

The Search for the Tsunami Debris

Nikolai Maximenko and Jan Hafner were featured in the media world wide: Their computer-modelled projections of where the debris would travel in the ocean, their search for verification, and finally the finding of tsunami debris by *Pallada*. The IPRC has created a series of web pages dedicated to marine and tsunami debris information. The address is soest.hawaii.edu/iprc/news/marine_and_tsunami_debris/debris_news.php

In the True Spirit of Science

The Second Expedition to Kamilo and Hanalua Beach



Marine Debris is an emerging field of study, charting new territory. We know much about the movement of the large subtropical ocean gyres that collect debris in the garbage patches of the World Ocean, but so little about the transient currents that let masses of man-made debris escape out of the garbage patches and throw it onto such special places as Kamilo Beach, which has been called the “dirtiest beach on Earth.”

Nikolai Maximenko

There are no paved roads to Kamilo Beach in the Ka’ū district on the remote southern tip of the Island of Hawai’i. The beach is a sandy crescent that hugs a lava-terraced bay laced with tide pools and deep channels cut by powerful waves. Much of the terrace is above water during low tide and awash during high

tide. The beach has made headlines, not for its good swimming or surfing, but for the huge amount of trash that keeps washing up on its narrow strip of white sand.

“A surreal picture...nearly no sand, only debris. You can’t walk without treading on some kind of stuff thrown out by the ocean,” describes IPRC

Assistant Researcher **Axel Lauer** his first visit. “And this only 8 weeks after **Bill Gilmartin**, **Megan Lamson**, and their clean-up team from the Hawai’i Wildlife Fund Debris Project were here.”

Why does Kamilo Beach collect so much debris? The search for answers led Lauer in summer 2011 to accompany Senior Researcher **Nikolai Maximenko**, a physical oceanographer at the IPRC, and his team on their trip to the notorious beach.

Maximenko became interested in marine debris when he realized that the thousands of drifting buoys, which oceanographers have been releasing over the past decades into the ocean to study its characteristics, are a form of marine debris. Studying the drifters’ paths and their final demise, he developed a model to understand marine debris behavior and to track it. Since



Nearly no sand, only debris on Kamilo Beach.

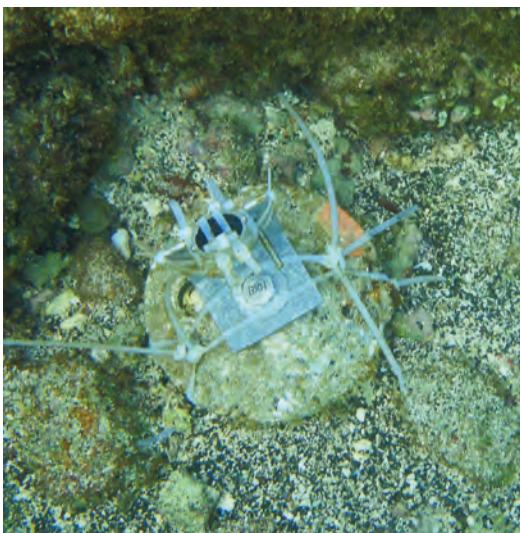
the March 2011 tsunami in Japan, he has adapted the model to study and track the debris swept by the tsunami into the ocean.

So it is no wonder that the stories of the massive trash collecting on Kamilo sparked Maximenko's interest, and in summer 2010 he took his team on its first exploration there. Now a year later, supported by funding from JIMAR, he is returning with a plan of action: gather more information about the currents inside Kamilo Bay and confirm his hunch that maybe the black lava rocks at nearby Hanalua Beach are sitting on much more plastic than a cursory look suggests.

The Currents at Kamilo

On this second visit to Kamilo Beach, the team is hoping to get more clues about the currents in the bay. The summer before, they had installed with great difficulty temperature sensors in the hope that they would reveal something about the daily flow of water in the bay. What disappointment: The sensors are gone, washed away by the power of the ocean. Valuable observations that might have told a story about the currents are lost!

They have to install new sensors, but finding the plates is nearly as hard as mounting them on to the lava the year before, because they have become overgrown with algae and now look just like the rocky bottom (picture). Just when Assistant Researcher **Oleg Melnichenko** finally finds a plate, Maximenko sees a fin and a shadow flitting in the water behind Melnichenko. He yells a warning. But against the wind Melnichenko can't hear him. The fin swims by ... and out to sea again! The new sensors get installed. Hopefully they will stay put and record data for a while.



Camouflaged temperature sensor and plate



Painted "bottle-drifters" in bush.

The "bottle-drifter" experiment is next. Back at the IPRC, the team had brainstormed about how to get more clues to the bay's currents. The usual instruments for studying currents are drifters with heavy, long drogues so that they stick out of the water only a little bit, and their movement reflects mostly the movements of the ocean and not the wind. But the team has no expensive drifters at their disposal. Such drifters would also be too big, too heavy, and their drogues would get entangled in no time in the rough lava-rock bottom of the bay. But what can they use in their place? How about soda bottles?

Now on site, they fill 2-litre coke bottles with sand and test how much sand the bottles need in order to float but not bob out of the water and ride before the wind like sailboats. Trial by error shows that bottles two-thirds full of sand will do it.

On the morning of day 2, the team arrives at Kamilo in eager anticipation: how will the drifter experiment work? Forty-three 2-litre coke bottles, filled two-thirds with sand and painted bright red or pink to see them against the blue ocean are to be dropped into the water far out in the bay. Sounds simple, but proves to be tricky. Melnichenko and UH Hilo Postdoctoral Fellow **Hank Carson** load the rubber dingy with bottles.

Hardly have they climbed in, the wind tips over the dingy and throws them into the shallow water with its sharp lava bottom. A second failed attempt, and they realize, the only way to get the bottles launched from the southern edge of the reef, is to swim them out pulling a net filled with bottles.

Anxiously watching from shore, the others notice a tongue of clear water that extends beyond the reef. It must mean a strong rip current leaving the bay. Warned, Melnichenko and Carson toss out the painted bottles just before reaching the



Swimming the bottles out to the reef.

dangerous rip. Thankfully, the rest of the bottles can be jettisoned from land, from the point projecting out into the bay (see “X” in image below).

The team had placed two cameras strategically along the shore and now, that the “drifters” are deployed, Scientific Computer Programmer **Jan Hafner** and Lauer take pictures every 10 seconds to see where the bottles go. These pictures are their “data” from which they hope to determine, using

the triangulation method, the path taken by the bottles. This will turn out to be a lot more challenging than Lauer had imagined.

