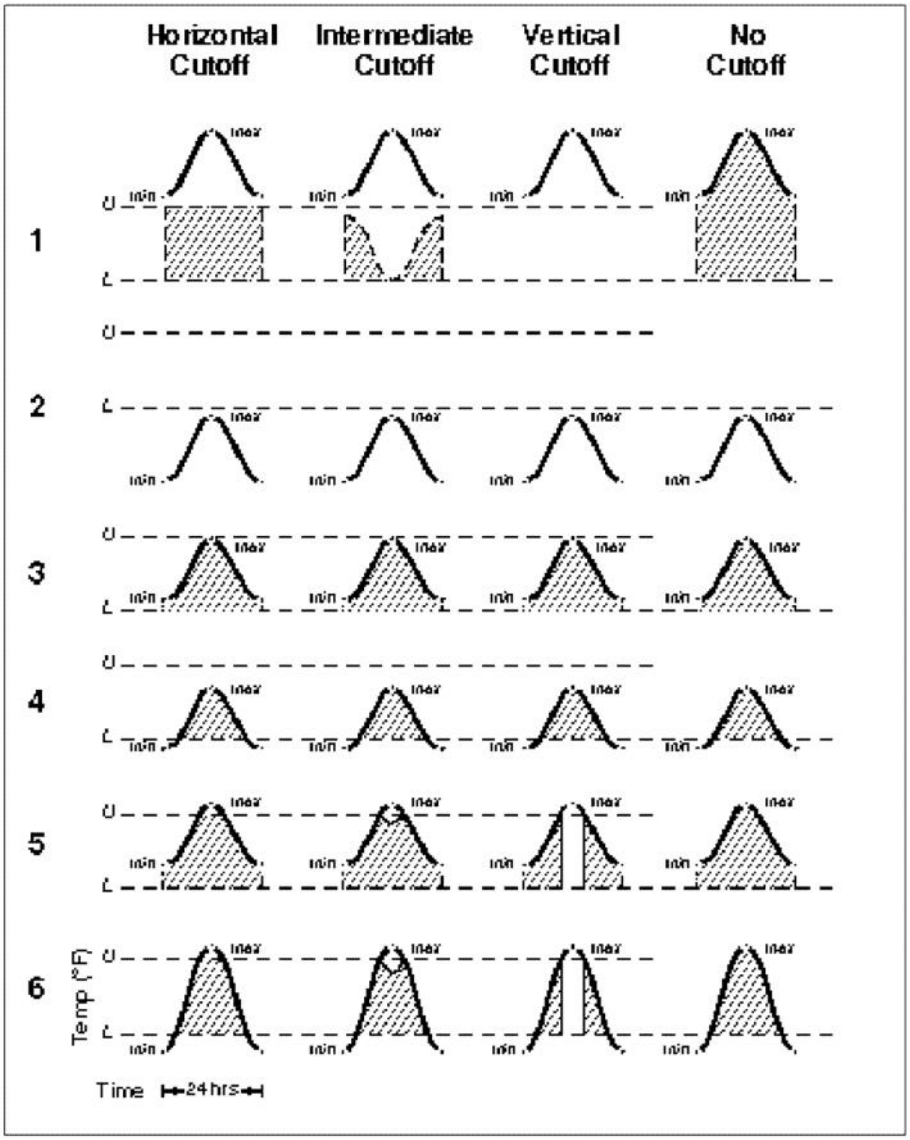

Figure 3.7. Six possible relationships can exist between the daily temperature cycle and the upper and lower thresholds. The temperature cycle can be:

1. Above both thresholds.
2. Below both thresholds.
3. Between both thresholds.
4. Intercepted by the lower threshold.
5. Intercepted by the upper threshold.
6. Intercepted by both thresholds.

(max = maximum daily temperature, min = minimum daily temperature, U = upper threshold, L =lower threshold)

Reference tables

Calculations of degree-days can be made with programmable calculators, computers, or reference tables. Reference degree-day tables are typically produced using a computer. They can be produced for organisms with known lower developmental thresholds or known lower and upper thresholds. Different tables must be used for organisms with different thresholds. Figure 3.8 is an example of a reference degree-day table calculated from the DDU Action Menu using the single sine method.

