Pedestrians of Eddy Avenue

"We have a nutrient source that is self contained, can endure for a long time, and be exploited by different fish populations."

Peter Oke
Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine and Atmospheric Research

by Agnieszka Gautier

Cruising south on the East Australian Current (EAC), the long-spined sea urchin, *Centrostephanous rodgersii*, has ventured further into Tasmania's warming waters, affecting a lucrative seafood industry, and leveling sea kelp forests into barren fields. These porcupines of the sea gnaw off the anchors of giant kelp, uprooting the entire plant. Nearly 95 percent of the giant forests have vanished. Within a decade all may disappear, and with them the sea snails, rock lobsters, and abalone that shelter within their canopies.

"The temperatures off the east of Tasmania are some of the fastest rising in the world," said Iain Suthers, a professor at the University of New South Wales (UNSW). Average winter sea temperatures have warmed to 12 degrees Celsius (54 degrees Fahrenheit), the survival threshold for spawning sea urchin, allowing them to reproduce longer. "This isn't unique to the EAC. All poleward boundary currents are strengthening," Suthers said. Boundary currents interact with coastlines, and unlike their eastern counterpart, western boundary currents move poleward within strong, deep, and narrow channels.

Long-spined sea urchins nest on a depleted kelp bed off the coast of eastern Tasmania. Lush sea kelp forests turn into barren fields of rock once the sea urchins take over. (Courtesy S. Ling)

Subtle shifts in ocean temperature significantly disrupt established food chains. As an underwater highway, the EAC transports warm, low-nutrient waters from the Coral Sea southward into the Tasman Sea, displacing cold, nutrient-rich waters. It now extends further south by 350 kilometers (220 miles). "Species are being transported well outside of their range," said Suthers. "The identification of Eddy Avenue is just one piece of the jigsaw to explain recent events."

Sighting the site

Eddy Avenue—playfully named after an actual street in Sydney, Australia, where all the researchers once waited for the bus—is a region within the Tasman Sea with an unusually high number of eddy formations. Eddies are little worlds of intense biological and physical productivity. "We suspect that commercial fishermen know eddies well and truly. They can look for certain features and efficiently target their catch," Oke said. "We're just filling in a bit of a gap."

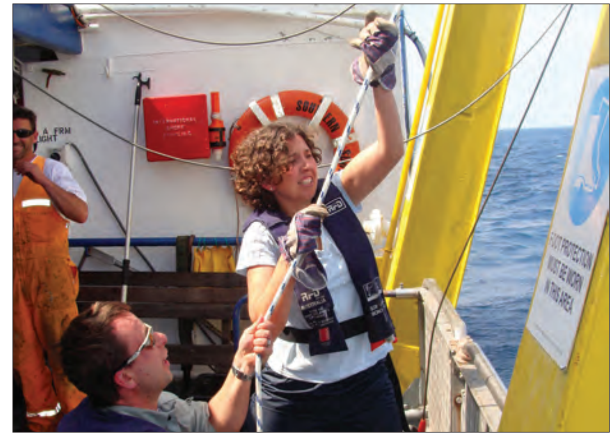
Everett and his team set out to locate and quantify the eddies within the Tasman Sea, and then link ocean circulation to different biological elements: phytoplankton, zooplankton, and fisheries. Eddy Avenue was not part of the initial plan. "But when we started, Eddy Avenue jumped out," said Jason Everett, a postdoctoral researcher at UNSW. Located close to the southeast coast of Australia, Eddy Avenue has 20 to 30 percent more eddies than the surrounding waters. Here, the eddies deviate from the global average with higher sea levels, faster rotations, and more chlorophyll, which means more nutrients to support a food chain.

Eddies are rotating blobs of water with warm or cold cores. They are the ocean's high or low pressure systems, instrumental in transporting heat within the ocean. "They're basically ocean weather," said Peter Oke, a research scientist with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for Marine and Atmospheric Research. Eddies form out of instabilities. Most result when the wavelike path of a current circles back onto itself, pinching off into spinning cylinders of water.

