Central Coast Climate Science Education

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Lesson 4: Weather, Climate & "Computability”

One of the most frequent misunderstandings one encounters in discussing climate science is the confusion between *“**weather**”* and *“**climate**”*. This confusion often results in typical remarks, like:

> "I just read that record low temperatures were set in several places in the U.S. this week, so isn't it ridiculous to talk about 'global warming'?"

Or:

> "Three days ago the weather bureau predicted that we were supposed to get over an inch of rain last night and we got hardly enough to get the ground wet! How can we possibly believe the predictions of climate scientists many decades into the future when they can't even get things right three days ahead of time?"

Such typical comments reflect the frequent confusion between weather and climate and the fundamental differences between them.

As a practical matter, ***weather*** refers to the day-to-day changes in temperature, cloud cover, wind, precipitation, etc. These changes can be dramatic in just a few hours. On the other hand, ***climate*** refers to the ***average*** of weather patterns for a given region of the Earth over many years. In fact, climate scientists recognize that at least 30 years are necessary to smooth out the 'natural variability' in the climate -- a term discussed below—before firm conclusions about climate change can be drawn.

There is 'weather' in our atmosphere featuring, for example, severe storms and cold fronts sweeping in from the ocean or the arctic in a matter of days. But there is also 'weather' of a sort in the oceans with back and forth 'sloshing' of ocean currents. These also involve wind patterns as well. These 'oscillations' have longer term effects on ordinary weather, and they don't occur over days but rather over years or even a decade or two.

The best known of these oscillations is "ENSO", which stands for the “El Niño-Southern Oscillation”. The term oscillation refers to the fact that the pattern can swing back and forth between the El Niño pattern, and the La Niña pattern--or something in between. An El Niño condition produces warmer, above-normal seawater temperatures in the eastern Pacific Ocean, especially off the coast of South America, but also along the California coast as well. A neutral condition produces normal ocean temperatures, while a La Niña pattern produces colder, below-normal ocean temperatures in the eastern Pacific Ocean.

These "ENSO events" have worldwide effects on the weather. For example, the El Niño phase generally brings wetter than normal weather to California, while the La Niña pattern brings drier than normal weather conditions. There are also periods when neither of these phases is dominant.

Even the average global temperatures are affected by ENSO events: In 1998 there was an unusually strong El Niño that resulted in an especially warm average global temperature.

Just as meteorologists cannot accurately predict the arrival time or intensity of storm events more than one or two weeks in advance, so neither can the time of occurrence, strength, or duration, of El Niño events be reliably predicted several years in advance. Moreover, the ENSO phenomenon, while being the best known of these ocean/atmosphere oscillations, is not the only one. Two other well known and longer term oscillations are the "Pacific Decadal Oscillation" and the "Atlantic Multidecadal Oscillation."

There are also long-term atmospheric oscillations. In January 2010 an unusually severe phase of an atmospheric oscillation called the 'arctic oscillation' caused a huge flow of cold arctic air to stream down over parts of North America, Great Britain and parts of Asia. This unusual spate of cold weather and snow was interpreted by some to mean that “global warming had stopped.”

But at the same time, unusually warm temperatures were being recorded in other parts of the world. This was true along the northwestern US pacific coast, Canada, Alaska and into the parts of the arctic. (In fact, during the 2010 Winter Olympics in British Columbia, Vancouver had one of the warmest winters ever, and several hundred thousand cubic feet of snow had to be trucked in to some Winter Olympic venues while some events have had to be postponed because of rain instead of snow).

Ironically, there is now a growing suspicion that the rapidly declining amount of summer arctic sea ice, which dramatically declined in September 2012 to its lowest area ever, may be starting to affect the arctic oscillation and may lead to more frequent outbreaks of arctic air into the US during some winters.

Critics complain that when cold snaps are dismissed by some who write about climate change as having little to do with overall global warming trends, these same writers also point to heat waves as positive evidence of global warming. "You can't have it both ways!" complain the critics, and they are right!
The correct statement is that both warm and cold fluctuations will always occur, but ***the frequency of occurrence*** of extreme warm events will slowly increase, while the frequency of extreme cold events will decrease.

