ECOLOGY

How frigate birds soar around the doldrums

Frigate birds forage over vast distances by getting boosts from thermals and trade winds

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In 1492, Columbus encountered frigate birds while en route to the New World and noted that the bird "does not alight on the sea nor depart from land 20 leagues" (*1*). Columbus observed correctly that frigate birds do not land on the sea, but he severely underestimated how far some frigate birds fly from land. On page 74 of this issue, Weimerskirch *et al.* (*2*) show that great frigate birds (*Fregata minor*) reduce transit costs by riding strong thermal updrafts beneath or inside cumulus clouds and then gliding long distances to another thermal, searching for food along the way. By exploiting cumulus clouds and trade winds in the Indian Ocean, the birds forage around the doldrums, a largely windless zone.

Satellite technology is revolutionizing migration studies on land and sea by tracking individuals in real time for long periods (*3*, *4*). To monitor the position and altitude of frigate birds, Weimerskirch *et al.* outfitted birds with solar-powered transmitters or data-loggers to measure heart rate, wing beat frequency, acceleration, altitude, and GPS coordinates. They used weather records to determine local wind speed and direction, and a bird's behavior and heart rate to infer whether the bird was actively flapping or soaring under or within cumulus updrafts.

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After breeding on an islet in the Mozambique Channel, adult frigate birds fly north to the Seychelles and forage from there for months. Some adults tracked in the study launched multiday treks, circumnavigating the doldrums (see the figure). One flew continuously for 48 days, averaging 420 km per day. Recently fledged juveniles departed separately from the breeding site and flew even farther and longer than their parents. One juvenile stayed aloft for 2.1 months; others stopped briefly on small islands but still flew almost continuously. One juvenile covered more than 55,000 km (greater than Earth's circumference) in 185 days, resting on islands for less than 4 days during this time.

How can frigate birds manage these long-distance feats? Soaring and gliding are energetically efficient modes of transport, especially for frigate birds, which have very long wings and the lowest wing loading of any bird. But before they can glide, they need a lift from thermals of warm air rising under and within cumulus clouds. Thermals inside a cloud are especially powerful and lift a frigate bird at rates of 4 to 5 m/s. Once aloft, the birds can glide for up to 60 km, giving them time to spot another cumulus cloud. Weimerskirch *et al.* show that frigate birds do little work during lifts and glides, with heart rates and wing beat frequencies generally low during these times. The birds repeat these soar-glides multiple times per day, rising more than 15 km on average; they mainly use flapping flight when pursuing prey near the sea surface.

Only a few other bird species stay aloft for such extended periods; one alpine swift flew continuously for 200 days (*5*). Whether and how frigate birds, swifts, and other long-distance migrants sleep on the wing is still unresolved (*2*). Miniature loggers that monitor sleep-wave patterns (*6*) should answer whether birds sleep "with open eye," as Chaucer stated in *The Canterbury Tales*.

Frigate birds and human gliders have much in common. Both use cumulus clouds as conspicuous signals of thermals. Nonetheless, human gliders tend to avoid soaring in clouds (*7*), whereas frigate birds use these clouds to gain altitude and thus to glide extra distance (*2*).

Human gliders and frigate birds also share a risk of a premature "land-out." Forced landing on a field is usually just an inconvenience for humans. But an ocean landing would be catastrophic to frigate birds, because their feathers are not oiled and would wet quickly. Frigate birds do not take rest stops on the water, as Columbus noted (*1*), and they can switch to costly flapping flight when their glide paths run short of the next thermal (*8*). Even so, the local unpredictability of thermals places frigate birds at some risk on their transoceanic migrations.

The flight paths of frigate birds often skirt the nearly windless doldrums; ancient mariners famously avoided these zones unless forced (*9*). However, the trade winds and thermals that surround the doldrums are regionally reliable, providing frigate birds with crucial lifts and assists (*2*). Still, the

Frigate birds on the wing. Great frigate birds (*Fregata minor*) are gliders par excellence, staying aloft for months at a time. Weimerskirch *et al*. show that the birds travel economically by repeatedly hitching lifts on rising thermals and then gliding for tens of kilometers.

obvious question is why frigate birds even bother to circumnavigate this region.

Many other birds migrate seasonally as they shuttle between breeding and overwintering grounds. But for frigate birds, the migratory journey is a "movable feast" as they travel continuously in search of food (*10*). The Indian Ocean is productive, but unlike other equatorial oceans, its seasonally reversing wind patterns increase phytoplankton productivity toward the west and away from the equator. Fish and squid can be locally abundant (*10*), especially in the western regions (*11*). But if frigate birds cannot land on the ocean, how do they catch marine food? They sometimes steal food from other birds, but they catch most of their food by skimming fish and squid from the sea surface, or even snagging flying fish chased into the air by tuna or other predators (*10*).

