Animal Planet

An ambitious new system will track scores of species from space — shedding light, scientists hope, on the lingering mysteries of animal movement.

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‘‘I’m going to do a set of coos,’’ Calandra Stanley whispered into the radio. The Georgetown ornithologist and her team had been hunting cuckoos, in an oak-and-hickory forest on the edge of a Southern Illinois cornfield, for weeks. Droplets of yesterday’s rain slid off the leaves above to those below in a steady drip. In the distance, bullfrogs croaked from a shallow lake, where locals go ice fishing in winter.

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As dawn broke and the rising sun lit the top of the canopy, the cuckoo finally arrived to investigate. Within moments the bird was ensnared, squawking and thrashing and flapping his wings in a knot of black netting. Stanley slowly unfurled the net, cupping him in her hands. He had a slim handsome head, bright eyes and long brown-and-white tail feathers soiled with a smear of feces. Stanley unceremoniously dumped him into a drawstring cloth bag and hooked it to a nearby tree. Inside the bag, he went silent, while the crew set up a tarp on a grassy opening nearby and spread out their gear.

With her instruments arrayed around her, Stanley gingerly drew the bird out of the bag, gripping him by his fuzzy white neck and scrawny legs. She blew all over his body, ruffling his down to look for the fat stores he might have built up for his coming journey. She clipped the claws at the end of his zygodactyl feet, two toes facing forward and two facing backward, and plucked one of his feathers, dropping it into a small manila envelope. She spread one of his wings so that she could get a blood sample. She measured him with calipers from various angles. He submitted, his eyes wide and glassy, except for when she took the width of his beak, which provoked a single, outraged yelp.

Then Stanley deposited a few drops of superglue to attach the object at the heart of her ministrations: a tiny solar-powered tracking device. She carried the cuckoo into a clearing a few feet away and asked me to open my palms, placing him inside them. Freed, he didn't hesitate for even a split second. As soon as she released her grip, he flew off into the trees, his feet ever so lightly grazing my open palm.

Last fall, teams of scientists began fanning out across the globe to stalk and capture thousands of other creatures — rhinos in South Africa, blackbirds in France, fruit bats in Zambia — in order to outfit them with an array of tracking devices that can run on solar energy and that weigh less than five grams. The data they collect will stream into an ambitious new project, two decades in the making and costing tens of millions of dollars, called the International Cooperation for Animal Research Using Space, or ICARUS, project. Each tag will collect data on its wearer's position, physiology and microclimate, sending it to a receiver on the International Space Station, which will beam it back down to computers on the ground. This will allow scientists to track the collective movements of wild creatures roaming the planet in ways technically unimaginable until recently: continuously, over the course of their lifetimes and nearly anywhere on Earth they may go.

By doing so, ICARUS could fundamentally reshape the way we understand the role of mobility on our changing planet. The scale and meaning of animal movements has been underestimated for decades. Although we share the landscape with wild species, their movements are mostly obscure to us, glimpsed episodically if at all. They leave behind only faint physical traces — a few paw prints in the hardening mud of a jungle path, a quickly fading arc of displaced air in the sky, a dissipating ripple under the water's surface. But unlike, say, the sequence of the human genome, or the nature of black holes, our lack of knowledge about where our fellow creatures go has not historically been regarded as a particularly pressing gap in scientific understanding. The assumption that animal movements are circumscribed and rare tended to limit scientific interest in the question. The 18th-century Swedish naturalist Carl Linnaeus, imagining nature as an expression of God's perfection, presumed each species belonged in its own singular locale, a notion embedded in his taxonomic system, which forms the foundation of a wide array of biological sciences to this day. Two centuries later, the zoologist Charles Elton, hailed as the "father of animal ecology," fixed species into place with his theory that each species nestles into its own peculiar "niche," like a pearl in a shell. Such concepts, like modern notions of “home ranges” and “territories,” presumed an underlying stationariness in undisturbed ecosystems.

But over the last few decades, new evidence has emerged suggesting that animals move farther, more readily and in more complex ways than previously imagined. And those movements, ecologists suspect, could be crucial to unraveling a wide range of ecological processes, including the spread of disease and species’ adaptations to habitat loss. ICARUS will allow scientists to observe animal movements in near totality for the first time. It will help create what its founder, Martin Wikelski, a biologist at the University of Konstanz and managing director of the Max Planck Institute of Animal Behavior in Germany, calls the “internet of animals.”