The minimum daily temperatures are charted along the top of the page and the maximum daily temperatures down the side of the page. To find the degree-days for a day (using single sine, single triangle, or Huber's), locate the minimum and maximum temperature for that day and follow the column and row to where they intersect. The number at the intersection represents the total degree-days for that day.

The reference table values are calculated for each half-day when your method is double sine or double triangle. Look up one value using the minimum and maximum for the day. Look up a second value using the maximum for the day and the minimum for the next day. Add the two values to determine the number of degree-days for the day. Figure 3.9 is an example of a double sine reference table.

DEGREE-DAY UTILITY - REFERENCE TABLE TABLE NAME

METHOD: Single sine   LOWER THRESHOLD: 51 F Horizontal cutoff   UPPER THRESHOLD: 90 F

MINIMUM TEMPERATURES

MAX TEMPS	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70
60	3	3	3	3	4	4	5	6	7	8	9					
61	3	3	3	4	4	5	5	6	7	8	9					
62	4	4	4	4	5	5	6	7	8	9	10	11				
63	4	4	4	5	5	6	6	7	8	9	10	11				
64	4	5	5	5	6	6	7	8	9	10	11	12	13			
65	5	5	5	6	6	7	7	8	9	10	11	12	13			
66	5	5	6	6	7	7	8	9	10	11	12	13	14	15		
67	6	6	6	7	7	8	8	9	10	11	12	13	14	15		
68	6	6	7	7	8	8	9	10	11	12	13	14	15	16	17	
69	7	7	7	8	8	9	9	10	11	12	13	14	15	16	17	
70	7	7	8	8	8	9	10	11	12	13	14	15	16	17	18	19
71	7	8	8	8	9	10	10	11	12	13	14	15	16	17	18	19
72	8	8	9	9	9	10	11	12	13	14	15	16	17	18	19	20
73	8	9	9	9	10	11	11	12	13	14	15	16	17	18	19	20
74	9	9	9	10	10	11	12	13	14	15	16	17	18	19	20	21
75	9	10	10	10	11	12	12	13	14	15	16	17	18	19	20	21

Figure 3.8. A reference degree-day table using the single sine method and a horizontal cutoff

DEGREE-DAY UTILITY - REFERENCE TABLE TABLE NAME

METHOD: Double Sine   LOWER THRESHOLD: 51.0 F HORIZONTAL CUTOFF   UPPER THRESHOLD: 90.0 F

This is a double method: read two entries for each day and add.

MINIMUM TEMPERATURES

MAX TEMPS	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70
60	1	1	2	2	2	2	3	3	4	4	5					
61	2	2	2	2	2	2	3	3	4	4	5					
62	2	2	2	2	2	3	3	4	4	5	5	6				
63	2	2	2	2	3	3	3	4	4	5	5	6				
64	2	2	2	3	3	3	4	4	5	5	6	6	7			

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65 | 2 2 3 3 3 3 4 4 5 5 6 6 7

66 | 3 3 3 3 3 4 4 5 5 6 6 7 7 8
67 | 3 3 3 3 4 4 4 5 5 6 6 7 7 8
68 | 3 3 3 4 4 4 5 5 6 6 7 7 8 8 9

69 | 3 3 4 4 4 4 5 5 6 6 7 7 8 8 9
70 | 3 4 4 4 4 5 5 6 6 7 7 8 8 9 9 10
71 | 4 4 4 4 4 5 5 6 6 7 7 8 8 9 9 10

