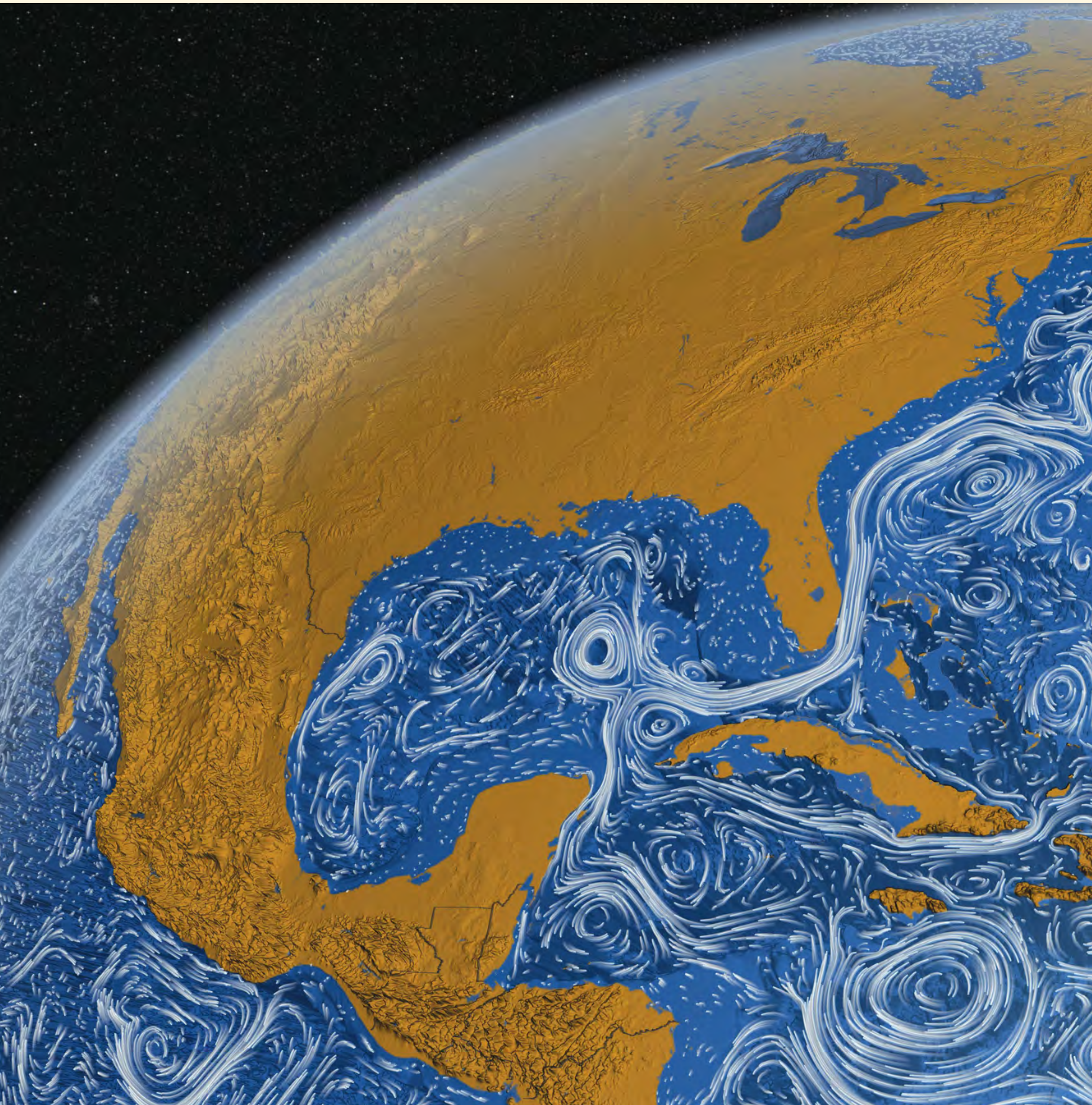
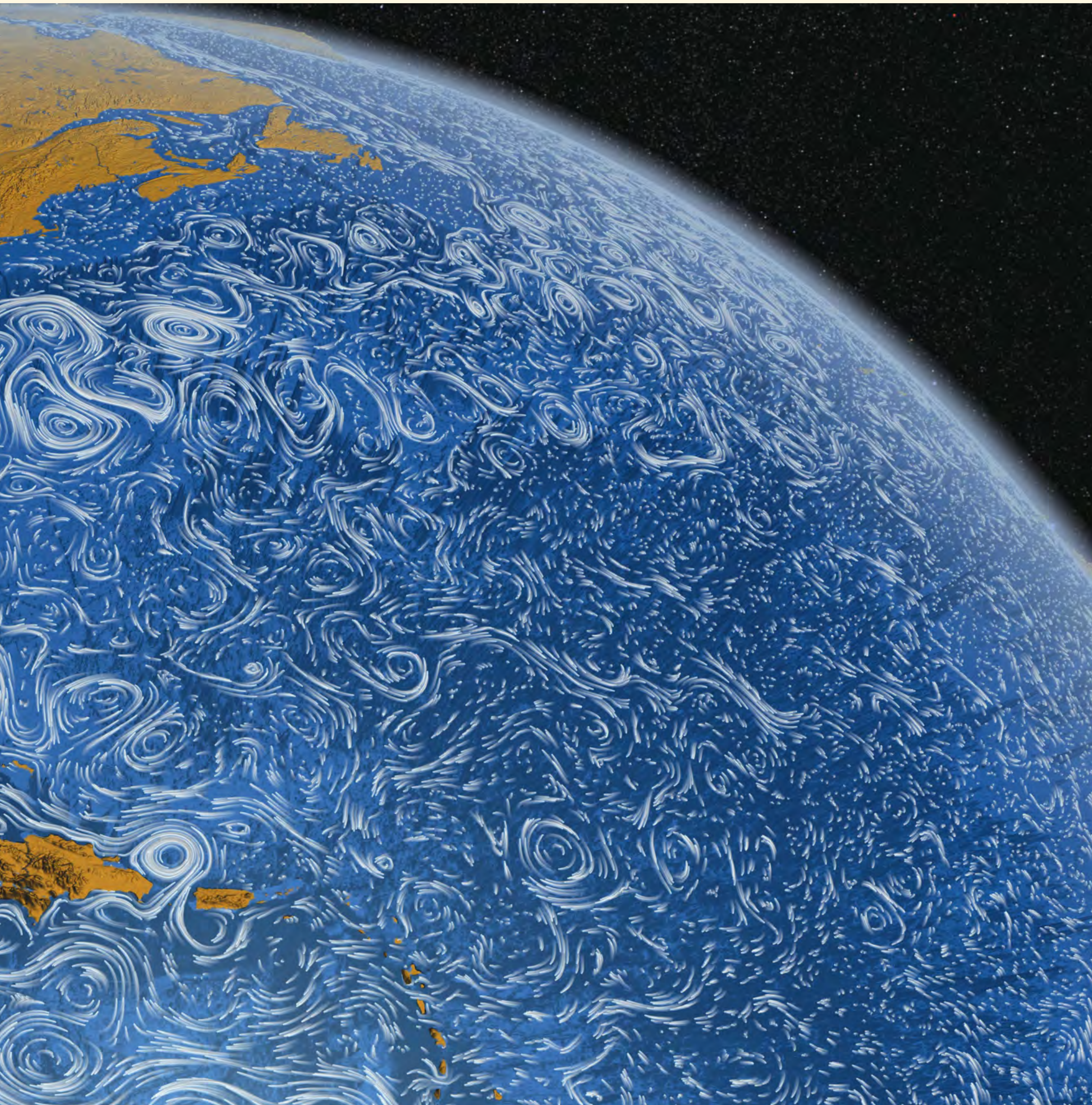
OCEAN CIRCULATION MODELS ARE SOLVING MYSTERIES OF SEA TURTLE LIFE HISTORY

