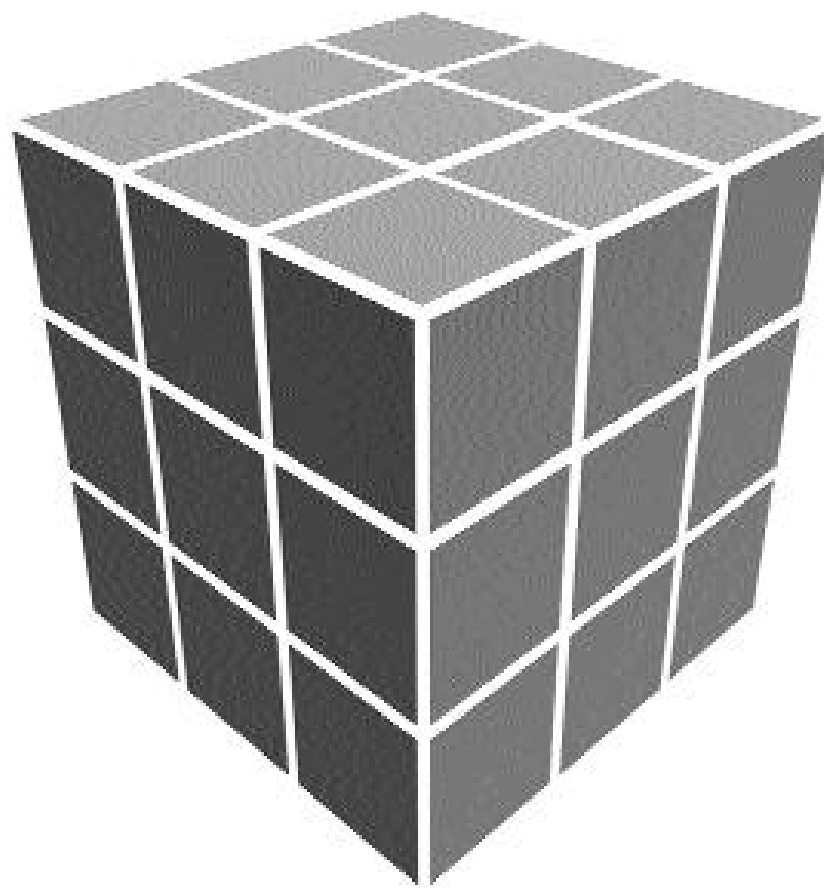
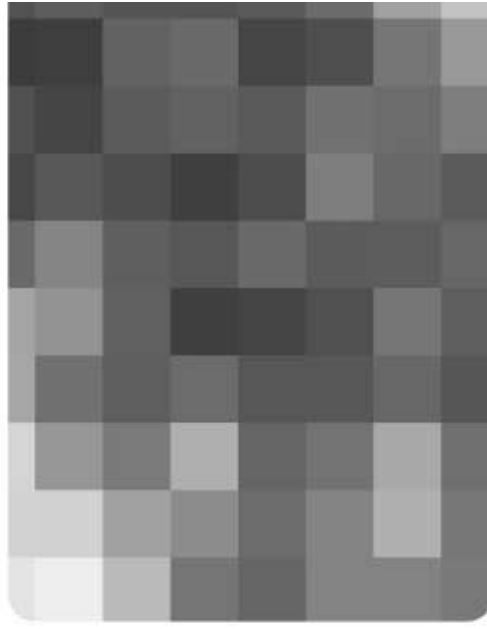


# UCLA GRADUATE SCIENCE JOURNAL





# LITTLE Things

By Johnny  
LIN

**H**anging on the wall at the Art Institute in Chicago, Georges Seurat's impressionist painting "A Sunday on La Grande Jatte—1884" gives us a snapshot of a lazy Sabbath day in Europe near the end of the 19th century. Ladies wearing bustles and carrying parasols gaze out towards the water. Dogs scamper around the feet of their mistresses, or snuffle in the grass in front of them. Shadows lengthen as the afternoon sun moves on. As we walk closer to the painting, however, we discover that the crisp features we saw from far away have become increasingly blurry. In fact, the closer we approach the painting, the more clearly we see that Seurat did not outline his figures with brush strokes at all, but rather composed his entire painting out of thousands upon thousands of dots. Individually, each dot is just a dab of paint on the canvas, but added together, the dots create the shapes of the painting's figures, the brilliance of its colors, and the feeling of a Sunday afternoon along the shore.

