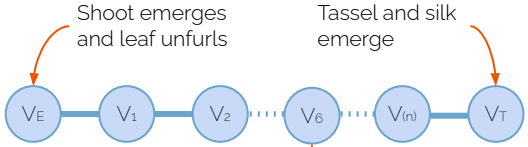
Heat units: a python tutorial

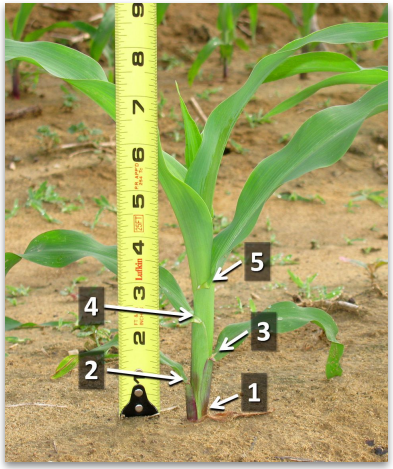
Andrew Balmos

OATS

Growth stages



Growing point near ground
Buds for ear/tassel develop
Brace roots form



Source Erick Larson
https://www.mississippi-crops.com/2019/05/25/how-to-determine-growth-stages-of-young-corn-or-sorghum

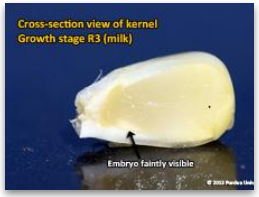
R1: Silking

R2: Blister

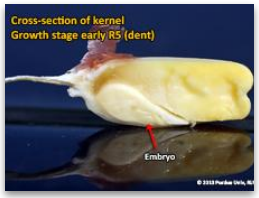
R3: Milk

Yum!

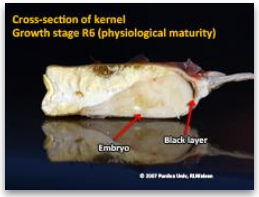
R4: Dough

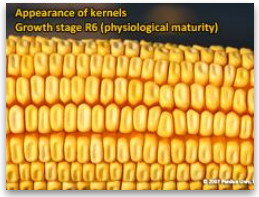


R5: Dent



R6: Maturity





Source RL Nielsen
https://www.agry.purdue.edu/ext/corn/news/timeless/GrainFill.html

The point?

Plant care, hence, farm logistics, are defined by growth!

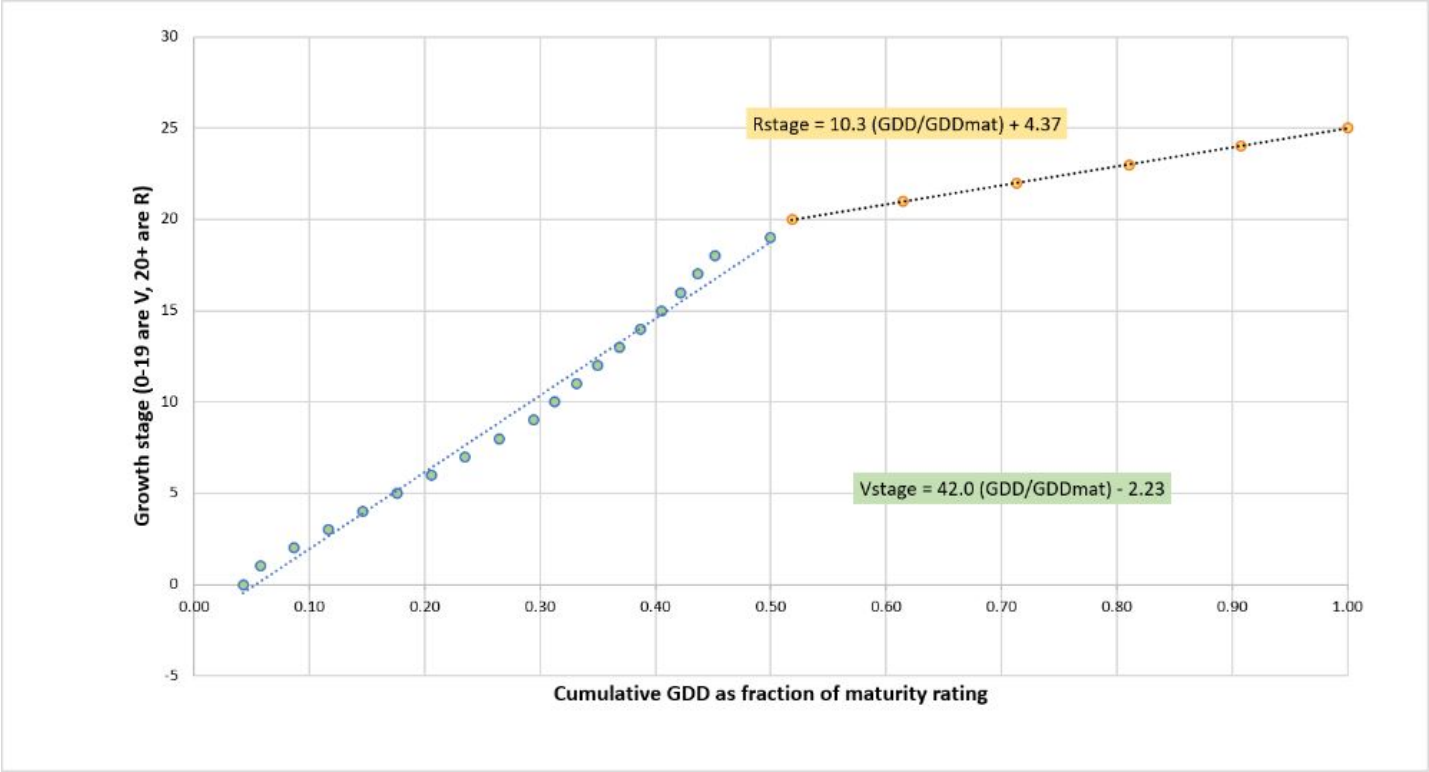
Herbicides and fungicides are applied at certain stages:
- VE to V3,
- V6 and later,
- etc.

