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Trails of the Wandering Albatross

Applying the mathematics of haphazard motion

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The wandering albatross flies extraordinary distances. Riding the wind on long, thin, rigidly outstretched wings, it skims the waves as it glides for hours over the ocean surface.

Truly a world traveler, this seabird (*Diomedea exulans*) regularly circles the globe at southern latitudes, plunging into the sea to scoop up squid and fish along the way. It sometimes follows cruise ships and other vessels to pick up scraps thrown overboard. Its white plumage, white beak, black wing tips, and wingspan of 11 feet or more make it a dramatic sight in the sky.

Biologists at the British Antarctic Survey in Cambridge, England, are investigating the role of the albatross, other seabirds, and seals as the top predators in the marine food web of the southern ocean. Their long-term goal is to assess the impact of these animals on the ecosystem.

As one component of this effort, Peter A. Prince and his coworkers have equipped wandering albatrosses with electronic activity recorders or radio transmitters for satellite tracking. “We’re interested in the bird’s foraging behavior—what it does and how it does it,” Prince says.

The data show, for example, that a wandering albatross can travel nearly 4,000 kilometers in just 8 days on a single foray to gather food for its chick. “It’s probably got the largest foraging range of any [bird] species in the world,” Prince remarks.

To cope with the large quantities of data generated by such studies, the researchers have enlisted the help of physicists to identify patterns in the paths these birds follow in their search for food. Preliminary results show that the trails of wandering albatrosses—as they fly, settle on the sea, then fly off again—fit a special type of random motion, in which the birds make long journeys interspersed with short foraging flights clustered in a small area.

Physicists call this type of random motion a Lévy flight. The mathematics underlying Lévy flights can model the distribution of matter in the universe, the diffusion of particles in turbulent liquids, and the recovery of glassy materials from stress (SN: 3/11/89, p. 157). Now, researchers are starting to apply this mathematics to biological systems, from the foraging of birds to heartbeat rhythms (SN: 9/5/92, p. 156).

“There’s a growing interest in this area,” says physicist Bruce J. West, who heads the Center for Nonlinear Science at the University of North Texas in Denton.

Random movements play a significant role in a wide variety of natural phenomena. A tiny pollen grain suspended in water, for example, appears under a microscope to be in a state of continuous, erratic activity. Known as Brownian motion, this constant jiggling arises from collisions between randomly moving water molecules and the suspended particle, which gets pushed in different directions by the combined effect of these small impacts.

One way to model Brownian motion mathematically is as a random walk. Suppose a walker is confined to a long, narrow path and moves forward or backward according to the results of repeatedly tossing a coin. The walker takes a step in one direction if the outcome is heads and in the opposite direction if the outcome is tails.

The resulting trail wanders back and forth along the track, and the probability that the wanderer will be a certain distance away from the starting point after taking a given number of steps is defined by a bell-shaped curve known as a Gaussian distribution. For infinitely many coin tosses, a random walk confined to a line corresponds to one-dimensional Brownian motion.

It's straightforward to extend this random-walk model to two dimensions by taking steps to the east, west, north, or south, randomly choosing each direction with equal probability, or to three dimensions by also including steps up and down. Researchers have used such random walks to model a wide range of phenomena, from the diffusion of perfume molecules through still air to the twists and turns of polymer strands.

It's also possible, however, to have random walks in which the sizes of the steps are not fixed but vary in particular ways. In the early part of this century, French mathematician Paul Lévy explored these possibilities and discovered a class of random walks in which the steps vary in size, from infinitesimally small to infinitely large, so no average or characteristic length can be calculated. These are different from Brownian motion in that a Lévy walker takes steps of different lengths, with longer steps occurring proportionally less often than shorter steps. A jump 10 times longer than another, for example, would happen only one-tenth of the time.

In two dimensions, these Lévy flights correspond roughly to a sequence of long jumps separated by what look like periods of shorter ventures in different directions, which the scientists call stopovers. Each stopover, however, is itself made up of extended flights separated by clusters of short flights, and so on. Magnifying any of the clusters or subclusters reveals a pattern that closely resembles the original large-scale pattern, which means that Lévy flights have a fractal geometry—the parts on all scales closely resemble the whole.

In two dimensions, the most striking visual difference between Brownian random walks and Lévy flights is the area they cover in a given time. Lévy flights sample a much larger territory than the corresponding Brownian random walks. "You can cover huge distances in a very short time with a Lévy flight," says physics graduate student Gandhimohan M. Viswanathan of Boston University.