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If successful, ICARUS will help us understand where animals go: the locations where they perish, the precise pathways of their migrations, their mysterious radiations into novel habitats — phenomena scientists have puzzled over for generations. “These are questions we’ve been trying to answer for 30 years,” says the butterfly biologist Camille Parmesan, research director of the French National Center for Scientific Research. “It’s fabulous.” Peter Marra, an ecologist and the director of the Georgetown Environment Initiative at Georgetown University, agrees. ICARUS, he says, will be an “incredibly powerful tool to start asking these fundamental questions” in ecology, and to address “enormously vexing problems in conservation biology.” The evolutionary ecologist Susanne Akesson, chairwoman of the Center for Animal Movement Research at Lund University in Sweden, notes that ICARUS “gives many possibilities for new research which has not been possible.” The conservation ecologist Francesca Cagnacci, who coordinates a research consortium dedicated to studying the movement of terrestrial mammals, likens ICARUS to a sports car compared with a normal car. It will, she says, “take us to another level.”

The ICARUS project challenges traditional paradigms whose tentacles run deep into science, politics and culture. It isn’t just that scientists were long unable to observe complex and long-distance wildlife movements, the way they had been unable to observe, say, the passage of DNA from parent to child. The scientific establishment presumed that what they couldn’t see didn’t exist. The absence of evidence of wild mobility, in other words, was taken as evidence of absence.

This wasn't a marginal notion with glancing significance. It was central to the way scientists, for decades, understood ecological processes, from climate change to how ecosystems established themselves and how diseases unfolded. When scientists predicted the impact of climate change, for example, many pictured immobile wild species marooned in newly inhospitable habitats, condemning them to extinction. When they considered the dispersal of seeds, which dictates the diversity and abundance of the plants that serve as the scaffolding of ecosystems, they dismissed the possibility that certain animals on the move played a role. Wild creatures like orchid bees, for example, could not possibly pollinate plants across long distances, scientists presumed, because they could not tolerate the heat stress of flying under direct sunlight; fruit-eating guácharos, or oilbirds, couldn't disperse seeds in the Venezuelan rainforest, because scientists thought the birds perched in their caves all day. The 19th-century naturalist Alexander von Humboldt dismissed the birds as parasites.

When scientists considered movements across barriers and borders, they characterized them as disruptive and outside the norm, even in the absence of direct evidence of either the movements themselves or the negative consequences they purportedly triggered. Popular hypotheses held that bats spread Ebola virus, for example, and gazelles foot-and-mouth disease. No one really knew where the bats or the gazelles went, though: The parallels between the intermittent and disruptive quality of epidemics and the presumed nature of wildlife movements spoke for themselves. Influential subdisciplines of biological inquiry focused on the negative impact of long-distance translocations of wild species, presuming that the most significant of these occurred not through the agency of animals on the move but when human trade and travel inadvertently deposited creatures into novel places. The result, experts in invasion biology and restoration biology said, could be so catastrophic for already-resident species that the interlopers should be repelled or, if already present, eradicated, even before they could cause any detectable damage.

Discoveries enabled by ICARUS, while impossible to predict, could have diffuse and wide-ranging implications. Findings that shed light on the factors that drive animal movement, for example, could help transform ecology from a field that traditionally describes the natural world and its inhabitants to one that can make predictions. Every year, billions of dollars depend on the ways in which wild species move and are distributed across the landscape, migrations that affect the abundance of fish we pull from the sea, the virulence of the pathogens we encounter, the predators that stalk our livestock and the birds and flowers that grace our landscapes. But nobody knows precisely when the bats will arrive in any given forest, or why some butterflies shift into new ranges while others do not, or whether elephants that run shrieking in the forests have sensed an impending natural disaster, or why some martins return to their summer nests and others do not.