72 | 4 4 4 4 5 5 6 6 7 7 8 8 9 9 10 10
73 | 4 4 4 5 5 5 6 6 7 7 8 8 9 9 10 10
74 | 4 5 5 5 5 6 6 7 7 8 8 9 9 10 10 11
75 | 5 5 5 5 5 6 6 7 7 8 8 9 9 10 10 11
```

Figure 3.9. A reference degree-day table using the double sine method and a horizontal cutoff

Each species requires a defined number of degree-days to complete its development. The accumulated degree-days from a starting point can help predict when a developmental stage will be reached. The date to begin accumulating degree-days, known as the biofix, varies with the species. Biofix points are usually based on specific biological events such as planting dates, first trap catch, and first occurrence of a pest.

To calculate accumulated degree-days using a reference table, add the degree-days for each day beginning with the date the biofix event occurred for the organism of interest. The degree-day value for each date is based upon the daily maximum and minimum temperatures. Accumulation of degree-days should be done regularly, especially when a control action decision is near.

Degree-Day References:

Baskerville, G.L. and P. Emin. 1969. Rapid Estimation of Heat Accumulation from Maximum and Minimum Temperatures. Ecology 50(3):514-517.

Andrewartha, H.G. and L.C. Birch. 1973. The History of Insect Ecology. In History of Entomology, ed. R.F. Smith, T.E. Mittler and C.N. Smith, 229-266. Annual Reviews Inc., Palo Alto, CA.

Allen, J.C. 1976. A Modified Sine Wave Method for Calculating Degree-Days. Environmental Entomology. 5(3):388-396.

Wilson, L.T. and W.W. Barnett. 1983. Degree-Days: An Aid in Crop and Pest Management. California Agriculture. 37:4-7.

Zalom, F.G., P.B. Goodell, L.T. Wilson, W.W. Barnett, and W.J. Bentley. 1983. Degree- Days: The Calculation and Use of Heat Units in Pest Management. University of California Division of Agriculture and Natural Resources Leaflet 21373.

Dictionary Of Terms:

degree-day: a unit combining time and temperature, used to measure the development of an organism from one point to another in its life cycle.

double sine: one method of simulating a temperature curve for a 24-hour period. Two sine curves are fit to the minimum and maximum temperatures for a day and the minimum temperature for the next day. Degree-day calculations are based on the area under the curve and between the threshold(s).

double triangle: one method of simulating a temperature curve for a 24-hour period. Two triangles are fit

to the minimum and maximum temperatures for a day and the minimum temperature for the next day. Degree-day calculations are based on the area under the curve and between the threshold(s).
Download: to copy a file from one computer system to another.
File: an organized collection of information stored as records and identified by a filename. The information in a file is stored in such a way that a computer can read information from a file or write information to a file. The file contents may represent a source program, the text of a document, or anything the user can express in the available keyboard symbols. Files are stored on floppy or hard disks. The DDU program is in a file on the floppy disk distributed with this user's guide.
Horizontal cutoff: a modification, in relation to the upper threshold, to the degree-day calculation method. A horizontal cutoff assumes that development continues at a constant rate at temperatures above the upper threshold.
Intermediate cutoff: a modification, in relation to the upper threshold, to the degreeday calculation method. An intermediate cutoff assumes that development slows as temperatures increase above the upper threshold.
Lower threshold: the temperature at and below which development stops.
Model: a simplified description of a system, used as an aid to understanding the system.
Parameter: a quantity or constant whose value varies with the circumstances of its application. Degree-day parameters in DDU include calculation method, temperature scale, lower threshold, upper threshold, and method for cutoff at the upper threshold.
Reference table: a table with minimum and maximum temperatures for a day that is used to look up degree-days.
Single sine: one method of simulating a temperature curve for a 24-hour period. A sine curve is fitted to the minimum and maximum temperatures for a day, in the assumption that temperatures are symmetrical around the maximum temperature.
Degree-day calculations are based on the area under the curve and between the threshold(s).
Single triangle: one method of simulating a temperature curve for a 24-hour period. One triangle is fitted to the minimum and maximum temperatures for a day, in the assumption that temperatures are symmetrical around the maximum temperature. Degree-day calculations are based on the area under the curve and between the threshold(s).
Threshold: (Physiological) the point at which a stimulus is just strong enough to be perceived or to produce a response.
Upper threshold: the temperature at and above which the rate of growth or development begins to decrease or stop as determined by the cutoff method.
User response: information typed from a computer's keyboard in reply to a prompt.
Vertical cutoff: a modification, in relation to the upper threshold, to the degree-day calculation method. A vertical cutoff assumes that development does not occur at temperatures above the upper threshold.

Source from: UCIPM (http://www.ipm.ucdavis.edu/WEATHER/index.html)