Mathematician Benoit B. Mandelbrot of Yale University originally learned about these different random walks from Lévy himself, and he later extended and applied Lévy's ideas in his formulation of fractal geometry.

Mandelbrot found that he could use Lévy flights to create convincing portraits of the distribution of matter in the universe. He simply erased the long jumps and made each stopover represent a star, galaxy, or some other blob of matter. The resulting pattern of clustered spots, each of which in turn is made up of subclusters, resembles the sheets, bubbles, and other aggregations of galaxies evident in astronomical observations.

Mandelbrot's model doesn't necessarily account for the way galaxies actually formed in the universe, but it does suggest a fractal structure.

Lévy flights and the statistics associated with them also provide useful models of turbulent diffusion. If you add a drop of cream to your coffee without unduly disturbing the liquid, the random motion of the molecules slowly spreads the cream into the coffee. Stirring, however, adds turbulence, and the liquids mix much more rapidly.

Mathematically, it's possible to think of turbulence as the combined effect of a large number of vortices—whirlpools of all sizes and strengths. Any particles (or molecules of the constituents of cream) caught in such whirlpools would be rapidly separated and dispersed. A plot of changes in the distance between two initially adjacent particles would look much more like a Lévy flight than a Brownian random walk.

In general, Lévy flights arise out of chaotic systems, in which a sensitive dependence on initial conditions plays a crucial role. A new statistics based on Lévy flights must be used to characterize these unpredictable phenomena. Such models may be useful for describing, for example, the transport of pollutants and mixing of gases in Earth's atmosphere.

"In these complex systems, Lévy flights seem to be as prevalent as diffusion is in simpler systems," notes physicist Michael F. Shlesinger of the Office of Naval Research in Arlington, Va., who pioneered the application of Lévy statistics to turbulent diffusion and other physical phenomena.

Whether in the atmosphere or the ocean, fractal patterns associated with turbulence may have a strong influence on ecosystems, affecting the foraging patterns of birds. Both weather systems and the distribution of plankton, krill, and other organisms in the ocean may guide flight patterns.

"In the southern ocean, krill in particular are patchily distributed," says Eugene J. Murphy of the British Antarctic Survey. "If the underlying physical environment and the distribution of prey appear related, it raises all sorts of questions about how these distributions are generated and maintained."

To see how the wandering albatross fits into its ecosystem, Prince and his colleagues have been studying the bird's foraging strategy by tracking albatrosses nesting on Bird Island in the South Georgia group of islands in the South Atlantic. In one experiment, the researchers attached electronic activity recorders to the legs of five adult birds, which made 19 foraging trips. The devices recorded the number of 15-second intervals in each hour for which the animal was wet for 9 seconds or more. The wet periods indicated interruptions in a bird's flight path when it alighted on the water to eat or rest.

In analyzing the data, Viswanathan, S.V. Buldyrev, and H. Eugene Stanley, also at Boston, assumed that the distance the bird flew was roughly proportional to the time spent in the air and that the flight direction changed randomly after each stopover.

Their analysis showed that the data appear to fit the pattern of a Lévy flight. The Boston group and their collaborators at the British Antarctic Survey describe their results in the May 30 Nature.

"The results are very interesting, but it's too early to tell yet how useful this approach will be," Prince says.

Ecologists speculate that the flight patterns of the wandering albatross have evolved to exploit the patchy distribution of fish and squid, which may reflect the distribution of plankton in the restless ocean.

"The most interesting thing is that these distributions exist for these organisms, and now we've got to try to understand how they come about," Murphy says.

Researchers at the British Antarctic Survey have recently combined satellite tracking data with wandering albatross activity data to provide a more complete picture of the bird's foraging behavior. They are also collecting similar information on other albatross species, which have different foraging strategies. These data have yet to be analyzed for Lévy flight patterns.

Such patterns may also arise in other biological systems. Some scientists are now looking at potential applications of Lévy random walks and Lévy statistics to the foraging behavior of ants and bees. Others are studying possible uses of these models in physiology and medicine, including the characterization of heartbeat rhythms and the branched structure of the lung's airways.

"When you look at biological systems, there seems to be an evolutionary advantage to having Lévy statistics," West says.

Because the environment appears to be fractal, an organism that behaves fractally can better take advantage of these patchy opportunities, West argues.

For the wandering albatross, it means wide-ranging, stop-and-go searches for food that may be unpredictably scattered across the ocean. □