Climate models developed originally out of weather forecasting models, but modeling the climate entails some different considerations from modeling the weather. Let's think about this in terms of a very simple climate signal, which is the seasonal march of temperature. Here's a diagram that shows the actual daily minimum and daily maximum temperatures recorded at Boston, Massachusetts, over the calendar year, 2013. So, naturally the temperatures are lowest in winter, increase into the summer, and then decrease again into the fall.

But you'll notice that there is a lot of noise superimposed upon this kind of series, and that, of course, is the weather. Weather variability has been shown to be chaotic, that is, it has limited or finite predictability. This chaotic weather noise, which everyone is familiar with, is superimposed upon the gradual march of the seasons-- which, of course, are forced by the changing latitudinal distribution of incoming sunlight.

Now it's easy to see when we look at an entire year, the difference between the climate signal in this case, which is the seasonal march of temperatures, and the weather signals, which is the noise that's superimposed on top of it. But if we were forced to deal with more limited segments of time-- for example, let's look at the period of time from 95 to 135 days into the calendar year-- we see the march of high temperatures here at the upper left, and the march of low temperatures in blue, it's very hard to see a trend. So, even though this is a good 40 days of record, which one would think would be large enough to see the springtime increase in temperatures, it's very hard to see that. Statistically, it's probably not even significant when we look at the trends in the high and low temperatures for this period of time.

Similarly, if we look from Day 260 to 290, a 30-day period in the fall when the seasonal march of temperatures is declining, we see this particular stretch of time, no indication of a fall in temperature. So, one can easily be fooled by the noise in the system. And it's necessary to look at a sufficiently long record to distinguish weather from climate. Now, the chaotic variability that we know as day-to-day weather variations are one thing, but the climate itself has chaotic variability on much longer timescales.

To take one example, we have the alternation between the states in the Pacific climate we call El Nino and La Nina states. These alterations occur on the period of years. So there is, in fact, natural climate variability superimposed upon forced climate variability. And it's difficult to make that distinction, particularly because we don't have nearly as good an idea of what natural climate variability looks like, as we do of the natural variability of weather.

Having said that, what is a climate model? And how does it differ from a weather forecast model? Well, there are several different components of a climate model. We begin with an atmospheric GCM, or General Circulation Model, which calculates the dynamics of the atmosphere. It solves the equations of motion, and so forth. It also consists of a myriad of parameterizations of physical processes that can't be resolved on the model's grid. This includes turbulence, convective clouds, layered clouds. We also have to represent the transfer of solar and infrared radiation, and many other processes as well.

In modern climate models, the atmospheric GCM is usually coupled to an ocean GCM -- an Ocean General Circulation Model -- which like the atmosphere, solves the equations of motions on an explicit scale. But it also has to concern itself with things like the distribution of sea ice, which greatly affects the albedo locally, and also the flow of heat and momentum between the ocean and the atmosphere. The sea ice model has to concern itself with things like elastic dynamics, and thermodynamics of ice.

In addition, we have to model the land surface and how it interacts with the atmosphere. This includes exchanges of energy and moisture, and has a biological component which, for example affects the water availability and the albedo. We nowadays solve equations governing the chemistry of the atmosphere and, of course, advect certain key trace constituents, like ozone around.

A modern climate model is arguably one of the most complex pieces of software ever devised by mankind. Here is a flow diagram showing lots of different interacting components of a climate model. We have external influences on the left in orange. Here, such as sun and volcanoes. These are just specified, possibly as a function of time.

We have atmospheric physics and dynamics. We have to take into account the ocean, the land surface, greenhouse gases, soil, terrestrial ecosystems, land use, chemistry in the troposphere, also in the stratosphere, and the influence of human activities on some of these components. Modern climate models are forced by changing solar irradiance, natural and anthropogenic aerosols, and greenhouse gases. The variables that are solved for include temperature, pressure, wind, water vapor, clouds, soil moisture, ocean currents, salinity, sea ice just to name a few.

Today's models have spatial resolutions that can be less than a degree of latitude and longitude, that is less than about 100 kilometers. There can be as many as 50 layers in the atmosphere and 30 in the ocean. Often about 10 layers of the soil are represented, giving about 6 and 1/2 million grid boxes. Time steps have been reduced to a few minutes. And rather than just run a climate simulation once, we run it many different times, with perhaps slightly different realizations of the physics, and different initial conditions to get some idea of how climate noise might be affecting these simulations.

Experiments with modern climate models over a range of 300 years or so, take weeks to months to complete on modern supercomputers. If we compare today's climate models to the models that were developed in the 1970s, we can see that many more processes are represented today than used to be the case. So, the earliest climate models really only simulated the atmosphere, with specified ocean temperatures. By the mid 1980s, we were solving for land surface temperature and beginning to experiment with coupling to ocean and sea ice models.

But today we have the whole works, the atmosphere, the land, ocean, sea ice, aerosols in the atmosphere. We try to simulate the carbon cycle. We often have dynamic vegetation models, vegetation that responds to changing sunlight, precipitation and so forth, and atmospheric chemistry. So, models have become somewhat more complex and certainly more finely resolved.

This advance in the complexity of models is made possible, of course, by Moore's Law-- the exponential increase in the power of computing-- that's shown by this graph, which shows a measure of the performance of computers over the interval from just 1993 to 2013. So, the red curve here is essentially the very top of the fastest 500 computers in the planet. The yellow is the mean of that. And the blue is what would happen if you basically used all the supercomputers in the top 500 to make computations.

The red dot here shows the performance metric of something called the Earth Simulator, which is one of the largest computers ever to have been used to do climate modeling. Here is a photograph of the Earth Simulator in Japan, basically a warehouse filled with machinery.