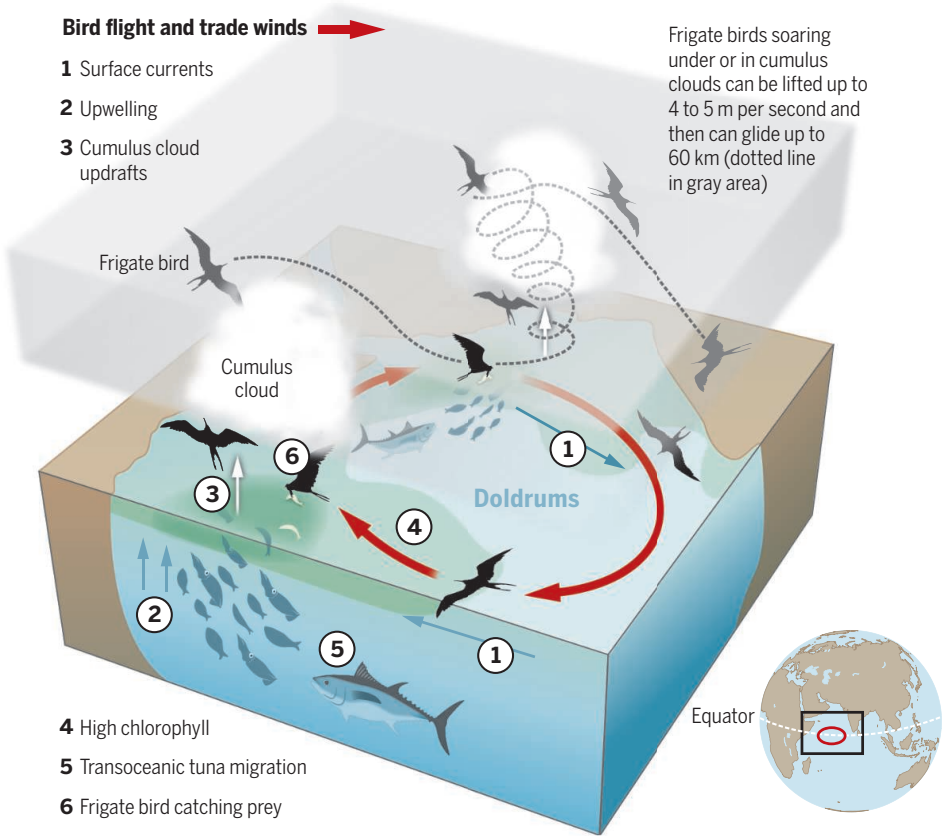
Columbus reported seeing frigate birds, boobies, and tropic birds on days when the sea was "thick with tuna" (*1*). This spatial congruence of marine birds with tuna is likely not a coincidence. Tuna and dolphinfish can chase small fish to the surface, where frigate birds can catch them (*10*). Surface-foraging schools of tuna—or associated flocks of foraging seabirds—will be conspicuous to high-flying frigate birds, which can shift their flight directions accordingly. In fact, human fishermen use seabird flocks to locate tuna.

The doldrums, and the atmospheric and oceanic circulations that surround them, thus play multiple roles in the lives of frigate birds and other marine birds. As Weimerskirch *et al*. document, trade winds and their cumulus clouds allow frigate birds to soar and glide in search of food that is spatially and temporarily patchy (*10*). Moreover, these trade winds create seasonal patterns of upwelling and a large gyre of surface currents that sustain a rich marine ecosystem and coincide with transoceanic tuna migrations (*11*). Thus, atmospheric circulation provides both transportation and food for frigate birds. Curiously, frigate birds seem to avoid some productive areas near the doldrums (Arabian Sea, Bay of Bengal, southern Indian Ocean). Perhaps high storm frequencies or wind intensities in these areas (*12*) are too much of a good thing, or return winds are not available when needed.

Studies of bird migration over land are now elucidating how orographic and meteorological patterns influence bird flight trajectories (*13*). Similar studies of bird migration over oceans may require simultaneous information on spatial and temporal patterns of wind and clouds, currents and upwelling, primary productivity (*14*, *15*), forage fish accessibility, and even the abundance and depth of marine predators such as tuna (*11*) that can chase forage fish to the surface. Simultaneous studies both above and below the sea surface will be logistically challenging but should clarify why frigate birds and other marine birds go where they go, why they do not go elsewhere, and where they will be forced to go in the future.

It will also be interesting to compare detailed flight behavior of frigate birds and other marine birds (*8*) against an emerging stochastic theory of optimal glider flying (*7*). That theory will need expansion to account for small-scale ocean fronts and eddies that aggregate food resources but are spatially and temporally unpredictable on a local scale.

As Weimerskirch *et al*. caution, climate change may soon disrupt meteorological conditions that currently enable frigate birds to exploit these regions. Climate change is also rapidly warming surface temperatures in the Indian Ocean, phytoplankton populations are declining, and continued warming may convert this still-productive region into an "ecological desert" (*15*). For either or both reasons, great frigate birds and other marine birds may no longer soar and glide over these vast regions. ■



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Circumnavigating the doldrums. Weimerskirch *et al.* used satellite technology to track the flight paths of frigate birds around the Indian Ocean. Trade winds run clockwise around the doldrums, driving surface currents, upwelling, cumulus clouds, and high primary productivity (chlorophyll), especially in the west. Tuna chase fish and squid to the surface and make them accessible to frigate birds in these regions. Trade winds and their cumulus clouds thus give frigate birds low-cost access to rich foraging zones that can be distant from land.

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ACKNOWLEDGMENTS

Supported by NSF grant IOS 1038016 (R.B.H.), NSF grants OCE 1419323 and 1458967 (C.D.), and Gordon and Betty Moore Foundation grant GBMF 3775. We thank H. Weimerskirch for comments and W. Moody for the Chaucer quote.

10.1126/science.aag1865