



## Degree-days and Phenology Models

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## Using the UC IPM Degree-day Calculator

This [degree-day calculator](#) has two branches. You can run preset models that have been recommended by UC Cooperative Extension, or you can specify the thresholds and method of calculation for any model. Weather data for the calculations may come from the UC IPM database for California, a file you supply, or data you enter online.

### **Specify Source of Temperature Data**

Weather data for the calculations may come from the UC IPM database for California, a file you supply, or data you enter online.

**Data from UC IPM Weather database.** The database originated in 1980 as part of the original IMPACT online computer system and stores both current and historical daily weather data for approximately 350 weather stations throughout California. In 1996 it was converted to run on a new computer, with access through the World Wide Web.

Overview of variables, time periods, and averages available for Automatic, TouchTone, Climate, and PestCast stations								
Station Type	Automatic (approx. 100 stations)		TouchTone (approx. 40 stations)		Climate (approx. 135 stations)		PestCast (approx. 40 stations)	
Source of data	DWR (CIMIS)		Volunteers		NOAA		UC and Cooperators	
Period of record stored	6/82 to present or when available		8/81 to present or when available		1951 to present (6-month delay)		1995 to present or when available	
Variables	available	avgs.	available	avgs.	available	avgs.	available	avgs.
Air Temperature, maximum	X	—	X*	—	X	X (30- yr.)	X	—
Air Temperature, minimum	X	—	X*	—	X	X (30- yr.)	X	—
Soil Temperature, maximum	X	—	X*	—	X*	X*	—	—
Soil Temperature, minimum	X	—	X*	—	X*	X*	—	—
* = where available								

1. **Select the county** in which you're interested. Choose from California's 58 counties.
2. **Select a weather station** from the list of stations available in the selected county. A table lists the temperature variables and time period for which data are stored, and whether long-term averages have been calculated and are available. In case your selected county doesn't have the station you're looking for, tables of stations located in surrounding counties are also shown.
3. **Select a time period**, a range of dates. From the lists, indicate the first date (month, day, and year) for which you want to calculate degree-days, and the last date (month, day, and year).
  - o The default dates supplied by the computer are usually March 15 of the current year and the last date for which the selected station can be expected to have data.
  - o To add long-term averages (as a climatological "**forecast**") to the end of your data request, indicate an ending date that is in the future,

beyond yesterday's date.

4. **Select the temperature variable and backup stations.** The Step 5 table includes the variables stored for the selected station, and below it is some additional information about the measurements that may be helpful. In the table, click on the radio button next to a variable name to mark it for retrieval. The request for data will be filled first from the selected station, then from the backup and long-term average stations, left to right.
  - **Backup Stations.** Backup stations listed in the table are nearby stations that can be used to fill in data gaps. Shown will be either a station name or "none recommended."
    - When a station is listed, do nothing if you want it to supply data when data from the selected station is missing. If you do not want to include substitutes for missing data, click on the backup station name and select "do not fill gaps."
    - If "none recommended" is shown, no station is considered to be similar enough to the selected station to be used as a backup.
    - Backup station 1 is used first to supply missing data; if the data value for the date is also missing in Backup station 1, Backup station 2 will be used. Any data gaps will be filled in from the backup stations, if possible.
  - **Long-term Average Station.** If a data value for a date is not available from the selected station or either of the backup stations, the long-term average for the date will be used if a station is recommended in the table.
    - All stations have a recommended long-term average for air temperature, and some have a recommended average for soil temperature.
    - If you do not wish for long-term averages to be used to fill in data gaps, click on the station name and select "do not fill gaps."
    - "Forecasts" based on long-term averages can be included if you specify a time period that includes dates in the future.

**Note:** If there are data gaps in the file when data are retrieved, the accumulation will start over after each gap.

5. **Select the output format.** The calculation can be presented in two formats:
  - **Formatted report** (for viewing or printing) includes max/min temperatures, daily degree-days, and accumulated degree-days for each value in a table with column headings, and indicates the source of any data that were supplied by a backup or long-term average station.
  - **Comma-delimited data file** (for use with spreadsheets) displays a text file of data, with values separated by commas. The file can be saved to your disk and then imported into a spreadsheet program.
6. **Press the CALCULATE DEGREE-DAYS button** to complete the calculation.