By NATHAN F. PUTMAN, F. ALBERTO ABREU-GROBOIS, and EMILY M. PUTMAN



Despite being big, charismatic animals that cross oceans and nest on beaches around the globe, sea turtles remain mysterious in many ways. We have come a long way in solving those mysteries, but we have yet to figure out some essential aspects of sea turtle biology. When we consider that sea turtle life histories play out over entire oceans and span decades, it's no wonder that direct observations of survival rates, growth rates, age at maturity, and other critical data from turtles in the wild are hard to come by. These obstacles of scale and accessibility have hindered our ability to obtain information on sea turtle distributions in oceanic habitats and to detect underlying drivers of population trends observed at nesting beaches.



Overcoming these obstacles is vitally important because, on a fundamental level, successful conservation and management of sea turtle populations require an in-depth understanding of factors that influence population dynamics. Whether a population grows or declines is based on survival rates, reproductive output, and the number of individuals joining and departing the population being studied. And these demographic parameters are all based, to some extent, on the movement of individual animals. If a just-hatched baby turtle can escape nearshore waters where predators are most abundant, it is more likely to survive its first few days of life. Whether a turtle finds high-quality feeding areas will influence growth rates, time to maturity, and reproductive success. An adult turtle will contribute to its natal population if it can navigate back to its home beach. In all of these scenarios, turtle movements—and a variety of factors that influence them—are key to understanding these vital population parameters.

