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 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 acceleraator 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, or NWP. 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, 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.

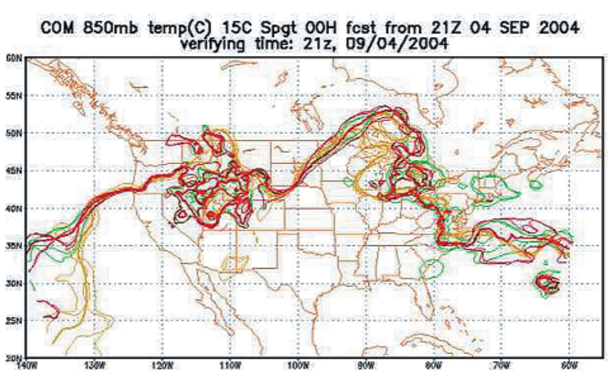

Fig. 1 Initial Time

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