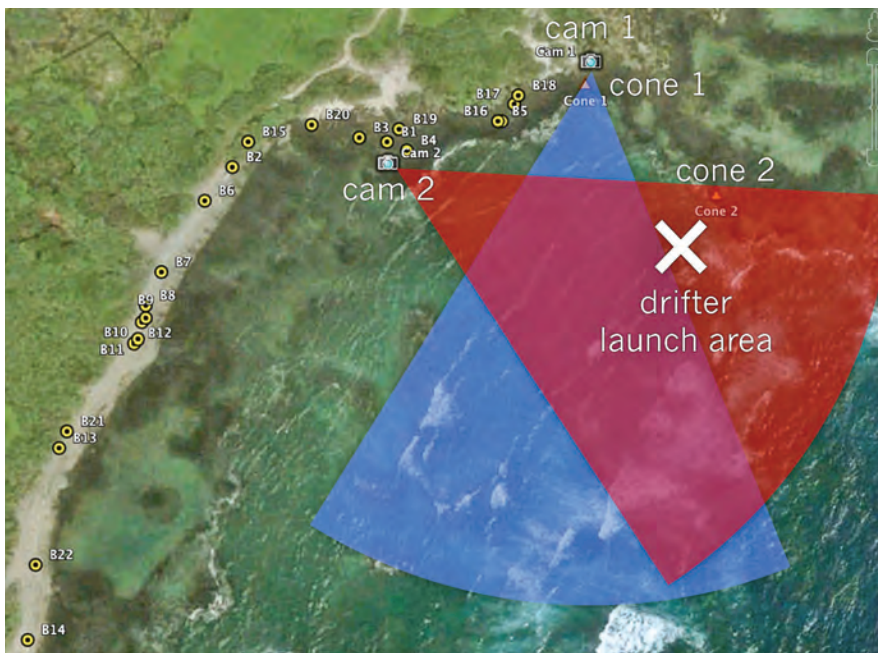
The bottles first float parallel to the shoreline far out in the bay. Then many get caught up in the rip current, which is so strong that it pushes the bottles against the wind beyond the reef. Will they drift further out to sea and join the subtropical gyre circulation and the Great Pacific Garbage Patch?

After a while the bottles appear again, riding on waves back across the reef. There must be an eddy that flows out and loops beyond the reef back again into the bay. The bottles eventually escape the eddy and drift toward shore. They land not in one or two spots, as might be expected, but widely dispersed along the whole beach. By the time the team has packed up for the day and is ready to leave, 26 of the 43

bottles have washed up on the beach. The remainder were picked up by **Megan Lamson** the next day. Though many bottles had ventured out beyond the reef, only one of the whole lot never returned.

Back at the IPRC, Lauer has to determine from the pictures the currents in the bay. This requires much ingenuity. He had not anticipated that the bottles would disappear in the waves for minutes at a time and that he wouldn’t be able to follow a single bottle from the place it was dropped into the water to shore. By counting the bottles that are visible and graphing their position in each and every of the 1,646 pictures, Lauer is able to develop a chart representing the overall flow pattern (Figure page 12). Violet-blue are the bottle positions at the beginning of the experiment, while red-yellow are the positions during the last half hour. The black lines with arrows show the approximate paths taken by the bottles. The graph shows what the team had suspected: a fair number of bottles circulate for a long time far out, at times floating beyond the reef. Viewing the sequence of pictures from each camera yields a choppy animation of the bottles’ travels toward the beach.

Lauer reflects on his results: “I don’t think that the incoming tide alone was responsible that most of the bottles washed up on the beach again. When we dropped the bottles into the water, they were quickly taken out to sea in the strong rip current along the reef, but that current also seemed to bring them back in. The mini-gyres we saw within the bay certainly help to bring the junk from outside the bay ashore. The name ‘Kamilo’ means the twisting or swirling current in Hawaiian,



Schematic view of the setup of the drifter experiment at Kamilo Beach. The camera positions are indicated as “cam 1” and “cam 2”; the two reference cones as “cone 1” and “cone 2”. The blue and red areas show the fields of view of the two cameras. Also shown is the drifter launch area marked with an “x” as well as the positions of the bottles (B1 to B20) that beached during the first two hours of the experiment.



suggesting the Hawaiians have been aware for a long time what makes this place so special. And that we retrieved all the bottles except one also suggests that once something enters the bay, it tends not to leave. Although the bottles were dropped into water within 25 meters of each other, their path toward shore varied greatly as shown by how far apart they washed up along the shore.”

He adds, “We learned a lot about the technical difficulties in conducting the experiment, and it gives us new ideas about what to try next.”

The Hidden Plastic of Hanalua Beach

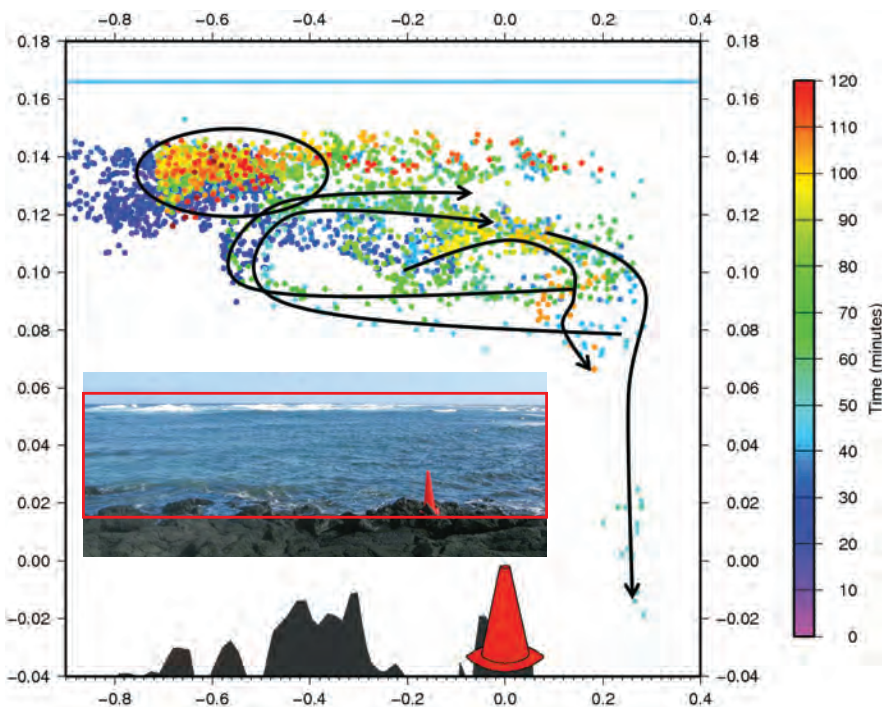
Driving last summer along the coast between Green Sand Beach and South Point revealed a rocky beach with surprisingly little debris compared to Kamilo Beach just a few miles away. Do the currents and winds keep the stuff away? Or do the retreating tides suck it back out? Melnichenko had noticed some plastic sticking out from under the rocks, and when he removed a few rocks, he saw a pile of

plastic hidden underneath. On this trip, therefore, the team wants to find out what is buried below the rocks.

It is a brutally hot, sunny day. Thank goodness for the canopy that shades at least the 3 m x 3 m hole, which they are digging in order to get a rough estimate of the amount of plastic that has piled up on the beach. Their technique: with the top layer, about 30 cm deep, they pick up and get rid of all the plastic found on the beach. The plastic is stored in a bag and kept to be weighed back at the IPRC. In the next layer, they find the plastic pieces are so tiny, that the only way to collect them efficiently is to shovel the plastic-sand mixture into a bucket of water and then skim the floating plastic off the surface. This second layer reaches a depth of 60 cm. Again they store all the plastic from this layer in a huge plastic bag.

They dig much of the day. The work is grueling! They brainstorm: How about a vacuum cleaner the next time to suck up all the stuff?

Most surprising and frightening, as they dig deeper they are finding that the concentration of plastic increases. With their third layer, at a depth of about 90 cm, they call it quits. They place the plastic bags containing their hard-earned plastic trash into containers to take them back home to weigh. The containers are very, very heavy.



Positions of the bottles (colored dots) as seen from camera 1 during the first two hours of the experiment. The positions are given in coordinates relative to the tip of the red cone on the point of origin (0.0). The color shading of the dots represents the time of sighting in minutes after the bottles were released. The black arrows depict some of the bottle trajectories observed during the experiment. It is remarkable that, although many bottles were still far out after two hours, all bottles save one eventually returned.



The untouched surface.



The layer after removing the rocks.

