Deciphering Uncertainty in a Changing Climate

by Joe Lilek (Summer 2015 Hollings Intern for Science On a Sphere)

This live program explains the three types of scientific uncertainty: natural variability, model uncertainty, and scenario uncertainty. To better understand the difficulty that comes with communicating uncertainty, audience members play an estimation game to guess the precise percentage of likelihood that corresponds to phrases used in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report like "very likely" and "virtually certain."

Live Program Script:

**Note:

- Lines that begin with ">>" and bracketed text denote presenter instructions. *In this version of the script, these are also italicized.*
- "(Q?)" denotes discussion questions.

---(1) Blue Marble with confidence PIP---

>>After introducing SOS and the topic of this presentation, open up with a few questions about confidence. Below are some examples-- feel free to use them or create your own.

- How confident are you that the Sun will rise tomorrow?
- How confident are you in gravity?
- How confident are you that you will have cellular service when you need it?
- How confident are you that it will rain on your birthday?
- How confident are you that there will be traffic on your drive home?
- How confident are you that if you stepped up to the plate, you would hit a home run?

Lots of factors can affect our degree of confidence about pretty much anything. According to the Intergovernmental Panel on Climate Change (IPCC), an international group of scientists created by the United Nations, confidence is determined by the level of agreement and the strength of the evidence.

The degree of confidence is very important in science because it allows us to talk about uncertainty. But what is uncertainty?

Uncertainty is a word often used interchangeably with doubt and mistrust, which is one of the reasons why it is thought of as a bad thing. Scientific uncertainty is difficult to define because it doesn't refer to just one thing. Uncertainty can be separated into three categories:

- (1) natural variability, or uncertainty about what might happen in the sense of chance, randomness or essential unpredictability,
- (2) model uncertainty, which arises due to lack of knowledge or computing power
- (3) scenario uncertainty, which arises from the outcomes of future human behavior and decisions.

---(2) Fractals: Morphing---

Let's talk about the first type of uncertainty. The future is constantly in motion and although we have become good at making predictions, we never have 100% confidence in our predictions. In all things, there is natural variability. Some people have green eyes and some have blue eyes. Some ocean waves are tall and some are short. This natural variability is especially important in climate science because sometimes a seemingly small thing can have a big effect later. As the common saying goes, “A butterfly flapping its wings in the prairie, can cause a storm in the desert.”

This dataset shows fractals, detailed self-repeating patterns that are constantly shifting. Patterns like these are a representation of the complexity in the atmosphere and oceans and other things in nature. Our understanding of this type of uncertainty is growing, but natural variability will always be present and there will always be some uncertainty in scientific discovery.

---(3) Cumulative Hurricane Tracks 1950-2005---

This dataset shows the tracks of tropical cyclones around the world. Notice that almost all of these storms begin in the same place along the equator but diverge on wildly different paths. Small changes, like the butterfly flapping its wings, can result in huge changes down the road. Even though natural variability is always present, patterns still emerge that help us to make informed predictions. Notice that all tropical cyclones form near the equator in a region called the intertropical convergence zone or ITCZ. Observations like the hurricane tracks on this dataset are extremely useful for understanding the potential paths of future storms.

Main takeaway: Even though natural variability is always present, patterns still emerge that help us to make informed predictions.

The second type of uncertainty has to do with facts and observations. As our knowledge grows through research and data collection, this type of uncertainty will be gradually reduced. Today we have more data than ever before, and we are able to use this huge amount of data in predictions by running it in “models”.

---(4) ”What is a Model?”---

So, what is a model exactly? All of these pictures have something in common. They are all simplified versions of things in the real world:

- A model of the DNA helps us understand the double-helix structure.
- A blueprint gives the dimensions and layout of a house that will soon be built.
- A model airplane has the basic appearance of a real airplane, and some of the functionality.
- SOS itself is a model of the Earth.

But today we’re not talking about model airplanes or Derek Zoolander... we’re talking about *mathematical* models. A mathematical or numerical model is a tool to help us understand the world around us or predict future changes. These use collected data like surface temperature, total rainfall, and wind speed and direction to predict weather and climate. Numerical models are computer programs that use these real-world data and math to approximate the behavior of different things. It’s like creating a new world from math and physics equations.