**Special note.** Saving these specifications to use them again without having to repeat every step is easy. Use the save as (or equivalent) command in your browser and save the document as "source." To submit the file again, start your browser, use the "Open file" (or equivalent) command, make any necessary changes such as the time period, then press the CALCULATE DEGREE-DAYS button.

**Data from your file.** You may enter your own temperatures into a file and then use that file to calculate degree-days. Temperatures may be entered in Fahrenheit or Celsius; you will be asked to specify the units when you calculate degree-days.

To be correctly interpreted, note the following requirements for the data file.

- The file must be a text file.
- Data values must be separated by either a comma or a tab character.
- Be prepared to supply the position of date, minimum temperature and maximum temperature in a row. (The position must be the same for every row of data.)
- Each day's temperatures must be on a separate line in the file.
- Any row in the file that begins with a double-quote mark (") or a single-quote mark (') will be treated as a comment and ignored in the calculations.

For more information about preparing the file, see [Format for Data File for Degree-day Calculations](#).

To specify the file, press the **Browse** button and locate the file on your computer.

**Data you enter online.** With this option you may enter maximum and minimum temperature pairs directly into a form on the Web.

### Run Models or Calculate Degree-Days

To calculate degree-days you must select a model or thresholds and method of calculation, in addition to supplying temperature data.

**NOTE:** Are you retrieving data regularly, perhaps as often as daily or weekly? See the [Special note](#) below on reusing these specifications.

Click on one of the models, then press the **Run model** button. If the model you're interested in isn't listed, enter the lower (and upper) threshold(s), specify whether the threshold is in Fahrenheit or Celsius, select the calculation and upper cutoff methods if you wish, then click on the **Calculate** button.

**Special note.** Saving these specifications to use them again without having to repeat every step is easy. Use the save as (or equivalent) command in your browser and save the document as "source." To submit the file again, start your browser, use the "Open file" (or equivalent) command, make any necessary changes such as the time period, and then press the CALCULATE DEGREE-DAYS button.

### Reports

Reports include the data for the selected station over the requested time period, in the units and format specified. In any format, the output includes

- information about the selected station and its variables
- a "retrieval report" that indicates the number of data values supplied by the selected station and any backup or long-term average stations
- a description of the file format
- the data that were retrieved and the degree-days that were calculated

**Formatted Report.** Column headings make this report easy to read. The source of each temperature is indicated immediately following the value (in the column headed by a "\*"). When a temperature is from the selected station, the column is blank; if the value is not supplied by the selected station, a code (1, 2, or A) indicates the source of the value: backup station 1, backup station 2, or the long-term average station.

**Comma-delimited Data File.** This format uses the quote character ("), recognized by most spreadsheets, to designate information documenting the calculation results and file format. Otherwise, values for each date are separated by commas, and can be imported into spreadsheet or database software for further processing or analysis.

To save the data page as a file that can be used with a spreadsheet or database program, use your browser's "save as" command (usually on the File menu), specify a descriptive name if you wish, and save the file as text. You can also select all of the data displayed, copy and paste it to a new document in a text editor or word processor, and then save it as text.

The file is a text file, in the following format.

VARIABLE	DESCRIPTION	UNITS
1	Station code	
2	Date: year,month,day	yyyymmdd
3	Air temperature, maximum	Fahrenheit
4	Air temperature, minimum	Fahrenheit
5	Soil temperature, maximum	Fahrenheit
6	Soil temperature, minimum	Fahrenheit
7	Degree-days	Fahrenheit
8	Accumulated Degree-days	Fahrenheit

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## Degree-day Concepts

Temperature controls the developmental rate of many organisms. Plants and invertebrate animals, including insects and nematodes, require a certain amount of heat to develop from one point in their life cycles to another. This measure of accumulated heat is known as physiological time. Theoretically, physiological time provides a common reference for the development of organisms. The amount of heat required to complete a given organism's development does not vary—the combination of temperature (between thresholds) and time will always be the same. Physiological time is often expressed and approximated in units called degree-days (°D).

Consult Baskerville & Emin (1969), Andrewartha & Birch (1973), Allen (1976), Zalom et al. (1983), and Wilson & Barnett (1983) if you are interested in the historical development of the degree-day concept. Degree-day [references](#).

