The math of chaos: Why weather and climate are unpredictable.

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By David Wojick |February 10th, 2023

That the weather is often unpredictable is well known. What may surprise you is that it will always be that way, especially long-range weather, like a season or year ahead. And since climate is just average weather, it too will always be unpredictable. More on that later.

Before we look at why long-range weather is perfectly unpredictable, let's acknowledge that there are a lot of people selling long range weather and climate forecasts. They often disagree with one another, which is a strong hint that it can't be done. Given a lot of different predictions, someone is likely to be right but that is like winning the lottery, pure luck. But there is no money in unpredictability, so the paid-for forecasts keep coming. Do not rely on them, because relying on a bad forecast is often worse than relying on none.

Now to the perfect unpredictability. It is a matter of math. Not that we are going to do any math, but I am going to describe what is says and why, in very nontechnical ways. In fact the math has a nontechnical name, which is "chaos". Its technical name is "nonlinear dynamics" but we will not go into that.

Lots of things in the world fit the math of chaos and they are said to be chaotic. A rushing mountain stream is a good example. Throw something small into such a stream and it may go far before it stops, or hardly move at all, or something in between. Where it ends up is unpredictable. And so it is with weather. We live at the bottom of an ocean of air and that air is typically moving. Warm air is trying to rise, and cool, often creating clouds and rain or snow when it does. The cool air then tries to fall, often creating clear skies.

Here on the surface we experience sunny highs (high pressure) and stormy lows (low pressure). Highs are air falling while lows are air rising. In between we get wind as air also is forced to flow horizontally from low to high pressure. The result is a great deal of motion, made much more complex because it all happens on a spinning globe warmed by a single sun.

Predicting the weather means correctly saying what all this complexity will look like for some period of time, some time from now. Will next winter be cold or mild and how snowy? Will next summer be hot or not, wet or dry? How about next year, or just next month? The complexity makes forecasting difficult, but not impossible. After all we have giant computers to model the weather and satellites taking data, around the clock and around the world.

What makes prediction impossible is the math. Not that the math is difficult or complex, so it is not the doing of the math that makes long term prediction impossible. Rather it is what the math tells us. Let me explain. To begin with, imagine we are going to do a computer weather forecast. We first enter a lot of data describing what and where the weather is now. This is mostly stuff like temperatures, pressures, wind and precipitation. These are are called the "initial conditions".

The computer then operates on these initial conditions to produce a forecast for the next day. Then it repeats the process, taking that day as the initial conditions to produce a forecast for the next day. This step-by-step process is repeated, going as far into the future as needed for the desired forecast. In some cases the step interval is longer than a day, especially if we are doing a long range climate forecast, which can go out hundreds of years. For simplicity let's talk about six-month forecasts. Suppose we do multiple runs, say with different initial conditions or on different computers, so getting different forecasts. This often happens, especially if the initial conditions are very different.

Now at last, we get to chaos. The math says that under certain circumstances something very strange happens. It is called "extreme sensitivity to initial conditions". What this means is that the slightest change to the initial conditions dramatically changes the forecast. This strangeness applies to weather forecasts. It might change a winter forecast from cold to mild, or vice versa. Same for wet versus dry, windy versus not so much, and so on for all the forecast features. Moreover, these great differences show up quickly, in many cases in just a week or two, changing the entire forecast.

What makes it really bad is that these differences in initial conditions, that create very different forecasts, are so small they are undetectable. In the math they are called "infinitesimal" meaning infinitely small. In fact they are so small that we cannot tell what the real initial conditions actually are. That is, suppose we use a temperature somewhere of 53.6 degrees, but the actual value is 53.6000002. This tiny difference in initial conditions is enough to quickly throw our forecast way off. In fact an error if a millionth of a degree is enough to give us a very false forecast.

In short the only way to get an accurate forecast is to know things we cannot possibly know because they are too small to measure. Thus, chaos makes even roughly accurate forecasting impossible. The technical term for this is "intrinsically unpredictable". Beyond a week or two, weather is simply intrinsically unpredictable. Note that weather is still theoretically predictable, but you would have to know the exact initial conditions, and this is impossible as a practical, real life matter.

Moreover, given that climate is defined as average weather, it too is intrinsically unpredictable. All the dire climate predictions we hear about are done by computers that either ignore chaos or keep it unrealistically small. We should not believe these forecasts. The future could be fine.

In summary, intrinsic unpredictability due to chaos makes accurate long-range weather and climate forecasting impossible. Do not act on these forecasts.