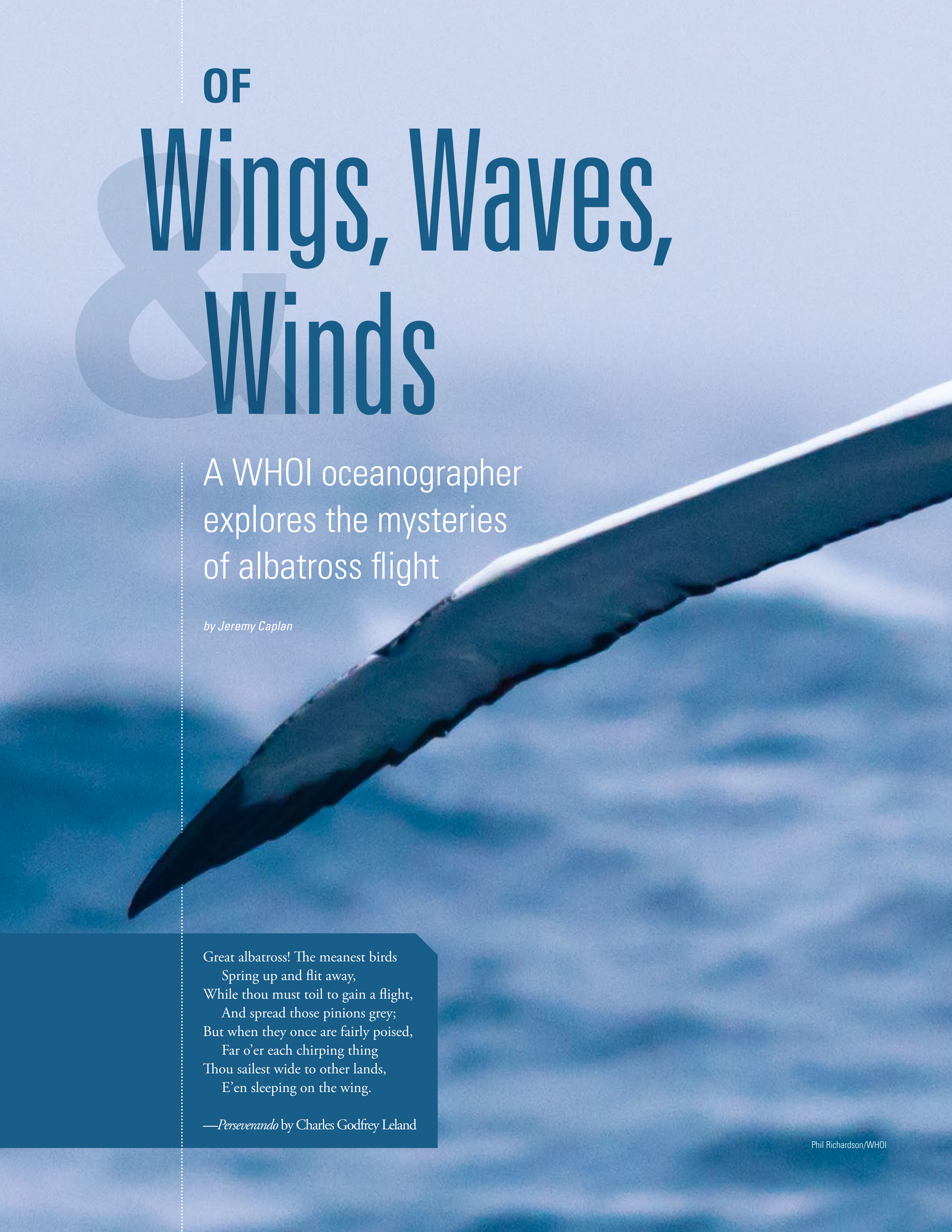
OF Wings, Waves, & Winds

A WHOI oceanographer explores the mysteries of albatross flight

by Jeremy Caplan

Great albatross! The meanest birds
    Spring up and flit away,
While thou must toil to gain a flight,
    And spread those pinions grey;
But when they once are fairly poised,
    Far o'er each chirping thing
Thou sailest wide to other lands,
    E'en sleeping on the wing.