Picturing the Climate System

Like Seurat's pointillist painting, the motion of the atmosphere consists of structures at a variety of different sizes. At the small end, tiny turbulent eddies, on the order of fractions of millimeters, dissipate energy in the form of heat. At the large end, gyres, on a global scale, churn the atmosphere. Examples of these large gyres, termed the general circulation, include the Arctic and Antarctic circumpolar jets, horizontal winds away from the earth's surface which blow counter-clockwise in the north (and clockwise in the south) around the poles, and the Hadley circulation, where air warmed by the sun in the tropics rises and is transported away from the equator into the subtropics, where it cools and falls. In between these two extremes of size we find all other types of atmospheric motion, ranging from the fluttering of a flag on a windy day, to the devastation of a hurricane as it makes landfall.

When climate researchers simulate the earth's climate, they need to account for this variety of scales of motion in the earth's atmosphere, but mathematical constraints hamper their ability to solve the basic equations governing the motion of the atmosphere. Although these equations have been known for over a century, pure mathematical solutions of the equations, solutions that do not require the use of a computer, remain limited to a few very special cases. Almost all real-world cases require the use of a computer, but even with such equipment, solutions of the basic equations are limited.

For instance, the current spatial resolution of some of the most advanced and comprehensive global climate models is approximately 1 degree latitude by 1 degree longitude.

In time, the resolution is perhaps a few minutes to a half an hour, which means that the computer is solving the governing equations for the atmosphere at locations (called model grid points) separated by about 100 km, every few minutes. What about phenomena smaller than 100 km in size, such as thunderstorms or phenomena evolving and changing faster than a few minutes, such as turbulent eddies? As far as the climate model is concerned, they don't exist.

#### Painting Dots With a Computer

In an effort to model such small-scale phenomena in a computer, researchers use a computational version of "pulling yourself up by your bootstraps" called parameterization. In parameterization, the behavior of the unresolved feature (the thunderstorm) is described as a function of the resolved features (the temperature and humidity at the model grid points). For instance, if the computer calculates humidity at a model grid point as 100%, a thunderstorm parameterization might then say there is a thunderstorm cloud present there that might rain.

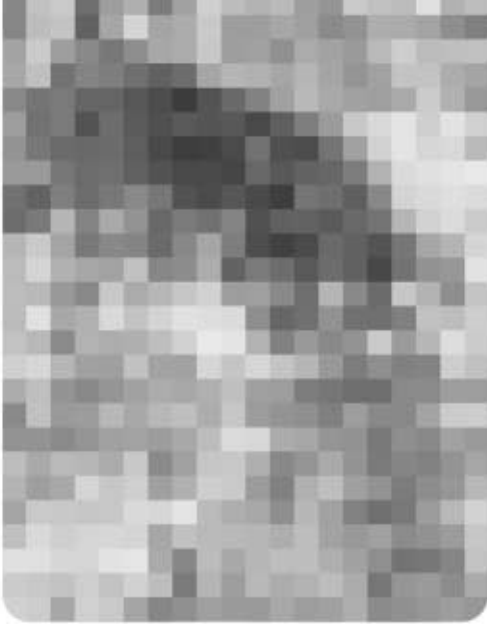
Of course, how a real thunderstorm looks and acts depends on much more than just the humidity at a single point. Parameterization, however, paints the thunderstorm as a discrete and distinct "dot." Nonetheless, even if parameterization poorly simulates all the variability in an individual thunderstorm, it does reasonably well in simulating the average behavior of thunderstorms. That models using such parameterizations are able to reproduce the most prominent features of the global climate has given researchers hope that small-scale features are really important in only an aggregate or bulk sense.

But does the earth's climate really only care about the bulk or average effects of small-scale motions? What if the aspects of small-scale motions that parameterizations do not currently account for do, in fact, affect large-scale motions? What if it makes a difference whether the dot painted by parameterization is fuzzy or not?