> Advances in computing power, simulation modeling software, remotely sensed data for ocean currents, sea surface temperatures, and other conditions, and new data on sea turtle biology are giving rise to a new generation of problem-solving tools for sea turtle research and conservation.

It's one thing to know what factors are important; it's another to be able to measure them. Collecting biological data on sea turtles has historically meant investing in substantial people power for patrolling nesting beaches and in-water habitats to take measurements on live turtles in real time. These data are incredibly valuable, but we haven't collected enough to fully answer all of the questions raised above. But what if we could speed up turtle time scales, zoom out on ocean basins, and watch how turtles move around oceans? Using such data, maybe we could assess where turtles are, how they get there, and when and why they are there, and thereby shed some light on their secret lives.

We now have available some technologically clever ways to do just that. By turning to computer models to put all those hard-won biological data to use in reconstructing—really, reimagining—turtles' lives, we are beginning to get a new perspective on how turtles live and how turtle populations work. Advances in computing power; simulation modeling software; remotely sensed data for ocean currents, sea surface temperatures, and other conditions; and new data on sea turtle biology are giving rise to a new generation of problem-solving tools for sea turtle research and conservation.

Of course, these models are only as good as the information and assumptions used to build them. Fortunately, a lot of the biological information needed to build basic models has been collected during the past several decades of laboratory, field, and tracking studies. This information is fed into realistic environmental models that take into account variations in environmental conditions that influence turtles' survival and growth. And because the movement of a turtle at sea is a combination of its own swimming behavior and the ocean currents it encounters, information on ocean conditions is important. To this end, rapid progress has also been made in modeling the complexity of physical processes in the ocean and the space and time scales over which they are quantified. Sophisticated ocean circulation models can incorporate measurements from satellites and from the oceans themselves to accurately characterize ocean current patterns around the globe. The output of these models, called current velocity fields, can be paired with particle-tracking software that computes the trajectories of virtual particles drifting through the ocean environment. Thousands of particles can be released from specific locations, under a specific set of conditions, and their subsequent locations can be recorded through time (see figure 1). If you replace the word "particles" with "turtles," you can begin to imagine how these models can help us solve previously intractable problems of understanding how turtles move over vast areas and over several years.

The simplest use of such techniques considers only the particle movements attributable to ocean currents, but this approach can still address questions that are impractical to study with field- or laboratory-based observations. Recent studies that modeled the passive drift of "turtle particles" across the nesting ranges of Kemp's ridley, Japanese loggerhead, U.S. loggerhead, and eastern Pacific leatherback populations show that the highest nest densities for each population occur at sites with nearby currents that are capable of whisking away hatchling turtles from dangerous nearshore areas full of predators to safer offshore waters full of food and hiding places. These results give a better understanding of the evolution of natal homing by adult females and help explain why nesting abundance varies among nesting sites: females are likely to nest in greatest numbers at beaches that produced the most surviving hatchlings, and these beaches, in turn, are likely to be close to currents that carry hatchlings offshore quickly.

Modeling that uses simulated turtles in ocean currents has also helped answer numerous, more complex questions about how turtle movement patterns can influence life history traits. Among the topics that have recently been explored by combining observed behaviors and computer modeling are: (1) whether the population structure of Caribbean hawksbill foraging grounds reflects ocean current patterns; (2) whether the foraging grounds of adult Pacific leatherbacks and Mediterranean loggerheads can be predicted by modeled dispersal patterns of hatchlings; (3) whether transit times of loggerheads between Florida nesting beaches and the waters around the United Kingdom and the Azores can be predicted; and, (4) whether the transatlantic dispersal in juvenile green turtles from Guinea Bissau is likely.

