**Model design**

We developed a non-spatial agent-based simulation model of the evolution of emergence behavior in order to develop an understanding for when organisms should evolve to depend on different environmental cues.

In our simulation, a fixed number of organisms choose to emerge based on environmental conditions, gain fitness depending on the environmental conditions, and then produce offspring based on the fitness gained. Offspring largely resemble their parents, but with some chance of mutation in the way they decide to emerge.

**Emergence Decisions**

The backbone of our model is how organisms decide when to emerge. They do so by following a simple rule. Each individual is characterized by three traits: b.day, b.temp, and b.precip. Those traits are numbers for the set of real numbers (so positive or neg, can be fractions). Every day, organisms decide to emerge or not by calculating an emerge value E based on their traits and the environmental conditions:

E = b.day \* day + b.temp \* temp + b.precip \* precip

Where day is the day of the year (which organisms can determine using photoperiod), temp is the day’s temperature (treated as constant), and precip is the day’s precipitation. The first time an individual has an E value greater than 100, they emerge. This “first time” threshold approach biases emergences in favor of earlier times; this is biologically reasonable as we’re interested in emergence from overwintering.

Values of b.day, b.temp, and b.precip in the initial population are assigned randomly from uniform distributions (currently uniform between -1 and 1, but that’s in flux).

Individuals emerge on the last day of the year if they haven’t before. Fitness is not gained for days after the last day of the year, so if an individual emerged on day 364, they would only obtain fitness for two days (364 and 365) instead of the full ten days most other individuals had.

**Fitness**

When an individual emerges, they “collect” daily fitness for every day of their lifespan (which currently is 10 days). Fitness for each day is calculated from precipitation and temperature, by the equation

F = f(precip)\*g(temp)

Where f and g are Gaussian functions centered on an optimal precipitation and temperature, and precip and temp are the day’s precipitation and temperature measures, respectively. This measure of fitness is the same for all individuals regardless of their traits – for any given year there is a single fitness curve through time, and organisms do well or poorly depending on where on that curve they emerge.

**Reproduction and mutation**

Once all individuals emerge and their fitness is calculated, the reproduction step occurs. Parents are assigned offspring using a multinomial distribution where the probabilities are proportional to the parents’ fitnesses. We assume that all individuals can reproduce, and produce offspring that are identical to the parent unless there is mutation, so offspring are assigned trait values identical to their parents. The use of the multinomial distribution makes it trivial to keep the population sized fixed through all generations.

After reproduction, the offspring individuals are assigned mutations randomly. Each trait (b.temp, b.day, b.precip) of each individual has a small independent chance (currently .01) of mutating, and individuals can receive zero mutations or several (only one per trait, though). Any trait that was selected for mutation has a new number added to the current trait value, with the new number drawn from a normal distribution with mean zero, and standard deviation [variable and being tweaked].

These new individuals were used as the generation for the following year. This means that the model is representing a univoltine organism (one that has only a single generation per year).

**Climate Data**

The environmental values are taken from actual data. 101 years of daily weather at Davis (from 19\*\* to 20\*\*) and [] at Ithaca. We used the daily precipitation and the daily max temperature as our precip and temp values, respectively. Missing days (years had no more than 17 missing days of data) were imputed using the Amelia package, with negative precipitation values set to zero.

In order to compare how evolution would differ between different climate regimes, we have created artificial combinations of the real yearly conditions. [currently we haven’t done this yet, so I won’t worry about describing our specific approaches].