Main takeaway: Models are computer programs that use physics and math to mimic and predict real life.

---(5) FIM Clouds Real-time---

>>Disable PIPs and begin the animation

This model (the Flow-following finite-volume icosahedral model or FIM for short) was developed by NOAA and gives a 10 day forecast for clouds and weather systems around the world.

Models can be simple or complex. To make the model look like the real world, it needs to be *very* complex. Scientists increase the complexity of a model by using better physics and observations. Some models ignore certain parts of physics or use imprecise approximations. For example, a model might neglect friction in the air or replace mountains with flat ground. Model accuracy also depends on observations-- if the collected data is not good, the model output won’t be either. Scientists can also make a model better by increasing its spatial and temporal resolution.

>>Enable spatial resolution PIP

In this map of the United States, you can see that as the spatial resolution increases, the pixel size gets smaller. In each of these pixels, data is input into the model equations and the solution to the equations, called the output, is shown on the map as a color. More features can be seen on a map with higher spatial resolution-- notice how in the first map, the entire state of Florida is contained within two pixels! When we increase the spatial resolution, we can obtain more detailed information about how the climate is changing.

>>Fade out spatial resolution PIP.

Let's look back at the FIM model. Temporal resolution refers to the amount of time between model outputs. The FIM shows hourly forecasts whereas some climate models show yearly forecasts. Models with high spatial and temporal resolution give more detailed visual information but require a lot more computing power to run. For example, halving the length of each grid cell requires four times as much computing power! This is why global climate models typically have lower resolutions than regional or local climate models or weather models. Assuming the observations and the physics are sound, we can understand the following: as the resolution increases, scientists are able to reduce uncertainty and increase confidence in their predictions.

Main takeaway: Higher resolution resolves more uncertainty but requires a lot more computing power, so models don't always use the highest resolution.

The third type of uncertainty has more to do with human behavior. With respect to climate change, we don't know what we will do as a species over the next century. Because of this uncertainty, we examine multiple scenarios working off of well-founded assumptions.

---(6) Climate Model: Temperature Change (RCP 8.5) - 2006-2100---

This dataset shows the Representative Concentration Pathways (RCP) model developed by NOAA's Geophysical Fluid Dynamics Laboratory. It models surface temperatures around the world from 2006 to 2100. The temporal resolution for this model is yearly and the length of each grid cell is 0.5 degrees. Notice that temperatures are different around the world and vary from year to year, sometimes warmer than average, sometimes cooler.

(Q?) How will human behavior impact the model output?

>>Start the animation

This scenario runs under the assumption that CO2 emissions are allowed to grow unchecked. The CO2 concentration reaches 936 parts per million by 2100-- more than doubling today's CO2 concentration-- and the average global temperature increases on the range of 9 to 11 degrees F above the 20th century average. Notice that just as some locations were warmer or cooler than average in 2006, some locations warm more, some less.

This scenario is called the RCP 8.5, referring to 8.5 Watts per square meter (W/m^2) of increased radiative forcing. Radiative forcing is a way of talking about the heat that is being added to or subtracted from the Earth's energy balance. For example, a volcanic eruption releases ash into the atmosphere that blocks sunlight and cools the planet, so it would correspond to negative radiative forcing because heat is being effectively subtracted. A positive radiative forcing of 8.5 W/m^2 corresponds to 1370 ppm of CO2 in the atmosphere which this scenario anticipates by the year 2200. This is a “worst case scenario.” But this outcome isn’t certain.

---(7) Climate Model: Temperature Change (RCP 2.6) - 2006-2100---

This dataset shows the same model as before-- the same resolution, the same physics, the same observations. However, this one makes a different assumption about human behavior.

In this scenario, humans reduce carbon emissions enough that the CO2 concentration peaks around 2050 and then steadily decreases to 421 ppm by 2100, with indications that it will continue to decrease. Notice that the temperature increases around the globe are smaller than in the last dataset. The radiative forcing in this scenario is only 2.6 W/m^2, corresponding to a much lower CO2 concentration.

Main takeaway: Actions that we take today can hugely affect future outcomes.

