Forecasting with Spaghetti

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You're driving around the beltway (you're brave), and you want to speed up a bit by pressing the car's accelerator. As the car's speed increases, you then hold the accelerator pedal steady to maintain a constant speed. When you exit the beltway, you move your foot from the accelerator to the brake pedal and push down and the car slows. The harder you push, the quicker the car slows. Your car, its acceleration, speed and braking constitute a linear system. A small initial force on the accelerator or brake pedal produces a predictable corresponding (linear) change in the car's speed.

Now imagine you are driving (not on the beltway for this example), and you press the accelerator, and the car's speed begins to increase. You ease up the accelerator pressure, but the car speeds faster. Then suddenly it slows down, and then a few seconds later it speeds up again. Even though your foot is off the accelerator, the car continues to do all sorts of speed changes on its own, accelerating, slowing down but gradually increasing in speed. Your small initial press on the accelerator has produced all sorts of weird changes in the car's speed. This is a nonlinear system (which fortunately for our cars exists only in this imaginary example). You have no idea what this car will do next. It's become unpredictable. It's chaotic.

You've probably heard of "The Butterfly Effect," the famous term coined, a bit tongue in cheek, by Dr. Edward Lorenz, a famous meteorologist, to describe the nonlinear, chaotic behavior of our weather. The weather is indeed an incredibly complex system with many different physical processes (such as winds, evaporation, friction, and radiation) influencing the future state of the atmosphere . . . the future weather. Small differences on very small scales, or initial conditions (such as the "breeze" from the flap of a butterfly's wings), can eventually grow (remember our "nonlinear car" example above) to make a large difference in the future or predicted state of the atmosphere. The realization of the nonlinear behavior of the atmosphere led Lorenz to conclude that detailed (such as our day-to-day forecasts) long-range weather forecasts were impossible beyond certain limits.

We now can measure the atmosphere in a detail not possible 40 years ago when Lorenz described the chaotic nature of the weather. But even making initial measurements of the atmosphere down to scales of a few miles will extend our ability to make detailed, deterministic weather forecasts only out a number of days, rather than weeks or months. But what if small changes in our initial weather or initial measurements all still produced similar, if not exactly the same, weather forecast results? Then we would have more confidence in those forecasts and could say that for some weather and weather patterns little changes or errors in our measurement of wind, temperature, and humidity might not matter that much. The atmosphere and our weather are less chaotic on some scales than on others.

The core of today's weather forecasts is numerical weather prediction. The physical laws, the basic science of weather, are known. We solve a number of fundamental equations of physics that govern the weather in order to predict the future of the weather. Detailed measurements from satellites, the ground, radar, aircraft, ocean buoys, and ships provide the initial data. Then supercomputers use the data to solve the equations and give us meteorologists numerical outputs which we use, together with our own knowledge, experience, and observations to produce the forecasts you hear, read or see.

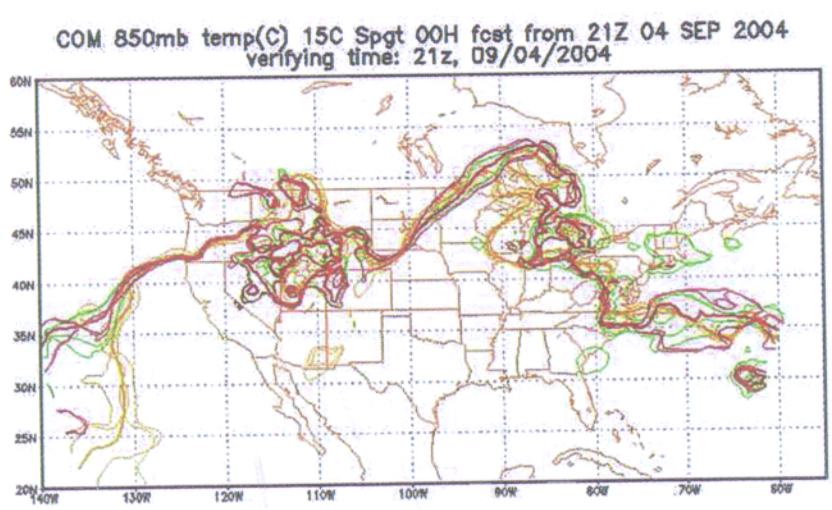

Fig. 1 Initial Time

If we purposely make small changes to the initial data that we use to generate our numerical (computer model) forecasts, or make very small changes in the equations we use, and observe the range of results, we can get a sense of how chaotic the system is and also know how confident we can be about the forecast. Look at the three temperature diagrams. Do the lines look like spaghetti? We meteorologists do call them spaghetti diagrams. Now you see where my weird title came from. These diagrams show the location of a temperature of about 60° about one mile high in the atmosphere. The initial location (Figure 1) of 60° is varied, because different computer models are used to begin the creation of a variety of computer solutions for this weather variable.

