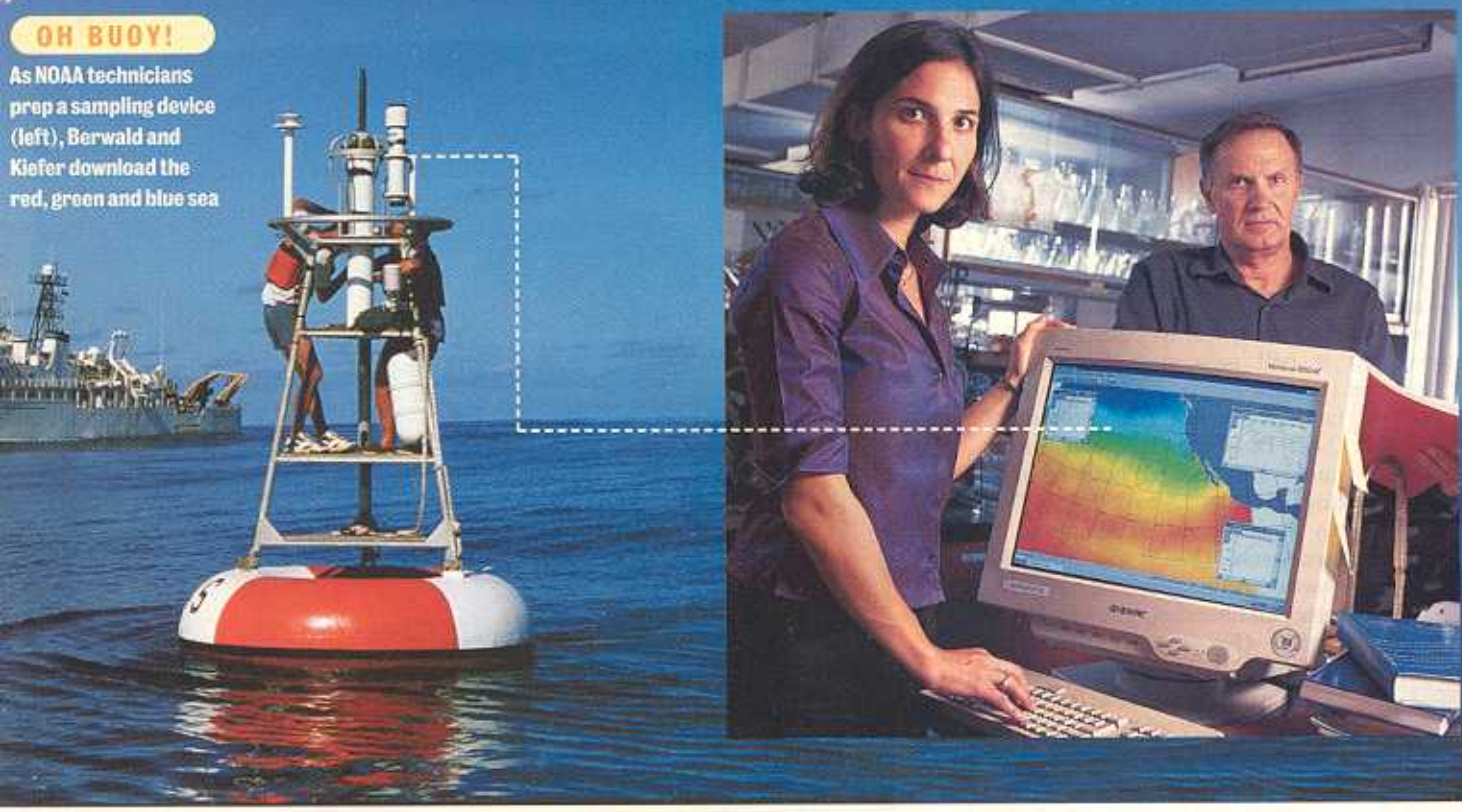

OH BUOY!
As NOAA technicians prep a sampling device (left), Berwald and Kiefer download the red, green and blue sea

oceans of research flowing together

SCIENTISTS WERE AMONG THE FIRST TO USE THE NET. NOW IT'S STANDARD EQUIPMENT FOR COLLECTING DATA AND SHARING THEM WITH THE WORLD. BY THOMAS HAYDEN

WHEN JULI BERWALD STARTED her research career a decade ago, oceanography was no discipline for landlubbers. Whether it was an afternoon on Santa Monica Bay or monthlong research expeditions to the South Pacific, collecting data meant going out to sea and dropping bottles, thermometers and probes down into the deep. Times are changing. These days, much of her data come in over the Internet, from automated sampling equipment, satellites and colleagues around the world. Sitting at her desk on the University of Southern California's South-Central L.A. campus, Berwald can summon up water-temperature measurements from the Sargasso Sea, current speeds and directions off Hawaii and the concentration of dissolved nitrate in Monterey Bay, Calif., much of it in real time. For wired oceanographers like Berwald, carpal tunnel syndrome is replacing seasickness as the major job hazard. "It's kind of terrible, actually," she says. "I really don't have to go to sea anymore at all."