Back at the IPRC, the carefully labeled bags are weighed and the weight of plastic per square foot at each layer of depth determined (see table). Their impression turns out to be right...the amount of plastic increases with depth. From this sample, they can now calcu-

team did not even reach the depth of maximum density of plastic.

Perhaps it is not a difference in currents that makes Kamilo “the dirtiest beach” and Hanalua Beach look so clean by comparison, but rather the difference between a sandy and a rocky beach,

“This is so different from the science I usually do....sit in front of the computer screen and press keyboard buttons to run my modeling experiments,” Lauer recalls. “To go explore in the outdoors, without knowing what we will find or how things will turn out is thrilling. Figuring out how to use the bottles as drifters, the challenge in deploying them, nervously watching how the bottles are swept out beyond the reef, worried that they might add to the plastic in the ocean, the hard work of digging in the sand and the astonishment of finding how much plastic is buried beneath the rocks, all that is energizing, challenging—that’s the true spirit of science.”



The plastic collectors, from left Hank Carson, Nikolai Maximenko, Axel Lauer, Oleg Melnichenko, and Jan Hafner.

late how much plastic lies on the whole beach. The result of their calculations? At least 25 tons of plastic lie buried under the black, plastic-free-looking rocks at this beach that is about 200 meters long and 10 meters wide! This impressive figure is clearly an underestimation as the

where the plastic slips down between the crevices, gets ground up into smaller and smaller bits by the sharp rocks and sinks further and further down into the sand, creating a plastic carpet. As smaller rocks sink further down over time, they continue their plastic grinding.

This story is based on an interview with IPRC Assistant Researcher Axel Lauer.

Layer	Plastic density, kg/m ³
0-30 cm	5.9
30-60 cm	14.2
60-90 cm	17.3

The density of plastic in kg per cubic meter in each of the 3 layers.

Tsunami Debris on Kaho'olawe?

It is early morning at the small Kihei boat harbor on Maui. We, the members of the IPRC marine and tsunami debris project (**Nikolai Maximenko**, **Jan Hafner**, and **Gisela Speidel**) are with the Hawai'i State International Coastal Cleanup Coordinator **Chris Woolaway** and with a Japanese team from NHK television network: **Jun Matsuda** (Program Director of NHK's News Features Production Center), **Tsuyoshi Namekawa** (camera man) and **Yasue Drabble** (project coordinator). The NHK team is here to film a documentary on marine and tsunami debris with the explanation: "Hawai'i is the last place for the marine debris, which floats around the Pacific Ocean, to end up, and in the future, a lot of debris from the March 2011 Tohoku tsunami will arrive here."

We are all going to the tiny volcanic island of Kaho'olawe. The island was once a military training ground that has only partly been cleared of un-



exploded ordinance. Now as a Native Hawaiian cultural heritage site, the island can be visited by special permission only. We are meeting **Michael Naho'opi'i**, Executive Director of the Kaho'olawe Island Restoration Commission (KIRC). Less than a year ago, 15 tons of marine debris were airlifted off Kanapou beach, the beach to which we are going. New debris is already accumulating, and Naho'opi'i, concerned about marine debris on this special island, is giving us the opportunity to

study its accumulation in Kanapou Bay.

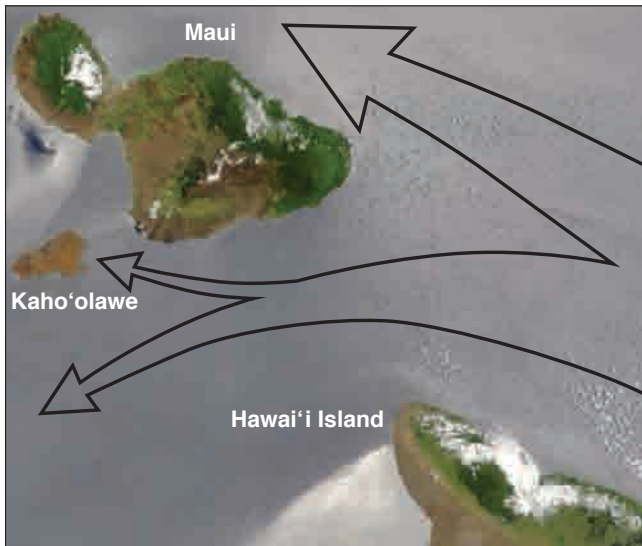
IPRC's marine debris project leader, Senior Scientist Nikolai Maximenko, was at first surprised to hear that Kaho'olawe gets much marine debris as it lies in the wind shadow of Maui. The Hawaiian Islands collect marine debris mostly along their windward-facing beaches.

We travel to the island on the KIRC boat, a flat-bottomed, 40-foot-long landing craft with a rectangular bow that can be lowered to drop people and cargo off in the water. After a high-speed trip of some 30–40 minutes out of Kihei, we approach Kanapou Bay. The vertical cliffs look forbidding and inaccessible. But finally a narrow, mud-brown strip of sand appears wedged between the sheer cliffs.

Some 100 yards from shore, the bow is lowered. We must jump into the deep water and swim to shore with our gear. Already as we step on to the sand, a thick rim of debris greets us above the waterline. It is hard to believe that the beach was cleaned by KIRC volunteers less than a year ago!







Likely path of wind-driven debris.

Why does this beach, which appears to be protected by Maui to the windward and which has no visitors except for the occasional KIRC volunteers, collect so much debris? “The combined funneling of the northeast trade winds and prevailing currents choke the five miles of the Bay with debris from the ocean,” explains the KIRC brochure.

In addition to heaps of tangled, derelict fishing nets and gear, much intact debris is strewn across the beach: blue barrels, about 3-5 feet tall, different-colored crates and buckets, lots of fins, and hard hats, and even a child’s baseball bat and ball. US Coast Guard and Navy buoys are scattered in the sand.

Much of the debris is still usable. Even though some objects have Japanese, Korean, or Chinese characters printed on them, the pieces are astonishingly free of barnacles, which commonly cling to objects on their long ocean voyages. Maximenko says that on no other Hawaiian beach did he ever see such large debris with so little wear and tear, not even on remote Kamilo Bay on the southwest corner of the Big Island. These items, he concludes, must be local debris, and because of the prevailing currents, the debris must have come from Maui and Hawai’i Island, or have been lost from boats navigating near these two islands (see map).

The typical international marine debris that accumulates on the beaches of the Hawaiian Islands is also here: the hag fish traps and the oyster spacers from Asia. Also typical of other wind-facing beaches is the large amount of microplastic, the end condition of plastic objects that have either chemically disintegrated or have been ground into tiny piec-

es by machines, water or sand. **Jennifer Vander Veur**, the KIRC ocean specialist, has studied the accumulation of these tiny plastic pieces on the beach here. It collects further up on the beach, and she says that when she dug deeper down, the amount seemed to increase with depth, something that Maximenko has also noticed on other beaches, such as the rocky beach near South Point (*IPRC Climate*, vol.12, no. 1).

Most intriguing are two large, red light bulbs with Japanese characters. Such bulbs have recently been found on Hawaiian shores and are thought to come from Japanese fishing boats lost in the tsunami. A further hint of the tsunami is a huge oyster buoy that lies only a few feet from the water’s edge. Numerous oyster buoys have washed up on the Washington State coastline and are thought to be from the tsunami. How long has this buoy been here? We do know that it arrived after the last cleanup in 2011. Does it mean tsunami debris has arrived here, as on other islands?

Suddenly we are told to pack up. The boat is back, the captain is impatient, urging us to the boat. “Never stay till after noon!” It is nearly noon and the wind is picking up. If the waves get any higher, we’ll have trouble swimming out to the boat and might get stranded on the beach.