Most studies have focused on young sea turtles and assumed that their movements would be well represented with information about ocean currents, because little turtles are presumed to have limited swimming abilities. This assumption can still lead to informative predictions even for larger turtles with stronger swimming abilities, such as adult leatherbacks. For example, by subtracting the speed and

Hatchling loggerhead turtles take refuge in Sargassum weed near Juno Beach, FL, U.S.A. After swimming out to sea, hatchling turtles may spend years swimming actively in and passively drifting with ocean currents. © MASA USHIODA / COOLWATERPHOTO.COM PREVIOUS SPREAD: The swirling glows of tens of thousands of ocean surface currents are shown in this scientific visualization created at NASA's Goddard Space Flight Center. Researchers are using computer models of ocean currents to predict the movements of hatchling turtles during their "lost years" at sea. © NASA / SVS

direction of currents from the paths of satellite-tracked sea turtles and then comparing the current-corrected tracks with those of passively drifting particles released along the animal's track, researchers can figure out how much influence currents have on observed turtle migration patterns. These types of results provide valuable insights into the physical cost of migration in relation to ocean currents, and thus its potential influence on reproductive output.

Recently, sea turtle researchers have also begun to incorporate additional biological information into particle-tracking simulations, including swimming behavior that could be random, fixed-directional, or a response to specific environmental cues; metabolic rates in response to temperature; growth rates related to age; and mortality based on temperature and nearshore predation. These studies have demonstrated that accounting for key biological factors can have a dramatic influence on predicted trajectories and their ecological consequences for sea turtles.

For instance, using information obtained from laboratory studies on magnetic orientation in hatchling loggerheads from Florida (U.S.A.), researchers programmed particles to swim in the same direction as lab-tested turtles when they encountered the oceanic regions where the magnetic fields existed. Though speeds at which particles swam might have seemed too slow to make a difference (about two kilometers per day), these swimming particles were nearly 190 percent more likely to reach foraging grounds near the Azores than were passively drifting or randomly swimming particles within the same five-year period. These findings show that even little turtles are able to navigate and actively swim toward their targets, despite being in a big ocean with strong currents pushing them around.

Although characterizing the open sea navigation of young sea turtles is important, nearshore swimming also has long-lasting effects on their distribution. In simulations of newly hatched flatbacks, which remain in nearshore waters their entire lives, particles remained in favorable reef habitat by swimming into waves and then in the direction of the current, whereas particles that drifted passively tended to disperse over less favorable areas. Other recent analyses that incorporated mortality from cold temperatures and predation over the continental shelf suggested that even minimal swimming by hatchling turtles could have substantial benefits. A recent study showed that about 10 percent of virtual loggerheads released near southeast Florida survived their first two years of life when they drifted passively, whereas survival increased to about 30 percent when the virtual turtles were programmed to swim offshore over the course of a week.

Such wide discrepancies between predictions based on passive drift and oriented swimming show that despite their diminutive stature, young turtles can, to some extent, control their own destinies. More data on sea turtle orientation and navigation behavior would help to improve models of turtle movements and generate a better understanding of their implications for demographic and population dynamics.

So far, models have focused primarily on testing hypotheses specific to a single life stage, but the techniques exist for studying multiple stages and large-scale, long-term ecological processes in sea turtles. Such models can explicitly track individuals that are not amenable to other kinds of tracking, such as when turtles are too small to carry satellite transmitters or when lack of genetic resolution prohibits assigning a beach of origin for turtles caught at sea. Variability in oceanic conditions across years, which significantly affects demographic and dispersal processes, can be readily incorporated in such approaches. Likewise, models can assess effects of ecological disturbances caused by human activities, such as oil spills and fisheries. In essence, these techniques allow researchers to investigate big questions that might be logistically or financially impossible to test using conventional methods.

Of course, these modeling techniques also have limitations. All models depend on the quality and accuracy of the information that goes into them ("garbage in, garbage out," as the well-known saying goes). Using daily or hourly recordings of current velocity fields can capture the effects of fine-scale weather events (think of tropical cyclones) that average monthly velocity fields cannot. Likewise, a model set up to work at scales of kilometers will be able to depict fine-scale features associated with ocean currents, such as fronts and eddies, whereas coarser model scales (10 to 100 kilometers) will be unable to characterize these features. Better data on nearshore and inshore currents in sea turtle–rich regions are necessary to improve the accuracy of hatchling transport models, especially for populations that exhibit life histories that are closely associated with coastal habitats, such as those of the eastern Pacific hawksbill. An obvious consequence of these limitations is that results—and how they should be interpreted—will vary greatly depending on the scale and quality of available data used to build models.

… as these collaborative efforts between modelers, field biologists, and lab-based researchers progress, they will make the lives of sea turtles a little less mysterious.

As physical models of the ocean continue to improve along with our ability to program turtle behavior, the types of questions that they can meaningfully address will greatly expand. Models will become increasingly useful in providing insights about sea turtle demography, predictions about how turtle populations respond to their dynamic environment, and about juvenile dispersal routes and adult migratory routes that link nesting beaches with oceanic and nearshore foraging areas. In the future, these models could potentially be used to predict interactions between turtles and fishing gear or other anthropogenic influences, to highlight ocean areas of high conservation priority, and to evaluate the effectiveness of management strategies.