Scientists were e-mailing lab results and "Far Side" punch lines back and forth for years before the phrase "you've got mail" entered the lexicon. In the two decades since the debut of Bitnet, one of the predecessors of today's Internet, communicating by computer has worked its way into nearly every facet of scientific endeavor. There are plenty of flashy high-tech applications—Web-controlled robotic lab assistants, telescopes that respond to e-mail commands—but the most significant impact of e-science may be the most basic. The Internet makes it possible to share specialized knowledge and large amounts of data quickly and efficiently with colleagues around the world. The resulting synergy is transforming every discipline of science, from particle physics to phylogeny. The effects are particularly evident in fields like oceanography and marine biology, in which widely dispersed groups of investigators work together and generate vast amounts of data that require specialized interpretation.

"I really have no idea how I would get any of this done without [the Internet]," says Berwald, a postdoctoral researcher. Working with USC oceanography professor Dale Kiefer, she distills years' worth of precise observations—e-mailed to her directly or posted to Web sites by colleagues around the world—into elegant sets of equations that can be used to predict how a particular part of the ocean might respond to changes, such as increased fishing or discharge from a nearby pulp mill.

That sort of work requires vast quantities of pure data, which is where scientists like Michael McPhaden come in. A physical

D. SWEENEY—NOAA (LEFT); MICHAEL LEWIS

oceanographer with the National Oceanic and Atmospheric Administration in Seattle, McPhaden oversees the Tropical Atmosphere-Ocean (TAO) project, a network of 70 sampling buoys spread across the equatorial Pacific from Indonesia to the Galápagos Islands. The buoys gather some two megabytes of air and ocean data every day and transmit a condensed version of the information to shore via satellite. The raw datastream is zapped over the Net to McPhaden's lab for processing and also forwarded to researchers and weather forecasters, and posted to the project Web site (www.pmel.noaa.gov/toga-tao/home.html), often within hours of being collected. The system made the accurate and early prediction of the 1997 El Niño possible and has become an integral part of weather forecasting. "Our intent is to spread the data as widely as we can," says McPhaden. "More availability means more scientific return."

E-science does not have to be particularly high tech in order to be high impact. Decades' worth of data, much of it once all but hidden in obscure libraries and the back corners of musty old labs, have been dusted off, digitized and posted on the Web. Jeremy Jackson, a paleobiologist at Scripps Institution of Oceanography in San Diego, studies the evolution of coral reefs. Together with more than 30 colleagues from seven countries and around the United States, Jackson is contributing to a Web catalog and identification guide, developed by Ann Budd at the University of Iowa, for every species of marine animal known to have lived in the seas of tropical America over the past 24 million years. "In many ways the work we're doing is 19th-century science," says Jackson, "but on a scale that has never before been possible." Now, instead of taking a month to dig through collections of shells and preserved specimens, researchers and students will be able to surf over to nmita.geology.uiowa.edu to access the biological treasures of 500 different museum collections, information once available only to specialists with generous travel grants. The impact in Europe and North America is significant, Jackson says, but in Latin America, where research funding is hard to come by and technology-starved colleagues have been known to monopolize the local Internet cafés for hours at a time, the Web is making top-level research possible for the first time. "Everything the Internet does here, it does all those things and more in the developing world."

Sometimes e-science can be as simple as a collegial helping hand. "Say I've got a snail and I don't know what it is," says Jackson. "The world expert lives in New Zealand and I'm in Panama. So I send an image" and an answer comes back within days. Sure, you could do the same thing the old-fashioned way, speaking of snails, but e-mail means never having to rely on the postal service of Micronesia. The interactions can be much more involved than that. "With one collaborator," recalls McPhaden, "we wrote and revised a paper, submitted it and had it published before we ever met in person." The work was conducted almost entirely over the Internet and lasted more than a year, considerably longer, one would suspect, than most online relationships.

As for Berwald, she says she misses going on research expeditions, and being at arm's length from the object of her study has its drawbacks. "You gain a lot going to sea," she says, "intuition you don't get sitting at a desk." In science as in the rest of the wired world, the paradox of e-mail applies; the more connected you are the less real contact you have with the world. It's just that in science, all that e-mailing might actually be helping to get some work done.

With ERIKA CHECK

FAT FISH

Marine biologists are getting wired, too. A trip to the watery depths is now often followed by a trip to the Web.

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