Reflecting on what he has observed, Maximenko thinks that a marine debris monitoring site at Kanapou Bay on Kaho’olawe would have great advantages: it would allow gathering systematic information about the nature of marine debris accumulation free from outside influence other than wind, ocean currents and waves, and the shape and structure of the bay and beach. The type of objects we saw suggests moreover that the beach would be ideal to study the footprint of local debris, produced by ocean activities around the Hawaiian Islands, as well as debris from the whole North Pacific subtropical gyre.

Story and photos by Gisela E. Speidel.



Mitigating the Impact of Tsunami Debris on Coastlines

The March 11 tsunami in Japan swept millions of tons of debris into the ocean. Visible from airplanes during the first weeks as distinct mats of complex composition, the debris drifted offshore, dispersed and became ef-

fectively invisible to observing systems. The model debris-path predictions made by IPRC's **Nikolai Maximenko** and **Jan Hafner** have recently been confirmed by ship observations that showed end of September the leading edge of the debris only about 400 km northwest of Midway and the Papahānaumokuākea Marine Monument (see p. 14).

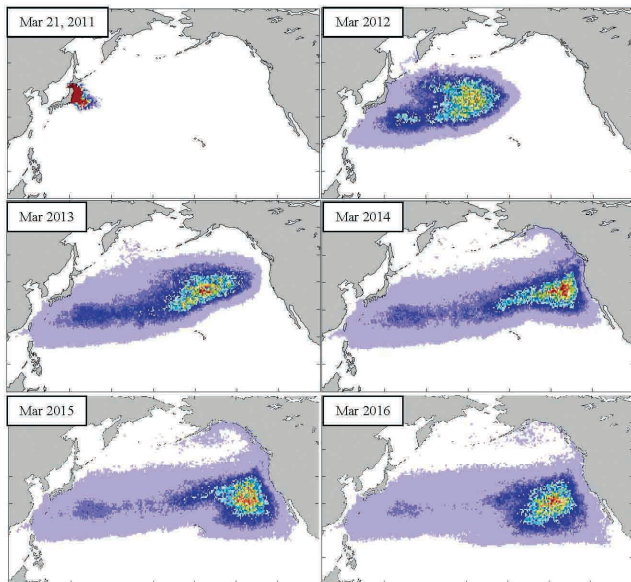
The workshop was convened at the IPRC on November 14 by Maximenko to discuss the necessity and feasibility of mitigating the tsunami debris impact and to propose a science-based plan for effective use of available limited resources to explore, monitor, and handle tsunami debris drifting toward Midway, the Hawaiian Islands, and the US/Canada West Coast. The workshop

was accessible live by WebEx, set up and monitored by Post-doctoral Fellow **Ali Bel Madani**, Assistant Researcher **Oleg Melnichenko**, and Computer Systems Manager **Ron Merrill**. Scientific Computer Programmer **Jan Hafner** ran demonstrations of computer movies on the Magic Planet and explained debris samples collected on Hawaiian beaches.

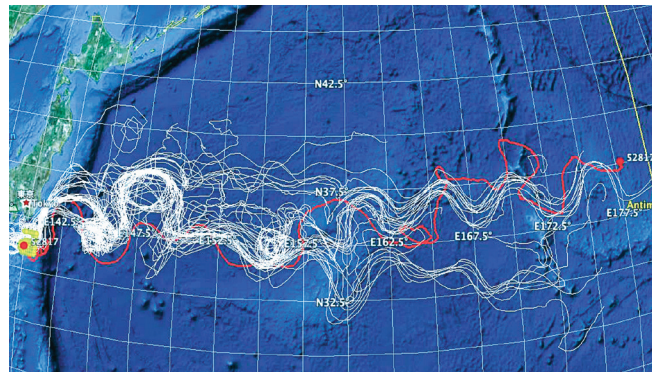
Robin Bond (Hawai'i Ocean Safety Team) opened the meeting with a first-hand account of the tsunami aftermath in Japan. Bond, who had been invited by the famous Hawai'i-born sumo wrestler **Konishiki Yasokichi** to visit the Sendai region 100 days after the tsunami to document in pictures the destruction and the cleanup, showed photos of once beautiful coastal towns from Fukushima to Hokkaido now as flat cement foundations. Other pictures showed huge mats of floating wood.

Rick Lumpkin (NOAA Atlantic Oceanographic and Meteorological Laboratory), presenting over WebEx, explained how drifter trajectories can be used to predict the paths of floating marine debris, a method used by Maximenko and Hafner to develop their models of the debris trajectory.

Maximenko reviewed the ten-year projection of the tsunami-debris field in his statistical model (see below) and then the results from the real-time diagnostic model called Surface Currents Diagnostic or SCUD model. Driven by satellite-measured winds and sea-level height, this latter model yields daily updates of the estimated location of the debris field. On its Honolulu-to-Vladivostok journey end of Sep-



The ten-year projection of the tsunamis-debris field in the statistical model. Image courtesy Maximenko and Hafner.



Observed drifter (red) and tracer paths in model run by Yi Chao. Image courtesy Yi Chao.

tember, the Russian Sail Training Ship *Pallada* encountered flotsam that was identifiable as tsunami debris in regions predicted by the model.

Using a different approach to projecting the debris path, **Yi Chao** (NASA Jet Propulsion Laboratory) over WebEx described a two tier system, in which nine-month forecasts of global atmosphere and ocean models are assimilated into the JPL Regional Ocean Modeling System to predict how the debris will spread. “Drifters” introduced into this model-system in April 2011 have a similar trajectory as in Maximenko’s diagnostic model, some of which have already crossed the Date Line.

Henrieta Dulaiova (SOEST, University of Hawai'i) reviewed the likelihood of the debris being radioactive. Radioactive fumes from one of the Fukushima plants first escaped into the atmosphere the day after the tsunami and was blown northwest over Japan. Release of radioactive water into the ocean was the largest in history, but the earliest release occurred on March 28, i.e., 17 days after the tsunami. Given this sequence of events, radioactivity of the debris should pose no health threat.

Samuel Pooley (Director of the NOAA Pacific Islands Fisheries Science Center) described how existing marine debris has been harming the endangered monk seal, sea turtle, and albatross at the Papahānaumokuākea Marine National Monument through entanglement, ingestion of microplastics and larger objects (such as cigarette lighters), modification of habitat, and introduction of invasive species. The arrival of the tsunami debris, together with its possible toxins and invasives, will further endanger these animals. NOAA has been talking with EPA about the tsunami debris. The foremost issue is to gain more knowledge of the debris composition and whereabouts.



Nikolai Maximenko with NHK Los Angeles Bureau Chief Noboru Nakashima at the workshop.

Chris Woolaway (Hawai'i Ocean Safety Team) reviewed work on various marine-debris cleanup projects, the most ambitious being the Ocean Conservancy's International Coastal Cleanup Project: over 25 years, nearly 9 million volunteers in 152 countries removed over 144 million pounds of trash along 291,514 miles of coastlines and waterways.

The present Midway Atoll–Marine Debris Coastal Monitoring Pilot Project has developed a marine debris monitoring protocol for Midway and Papahānaumokuākea. People on Midway, already trained to sort and clean up marine debris using a standardized format, now need to know what to expect with the tsunami debris and how it will be dealt with. Currently much of the debris is shipped back to Honolulu after removal from shores.

Mary Crowley, Director of Project Kaisei of the Ocean Voyages Institute, and her “Marine Debris Think Tank” are bringing together “new technologies, innovations, and capabilities” to help clean debris from our oceans. Based on the debris encountered during her ocean voyages, she has devel-

oped categories and technologies for removal. The tsunami debris forms a new category of large debris, such as telephone poles, and requires further research into the appropriate technology for cleanup.