ICARUS could unlock that knowledge. It could enable scientists to unravel wild animals' social dynamics as they move around the globe in flocks, swarms and colonies; to study what influence animals' conflicts and alliances with other species have on where they go and how they get there; and to chart the depth of their perceptions and the dynamism of their responses to the environmental phenomena they encounter on their journeys. Scientists may be able to detect shared strategies across populations, species and taxa by observing the way various species navigate obstacles like roads and highways and the way they capitalize on environmental factors like currents in the sea and thermals in the air. Overlaying tracking data with data on weather, climate and vegetation could reveal how the fragmentation of habitats affects animals' movement, which corridors they use to move, where they pause on their journeys, when they use environmental or atmospheric factors to facilitate their movement and how they might fare if those factors were to collapse or to change — drawing us closer to a future in which the movement of animals could be forecast, like the weather. The potential applications could include preventing outbreaks of disease that can precipitate pandemics, managing landscapes and conserving biodiversity.

Almost certainly, prospectively tracking wild animals will reveal more extensive movements than previously known. A handful of tracking studies in recent years have established that wild animals wander across expansive ranges, oblivious to the boundaries of parks and conservation areas drawn to contain them. These studies uncovered several "megadispersals": a wolf that made it from Italy to France; a leopard that moved across three countries in southern Africa; mule deer that accomplished one of the longest land migrations of any species in North America. By tracking yellow-billed cuckoos, Stanley and Marra discovered that the birds move hundreds of kilometers, even on their breeding grounds, and are far less sedentary than previously thought. That finding torpedoes the traditional model of migration, in which the migratory journey is bracketed by stillness on both wintering and breeding grounds. ICARUS could mean a steady release of similarly confounding findings. It will "allow us to rewrite textbooks," Marra says.

Findings of novel long-distance peregrinations beyond the borders of recognized habitats unsettle deeply rooted ideas about our place in nature. They may suggest that wild animals have greater capacities for navigation and cognition than we've presumed, which could complicate the moral and political order we've justified on the basis of our supposedly unique cognitive abilities. They could suggest that we've misunderstood the role of geographic barriers in our migratory past and overestimated their role in the migrations to come. The planet may well be crisscrossed with "environmental highways" that usher wild migrants around the globe effortlessly, the way the trade winds ferried sailors across the Atlantic. Such a network has been proposed in modeling studies as an explanation for why migratory birds don't travel along the most direct paths but take looping, circuitous routes instead.

The delicate filigree of tracks that ICARUS exposes, in other words, could be "where the music is, where all the juice is," as Wikelski puts it. It's "the missing link that shapes everything."

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Martin Wikelski is a soft-spoken 55-year-old biologist with spiky dark hair and retro, black-framed glasses. We first spoke in 2017 and then reconnected over a series of video chats during the summer of 2020. A subtly mischievous expression animated his angular features as he told me, in the particular singsong lilt of some native German speakers' English, about his childhood dreams of knowing where animals go.

He remembers being about 10 and peering into the abandoned swallows' nests in the eaves of his grandfather's barn in Bavaria in winter, wondering why they had vanished. It was an absence that had mystified European thinkers for centuries. The 16th-century Swedish writer Olaus Magnus claimed that the swallows spent their winters submerged in lakes; the English minister Charles Morton suggested that they flew to the moon. When a teacher told Wikelski, in an offhand way, that the 20-gram birds flew thousands of miles away to Africa, it seemed to him an equally fantastic tale.

But the methods available to confirm the swallows' itinerary — or any other wild creatures' — were crude and few. To verify his teacher's pronouncement, Wikelski wrote a letter to relatives in South Africa asking them if they'd seen any swallows there. He watched a television program on bird banding and learned how to sneak into the swallows' nests to affix tiny metal bands to the young birds before they left, then traipsed around the half-dozen farmhouses in the village to see if any returned to their vacated nests.

Fifteen years later, Wikelski had acquired a Ph.D. in zoology, but wildlife tracking methods had only marginally improved. Commonly used "mark and recapture" techniques involved marking individual animals in some way and then seeing if they could be caught again, some distance away. Butterflies' wings might be inscribed with Magic Markers; birds' legs banded; or the landscape itself wired with motion-sensing cameras to surreptitiously snap photos of wild creatures as they skulked by. But such methods could only corroborate that animals moved wherever scientists thought to look for them. The marked birds and butterflies who evaded recapture and the animals who strayed beyond the range of motion-sensing cameras escaped scrutiny. Some scientists circumvented the confirmation bias of mark-and-recapture strategies by outfitting animals with signal-emitting devices and then capturing the signals on hand-held or fixed receivers. But skeptics scoffed at wildlife telemetry as a sterile substitute for the traditional fieldwork of surreptitiously observing animals in the wild. At the time, wildlife tracking was generally considered on "the margins of ecological research," as Wikelski and colleagues would later write in a 2015 paper in Science. Attaching a tracking device to a wild animal generally required trapping it first, which was hard enough. On top of that, the devices themselves could be expensive, awkward and bulky, and capturing the signals often required scientists to embark on fruitless chases of their tagged subjects, receivers in tow.