Climate models are impacted by all three types of uncertainty and no matter how sophisticated our models get, we will never have 100% confidence in them. However, although we will never reach 100% confidence, scientists are getting us very close. This clip from NOAA’s Environmental Visualization Lab shows how close models are getting to approximating real life:

---(8) Model versus Satellite---

This model was able to predict the paths of weather systems with high accuracy. This visualization shows satellite imagery and model data collected during the same time period side by side. Notice how well the model and the satellite align-- the same storms seen in the satellite are correctly positioned by the model!

Main takeaway: Our models are not perfect, but they do a really good job!

So, we now understand what uncertainty is, but why is it such a big problem? Science can be difficult to grasp, especially due to the use of technical language. As a result, many people view climate change science with skepticism. Just how sure are these scientists? The IPCC describes the uncertainty in its statements with a likelihood terminology where phrases correspond to percentages. To give you an idea of how difficult it is to communicate uncertainty, let’s see how well you can match the statements with their likelihoods...

---(9) Scale of Percentages---

This scale goes from 0% to 100% in 1% increments. Let's split you into two teams. I am going to read a few statements from the most recent IPCC report and each team will try to guess the percentage likelihood they are trying to communicate. Ready?

>>Give time to guess and discuss. Make sure the audience agrees with where their estimate goes. Depending on the amount of time you have and the level of audience engagement, you may choose to read all or only some of the following statements.

>>Explain the physics of the statements in easy to understand terms and then ask the audience what each of the starred terms mean. After they have made guesses for the first two statements, show their estimate and use the annotation feature to draw in the correct range of likelihood for each phrase.

- It is *very likely* that regions of high salinity, where evaporation dominates, have become more saline, while regions of low salinity, where precipitation dominates, have become fresher since the 1950s.
    - Very likely is 90 to 100%
- Warming is *likely* to exceed 2°C for RCP6.0 and RCP8.5 (high confidence), *more likely than not* to exceed 2°C for RCP4.5 (medium confidence), but *unlikely* to exceed 2°C for RCP2.6 (medium confidence).
    - Likely is 66 to 100%
    - More likely than not is >50% to 100%
    - Unlikely is 0 to 33%

>>Give answers for the first two statements.

- Mitigation scenarios reaching concentration levels of about 500 ppm CO2 by 2100 are *more likely than not* to limit temperature change to less than 2°C, unless they temporarily overshoot concentration levels of roughly 530 ppm CO2 before 2100, in which case they are *about as likely as not* to achieve that goal.
    - More likely than not is >50% to 100%
    - About as likely as not is 33 to 66%
- It is *virtually certain* that the upper ocean (0−700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971.
    - Virtually certain is 99 to 100%
    - >>Explain uncertainty in past measurements-- the less than 1% uncertainty is included to account for the quality of past observations for 1971 to 2010 and more uncertainty is associated with less reliable measurements from before 1971.

>>Enable scale layer

(Q?) Why do these descriptors give ranges of probabilities instead of exact percentages?

Potential answer: Sometimes we are uncertain about what we are uncertain about. We don't know what we don't know!

According to a study by researchers at the University of Illinois Urbana-Champaign, people tended to associate these phrases with lower percentages than the IPCC actually meant. This might explain why people believe that the scientific consensus about climate change is not as strong as it actually is. Although there is uncertainty from natural variability, model resolution and assumptions, and the difficulty of predicting human behavior, scientists still agree that we have enough information to act.

---(10) Flu Virus Model: H1N1 - 2009---

This final dataset shows how important models and uncertainty are in our lives.
>>Take guesses from the audience about what the dataset shows.

This is a model of the H1N1 outbreak of 2009, also known as swine flu. The lines represent flights and the color represents the estimated number of cases of H1N1. To develop this model of disease transmission, scientists included all three types of uncertainty that we have discussed. This model was updated with real-time data during the outbreak and was able to predict an early peak in the epidemic.

Consider this: if 97% of doctors told you that you were sick and required immediate treatment, would you follow their advice or would you seek out the 3% that told you that you were fine?

97% percent of climate scientists agree that we are changing the climate. While it's important to understand the risks associated with uncertainty, we are confident that we know enough to act on climate change. And although uncertainty can be scary, it also brings opportunity. Science thrives on uncertainty-- it is exciting because we are learning new things that we didn't know before. If a butterfly idly flapping its wings can make a storm, imagine what effects on the world you can have.

**Give your location's customary farewell.*