—*Perseverando* by Charles Godfrey Leland



Phil Richardson/WHOI

For Phil Richardson, it began with a simple question. How do albatross soar so effortlessly, flying around the world without flapping their wings?

On an expedition in 1997 to the South Atlantic Ocean off Cape Town, South Africa, he added himself to the list of sailors, scientists, and poets who for centuries have been captivated by this wide-winged symbol of power and elegance overhead. Long before Samuel Taylor Coleridge immortalized the bird in *The Rime of the Ancient Mariner,* sailors looked on them with awe. "Certain great fowles as big as swannes, soared about us," wrote the great English sailor Richard Hawkins in 1593.

More than 400 years later, Richardson, a physical oceanographer at Woods Hole Oceanographic Institution (WHOI), found himself similarly fascinated by the bird's dramatic, swooping flight pattern, its grace and efficiency.

"It was surprising and delightful to see them almost magically soar upwind in wind speeds of 10 to 20 knots," Richardson said.

A lover of sailing, plane piloting, and the natural patterns of the ocean, Richardson was intrigued by the aerodynamics of the bird and its soaring capacity. His scientific instincts kicked in.

He wondered how albatross could soar in any direction they chose. What particularly amazed him was how the albatross seemed to fly *into* the wind, without losing speed or steadiness in their flight, and with no wing flapping and scant apparent effort.

Other work got in the way, but a decade after he first observed the albatross, Richardson found time to pursue his wonder. He pored over historical studies of albatross aerodynamics, adding his own experiences and insights, and he slowly constructed a new picture to explain the mechanics of albatross flight.

Nearly 14 years after his 1997 cruise, Richardson published his findings in 2011 in the journal *Progress in Oceanography*. To achieve his new understanding, Richardson capitalized on interests and experiences over a life's journey.

A boy's life

Heidi Richardson

WHOI oceanographer Phil Richardson

Richardson grew up loving the wind and the water. Raised on a cattle ranch north of San Francisco, he was particularly fond of science class, even though he missed school from time to time for cattle roundups.

His father, Arthur Richardson, who died when Richardson was four, was an architect. So was his grandfather. His great-grandfather, Henry Hobson Richardson designed Trinity Church in Boston. The youngest Richardson tried architecture, too, he said, "but it didn't take."

Richardson's stepfather, George Wheelwright III, was a physicist-turned-rancher who co-founded Polaroid Corporation with Edwin Land, the pioneering camera inventor. Wheelwright moved out West after working as a flight navigator during World War II.

As a boy, Richardson picked up a love of flying. He enjoyed model planes, and when he grew older, he earned a pilot's license. He enjoyed gliders, too, even hang-gliding. A lifelong love for sailing began on the old sailboat that his family used when they summered in Maine.

After high school, Richardson left the cattle ranch behind and headed off to study civil engineering at the University of California, Berkeley. After college, in the Vietnam War era, Richardson opted for alternative service, becoming an officer with the U.S. Coast and Geodetic Survey, a federal agency that surveyed and charted waterways and coastal regions.

Soon after, Richardson had a conversation with his cousin Columbus Iselin, a former director of WHOI, who encouraged him to earn a Ph.D. in physical oceanography at the University of Rhode Island. Upon graduation, Richardson came to work at WHOI in 1974.

Not much was known about the ocean's currents at that time. Research methods had yet to advance significantly from 19th-century approaches. A few nascent current meters existed, but oceanographers more often than not measured ship drifts or sent off messages in bottles.

"They would record where the bottles were picked up and how long they took to get there," Richardson said. "They'd put out hundreds of those things. But you only knew where a bottle started and stopped. We wanted to know *how* it got there. What was its real path?"

Pioneering studies

To find out more about the movement of the ocean's currents, Richardson and others began taking advantage of new technologies. Their "bottles" evolved into sophisticated floats equipped with scientific instruments, which drifted along with currents to reveal something about the ocean's fluid pathways through the ocean.

"It was a time of interesting theories," Richardson said. "It was not easy to make measurements, so almost any measurement you made told you something new about the ocean. It was very exciting. As my father was an architect, I guess I studied the architecture of the ocean."