## Developmental Thresholds

Upper and lower developmental thresholds have been determined for some organisms through carefully controlled laboratory and field experiments. For

example, the lower developmental threshold is 51°F and the upper developmental threshold is 90°F for the San Jose scale (*Quadraspidiotus perniciosus*). Thresholds vary with different organisms.

The lower developmental threshold for an organism is the temperature 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 above which the rate of growth or development begins to decrease or stop as determined by the cutoff method. The physiological interpretation of the upper threshold is dependent on the [cutoff method](#).

### 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 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.

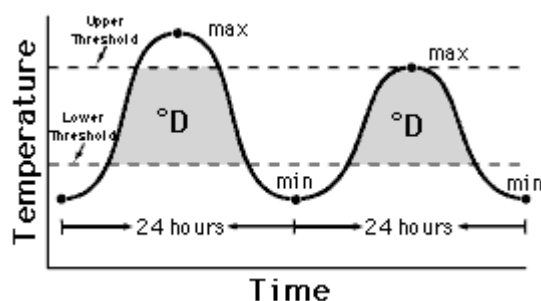
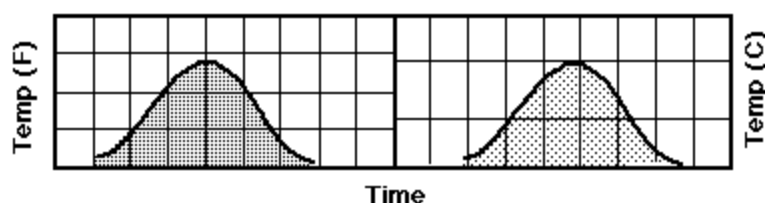


Figure 1. Thresholds and accumulated degree-days

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.  $DD_c = 5/9 (DD_f)$  and  $DD_f = 9/5 (DD_c)$ . Figure 2 shows that the areas under the temperature curve represented in Fahrenheit and Celsius units are equal, but the units differ. Each model in the UC IPM's [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 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.

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### **Degree-day Calculation Methods—[Detailed figures and formulas](#)**

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.)

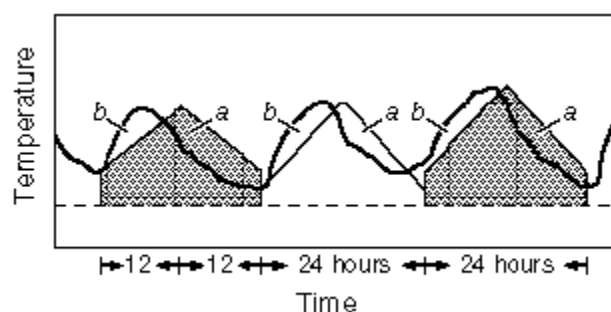
The degree-day calculation methods differ somewhat in complexity. Season and climatic region also cause these methods to vary in how accurately they reflect actual degree-days. Whichever method is used, it is important to use the same method as that used in developing the organism's biological growth 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 in California.

Degree-day calculations and accumulations are based on the area under the diurnal temperature curve and between the thresholds. Different methods for calculating degree-days 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.

**Note:** Figures 3 through 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.

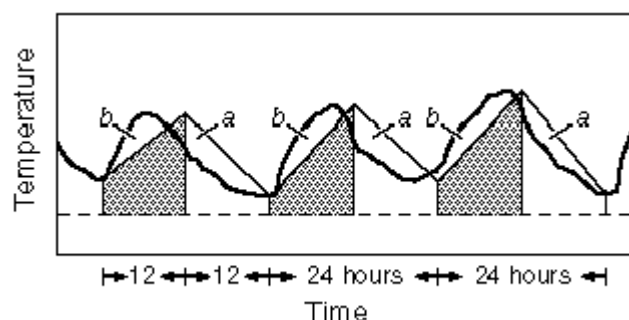
### Triangle Methods

Figure 3 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. The single triangle method of accumulating degree-days**

The double triangle method is illustrated in Figure 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 degree-days for the two half-days. See [Note](#).



