Activity 3: Atlas of Change
Understanding Presentation: Teacher Notes

Slide	Notes
1	This presentation introduces models and the nature of scientific uncertainty. It also explains how models are used to simulate processes and systems over time.
2	What do you think about when you hear the word "model?" This word means different things to different people. For example, some of you might think about fashion models, or model airplanes and cars, or even models of the solar system or the ocean floor. All of these examples are models and they share many, but not all, characteristics with the things they represent.
3	The same can be said about scientific models. A scientific model is a representation of the real world. By definition, a model is simpler than the thing it is meant to represent. It shares some characteristics with the real thing, but not all of them. There are many different types of models. Models can be simple, complex, conceptual, or mathematical. This is why statistician George Box famously said, "All models are wrong, but some are useful." All models are wrong in the sense that they do not have all the characteristics of the thing they are intended to represent. Now let's look at what makes a model useful.
4	Models are both explanations of how things came to be the way they are and projections of how they will be in the future. One example of a model is the geocentric (Earth-centered) model of the solar system. Ancient Greeks observed the way that the formation of the stars and planets changed in the sky through the course of a year. To explain this, they developed a model of the solar system that illustrated how they believed the stars (including the sun) and planets revolved around the earth at varying speeds. Using a complicated set of equations, ancient astronomers could predict the position of the stars in the sky. This model was used until just a few hundred years ago. However, as more information was collected about the stars' movements, astronomers had to make more and more adjustments to the model in order for it to fit these new observations.
5	In the 16th century, Copernicus offered the first real challenge to the geocentric model. He argued that the sun (not the Earth) was at the center of the solar system. This heliocentric (or sun-centered) model could explain some of the observations that the geocentric model did not explain. (For example, Mars appeared to reverse direction for brief periods of time. The geocentric model could not explain that observation, but the heliocentric model could.) Over time, many observations were made that did not fit the geocentric model, leading it to be replaced with the heliocentric model. Today, the geocentric model has become little more than an historical footnote.
6	The transition from the geocentric model to the heliocentric model provides a good context for

	discussing how we assess the usefulness of models. Perhaps the most important criterion is the accuracy of the predictions that result from the model. To assess the accuracy of a model's predictions, we start by looking backward. This is often called a "hindcast" as opposed to a forecast. Can the model accurately "predict" the observations already made regarding a phenomenon? Here we have the results of a test of a model designed to describe the formation of ice in the Bering Sea. The modelers used the time period from 1996 to 2004 to test their model. The amount of ice predicted by the model is in red, and the actual amount of ice measured during those years is in blue. We can see that the model does a good job of predicting the amount of ice during that period. This model could be useful to project future sea ice changes because it has done a good job of predicting what we have actually experienced.
7	Climate modelers test their models against actual data taken during the last several decades. In addition, they test the same models against climate data from millions of years ago. By using data collected from tree rings, ice cores, and sediment cores, scientists can understand what the climate was like thousands and even millions of years ago. These data can be used to test a climate model under a set of conditions different from the past century. Modelers also compare results with each other in the same way that you might check your math homework answers with a friend. If you work independently and you get the same answer on a homework problem as your friend, it doesn't necessarily mean that you are correct, but you probably feel more confident about your answer. Comparing results from several different models provides a range of possible outcomes. However, modelers are quick to point out that model results cannot be made with 100 percent certainty; there is an inherent degree of uncertainty that exists in all model predictions.
8	When people use the term "uncertainty" in their everyday interactions, they often mean that they don't have enough information to know the outcome of something for sure. If you don't know whether an interesting person will accept your suggestion for a date, you are uncertain about the wisdom of asking. However, when scientists use the term "uncertainty," they are talking about variability that is inherent in complex systems. These systems contain many variables and many processes that interact with each other in different ways, not all of which are known. In addition, there are many possible changes that could happen in the future to the factors that affect climate, and even small changes in present conditions can lead to major changes in future conditions. For example, humans could be emitting slightly more or slightly less greenhouse gases at the end of the next century, which could cause significant changes in climate. Therefore, learning more about the system may improve scientists' projections, but they will never have complete certainty. Going back to our dating example, if a friend told you that the interesting person would like to go out with you too, that would be good information. You could ask that person out with fairly high certainty that s/he would say "yes." But school is a complex system too. If you decide to wait a week, many things could change. So even with very good information, the inherent uncertainty of the situation increases the further you try to

	project into the future.
9	Because of the unavoidable uncertainties that exist within complex systems, scientists typically do not talk in terms of absolutes. Instead, they talk in terms of statistics and probabilities. Modelers have a number of techniques they use to deal with the uncertainty of projecting behavior in complex systems. For example, they can run a model many different times. It's a little like performing an experiment. Modelers can ask "what if" questions by slightly changing the conditions of the model to see how the projections change. Modelers can also use multiple models that they have developed independently. These models will likely have slightly different behavior, so they can illustrate a range of likely behaviors for a system. Finally, modelers can use statistics to figure out how likely a particular behavior is.
10	You are probably familiar with one type of model where these techniques are used–hurricane models. In this figure, we see the predicted path of Hurricane Sandy in the fall of 2012. The lines between the two yellow lines are the hurricane paths predicted by multiple models that were run multiple times. While they are not exactly the same, a pattern emerges. Therefore, while modelers cannot predict the precise path of the hurricane, they can be relatively confident that the path will lie between the two yellow lines. Notice that the yellow lines spread farther apart as we get farther from the current location. This illustrates the increased uncertainty we face as we consider what the hurricane will be doing further into the future.
11	Of course projections are not the only use for models. Those "virtual experiments" mentioned earlier can help us to understand *how* a system works. When studying bacteria, a scientist can conveniently run experiments in a lab to gain insights. However, studies on ecosystems or global climate do not lend themselves easily to laboratory experiments because they are too expensive or complex to replicate. So, scientists can run simulated experiments using models. In this figure, scientists have looked at global temperatures projected by the model when including human impacts and when those impacts are not included. Note that without human impacts, the model shows a much lower temperature (in blue). With human impacts, the model results roughly follow the observed temperatures (black line) over the last several decades. This model helps us to understand the relative role of natural effects and human effects on the climate system.
12	So far we have seen several different types of output from models, including graphs of specific variables and the map tracking Hurricane Sandy. Other models can show us how variables change in an area over time. These figures, developed by the U.S. Forest Service, tell us the mean temperatures for the eastern United States in July. First look at the figure on the left. This shows current mean temperature in Celsius in July. As you might expect, temperatures are relatively high in Florida (26-27^{o} C or 79-81^{o} F) and become progressively colder as we move north (< 24^{o} C or <75^{o} F in Maine). The middle and right figures show us two sets of temperatures for the year 2100 projected by

	the Hadley model. These temperatures will depend on the levels of greenhouse gases in the air. Those levels depend very much on the amount of greenhouse gas emissions that humans produce. Since we can't predict those now, the modelers here provide two sets of predictions. The middle figure shows us temperature predictions for the year 2100 based on a low emissions scenario. The right figure shows temperature predictions based on a high emissions scenario. Notice that the yellow band that was in Florida has moved north. July temperatures are projected to increase to 32-33^{o}C or 90-91^{o}F in Florida and 26-27^{o}C or 79-81^{o}F in Maine. In other words, under the high emissions scenario, if you were in Maine in July 2100, the temperature would feel very similar to the way it feels now in July in Florida.