Over his long oceanographic career, Richardson used floats, satellites, and hydrography—measurements of water characteristics such as temperature and salinity—to examine many of the major currents in the Atlantic Ocean. Each is something like a major highway in a global oceanic "interstate" system. He investigated the North Brazil Current transporting water northwestard over the equator; the Caribbean Current; the Gulf Stream; and the Agulhas Current carrying water from the Indian Ocean to the southern tip of Africa.

The Agulhas Current doesn't import water directly into the Atlantic, but as the Agulhas veers back eastward off South Africa, huge, swirling rings of water called eddies pinch off and spiral westward into the South Atlantic. Eddies spinning off from major currents became another major focus of Richardson's research, and he explored their formation, pathways, and impacts.

"Phil contributed to a better understanding of ocean currents and eddies," said WHOI physical oceanographer Amy Bower, a colleague and friend of Richardson's. "His figures are often used in textbooks, because of their clarity and his ability to portray complex ocean current circulation patterns in a relatively simple way."

Richardson's knowledge of ocean currents and his natural curiosity occasionally prompted forays into peripheral scientific territory. In the months leading up to the quincentennial of Columbus' 1492 voyage, for example, Richardson was intrigued by questions about which still-unverified island Columbus first landed on in the New World. He collaborated with WHOI researcher Roger Goldsmith, applying scientific information on the effects of currents, winds, and variations in Earth's magnetic field to records in Columbus' logbook of his compass readings and distances traveled. They concluded that Columbus landed on San Salvador in the Bahamas.

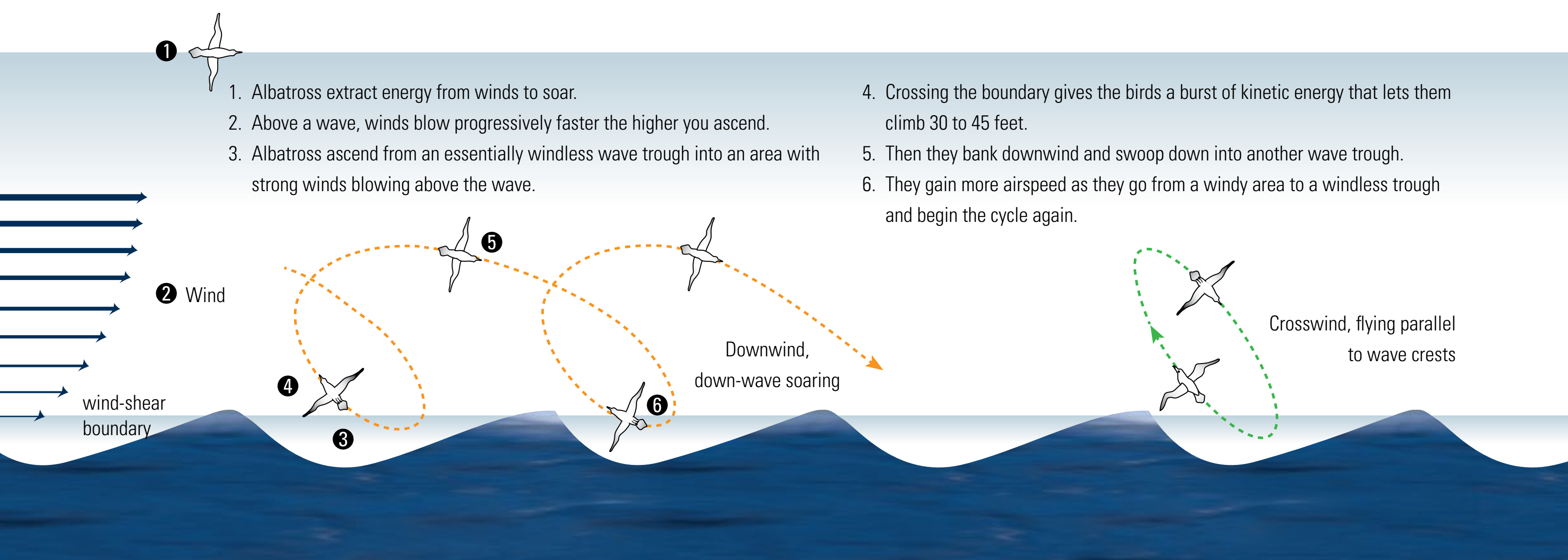
In 2000, Richardson became a scientist emeritus and had more time to pursue curiosities such as albatross flight. In doing so, he applied his understanding of ocean currents and physics, and he also drew on his love of sailing and flying.