Wikelski's first attempt to resolve the technical impasse unfolded in 2001 on Barro Colorado Island, a six-square-mile dripping jungle oasis in the middle of Gatun Lake in Panama, where he worked as a postdoctoral researcher for the Smithsonian Tropical Research Institute. The mammalogist Roland Kays, who would become a frequent collaborator, had been tracking nocturnal raccoonlike creatures called kinkajous nearby. To do it, he lured them into arboreal traps with bits of banana, then outfitted them with collars that emitted radio signals, which the thick vegetation readily absorbed. Then he spent his nights "trucking around the rainforest, chasing my kinkajous with my antenna," Kays recalls, "and thinking there must be some better way to do this."

The solution, Kays and Wikelski figured, was height. They devised a scheme to hoist receivers atop seven 130-foot towers dotted across the island. From their perch above the canopy, the receivers would be able to capture signals from tagged animals and automatically stream the data to a computer at the island's lab. They'd be able to track a range of species, simultaneously, across the entire island. They trapped and collared ocelots, sloths and capuchins. They affixed transmitters to the bodies of orchid bees, using drops of superglue mixed with eyelash glue. They suffered the scratches of an upset anteater, then took turns dousing each other's wounds with alcohol. According to the scientific literature at the time, the island's watery borders marooned its residents, making the island "its own little universe in a way," Wikelski says. With a more comprehensive view of the animals' movements, they'd be able to answer questions about basic ecological functions, like how the movement of orchid bees and the ocelots' predation of rodents influenced the dispersal of seeds from trees and rare tropical plants.

But addressing such grand questions required that the scientists' subjects remain attached to their tags and within range of the island's receivers. They didn't. Wikelski and Kays discovered the tag from one of their ocelots at the bottom of the lake, scratched and hair-covered, presumably after passing through the body of a crocodile. At one point, the two scientists squeezed into the back of a helicopter to chase radio signals shimmering off the iridescent body of a tagged bee after it buzzed through the humid air across Gatun Lake.

It started to dawn on Wikelski that "all our preconceptions about this little universe are wrong," he told me. "Little bees fly off and on, so do toucans — pretty much everything that people said could not move around between places did." One evening, he and Kays were relaxing over cold drinks while overlooking the Panama Canal. They were joined by a retired radio engineer named George Swenson, who was among the first radio astronomers to track the Sputnik satellite that the Soviet Union secretly launched in 1957, by picking up the radio signal the satellite emitted. He went on to design and help build elaborate systems for scanning the heavens in search of other meaningful signals, including the National Radio Astronomy Observatory's array of more than two dozen radio telescopes in New Mexico that detect black holes.

The engineer was not impressed with the ecologists' 130-foot-high towers, Wikelski recalls. "You ecologists," Swenson said, "you're stupid. You have this big topic you could address, but you're thinking too small." The ecologists were like the early astronomers, studying disconnected slivers of the sky with their single telescopes. That hadn't allowed astronomers to understand the universe, which only became possible after they built arrays of telescopes to surveil all of space at once. To answer the big questions in ecology, Swenson suggested, ecologists had to track all the swimming, flying and prowling creatures of the planet, everywhere, simultaneously. Hoisting receivers 130 feet in the air was not nearly high enough. The receiver had to be hundreds of miles away — in space.

Wikelski became "almost fanatical" about the idea, one of his colleagues at the Max Planck Society told a reporter for the scientific journal Nature in 2018. He spent months arranging a meeting at NASA to propose it. Their rejection did not deter him. He sought out new funding, new partners, new collaborators. According to the article, he became so preoccupied with getting the project off the ground that he nearly lost research funding for the Max Planck institute he directed. Wikelski's dogged pursuit of a lofty project like ICARUS most likely seemed as fanciful as trying to count all the leaves on a tree or the ripples in a lake.