To understand the high incidence of eddies in Eddy Avenue, one has to understand the EAC. "In the Tasman Sea, the eddies get spun up quickly after the EAC leaves the coast," Oke said. Typical eddies rotate at ten centimeters per second, but within Eddy Avenue they rotate at fifty centimeters per second, a slow walking speed. "When the current separates from the coast, it gets complicated. It starts to wobble; it meanders. Rather than going in a relatively straight path like the Gulf Stream in the North Atlantic, it walks like a drunk man." Not only does the EAC wobble, it U-turns. "Every boundary current has its own peculiarities. They're like people," Suthers said. "They have their own idiosyncrasies. The EAC is a bit anomalous." About two-thirds of the current retroflects back up into the eastern Pacific, breaking up the EAC further. "It really is a current of eddies." Such instabilities saturate Eddy Avenue with eddies.

Eddy biology

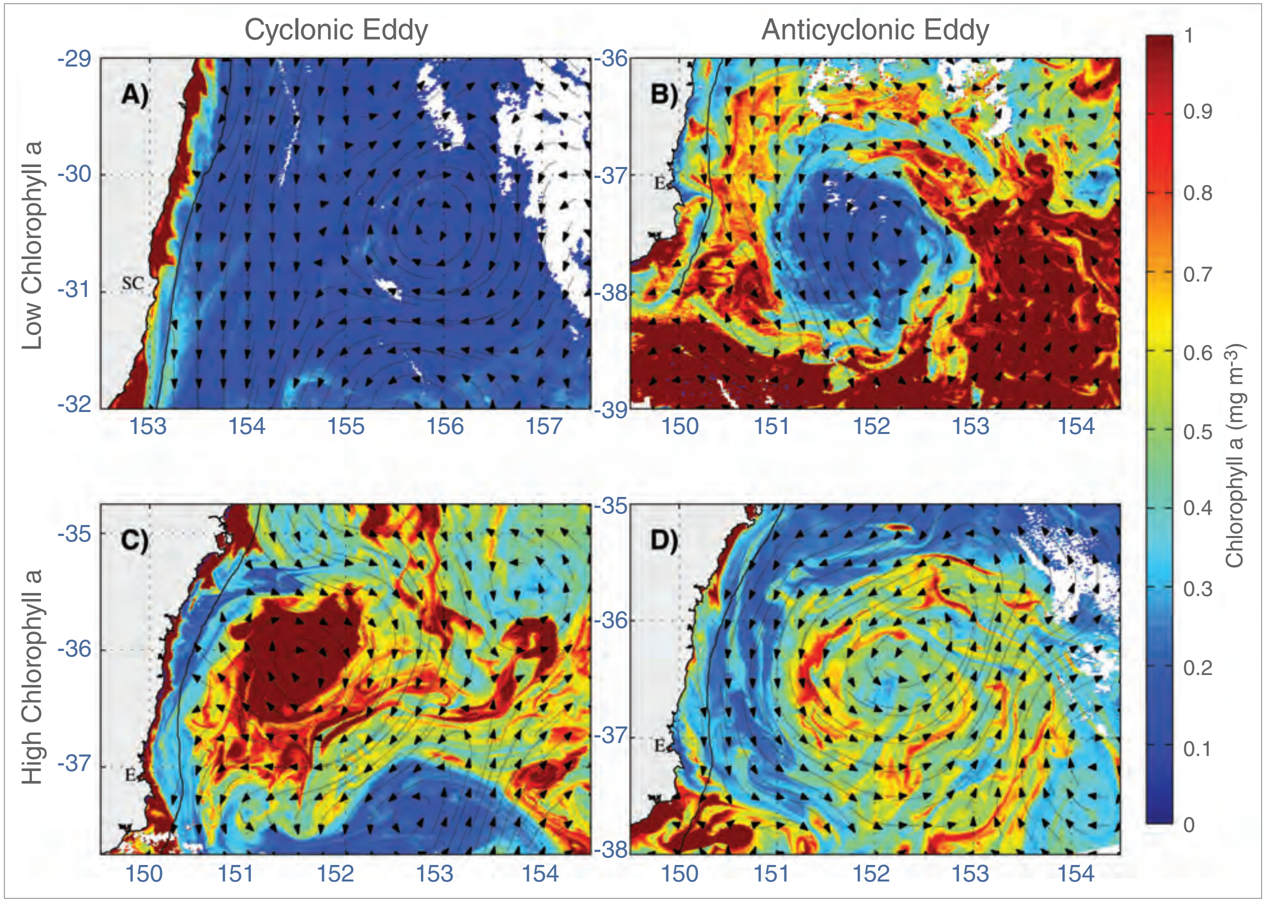
Eddy Avenue helps shed light on the migration of species out of their usual bounds. As key players in heat transportation, eddies provide nutrients for phytoplankton, photosynthesizing microscopic organisms, often green from the chlorophyll pigment present in their cells. Not all eddies do this, however. Two types exist: cyclonic and anticyclonic. The centers of cyclonic eddies dimple the ocean surface. The direction