But in the end, the extent to which such models can be applied to sea turtle conservation depends on researchers' continuing to get their hands wet collecting biological data for model inputs and validation of model predictions. And as these collaborative efforts between modelers, field biologists, and lab-based researchers progress, they will make the lives of sea turtles a little less mysterious. ■

AT RIGHT: A juvenile loggerhead wearing a satellite transmitter swims near Praia do Forte, Brazil. Newer, smaller satellite transmitters like this one are making it possible to study the movements of juvenile turtles, and these novel data will improve models of turtle distributions at sea. © PROJETO TAMAR IMAGE BANK

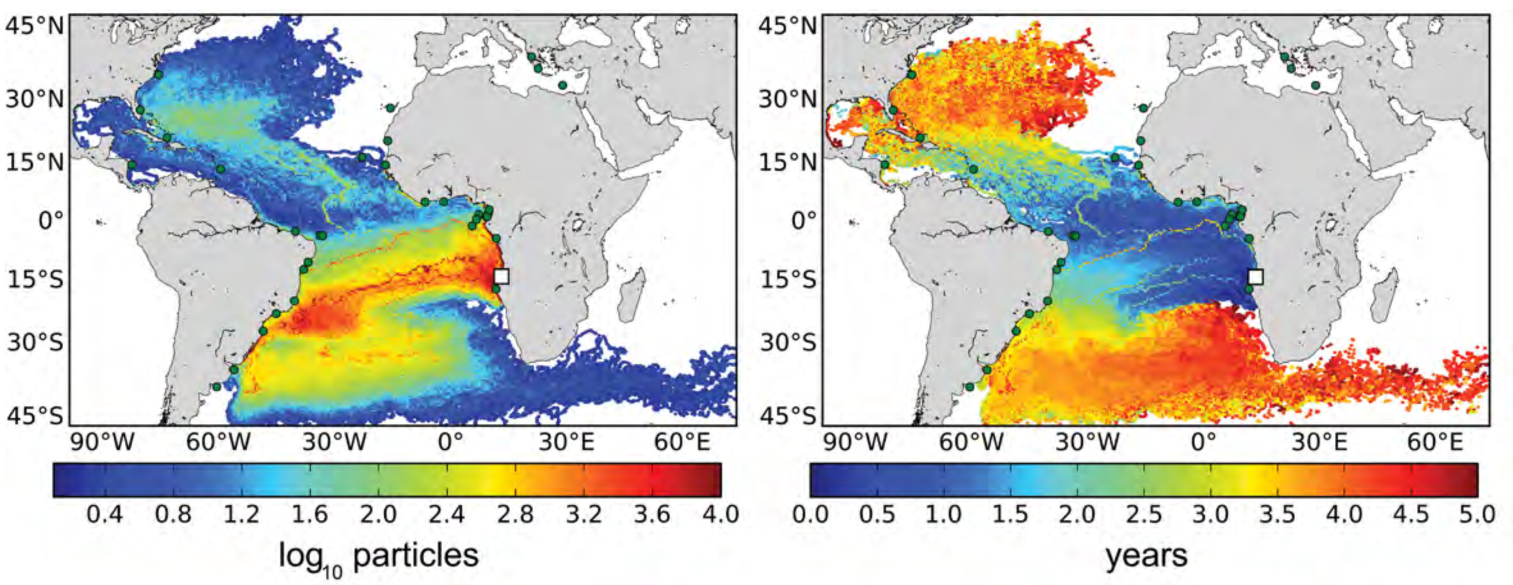


FIGURE 1. Dispersal of virtual particles released offshore of green sea turtle nesting beaches in Angola within the Global Hybrid Coordinate Ocean Model. The white square shows particle release location; green circles indicate known foraging grounds of juvenile green turtles in the Atlantic basin. The left-hand panel shows particle abundance throughout three five-year simulations (note log10 scale, 1 = 10, 2 = 100, etc.). The right-hand panel shows the mean age of particles at each location. The figure shows that more simulated hatchlings leaving Angola are expected to disperse west-southwest toward Brazil initially (left panel), before spreading into more northern and southern latitudes after three to five years at sea (right panel). Such simulations are useful for providing insights into data-limited populations by highlighting likely movement corridors for young sea turtles dispersing from their natal beach to foraging grounds.