Dynamic soaring

Albatross spend the majority of their long lives above the ocean. By the age of 50, an albatross has typically flown at least 1.5 million miles. Adults routinely fly hundreds of miles to gather food before returning home to feed their youngsters. Placing its beak next to its offspring's, the adult albatross injects liquid food, converted from its prey of fish, squid, or krill, directly into the baby's beak. In recent times, many albatross are being attracted to bait on long fishing lines and killed, Richardson said.

The young birds face a perilous path to adulthood. About 40 percent don't make it, because they themselves become prey or because they don't learn to fly well enough.

"Gravity and drag relentlessly force a gliding albatross down through the air," Richardson wrote in his paper. "To continuously soar, an albatross must extract sufficient energy from the atmosphere." But how?



1. Albatross extract energy from winds to soar.
2. Above a wave, winds blow progressively faster the higher you ascend.
3. Albatross ascend from an essentially windless wave trough into an area with strong winds blowing above the wave.
4. Crossing the boundary gives the birds a burst of kinetic energy that lets them climb 30 to 45 feet.
5. Then they bank downwind and swoop down into another wave trough.
6. They gain more airspeed as they go from a windy area to a windless trough and begin the cycle again.

Richardson knew waves had to play a vital role. Strong prevailing winds blow steady parades of waves across great stretches of the ocean, especially in the vast Southern Ocean. That makes the ocean surface and winds above it "lumpy and bumpy and gusty," he said. "An albatross can take advantage of that."

Early on, like many other students of albatross flight, Richardson assumed that the birds use updrafts of air that flow up the backs of waves—similar to updrafts that form over ridges on land. Certainly albatross exploit wave updrafts. And certainly they also gain energy from tailwinds blowing horizontally. But these couldn't account for the "accelerated twisting, turning, swooping flight of albatross" that Richardson had observed. Nor could it answer a question that kept nagging him: "How can they be flying *into* the wind and, at the same time, keep up alongside our ship?"

Richardson was inspired by a theory described by the Nobel Prize-winning physicist Lord Rayleigh in a paper written in 1883. Rayleigh knew that horizontal winds don't blow uniformly; often they can blow faster the higher you ascend. He proposed a two-layer scheme with an imaginary boundary, above which winds blew faster. This boundary is often referred to as a "wind shear." A bird flying up across a wind shear would abruptly gain airspeed and could use this pulse of kinetic energy to climb upward. Then the bird could turn and swoop downward. Descending through the boundary, it would gain airspeed by flying against weaker winds.

Richardson saw something similar going on in the ocean. Building on a hypothesis by British scientist Colin Pennycuick, he outlined the following scenario. In the trough of waves, there is little wind, because the waves block it. But above the waves and their troughs, winds blow briskly across the ocean in thin layers, stacked somewhat like cards in a deck: Lower layers are slowed by air-sea friction near the ocean surface, but wind speeds increase as you rise higher above the surface.

An albatross ascending from a wave trough at an angle would encounter progressively faster winds. This would increase the bird's speed through the air—a burst of kinetic energy that it uses to climb to heights of 30 to 45 feet. Then the albatross makes a tight turn downwind and swoops down into another wave trough, adding airspeed as it descends through the wind shear into progressively slower winds. Each addition of airspeed balances the loss of energy caused by drag on the bird. With another turn in the trough, the albatross ascends to begin the cycle again. Each swoop cycle takes about 10 seconds. (See diagram below.)

This phenomenon is called dynamic soaring. The pilot in Richardson knew that in the late 1990s, radio-controlled glider pilots began using the same tactic—looping in strong winds blowing over ridges, rather than waves—to achieve surprisingly fast speeds. A new world's record of 498 miles per hour was set in 2012 with an albatross-size glider.