The research team hauls in a fine mesh net to sample live salps during their asexual solitary stage, keeping them for only a few hours to determine their growth and fecundity. These gelatinous, barrel-shaped filter feeders are supremely abundant with an asexual stage that can release 240 buds in a week. They feed on a virtually unlimited carbon resource and thrive in rich phytoplankton areas. (Courtesy I. Suthers)

an eddy swirls depends on the hemisphere. In the southern hemisphere, clockwise rotation pulls deep water up the center, forming a cold depression of higher density water. The upwelling brings nutrients, submerged as decayed organic matter, into the light zone where it can be used by phytoplankton for growth and reproduction. "These cyclonic eddies are really the basis of the food chain," Suthers said.

Down under, anticyclonic eddies dot the ocean like pimples, pulling warm, low-density surface water into their core through a counterclockwise rotation. The differences in height and temperature allowed the team to take a broad look at the Tasman Sea with satellite altimetry and sea-surface temperature (SST) to map the circulation of the eddies. By applying ocean color data, which detects chlorophyll concentrations, they could estimate productivity levels. Green areas



These satellite images present the complex qualities of cyclonic and anticyclonic eddies within Eddy Avenue, proving they are not simply cold core and warm core, respectively. Geostrophic currents (from altimetry; black arrows) confirm the type of eddy based on ocean circulation. To find out what the biology was doing, the researchers used the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the NASA Aqua satellite to track concentrations of chlorophyll a (shading). (Courtesy P. Oke)

are phytoplankton hot zones. Brown and blue represent fallow ocean fields.

Using satellite data from 1993 to 2008, the researchers charted the frequency and quantity of eddies within the Tasman Sea. They identified 30,000 eddies with over half being anticyclonic. The unproductive warm cores were expected to have low chlorophyll, while chlorophyll should have clouded the centers of cyclonic eddies. Sometimes this was the case, but Eddy Avenue complicated matters. “Now we’re starting to understand eddies aren’t simply warm or cold core,” Suthers said.

Eddy chameleon

Sometimes cyclonic eddies had no cold core. As the EAC leaves the coast of Australia and breaks down into eddies, often a trace lingers—a fast slither weaving in and out of eddies. When it comes into contact with a cyclonic eddy, it floods it, capping it with warm water. “The importance here is if you were to look at SST from satellite data, you might not see the cyclonic eddies,” Oke said. “It’s only by pulling other data types, the satellite altimetry and ocean color, that we can go ‘Ah that’s warm, but it’s still a cyclonic eddy.’” Though this has happened before, the researchers had not seen it on this scale.