In the final presentation, Maximenko talked about ways to mitigate the impact. Only a fraction of the tsunami debris, he says, will threaten Mainland coastlines since much will travel into the North Pacific Garbage Patch. After 5 years, 95–99% of the debris will probably still be in the water, either having sunk or still floating.

For mitigation at sea, he recommends the following: explore the debris composition along the pathways predicted by SCUD; monitor the pathways continually with drifting buoys that relay their position via satellite; use available resources to clean and block passages. For mitigation at coastlines, he suggests using various observations along the pathways in order to project landfall for different types of debris.

Maximenko closed by broaching the larger issue: “We should use this tragic experiment of nature to understand the general dynamics of marine debris in the North Pacific and to develop the modeling tools for tracking. Sooner or later we will need to solve the overall debris problem. Marine Debris is an emerging science with specific tasks to develop prognostic models for debris circulation: tracking debris pathways; quantifying the dynamics and describing the characteristic of different kinds of debris; and determining the processes defining different trajectories for different types of debris in different years.”

The final discussion focused on practical solutions for the immediate threat to Midway and the Marine Sanctuary. Strong winter storms make monitoring and cleanup efforts in the region very dangerous, and the high seas make spotting the debris difficult even from airplanes.



From left, front row: Nikolai Maximenko, Mary Crowley, Chris Woolaway, John Bond; back row: Oleg Melnichenko, Ali Bel Madani, Ray Born, J.C. Hutchinson, and Jan Hafner.

Russian Ship Encounters Tsunami Debris

Ever since the March 11 Japan tsunami washed millions of tons of debris into the Pacific Ocean, IPRC's Senior Researcher **Nikolai Maximenko** and Scientific Programmer **Jan Hafner** have been trying to track the trajectory of this debris, which is a threat to marine life, small ships and coastlines. For nearly half a year they had only their state-of-the-art — but still untested — computer models of ocean currents to speculate where the debris might be traveling.

Then on September 11 a surprising event came to their aid when the Russian ship *Pallada* docked in Honolulu Harbor. *Pallada* is a “tall ship,” i.e., a traditionally rigged three-masted sailing vessel used for training Russian cadet seamen. The 354-foot-long *Pallada* had arrived in Honolulu on its homeward journey to Vladivostok at the end of a 3½-month training voyage. **Chris Woolaway** (Hawaiian Ocean Safety Team) arranged an interview on board the ship between Maximenko and Captain **Vasily Sviridenko** and Information and Education Mate **Natalia V. Borodina**.

Maximenko, a native of Russia, described in fluent Russian where the tsunami debris might be found, pointing to the September 11 computer-model plot of the debris field.



The STS *Pallada*. Images courtesy STS *Pallada*.

“The captain is seriously concerned about the debris,” translated Borodina. “The reason the huge commercial vessels travelling the North Pacific have not reported anything is because they cut through such stuff like a knife through butter. Although *Pallada* is one of the largest tall ships plying the seas, it is still by comparison a small ship and the debris is very dangerous for *Pallada*’s thin hull.”

When asked whether he would help in the search for the debris, the captain replied, “Sure! I will have our eager young cadets be on the lookout for debris 24 hours a day.”

After nearly two weeks, exciting email messages started coming from *Pallada*. Soon after passing Midway Islands (see plot below): “Yesterday, i.e. on September 22, in position 31°042,21’N and 174°045,21’E, we picked up on board the Japanese fishing boat. Radioactivity level – normal, we’ve measured it with the Geiger counter,” writes Borodina. “At the approaches to the mentioned position (maybe 10 – 15 minutes before) we also sighted a TV set, fridge and a couple of other home appliances.” Later, on September 27: “We keep sighting every day things like wooden boards, plastic bottles,



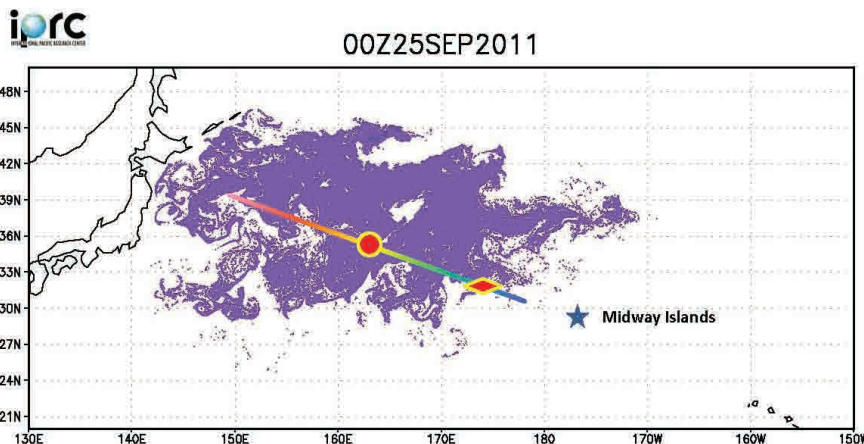
The fishing boat from Fukushima is being lifted aboard the *Pallada*.

buoys from fishing nets (small and big ones), an object resembling wash basin, drums, boots, other wastes. All these objects are floating by the ship.”

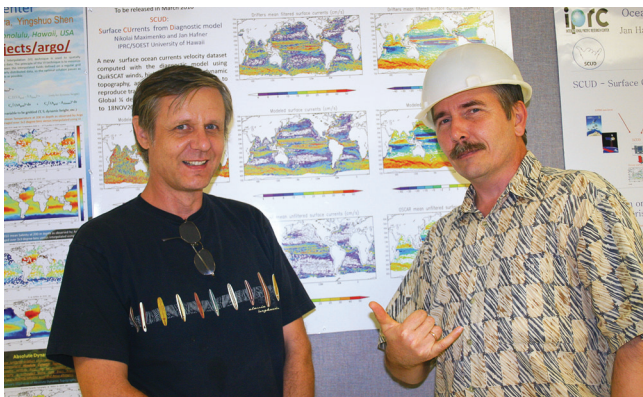
On October 8, *Pallada* entered the port of Vladivostok, and Borodina was able to send pictures. The most remarkable one was of a small fishing vessel about 20 feet long, which they were able to hoist up onto *Pallada*. The markings on the wheel house of the boat show its home port to be in the Fukushima Prefecture, the area hardest hit by the tsunami.

With the exact locations of some of the by now widely scattered debris, the scientists can make more accurate projections about when the debris might arrive at the Papahānaumokuākea Marine National Monument. The first landfall on Midway Islands is anticipated this winter. What misses Midway will continue towards the main Hawaiian Islands and the North American West Coast.

The IPRC has created a series of web pages dedicated to marine and tsunami debris information. The address is soest.hawaii.edu/iprc/news/marine_and_tsunami_debris/debris_news.php



Plot shows the stretch of *Pallada*’s route where debris was sighted between September 21 and 28, 2011. The red rhombus marks the location where the Japanese boat was found, and the red circle denotes maximum debris density experienced. Purple color shows the distribution of the tsunami debris in the Surface Current Diagnostic (SCUD) model on September 25.



Jan Hafner with Nikolai Maximenko wearing hard hat found at Barking Sands Beach.