The moral of the story is that looking at trends of only a few years in global temperatures or looking at temperatures in small portions of the globe are likely to be misleading in terms of long term climate changes. An analogy that many of us can identify with is the frustration that can result by looking at the up-and-downs of weighing oneself daily while trying to lose weight. One morning you might be encouraged to see a loss of two pounds from the previous morning's result, only to see a gain of two pounds on the morning after that! Only by taking a "running average" of 7 days or so will you begin to get a true picture of whether you are making any progress, and so it is with climate records.

Computer Climate Simulations, Non-Linearity, and "Computabilty"

In Lesson 1, it was stressed that nothing happens "by chance": our physical universe, of which the oceans and atmosphere are certainly a part, are governed by the same immutable physical laws as the rest of the universe. These include the basic laws of thermodynamics and the laws of fluid mechanics (which govern the flow of the atmosphere and ocean). The mathematical expressions of these basic laws are well known, so given our very powerful computers, why can't we predict the weather as well as the changes in climate with the same marvelous precision with which we can send space craft to land on Mars?

A rather over-simplified answer to this question has three parts to it:

1) While it is true that the basic laws of physics are understood, when it gets down to the nitty-gritty details, some processes can become so complex, even down to the microscopic level, that some of these processes important to the climate system are not fully understood. My guess is that if a poll were to be taken among climate scientists for the number one process on this list, it would be the details of the complex role clouds play in climate science, and, in particular, what role the tiny airborne particles ("aerosols") play in forming the nucleus for water droplets that form clouds. Another would be the exact mechanisms that influence how rapidly large glaciers disintegrate under warming conditions. So, there are still gaps in the details of processes that climate scientists are working extremely hard to close, aided by satellites currently in orbit and planned for future launch. And of course there is always the possibility

that some feedback mechanisms are lurking in the background that have not been anticipated.

2) Although the most advanced supercomputers now have truly astonishing power both in storage capacity and speed, they are taxed to their limit, taking tens or hundreds of hours to generate climate simulations, while accounting for all known physical processes on the surface of the land, the ocean and the atmosphere.

To carry out these simulations, climate computer scientists divide up the atmosphere, ocean and land into 'cells' of tens or hundreds of miles in size to see how they interact under these basic physical laws (and biological laws too, since changes in the vegetation on the Earth's surface need to be incorporated in the climate simulations). The smaller these 'cells' are, the more confidence in the overall results. Not just the overall results, but also the more reliable the regional climate simulations -- say California's coastal and mountain areas -- become.

But, one pays a very high price in computational time required for simulating a given amount of 'real' time as these cells are made smaller and smaller and consequently grow in number. Continued advances in computing power are expected (a hot topic in computer science these days is the possibility of eventually building 'quantum computers') and we can expect corresponding advances in both global and regional climate simulations as computer power continues to increase.

3) Nevertheless, even with completely understood physical laws and extremely powerful computers, there are some types of both physical and biological systems that simply cannot be computed accurately in advance. (For example, how populations of various species grow or shrink.) Such systems are often said to exhibit 'chaotic behavior', although to mathematicians there are more formal requirements for a system (or a mathematical equation) to exhibit 'chaotic behavior'.

For our purposes if a system—like the interactions between ocean and atmosphere -- are ***sufficiently non-linear*** and exhibit ***high sensitivity to initial conditions*** it may be impossible to calculate its future accurately very far in advance. Non-linearity simply means that a graph showing how a system evolves in time (say the speed of a particle plotted against time) may start off initially looking like a straight-line plot, but may depart very strongly and fairly suddenly from being a simple straight line.