Suthers said, “Cyclonic eddies are far more involved. If you look at a pair of twins, the big bald twin is the anticyclonic eddy and then you’ve got the cyclonic twin that has a range of colors, sizes, and personalities. They’re far more biologically interesting.” Both types of eddies interact with the continental shelf, but cyclonic eddies are able to entrain nutrient-rich water from the shelf, resulting in higher chlorophyll concentrations. Anticyclonic, for reasons yet undetermined, do not. “We didn’t expect that from the cyclonic eddies,” Everett said. “Our research points to two processes. You get uplifting, but closer to the coast within Eddy Avenue, there’s a second process: the entrainment of shelf water.”

Researchers once considered entrainment as a death trap, believing that when spawned fish were dragged from the coast, they would die. But entrainment provides a nutrient-rich environment with fewer predators. “Larval fish are growing faster and bigger within these smaller, coastal cyclonic eddies,” Everett said. “We’re in a neat position to see this in Eddy Avenue because of the number of eddies.” All eddies propagate to the west. This is partially due to Earth’s rotation. To the west is Australia. So the eddies just bobble there. Bumping up against the coast, they sweep in high-nutrient water, over and over. It is a productive environment—little plankton incubators, if you like. "We have a nutrient source that is self contained, can endure for a long time, and be exploited by different fish populations," Oke said.

A light on Eddy Avenue

The identification of Eddy Avenue has highlighted entrainment to explain high chlorophyll levels, but a missing link still exists. "It's quite easy to sample fish or zooplankton on the coast and then sample them in an eddy close by to show that the species are the same," Everett said, "but it's much harder to show that they actually came from the eddy nearby." Making that final connection is the next step.

For now the researchers are left with a bit of optimism. "Up until now, global climate models (GCMs) assumed that with global warming these would be less productive because the warmer layer of water would isolate upwelling and cap deep nutrient-rich water," said Suthers. Eddy Avenue has unlocked another possibility. As currents increase, more energy will propagate south. "Eddies will either have to get bigger or there will be more of them," Everett said. "We aren't sure which at this stage." More eddies and bigger eddies point to the possibility of more chlorophyll, perhaps pulling more carbon out of the atmosphere into phytoplankton and sustaining fisheries. "That was something that came from this research," Suthers said. "You bet, we've got a serious eddy production off the east coast of Australia and now it's being incorporated, being realized, into GCMs."

To access this article online, please visit http://earthdata.nasa.gov/sensing-our-planet/2013/pedestrians-eddy-avenue

About the remote sensing data used

Satellite	Aqua
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data set	Level 3 Ocean Color Web
Resolution	4 kilometer
Parameter	Chlorophyll a concentration
Data center	NASA Ocean Biology Processing Group (OBPG)

About the scientists

Jason Everett splits his time as a postdoctoral researcher at the University of New South Wales and at the University of Technology in Sydney, Australia. Everett is interested in how oceanographic features influence the productivity of phytoplankton and zooplankton communities. The Australian Research Council Discovery Project supported his research. See http://www.famer.unsw.edu.au/staff/jason.html. (Photograph courtesy J. Everett)

Peter Oke is a research scientist at Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine and Atmospheric Research in Hobart, Australia. Oke undertakes research in oceanography, using observations and numerical models to investigate ocean dynamics. The Australian Research Council Discovery Project supported his research. See http://www.marine.csiro.au/~oke060. (Photograph courtesy P. Oke)

Iain Suthers is a professor in the School of Biological, Earth and Environmental Sciences at the University of New South Wales and is partly based at the Sydney Institute of Marine Science. Suthers explores the basis and sustainability of estuarine and coastal ecosystems. The Australian Research Council Discovery Project supported his research. See http://www.bees.unsw.edu.au/iain-suthers. (Photograph courtesy I. Suthers)

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For more information

NASA Ocean Biology Processing Group
http://earthdata.nasa.gov/data/data-centers/obpg

Moderate Resolution Imaging Spectroradiometer (MODIS)
http://modis.gsfc.nasa.gov