Inspecting Marine Debris at the Pacific Missile Range Facility

IPRC's marine debris specialists **Nikolai Maximenko** and **Jan Hafner** were invited in July to inspect unusual pieces of marine debris that had just been found at the Pacific Missile Range Facility on Barking Sands Beach, on the west side of the island of Kaua'i. The beach is patrolled daily for security purposes. Since **Dennis Rowley**, Environmental Manager and Range Complex Sustainment Coordinator, took up his post 6 years ago, he had never seen such a large amount of marine debris on the beach! Maximenko thinks that this debris is from the March 11 tsunami — probably not from Japan but from some other Hawaiian island that was inundated by the tsunami.

Marine Debris

by

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Expedition to Kamilo Beach, the “Dirtiest Beach on Earth”

Five large garbage patches in the world ocean are predicted by **Nikolai Maximenko’s** surface current model (*IPRC Climate*, vol. 8, no. 2). The North Atlantic and North Pacific patches have already been found and are making news.

The debris from the North Pacific Patch occasionally escapes and the model shows it floats towards the Hawaiian Islands, making windward shores of the islands trashcans for marine debris. Kamilo Beach near South Point on the Big Island is arguably the most famous beach for the enormous amount of marine debris sweeping up on it. A BBC video labeled it as “The Dirtiest Beach in the World.” The beach is unusual, however, in that it lies not on the windward side of the island, but at its southern tip.

Curious about why this beach is so favored by marine garbage and what currents take it to this unusual location, Maximenko put together a team to investigate: Assistant Visiting Researcher **Oleg Melnichenko** took the lead in deploying current meters in the surf to determine the impact of currents, Scientific Computer Programmer **Jan Hafner** took charge of documenting the garbage and collecting samples, and undergraduate marine biology student **Jeremy Soares** was the “above-and-below-water” movie camera man.

The expedition took place in early June 2010. “We had prepared well, but everything turned out differently from what we had pictured in the IPRC conference room,” recalls Melnichenko. Already finding the way to Kamilo Beach was an adventure with so many unmarked rough little dirt roads.

“Without **Bill Gilmartin** as our guide, we might still be wandering around the lava,” says Maximenko.

Gilmartin, Director of Research from the Hawai‘i Wildlife Fund, has been leading clean ups of the beach since 2003, and over 100 tons of marine debris have been removed. Hafner was surprised by how clean the beach looked: “I was maybe a little disappointed, as our mission was to explore the garbage on Kamilo, though of course it is better this way.”

The largest piece of debris they saw was a 4-foot long tree trunk. Objects that typically litter the windward Hawai‘i beaches were there: Hagfish trap cones from the Pacific Northwest and oyster spacer tubes from East Asia. “The typical size of the debris, however, was 1 inch or smaller,” said Hafner.

Setting the current meters was a challenge. The surf breaks far out, rolling in over a long rocky distance to shore. So the meters had to be put in place during fairly strong waves. “The meters were too heavy for us to swim with them; so we crawled, pushing them forward and coming up for deep breaths,” said Melnichenko.

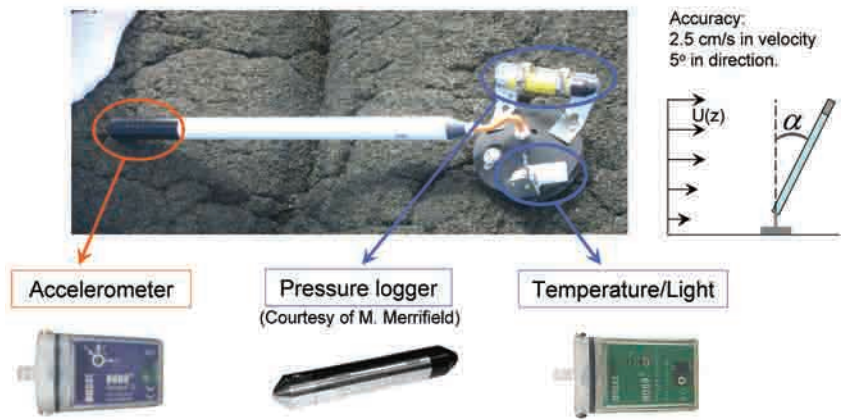


Kamilo Beach as it was several years ago, before the regular clean-up efforts. Image courtesy Mrs. Soares. Red dot in satellite-picture inset shows location of Kamilo Beach.

The pilot deployment showed the meters were feasible. Although “the environment is hostile” for the meters with waves pounding them ceaselessly, they held. Melnichenko: “Their design is simple and they are inexpensive. We were surprised how well they worked. With an accelerometer and with pressure, temperature and light sensors, they are flexible and can be deployed over uncharted ocean topography. You can move them readily if you want to redesign your experiment, for instance place, them in a line straight out from the beach, or along the beach. No drilling is needed so there is no harm to the environment. And they give instant data. The two days the meters stayed, we collected data that showed the daily cycle, the impact of waves and tides, and lower frequency variations of the currents.”

“We are still unclear about the current pattern that brings marine trash to this unusual southwest location. the picture is very complex; the meters are responding to many different things,” explained Melnichenko.

“Our exploration brought us no answers but inspired more questions and speculations,” said Maximenko. “We confirmed that some debris on Kamilo Beach has travelled in the Pacific subtropical gyre from far away East Asia and from the North American West Coast. The current meters tell us that the waves and the tides provide the energy, pushing the debris to shore like a broom. The rather long shore break may contribute to debris accumulation. But, we still need to understand the interaction between large-scale currents collecting debris from the entire North Pacific and the coastal dynamics that move the debris over the reef.”

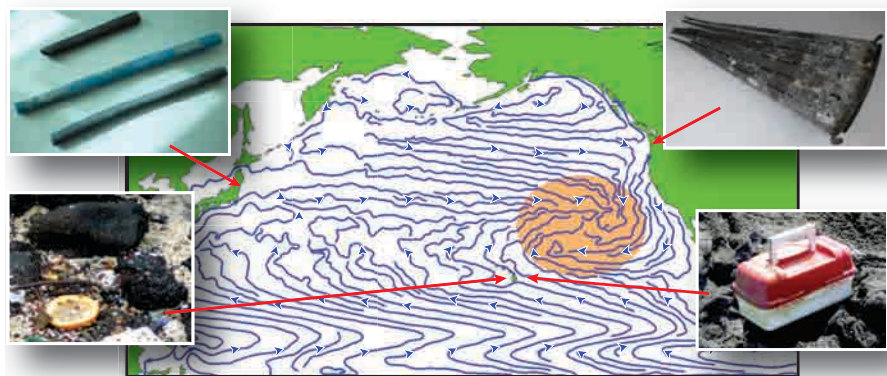


SeaHorse tilt current meter developed by Vitalii Sheremet from the University of Rhode Island. While in the water, a buoyant plastic pipe containing an accelerometer is anchored vertically to the sea floor. Currents cause the pipe to tilt. The angle of the tilt, measured by the accelerometer, is converted into velocity of the current. Additionally, temperature and pressure sensors are attached to the current meter’s anchor.

“I’m particularly curious about what happens over time to the plastic, how the small pieces form. The fragments have no sharp edges. Does the plastic dissolve? This could account for the puzzling results of our recent *Science* study with **Kara Lavender Law** on the North Atlantic Patch, which found no increase in plastic density over the decades, even though plastic production increased a lot during that time. If plastic dissolves, does it release CO₂ and contribute to ocean acidity?”

“We need chemists and we need unified global observations to tackle this marine debris problem,” Maximenko thinks. “Much is being done, but efforts are so varied that scientifically usable data has not yet been collected.”

In conjunction with the “5th International Marine Debris Conference” to be held in Honolulu in March 2011, Maximenko is organizing the “Hydrodynamics of Marine Debris Workshop” to try to generate a more unified and scientific approach to this huge problem facing our oceans and the life in it.