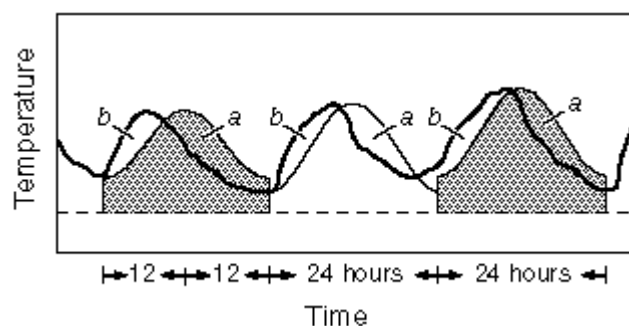
**Figure 4. The double triangle method of accumulating degree-days**

### Sine Methods

Figure 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.

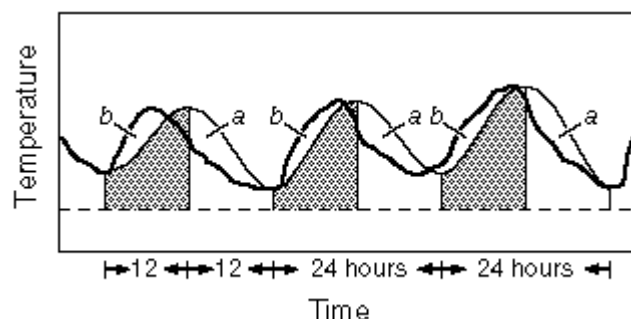


and below the curve. This method assumes the temperature curve is symmetrical around the maximum temperature. See [Note](#).



**Figure 5. The single sine method of accumulating degree-days**

Figure 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 degree-days for the two half-days. See [Note](#).



**Figure 6. The double sine method of accumulating degree-days**

**Huber's method.** This method produces the same result as a single sine with a horizontal cutoff, except that 0.3 Fahrenheit degree-days are subtracted from a day's degree-day accumulation if the minimum and maximum temperatures for that day are between the upper and lower thresholds. This method has been used in the desert southwest in cotton pest management.

### Cutoff Methods

The cutoff method refers to the manner in which the degree-day calculation area will be modified in relation to the upper threshold. UC IPM 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.

The degree-day calculation method 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 7](#) illustrates the modifications by each cutoff method to the single sine method of calculation.

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

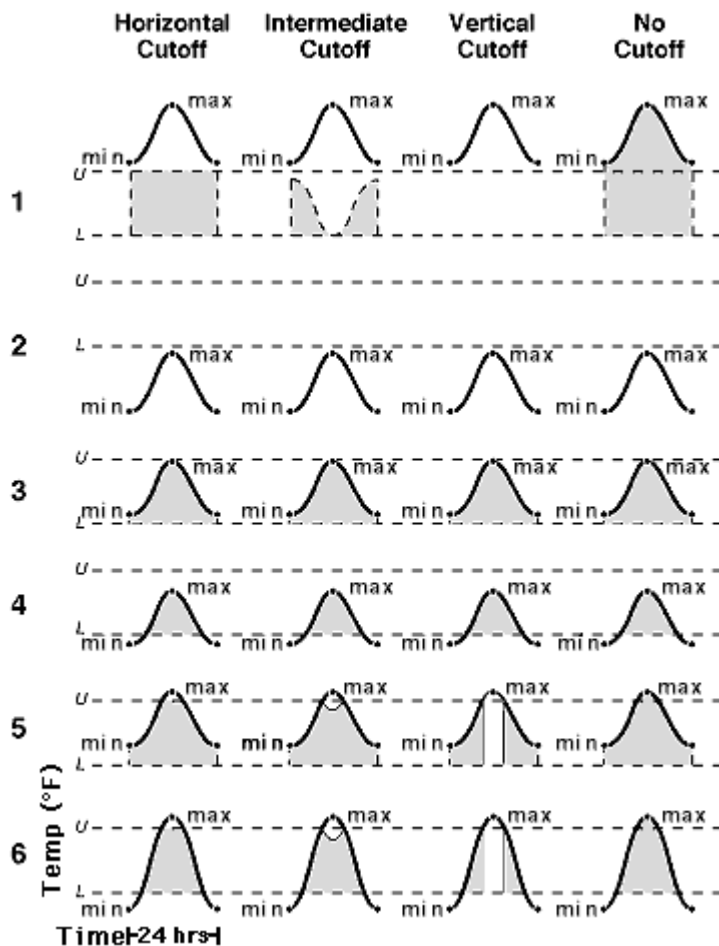


Figure 7. Six possible relationships can exist between the daily temperature cycle and the upper and lower thresholds. The temperature cycle can be:

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)

## Phenology Models

### What is a Phenology Model and How Can It Help Me?

Phenology models predict time of events in an organism's development.