Number of kernel rows is determined between V6 and V12
- Soil moisture, nutrient availability, and stress are critical for yield determination

Certain diseases / pests are more susceptible at different growth stages
- Checking for and dealing with such stress can dramatically improve yield

So, can how we track it?

By counting the "heat"!



So, whats a GDU?

A *Growing Degree Unit* or *Growing Degree Day* or *Heat Unit* is
the average number of degrees the plant **experienced in a day.**

Note: The unit is "degree" x "day"

$$\mathrm{GDU} = \frac{T_{\mathrm{high}} + T_{\mathrm{low}}}{2}$$

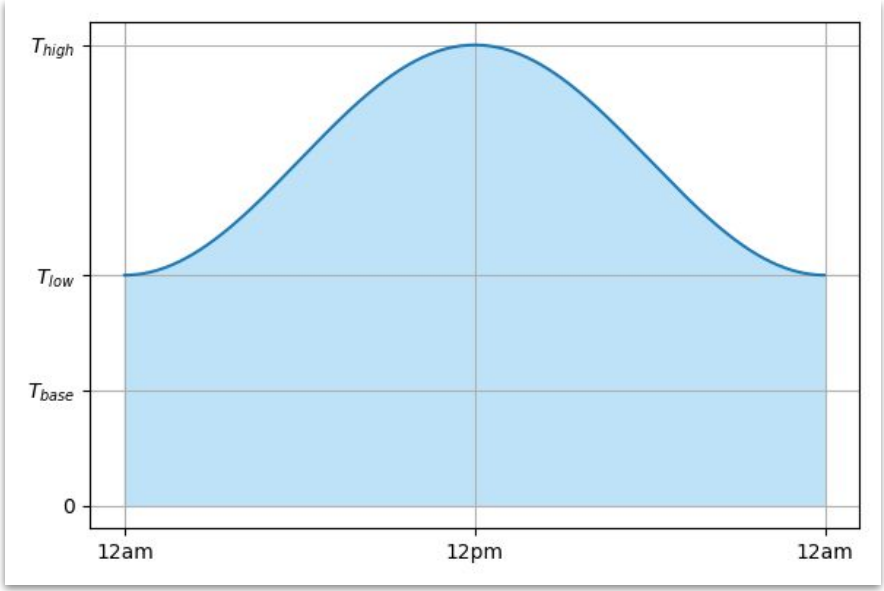
However, studies have shown that plants do not appreciably grow when
below a certain temperature, called the "base" temperature.
We can adjust the formula by subtracting it

$$\mathrm{GDU} = \frac{T_{\mathrm{high}} + T_{\mathrm{low}}}{2} - T_{\mathrm{base}}$$

Studies also show that plants don't grow any faster *above* a certain temperature.
We'll deal with that later.

Where did that come from?