#### Fuzzy Dots

When it comes to simulating weather (the short-term state of the atmosphere), fuzziness does matter. Researchers know that the atmosphere is a chaotic system characterized by the "Butterfly Effect," where even small deviations from its average state can amplify into larger and larger disturbances as time progresses. This effect is partially responsible for the difficulties forecasters have in predicting weather beyond a few days. Traditionally, however, researchers have considered climate, which can be thought of as an "average" of weather, somewhat resilient to the "Butterfly Effect." Without such resilience, prediction of climate variability (such as the El Niño phenomena) would be impossible. The precise extent of such resilience is, as yet, unknown.

Led by Professor David Neelin, researchers in the Climate Systems Interactions group in the UCLA Department of Atmospheric Sciences hope to shed some light on this question by looking at the





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Like Seurat's pointillist painting,

effects of adding randomness to a parameterization of storm activity. In doing so, they hope to mimic some of the variation we normally associate with storms: their quickly varying, sporadic “on—off” and “rain here—no rain there” nature. Instead of a distinct, discrete dot, these researchers hope to represent storm activity more like a fuzzy dot.

What does this fuzzy dot look like? Statistics provides a useful tool for describing the fuzziness, in the form of probability distributions. The probability distribution describes how likely a particular trait of rainfall will occur. For instance, the probability distribution of rainfall intensity tells us how often an area can expect storms of a given strength; however, the distribution cannot say when a storm of a given strength will occur, only its likelihood. For weather forecasters, this information has limited usefulness, since people want to know if it will rain tomorrow, not that it might or might not. For the purpose of simulating climate, however, this amount of information is enough. Climate modelers only need to know the combined effect of fuzziness; a precise description of the fuzziness may not be necessary.

#### *Equations of Motion:*

These refer to a set of equations that describe the movement of a fluid in response to the different forces that act on it (e.g. gravity, friction). Applied to the atmosphere, these equations simplify to the following set of partial differential equations:

Although these are partial differential equations, in reality they are only slightly more complicated versions of Newton's Second law, which tells us that force is proportional to acceleration.

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla \phi + \text{other forces}$$

$$\frac{\partial \phi}{\partial z} = g \frac{\theta}{\theta_0}$$

$$\nabla \cdot \mathbf{u} = 0$$

$$\frac{\partial \theta}{\partial t} + \mathbf{u} \cdot \nabla \theta = \frac{Q}{c_p}$$

where  $u$  is the horizontal velocity,  $\phi$  is the pressure,  $\theta$  is a measure of the energy of a parcel of air (called the potential temperature), and  $Q$  is a heating term. The vertical direction is  $z$ ,  $t$  is time,  $g$  is the gravitational constant,  $\theta_0$  is a normalization constant, and  $c_p$  is the specific heat capacity of air (at constant pressure).

Although these equations look forbidding, at their heart they are just elaborations of an old idea, that force is proportional to acceleration ( $F=ma$ ). Newton described this in *Principia*, published in 1686.



the motion of the atmosphere consists of structures at a variety of different sizes.

After adding in this randomness by specifying a probability distribution, the UCLA researchers run the climate model and examine the output to see whether atmospheric climate variability at longer timescales (on the order of a month or two) are affected by the presence of the “rain noise.” If these experiments do indicate sensitivity to this noise, it would imply that the current parameterization methods used by climate modelers may be inadequate, and would suggest that small scales affect large scales not only through their mean effects, but also their intermittency. If so, the palette used by climate modelers to simulate the atmosphere would need to be expanded to include fuzzy dots, not just distinct dots, giving new meaning to the saying “it’s the little things that matter.”

## B I O

Johnny Lin is a sixth-year Ph.D. student in the Department of Atmospheric Sciences at UCLA. He graduated from Stanford University with a B.S. in Mechanical Engineering in 1990, and an M.S. in Civil Engineering–Water Resources in 1992. For the next two years, he worked as a civil engineer, specializing in the modeling of rivers and estuaries for flood insurance studies and wetland restoration projects. His current research involves studying how tropical precipitation affects climate change.

He prefers to ponder the “little things” in life while eating a double scoop of his favorite ice creams, daiquiri ice and French vanilla. For more information about his research, please visit <http://www.atmos.ucla.edu/~csi>

To learn more about Johnny Lin and his research, please visit <http://www.atmos.ucla.edu/~jlin>