Development of many organisms which cannot internally regulate their own temperature, is dependent on temperatures to which they are exposed in the environment. Plants and invertebrates, including insects and nematodes, require a certain amount of heat to develop from one point in their life-cycle to another, e.g., from eggs to adults. Because of yearly variations in weather, calendar dates are not a good basis for making management decisions. Measuring the amount of heat accumulated over time provides a physiological time scale that is biologically more accurate than calendar days.

Two parameters are used when referring to the effect of temperature on growth and development. The **lower developmental threshold** for a species is the temperature below which development stops. The **upper developmental threshold** is less well defined, but is often taken as the temperature at which the rate of growth or development begins to decrease. For many organisms the upper thresholds are not used because data are lacking to obtain such estimates. Both lower and upper thresholds are determined through carefully controlled research and are unique for a specific organism.

The amount of heat needed by an organism to develop is known as **physiological time**. The amount of heat required to complete a given organism's development does not vary—the combination of temperature (between thresholds) and time will always be the same. **Physiological time is often expressed in units called degree-days**. For instance: if a species has a lower developmental threshold of 52° F, and the temperature remains at 53°F (or 1° above the lower developmental threshold) for 24 hours, one degree-day is accumulated.

Each stage of an organism's development has its own total heat requirement. Development can be estimated by accumulating degree-days between temperature thresholds throughout the season. The accumulation of degree-days from a starting point can help predict when a developmental stage will be reached. Degree-day monitoring does not indicate whether control action is warranted, but rather when a pest will reach susceptible life stages. If pests are abundant, monitoring degree-days helps to eliminate the guesswork otherwise required to determine the time for a control action.

### Using These Models: What Does Validation Mean?

The phenology model information in the [UC IPM database](http://www.ipm.ucdavis.edu/WEATHER/ddconcept.html) comes from published literature that we have assembled and put in a standard format. To be most confident in a particular model, it should be field tested in your particular area (or a similar area).

A model can be informally or formally tested or validated. Informal validation of a model simply involves testing a model in your region and observing how it works.

For example, compare the predicted generation time (degree-days) for an insect using a phenology model, and compare it to the actual degree-days for a generation

using some sampling method such as a pheromone trap. Each year that you use the model, the more fine-tuned you can make it to your area.

Or, you could observe the occurrence of a generation using some sampling method such as a pheromone trap, then compare the degree-days over that same period with the predicted generation time (in degree-days) from a phenology model of the organism. By observing the same events and comparing with model predictions over several years, you can fine-tune the model for your area.

Formal validation of a model is usually done by scientists and involves: (1) obtaining weather data from a given site (and preferably several other sites, some of which have unique climates or other variables); (2) sampling for the particular arthropod, nematode, or plant species, preferably at several stages of its development; (3) combining the weather and sampling data from a minimum of three years in conjunction with statistical computer programs to compute the degree-days and start dates (or biofixes). Formal validation is not necessary to make a model useful; many of the models in the UC IPM database are reported to function well under informal use.

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## References

### 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.

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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.

## Glossary

### biofix:

the date when you begin accumulating degree-days, usually associated with a biological event.

### 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).

**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.

**Huber's:**

a method for calculating degree-days that reduces the total degree-day accumulation if the minimum and maximum temperatures for the day are between the upper and lower thresholds.

**intermediate cutoff:**

a modification, in relation to the upper threshold, to the degree-day calculation method. An intermediate cutoff assumes that development slows as temperatures increase above the upper threshold.

**lower threshold:**

the temperature below which development stops.

**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 thresholds.

**threshold:**

(Physiological) the point at which a stimulus is just strong enough to be perceived or to produce a response.

**upper threshold:**

the temperature above which the rate of growth or development begins to decrease or stop as determined by the cutoff method.

**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.

## [Detailed Figures and Formulas](#)

## [Degree-day Routines](#)

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Unfortunately, we cannot provide individual solutions to specific pest problems. See [Manage Pests](#), or in the U.S., contact your local [Cooperative Extension](#) office for

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Webmaster: [ipmig@ucdavis.edu](mailto:ipmig@ucdavis.edu)