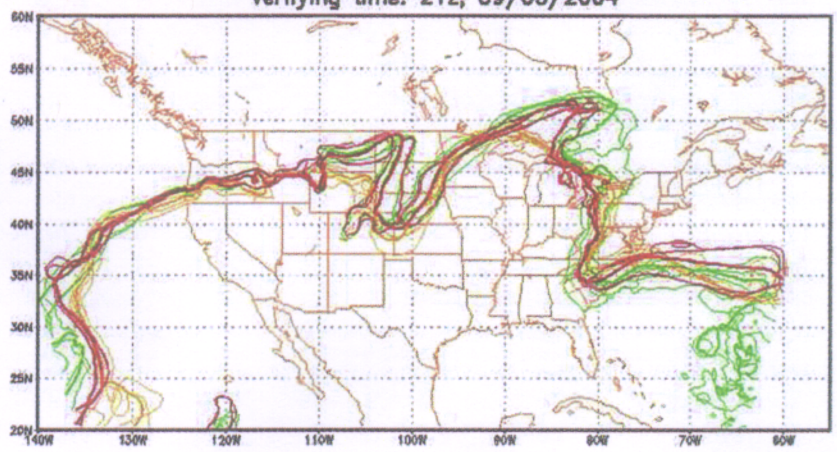

Fig. 2 1-Day Forecast

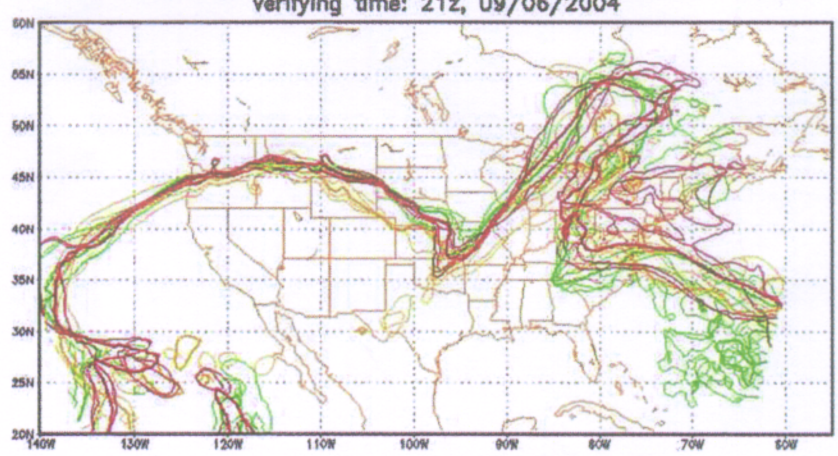

Fig. 3 2-Day Forecast

If you look closely, you can count 15 different 60° temperature lines or 15 separate pieces of spaghetti. There are 15 members of this "ensemble." Look how the range of solutions changes with time, out to two days. Would you have more confidence in the location of this 60° temperature at two days (Figure 3) near Portland, Oregon, or near Portland, Maine? Why the great differences? The Pacific Ocean's water temperature doesn't change dramatically from day to day; the air temperatures above the ocean are also rather stable compared to the great day-to-day, and day-to-night variation over the land. And because our weather and air generally move from west to east, those big predicted differences show up much more above Portland, Maine, than above Portland, Oregon.

These ensemble models are becoming a more powerful tool for forecasters. In addition to providing us information about the "spread" or uncertainty of weather variables, the mean or average of the ensemble gives us useful information to compare with single deterministic models. Ensembles are now used in hurricane track forecasts, winter precipitation-type forecasts, as well as day-to-day and long-range forecasts. In the future, ensemble forecasts will help us better forecast very short-term weather such as summer thunderstorm squall lines and even help us give probability estimates of different events caused by global changes. The statistical and probabilistic information we can derive from ensemble models is also helpful to anyone who has to make weather-related decisions, from power company managers to drivers, who hope their vehicles continue to operate in a linear manner.

Spaghetti: fun to eat, and great fun to have as a weather forecasting tool.