Consider a "typical" day with a sinusoidal temperature profile



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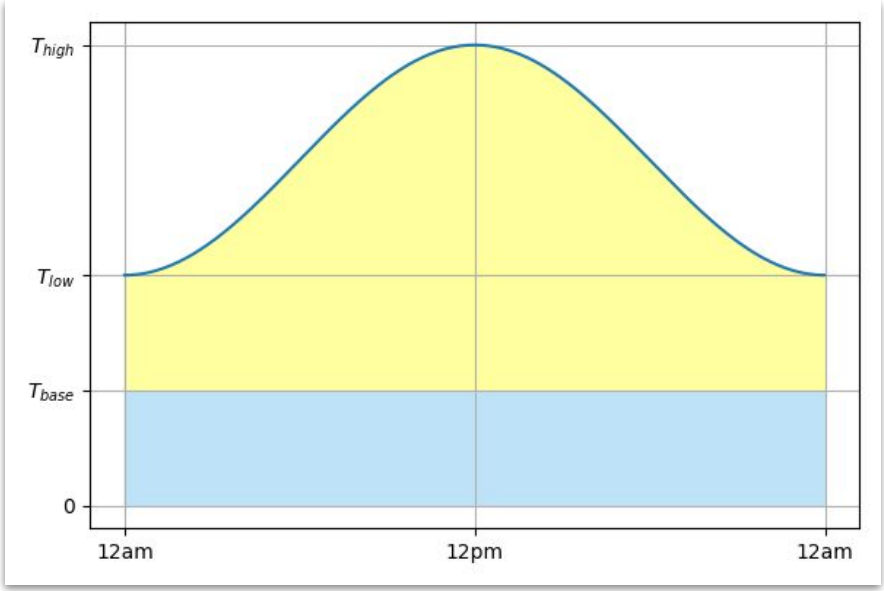
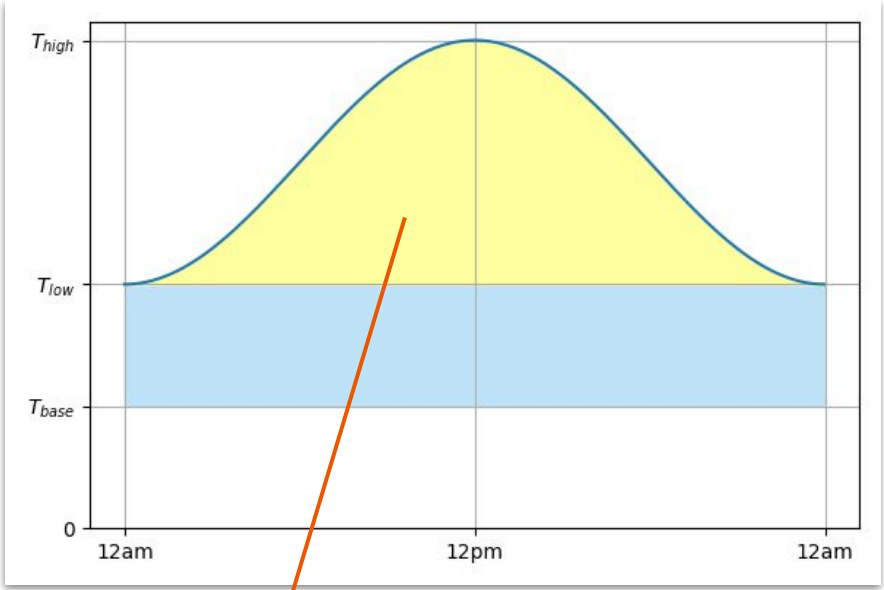


Then the total "heat" (above T_{base}) for the day is the area under the curve and above T_{base}

$$\mathrm{GDU} = \int_0^1 \left(\frac{T_{\mathrm{high}} - T_{\mathrm{low}}}{2} \sin\left(\frac{2\pi}{1\ \mathrm{day}} x \right) + \frac{T_{\mathrm{high}} + T_{\mathrm{low}}}{2} \right) \mathrm{d}x - T_{\mathrm{base}}$$

Okay, let's just do it in parts...

