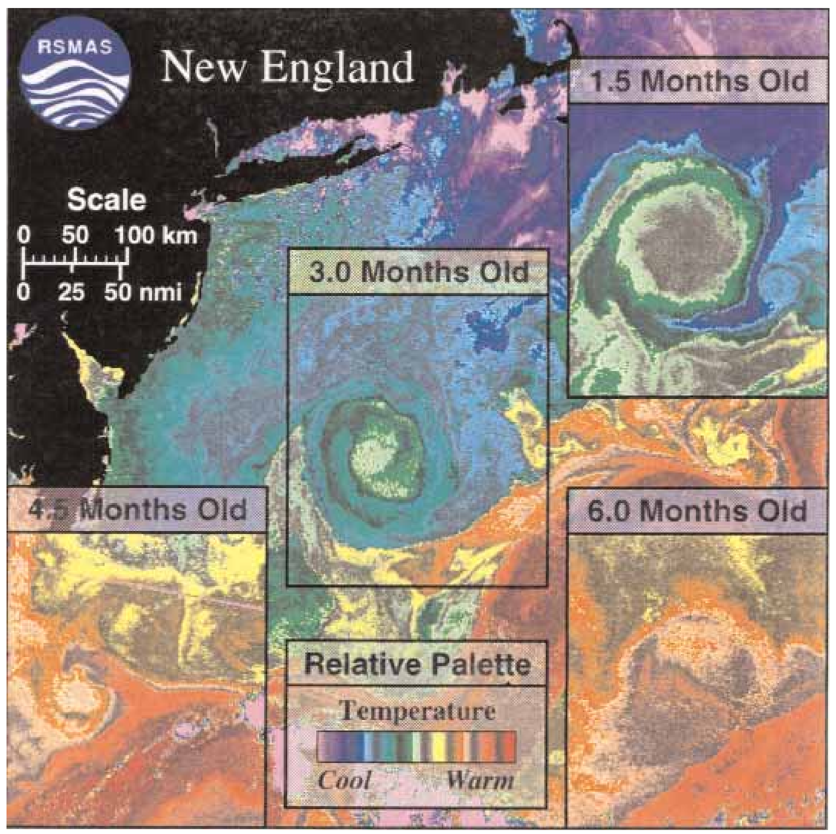
Computerizing the Ocean

BY JAMES SCHULTZ

Two miles off the Virginia coast a supertanker wallows in heavy seas. Earlier that afternoon, during a fierce coastal storm, it collided with a container ship. The second ship survived, limping into the Port of Hampton Roads with a crumpled bow. The oil-carrying leviathan wasn't as fortunate. Crippled, mortally wounded, the tanker is listing severely and pouring much of its cargo directly into the ocean.

The remnants of the storm will disperse some of the hundreds of thousands of gallons of leaking petroleum, but a huge slick is heading directly for shore and Virginia's tourist beaches. Can the spill be found and contained in time?



Parcels depict images of a warm core eddy from the Gulf Stream, at various times during it's life as it moves southwest along the Atlantic coast. (Reproduced from Holdzkom, J.J., II, S. B. Hooker and A. D. Kirwan, Jr., "A comparison of a hydrodynamic lens model to observations of a warm core ring," Journal of Geophysical Research, 100, C8, 15889-15897, 1985.)

One day, says A.D. Kirwan Jr., Old Dominion professor of oceanography, it will be possible to monitor the extent of such a potential disaster minute by minute with the help of software that he and colleagues have been developing for more than five years. Kirwan, professor of computer science and oceanography Chester E. Grosch and doctoral student John J. Holdzkom have collaborated to create "particle-in-cell" software that models changes in temperature, salinity, speed and tidal heights of ocean currents that develop and pass near coastlines. The effects of these oceanic "fronts" can extend for dozens of miles and profoundly affect sediment transport, pollution dispersal and, in deep water, the propagation and properties of sound.

For naval forces operating close to shore, abrupt changes in seawater composition and currents can delay or disrupt operations and troop deployment. The navy is thus beginning to explore ways of developing "Rapid Environmental Assessments," or REAs, computer programs able to instantly analyze a wealth of ocean conditions and predict their subsequent development. According to Kirwan, the predictive potential of the particle-in-cell program attracted the interest of the Office of Naval Research, which has spent roughly half a million dollars underwriting the project over the past five years.

"REA has definitely caught the navy's attention," he says. "In the days of the Cold War, all the action was in mid-ocean. But now the navy has to consider coastal waters. As you move closer to the coast it is really important to know currents in excruciatingly small detail."