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The view that tracking wild mobility had limited value corresponded with a vision of the planet as fundamentally resistant to movement, littered with impassable obstructions like oceans, deserts and mountains that constrained wild animals to their places. In mid-20th-century experiments that tried to characterize the physical challenge animals faced in migrating, for example, scientists trapped birds in wind tunnels — sealed tubes outfitted with fans that blew winds up to 20-m.p.h. steadily against them — and documented the birds' struggles to stay aloft. The wind tunnels simulated the conditions experts presumed flying creatures encountered in the wild: continuous, unrelenting resistance. Experiments like these concluded that long-distance migrations required herculean efforts, reinforcing presumptions about their peculiarity. According to the conventional wisdom, movement through even the most fluid mediums demanded propulsive force. As late as the 1940s, the roiling ocean was seen as a "place of eternal calm," as the biologist and writer Rachel Carson wrote, "its black recesses undisturbed by any movement of water more active than a slowly creeping current."

Skepticism about the prevalence of long-distance mass movements among wild species conformed, too, with the ways in which we negotiate settlement and migration in our own lives. Long-distance mass movements coordinated over short periods, in which hundreds of thousands of individuals left a certain place and then congregated again, weeks later, hundreds or thousands of miles away, required sophisticated coordination and navigation. Without the help of modern technology, Homo sapiens would not be able to achieve it as quickly as many wild species routinely do. Even with the help of advanced navigational technology and maps developed over generations, many of us get lost. That wild species — implicitly treated by many biologists and psychologists as "unthinking robots," as the zoologist Donald R. Griffin put it — might successfully accomplish superior feats of collective intelligence conflicted with the exceptionalism with which we made sense of ourselves in nature. As the ecologist Ran Nathan points out, "Many people consider animals very skillful, but not in cognition."

Over the decades that Wikelski struggled to launch ICARUS, technical advances in wildlife-tracking technology buoyed a newly emergent field of movement ecology, rattling norms about animal migration and helping to make the case for his project. The size and price of commercial GPS devices that could accurately pinpoint geographic locations plummeted, from the early one-and-a-half-pound devices sold for thousands of dollars to $50 tags the size of a coin, allowing the boutique manufacturing firms that produce wildlife-tracking tags to churn out smaller, more accurate and longer-lasting solar-powered tags. Wildlife telemetry entered what commentators called a "golden age," moving from the margins of ecological research toward the center. New, interdisciplinary research centers dedicated to the study of animal movement sprang up, including the CAnMove Center for Animal Movement Research at Lund University in Sweden, established in 2008, and the Minerva Center for Movement Ecology, which opened at the Hebrew University of Jerusalem in Israel in 2012, joining already-established research groups at the Smithsonian Migratory Bird Center and the Max Planck Institute for Ornithology, a part of which became the Max Planck Institute of Animal Behavior in 2019.

The new wildlife-tracking tags could not capture the totality of animal movements around the planet as Wikelski hoped ICARUS might: Most could affordably transmit data back to scientists only when their wearers stayed within range of cellphone towers, among other limitations. But they did allow scientists to expose how deeply the scale, complexity and meaning of animal movements had been misunderstood. In every wildlife-tracking project they took on, says Nathan, who directs the Minerva Center, the tags allowed scientists to make discoveries "quite in contrast to the simple explanations we had so far." Giraffes wandered beyond the borders of a national park in Ethiopia, the conservation scientist Julian Fennessy and his team found in GPS tracking studies. Jaguars in the Amazon padded across ranges 10 times larger than established by studies conducted with fixed camera traps, the wildlife ecologist Mathias Tobler discovered.

GPS studies challenged conventional understandings of wild animals' roles in seed dispersal and the spread of disease. In a 2009 GPS tracking study, Wikelski discovered that the oilbirds Alexander von Humboldt once condemned as parasites spent so much of their time dropping seeds onto the forest floor that they were "perhaps the most important long-distance seed-disperser in Neotropical forests." Gazelles in Mongolia, a GPS study revealed, could not be responsible for outbreaks of foot-and-mouth disease in livestock: The disease moved five times faster than the gazelles.

Wikelski soon discovered a "physiological ease" in the way animals moved that belied the belabored effort scientists traditionally pictured. In one tracking study, for example, he and his colleagues found that thrushes spent twice as much energy on stopovers as they did while they were in flight. The flying, in other words, was the easy part. In another, his team found "massive" differences in the heart rate of a thrush when migrating compared with when flying in a wind tunnel. The capacity for movement, he says, had been "totally underestimated."