Into the wind

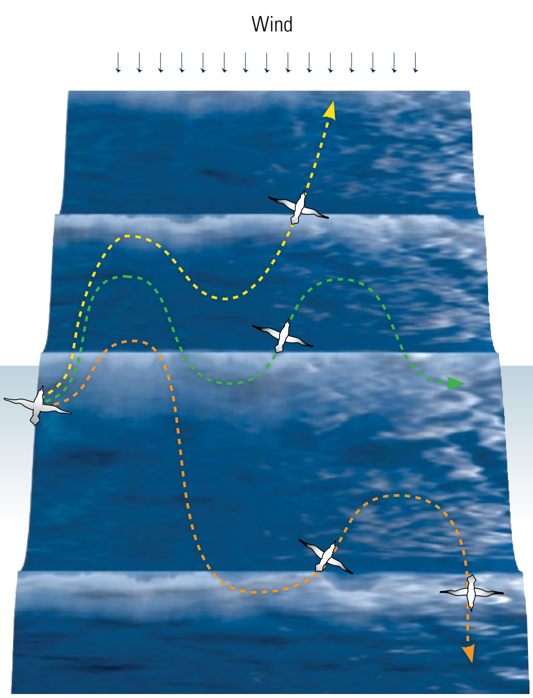
As he did with his diagrams portraying complex ocean currents, Richardson devised a relatively simple model that captures the essential physics of dynamic soaring of albatross, incorporating both winds and waves. Evaluating the two theories of albatross flight, he concluded that using wind shear, rather than updrafts from waves, accounted for 80 to 90 percent of the energy needed for albatross to fly.

But how did they fly upwind? Then Richardson thought about his experience sailing. That was his eureka moment.

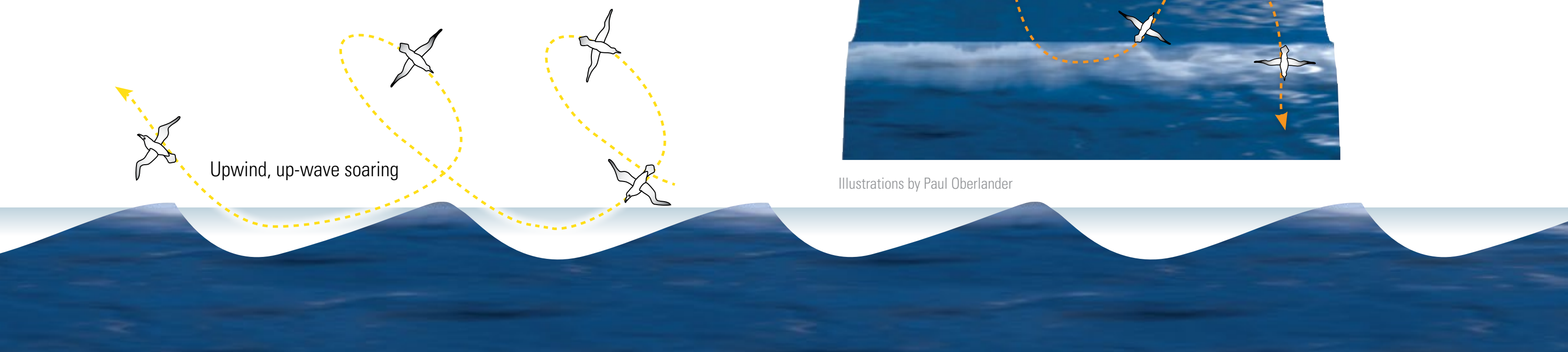
"To travel upwind, a sailor tacks into the wind, alternating sailing in a direction around 45 degrees to the right and then to the left of the wind direction," he said. "That's what albatross are doing—they're tacking!"

To paint a more precise picture of albatross flight, Richardson said he would love to see sophisticated microsensors developed that could be attached to albatross. Such sensors could measure the nuances of the birds' flights and their navigation through wind and wave patterns.

Richardson isn't alone in his interest in the mechanics of soaring and gliding. "Flight dynamics at small scales has suddenly become a hot topic," he said. "Bird, bat, and insect flight has become very interesting to the military." The new autonomous "drone" flying vehicles developed for military and other usage, especially the smaller ones, may benefit from the study of bird flight dynamics, he said. And that set Richardson off on yet another line of scientific inquiry (see next page.) ▲



After the birds gain height, they can proceed in any of three directions. Like a sailboat, they can tack to the right or left of the wind and head generally into the wind (yellow). They can swoop into the same wave trough, flying parallel to the waves and perpendicular to the wind (green). They can turn downwind, getting a boost from the tailwind (orange).



Illustrations by Paul Oberlander