As an example, consider trying to calculate on a computer the speed and location of a large number of very tiny beads carried along by a stream of water flowing down a gently sloping trough that suddenly becomes very steep (or maybe has a waterfall in it). At first things go well -- measurements of the speed of the water as well as the initial location of each bead in the flow at the head of the trough are fed into the computer, which calculates the subsequent position of each bead quite accurately as time goes by. But, when the trough gets very steep, and especially when the waterfall is encountered, the smooth regular flow of water begins to churn, froth and gurgle -- it becomes ***turbulent*** -- and the beads get tossed about seemingly (but not really) at random.

No matter how carefully one tries to measure the initial flow of water and bead positions, even an extremely tiny error in the measurement of the starting point for a bead, or simply the fact that there are 'round off errors' in any computer, means that it will be impossible to predict the location of any bead after the waterfall. Or, to put it another way, two tiny beads which were extremely close to each other initially will not remain at all close to each other after the flow becomes turbulent, due to the extreme ***sensitivity to initial conditions*** and the highly ***non-linear*** nature of turbulence.

Here is another analogy to illustrate a system that is very sensitive to initial conditions and is highly non-linear: A pitcher throws a fastball to a batter. The batter swings but the center of the bat is about a ½" below the center of the ball. The result is a "pop-up" that travels a meager 90 feet and is easily caught by the first baseman. But on his next time at bat, he hits the fastball with the center of the bat just 1/8th inch below the center of the ball. This time the ball soars out of the ballpark for a 400 foot home run. If we were to make a plot of the distance the ball travels versus the mis-alignment of the center of the ball and bat it would hardly be a straight line, going from zero travel (swing-and-a-miss), a ground ball, a 250 feet line drive, a home run, a pop-up and a swing-and-a-miss again, as we varied the misalignment between ball and bat center over just a couple of inches. So the ultimate distance the ball travels is very sensitivity to the "initial condition" (where ball and bat make contact) and has a highly non-linear dependence on this initial condition.

Many features of the Earth's climate system exhibit this type of behavior and climate scientists lump this type of behavior under the term 'natural variability'. (To be more precise, this should be termed 'internal natural variability' to distinguish it from the external natural variability associated with natural 'forcing functions', like the Sun's brightness, which also vary, as discussed in Lesson 2).

Does this mean, therefore, that projections of Earth's future climate are doomed to failure and are useless? No, not at all. In the example of the trough of water with the beads, each calculation of the trajectory of a bead will exhibit the seemingly random tossing to and fro of the bead after the flow becomes turbulent, and two calculations starting with only tiny differences in the initial position of the bead will have these to-and-fro tossings uncorrelated with each other. However -- and this is the crucial point as applied to climate models -- if the ***average*** is taken over a large number of calculations and compared with the ***average*** observed speed of the collection of beads as they move down the trough, the agreement is very good. In fact one can go beyond this and estimate the probability that the bead will end up after a certain interval of time within some distance of its average position at that time.

So it is with climate simulations. Each individual simulation starting with only slightly different initial conditions (including the details of the temperature and speed of wind and ocean currents everywhere on the Earth on, say, January 1st, 1970) and using a very sophisticated "general circulation model" incorporating the oceans and atmosphere and the interactions between them, is found to produce ENSO and other oscillations of the type described above. But each individual simulation will likely reproduce them at differing times and differing strengths. When averaged together, these oscillations get "washed out" -- what is left is not ***weather***, but ***long term trends*** in ***climate***.

While by no means perfect, and being continually improved, the most advanced computer simulations have correctly predicted long-term climate trends. In addition, by performing 'experiments' in the climate models, which we obviously cannot do with the real Earth, they serve as invaluable learning tools about what makes the Earth's climate system tick. There is, however, a quite different approach to understanding aspects of the climate system which does not rely on computer simulations. We will discuss this approach in Lesson 7 "Looking Forward by Looking Backwards".

For information on some of the longer term oscillations referred to above see:

Pacific Decadal Oscillation
http://jisao.washington.edu/pdo/

Atlantic Multidecadal Oscillation
http://www.aoml.noaa.gov/phod/amo_faq.php