Tracking studies began to endow animal movements with rich new meaning, revealing unexpected links between the movement of disconnected, far-flung species and obscure environmental phenomena. Scientists obtained tantalizing evidence of mysterious animal perceptions, including some that exceeded that of human technology. An unpublished tracking study led by Wikelski in 2011 uncovered correlations between the skittering of goat and sheep up and down the slopes of Mount Etna in Sicily and the intensity of volcanic eruptions, for example, and another tracking study published in 2020 found correlations between the kinetics of farm animals in the Italian village of Capriglia and their distance from the epicenter of earthquakes. In another unpublished tracking study, Wikelski found that the remote desert locations to which storks migrated from thousands of miles away were the same ones where desert locusts emerged, obscure sites that have largely eluded human detection since biblical times. In a study of caribou herds dispersed over thousands of kilometers, the earth scientist Natalie Boelman and her team discovered a correlation that "nobody knew about," Boelman says, between the timing of spring migrations and large-scale ocean-driven climate patterns.

The revolution in wildlife tracking offered a glimpse into the world that ICARUS seeks to reveal. It's one in which geographic borders are porous and migrants make their way across the globe almost effortlessly, like hang gliders on a front. It's one in which movements once deemed episodic are continuous, in which those regarded as rare are common, in which others dismissed as ineffectual are ecologically fundamental. It's a vision of a planet that vibrates with motion.

After nearly two decades, scores of international collaborations and tens of millions of dollars in funding, Wikelski finally catapulted the ICARUS wildlife-tracking receiver into space. It was built by DLR, the German space agency, and attached to the exterior of the International Space Station by Russian astronauts in 2018. It now orbits the earth, hundreds of miles above the surface, streaming geographic, environmental and health data collected from tagged animals across the planet to a ground station in Moscow, and from there to an open-source database called Movebank, which Wikelski and Kays first developed to track ocelots and orchid bees on Barro Colorado Island.

This fall, after refining the manufacture of the tags and the ICARUS software, Wikelski and his colleagues began attaching the tags to wild creatures. Larger tags have been affixed to rhinos, giraffes, zebras, wild dogs, hyenas and Saiga antelopes; smaller tags to blackbirds. Hundreds of research groups have been lined up to use the tags on their swimming, crawling and flying subjects — tags whose size Wikelski hopes will drop to just a single gram by 2025, allowing researchers to track small bats and even large insects like dragonflies, butterflies and desert locusts. As their faint tangle of tracks thickens and clarifies, the internet of animals blinks to life.

In following the movements of creatures as diverse as dragonflies, koalas and northern elephant seals, ICARUS may reveal general rules of mobility that are detectable across taxa and habitats and predictable by, say, body size or gait. But some of the most urgent questions ICARUS will answer will revolve around why animals die. Take the yellow-billed cuckoo, for example. The cuckoo's numbers have been shrinking in recent years, but conservation scientists are unsure why. Ornithologists knew they headed to South America in the winter, but just where in the continent remained obscure. A tracking study by Stanley and Marra, as yet unpublished, revealed that the cuckoos congregated in the Gran Chaco, one of the largest and most biodiverse forests in South America. This — as much as or even more than the degraded riparian areas that some scientist blamed — may explain the cuckoos' decline: The Gran Chaco is being rapidly denuded by the expansion of agribusiness. Global wildlife tracking could provide similarly revelatory detail on other declining species, one million of which currently face extinction, according to an assessment by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Such knowledge will be of immediate practical utility to the urgent task of stalling biodiversity loss.

In the past, scientists acquired such insights by accompanying animals into their wild places, with all the terror and tedium that entails. With ICARUS they will do so by watching blips on a screen and crunching satellite data. But that physical alienation from the living, breathing ferocity of wild creatures, Wikelski says, belies the deeper connection that wildlife tracking allows.

Through the pulses of data streaming from the tags to the ICARUS computers, the wild animals tell us "what they feel, what they see," he says. "It's the closest you can really — not talk to, but at least let the animal talk to you." What we hear could draw them closer to us, before they slip away.

Sonia Shah is a science journalist and the author of "The Next Great Migration: The Beauty and Terror of Life on the Move" and "Pandemic: Tracking Contagions From Cholera to Coronaviruses and Beyond."