Map showing the actual “mean trajectories of surface drifters” (blue lines with arrows) and the convergence associated with the garbage patch (in orange). The origins of objects found on Kamilo Beach are also shown: oyster spacer tubes from Asia, Hagfish trap cones from the US West Coast, and items from waters around the Big Island.

Tracking Ocean Debris



Mankind generates large amounts of debris that end up in the ocean: plastics thrown carelessly overboard, torn fishing nets, cargo ship losses, and all the junk carried by rivers into the ocean. Such debris is a hazard to shipping and to marine life. As more and more of the stuff accumulates, tracking and even removing it becomes necessary. But the oceans are vast and the debris is hard to track over the huge distances. Coastline surveys and air-borne monitoring systems are costly efforts. IPRC's **Nikolai Maximenko** has been heading a team that has developed a computer model to chart the likely paths of floating marine debris and where it may end up in the World oceans.

Maximenko's work on the debris problem started with basic research. In collaboration with **Peter Niiler** at Scripps Institution of Oceanography, he wanted to improve maps of ocean currents. Surface currents are mainly a combination of Ekman currents driven by local wind and geostrophic

currents maintained by the balance between pressure gradients and the Coriolis force. These surface currents are detectable from the paths taken by drifters released into the ocean. Almost 12,000 freely drifting buoys of a unified design have been deployed in the Global Drifter Program during and after such experiments as WOCE and CLIVAR. Maximenko thus determined the recent paths of the drifters tracked by satellites and combined the information with satellite altimetry,

wind and gravity measurements. In this way, he was able to create a high-resolution map of the mean dynamic ocean topography and derive the mean geostrophic and Ekman circulation in the upper ocean (Figure 1, Maximenko et al., *submitted*).

The distilled data reveal, among other things, the existence of narrow east-west jet-like streams that give the ocean-current map a striped look (Maximenko et al., 2008). Oceanographers had begun to detect such flows

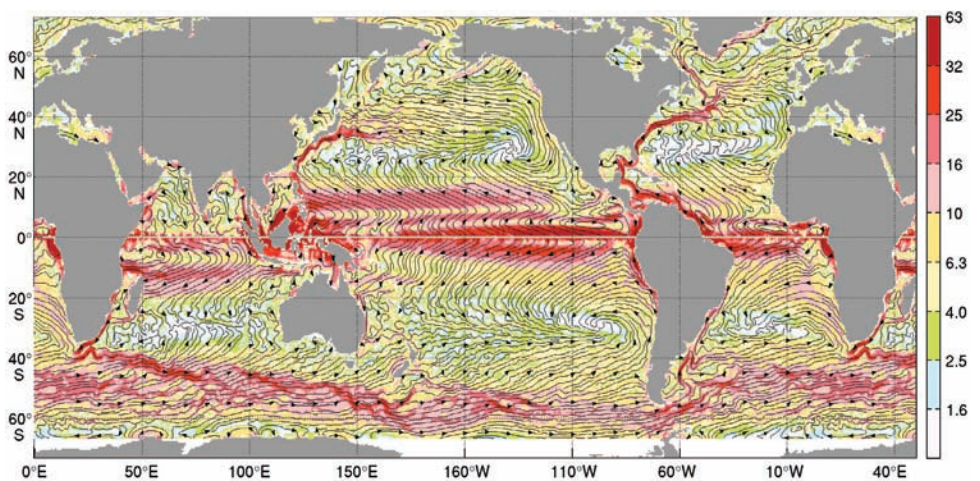


Figure 1. Mean near-surface current streamlines and mean zonal velocity (colors; unit cm/s) calculated at 1-m depth. Currents are calculated as a combination of geostrophic and Ekman currents.

at depth in high-resolution ocean general circulation model results, but were uncertain whether they were real or just a model artifact (*IPRC Climate*, vol. 5, no.1). Maximenko's observational data showed the "jets" are a real phenomenon and even more pronounced at the surface than indicated by the general circulation model simulations. The origin of the jets is still a mystery.

The freely drifting surface buoys also happen to provide a unique opportunity for tracking ocean debris. Carried along by ocean currents, the trajectories of these buoys yield estimates not only of ocean current velocities, but also, where the flows separate or diverge and where they come together or converge. Where flows diverge and water wells up from the deep, the ocean is often rich in nutrients for marine life. Where flows converge, debris can be expected to collect.

One approach to using drifters for determining flow divergence and convergence is to analyze the density of drifters. As a Lagrangian "particle," a drifter will stay longer in regions of surface convergence. Unfortunately, drifter density is affected by not only ocean currents but also the deployment scheme. The drifters have been deployed over many years and often in small areas for special regional experiments. Figure 2 illustrates how deployment and currents interact. Hundreds of drifters were let loose close to the equator but they were soon pushed to higher latitudes by the divergence associated with the equatorial upwelling forming the famous "cold tongue" along the equator. Other massive drifter launches occurred off the California and the US East Coast, as well as in the Japan Sea. These drifters have not been dispersed much by ocean currents. In contrast, although deployments in the mid-latitude South Pacific are scarce, the density of drifters, the blue dots in Figure 2c, is high and must therefore be ascribed to the ocean currents.

To skirt this problem of non-uniform drifter-distribution due to deployment, Maximenko developed a computer model that can use even short drifter trajectories to chart the probable paths of drifters over long time periods. The movement of each drifter in the model is based on the actual paths that the nearly 12,000 drifters took over five days from their various locations in the ocean. Maximenko first divided the globe surface into thousands of two-dimensional bins of a half degree in size; for each drifter, he used all its positions as given by the satellite determinations. From these displacements, he calculated the probability of a statistical drifter to move in 5 days into, or over, bins surrounding its original

location. This calculation yields estimates of both mean distance and dispersion of the drifters. The process can then be repeated in the model every five days for as long as is needed to determine the final maximum drifter density.

Once he had computed the behaviors of real drifters, Maximenko initiated his ocean model with uniformly distributed drifters (Figure 3a) and tracked the evolution in drifter density for as long as 1000 years, the assumption being that statistics of the winds and currents remain steady over this long period.

In the model, the drifters are lost only when they enter, but never leave, a bin. This typically occurs in shoreline bins where drifters are washed on shore. The model shows that such drifter losses are surprisingly scarce, implying that debris tends to stay in the ocean for a very long time. Wind-