Making The Real Realer

Scientists have known for decades that computers would one day be able to effectively model the movement of fluids like water and air. Only recently, however, have microprocessors become suitably powerful, and software sufficiently sophisticated, to render reasonably accurate simulations. Even now the models have difficulty in predicting real-world behavior — a limitation seasoned meteorologists and amateur weather watchers know all too well.

Still, significant progress has been made. In the case of the particle-in-cell program, Kirwan, Grosch and Holdzkom have utilized advances in parallel processing. It's a technique that divides a complex task into smaller tasks, each of which is handled by a separate microprocessor. Conventional computing relies on serial processing: the one-at-a-time, step-by-step execution of software instructions. Working in tandem, multiple processors outpace even the fastest serial microchip.

Particle-in-cell computations are made nearly half a world away, at a supercomputer facility located on the Hawaiian island of Maui. It is one of a handful of sites nationwide able to handle the program's complexity.

"You need lots of lots of memory to successfully make these computations," Grosch points out. "In the computational science field, this is what's known as an embarrassingly parallel computation. If you don't get good performance, you ought to be embarrassed."

The particle-in-cell program gets its name from the manner in which its designers describe the movement of a defined space — a "fluid parcel" — within the ocean. The parcels are mathematical constructs that encapsulate the composition, structure, movement and speed of cube-shaped volumes of seawater. Accurate fluid-parcel description is made possible by direct oceanographic observation, or data culled from the historical record.

The model is scaleable, able to represent movement of very small or extremely large ocean fronts. In nature, fronts vary dramatically in size: from inches to feet to several miles wide, to dozens of miles long and hundreds of feet deep. To accurately mimic real-world conditions, the particle-in-cell program incorporates millions of fluid parcels in each calculation.

From a computational point of view, determining the behavior of the boundary layer between seawater of different densities is particularly challenging. Typically, a light-density water "lens" floats on top of a heavier mass below. The lenses, offshoots of warm Gulf Stream currents, can persist for a year and carry for great distances whatever sea life or manmade substance is trapped within them. "Think of these kinds of computations as experiments," Grosch advises. "You're doing experiments on computers that you can't do in the real world. It's a tool to try to understand real-world dynamics."

Nowcasting at your Fingertips

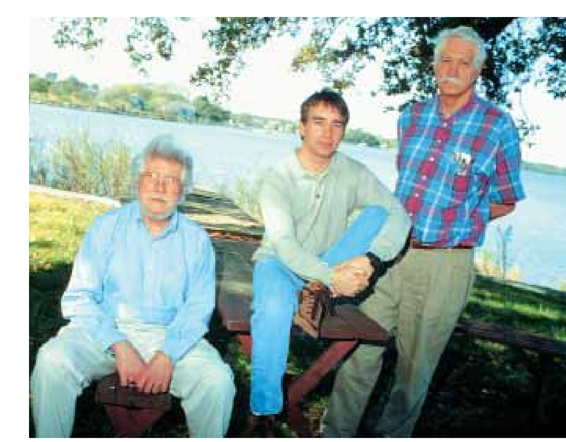
While the military remains the software's primary patron, oceanography professor Kirwan hopes to find other interested parties to fund the next generation of particle-in-cell programs. He says a fully mature version of the software could go a long way to create what some are calling "nowcasts": as-it-happens environmental profiles synonymous with the aforementioned REAs. "In the long run," Kirwan predicts, "the real application of REA will be in the civilian sector."

Future versions of the particle-in-cell software, Kirwan says, should one day be able to link to sensor arrays in the water, atmosphere and in space. The flood of information on water movement and composition could then be funneled over high-speed Internet connections to model-running computers. Naval officers and emergency workers alike would thus have another array of formidable tools at their disposal.

"My vision is that, in 10 years when the technology is mature, that knowledgeable people on ships would have massively parallel engines to do the calculations on site," Kirwan ventures. "Or otherwise to have high-speed, high-bandwidth connections so the work could be done somewhere on land."

Kirwan says he, Grosch and doctoral student Holdzkom have met their initial goal of developing solid proof-of-concept software that accurately models complex ocean processes. Should continued funding be secured, Kirwan says he hopes to develop a prototype that could simulate ocean fronts in "any coastal region in the world."

"We'll take this model and embed it in a [larger] regional-scale simulation," Kirwan promises. "We've made this thing run. And we have confidence in the results."



Chester Grosch, John Holdzkom and A.D. Kirwan look forward to widespread application of particle-in-cell technology to a wide variety of environmental problems.