The area under just the sinusoidal part

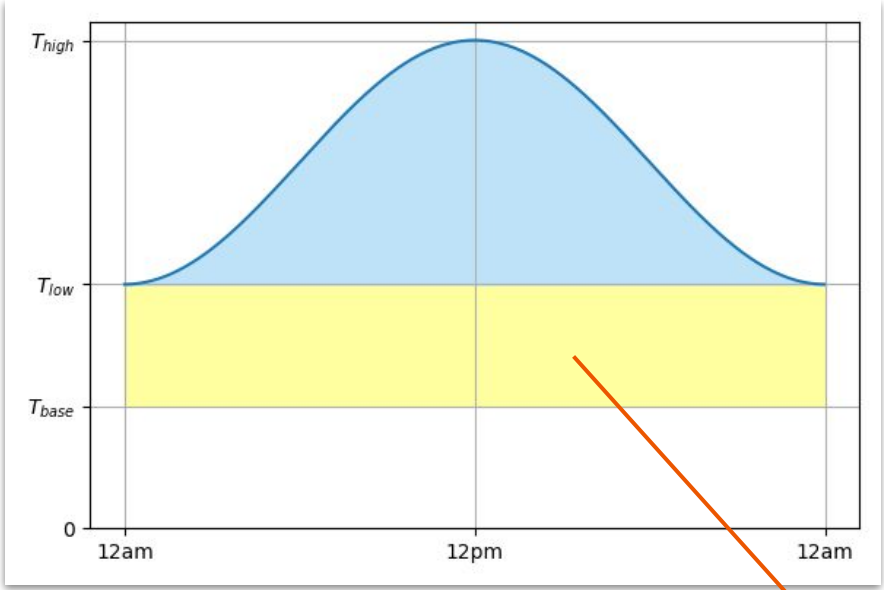


For a `sin` with an offset equal to its amplitude, the Area = Amplitude x Length.

$$\text{GDU} = \frac{T_{\text{high}} - T_{\text{low}}}{2} \times 1 \text{ day}$$

Okay, let's just do it in parts...

For the remaining area,



It is a simple rectangle with Area = Height x Length

$$\text{GDU} = \frac{T_{\text{high}} - T_{\text{low}}}{2} \times 1 \text{ day} + (T_{\text{low}} - T_{\text{base}}) \times 1\text{day}$$

Doing it in parts

Then, we can simplify terms:

$$\begin{aligned}
\text{GDU} &= \frac{T_{\text{high}} - T_{\text{low}}}{2} \times 1 \text{ day} + (T_{\text{low}} - T_{\text{base}}) \times 1\text{day} \\
&= \left(\frac{T_{\text{high}} - T_{\text{low}}}{2} + T_{\text{low}} - T_{\text{base}} \right) \times 1\text{day} \\
&= \left(\frac{T_{\text{high}} - T_{\text{low}} + 2T_{\text{low}}}{2} - T_{\text{base}} \right) \times 1\text{day} \\
&= \left(\frac{T_{\text{high}} + T_{\text{low}}}{2} - T_{\text{base}} \right) \times 1\text{day} = \boxed{(T_{\text{avg}} - T_{\text{base}}) \times 1\text{day}}
\end{aligned}$$

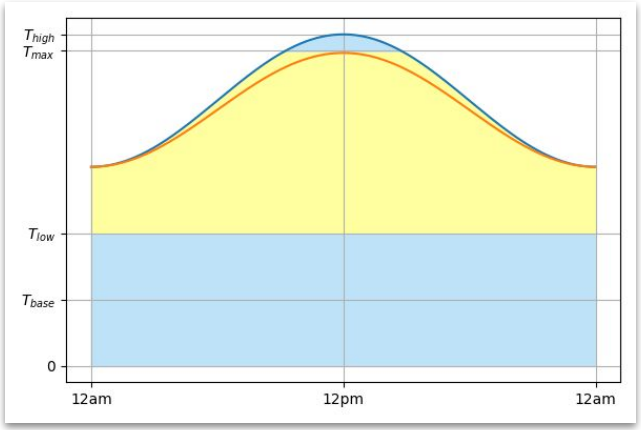
Some caveats

What if $T_{avg} < T_{base}$?

Result: Some days the "GDU" value is negative.
Solution: We replace negative values with 0.
Impact: A "negative" GDU day *could* have instantaneous temperatures over T_{base}, and, therefore, some growing would occur that we lost track of; however, this will only happen occasionally and only toward the start of year where GDU / day are small. In practice it is an acceptable error.

What if $T_{high} > T_{max}$?

Result: We are counting "heat" that did not translate into growth.
Solution: We replace T_{high} with T_{max} and continue as normal.
Impact: We end up "under counting" the total heat energy.
This is standard practice and would require more data to fix.



Let's get back to Python and try it out


Questions?