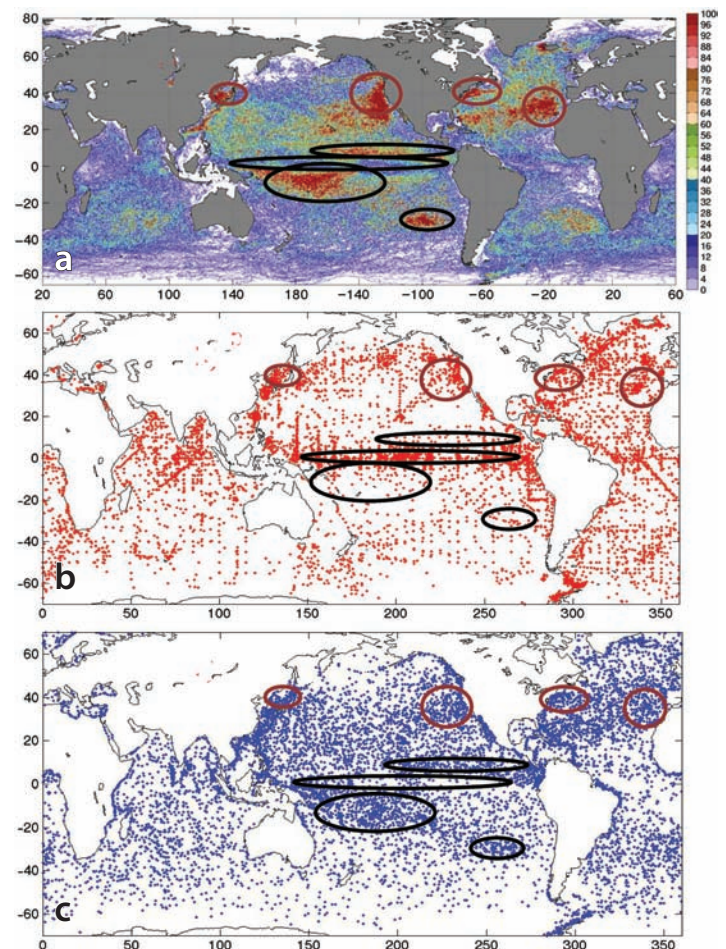


Figure 2. (a) Number of 6-hourly drifter fixes in 1/4-degree boxes, (b) locations of the drifter releases, and (c) last reported coordinates. Brown ellipses indicate regions where higher density of drifter data is consistent with the drifter deployments. Black ellipses indicate regions of highest and lowest drifter density that results from ocean currents.

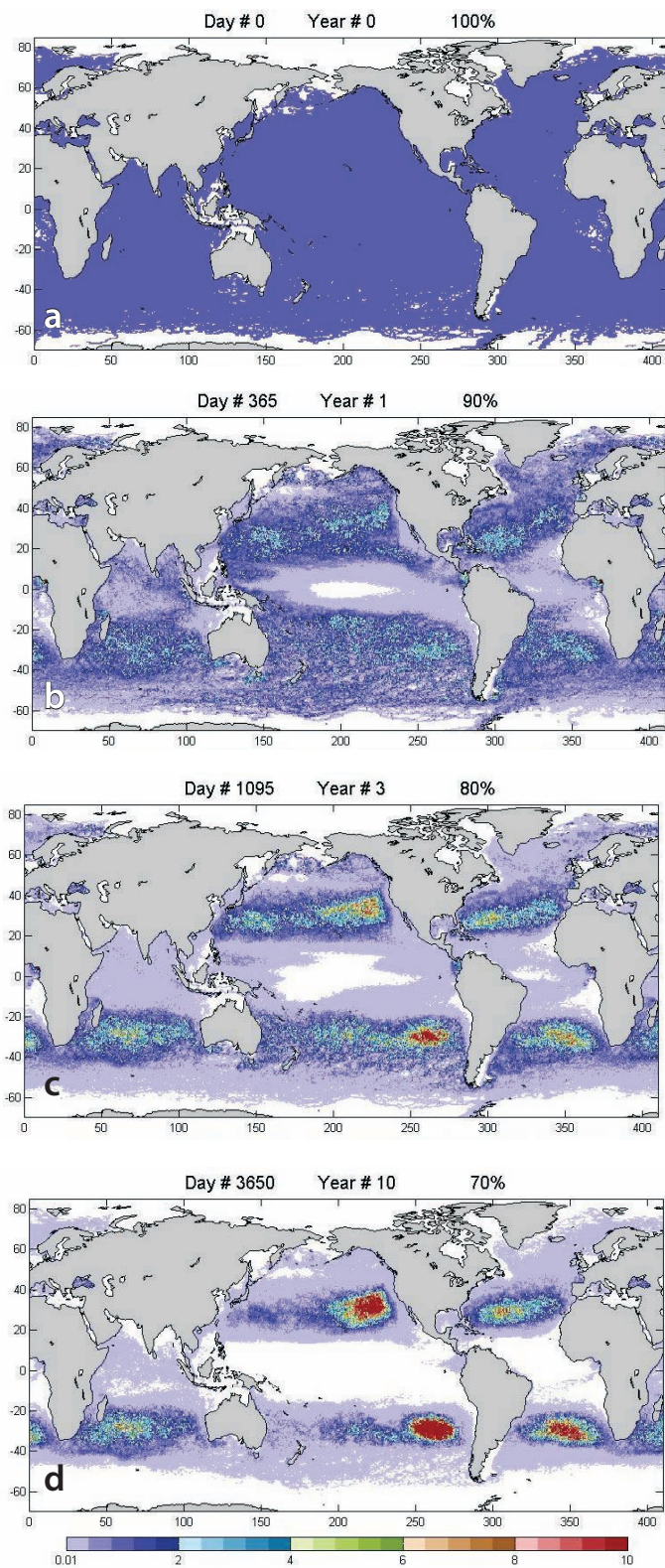


Figure 3. Simulation of evolution of drifter density (or marine debris): (a) from an initially homogeneous state, (b) after one year, (c) after 3 years, (d) after 10 years of advection by currents, as determined from real drifter movements. Units represent relative change in drifter concentration.

driven ocean currents are organized in such a way that most of the drifters are pushed offshore and kept in regions of convergences, which are far from the coast. After ten years of integration, only 30% of the model drifters had been lost.

Calculations show that the drifters tend to collect in five regions (Figure 3). These regions correspond to the centers of the five subtropical gyres.

The model shows that, before the drifters start to dissipate, their density increases to as much as 15 times their original density in the North Atlantic and South Indian Ocean, 30 times in the South Atlantic, 45 times in the North Pacific, and 150 times in the South Pacific.

The two regions where most drifters collect or converge are in the eastern North and South Pacific. In the North Pacific this place lies between Hawai'i and California and has been recently identified as the location of the Great Floating Garbage Patch, a huge cluster of partly defragmented plastic and ghost nets and other flotsam endangering marine life. The South Pacific patch has an even higher drifter-density in the model. Despite its predicted location being so close to Easter Island, this patch has not yet been detected in the real world. Perhaps this is because much less long-living debris is produced in the Southern Hemisphere than in the Northern Hemisphere.

In support of the NOAA Marine Debris Program, Maximenko is now developing further this diagnostic technique for identifying places in the ocean where debris is likely to collect and be retrieved.

Reference

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IPRC Teams with Adventure Sailor

There is a long tradition in oceanography and meteorology of employing “ships of opportunity” whose crew take measurements incidentally as they pursue their course through the ocean. IPRC has now engaged its own very unusual ship of opportunity, one that will take novel measurements of solid pollution in the ocean. The adventure sailor **Jim Mackey** is attempting a solo circumnavigation of the globe and has volunteered to take samples of floating debris as he makes his way from his starting point in the North Atlantic through the South Atlantic, Indian, and South Pacific Oceans, back into the Atlantic. To collect the samples, he will use a trawl designed and built by **Markus Eriksen** (Algalita Marine Research Foundation) especially for use on his small sailboat. By trawling for debris samples in seldom visited regions, his voyage will contribute to several scientific programs.

IPRC’s **Nikolai Maximenko** and **Jan Hafner** have supplied Jim with equipment and key navigational data so that he can measure the levels of



A Rival 34, the type of sailboat on which Jim is sailing. Photo source <http://www.yachtsnet.co.uk/index.htm>

Trawl built by Markus Eriksen for measuring marine debris from Jim’s boat.

partially defragmented plastics in the eastern part of the South Pacific, where Maximenko’s model predicts is the world’s ocean strongest convergence of flows and where floating matter collects from the Southern Hemisphere (see story in *IPRC Climate*, Vol. 8, No. 2). Guided by the model results, Jim will also be looking for plastic fragments in

the subtropical convergences of the South Atlantic and South Pacific and along the Antarctic Circumpolar Current.



Projected route of Jim Mackey’s solo circumnavigation.