Observing Oceanic Submesoscale Processes From Space

PAGE 488

Observations made by satellite altimeters since the 1980s have provided progressively improved views of the global ocean mesoscale eddy field, which contains most of the kinetic energy of the ocean circulation. Along with these improved views, ocean models have progressed from coarse-resolution, highly dissipative mesh grids to higher resolutions where mesoscale eddies dominate the model simulations. We are now able to produce simulations of the present state of the ocean that compare increasingly well with observations. However, the skill of these models in making long-range predictions of the ocean is still very limited, because the models lack a physically based representation of the submesoscales, i.e., scales of 1–100 kilometers, that are important for turbulent transport and energy dissipation. Ocean models running at sufficient resolutions to address submesoscale dynamics have just recently begun to emerge [e.g., *Capet et al.,* 2008], but we need global observations at these scales to guide the model development.

Conventional Radar Altimetry

Conventional nadir-looking radar altimeters have a footprint of the order of 2–10 kilometers. Even with thousands of pulses averaged over 1 second, the noise level of the sea surface height (SSH) measurement is substantial, making ocean SSH signals at wavelengths less than 100 kilometers not well observed. A typical wavenumber spectrum of SSH deviations from a time mean, sampled along a satellite pass (from the joint NASA/Centre National d'Etudes Spatiales Jason mission) from the Bering Sea to the Drake Passage in the Southern Ocean, is shown in Figure 1. At wavelengths longer than 100 kilometers, the power density increases with wavelength, a characteristic typical of large-scale ocean variability. The spectral slope levels off at wavelengths shorter than 100 kilometers, showing the dominance of measurement noise at the submesoscales. When such noisy measurements along nadir tracks are smoothed and merged to produce two-dimensional maps, the spatial resolution is of the order of 200 kilometers, even with combined data from two altimeters [*Ducet et al.,* 2000].

Wide-Swath Altimetry

The technique of radar interferometry, demonstrated by NASA's Shuttle Radar Topography Mission to map the world's land topography, offers an approach to mapping SSH at high spatial resolution over a finite swath. *Fu and Rodriguez* [2004] discussed the prospects of applying this technique for oceanographic applications, and *Alsdorf et al.* [2007] discussed its prospects for hydrological applications. The U.S. National Research Council's Decadal Survey in 2007 recommended that the concept of a wide-swath altimeter for studying both the oceans and land surface waters, called Surface Water and Ocean Topography (SWOT), be flown on a satellite mission in 2014–2016.

A group of oceanographers and satellite mission designers met at the Scripps Institution of Oceanography, in La Jolla, Calif., on 28–30 April 2008 to discuss the feasibility and requirements for SWOT to measure the oceanic submesoscale. SWOT will carry two synthetic aperture radar (SAR) antennas, each of which illuminates a swath of 60–70 kilometers with an incidence angle of approximately 4°. The backscattered signals are received by both antennas. The radar's precision timing system determines the range of the returned signals, while the phase difference between the signals received by the two antennas allows the determination of the incidence angle of the returned signals via the principle of interferometry. Once the range and incidence angle are known, SSH is calculated from triangulation. Because the spatial resolution of SAR is of the order of a few tens of meters, there are a large number of independent observations at scales of 1–100 kilometers. The measurement noise can be significantly reduced by averaging.

What It Takes to Make Significant Advances

To make an order of magnitude advance in resolution, the measurement noise level must be less than the magnitude of the ocean signal at a wavelength of 10 kilometers, as shown by the horizontal dashed line in Figure 1, in which the SSH spectrum is extended from its linear portion by a straight line to wavelengths of 10 kilometers. The threshold of noise level corresponds to 1 centimeter of random error at a sampling rate of 1 kilometer, compared with the noise of 5 centimeters at a 1-kilometer sampling rate for the Jason altimeter. This performance in SSH measurement translates to a geostrophic velocity error of 3 centimeters per second at a 10-kilometer wavelength at 45° latitude. The two-dimensional SSH map from SWOT would then allow the study of the submesoscale ocean eddies, fronts, narrow currents, and even the vertical velocity at these scales.

Potential Breakthroughs in Ocean Dynamics and Biogeochemistry

Global observations of the oceanic submesoscale are essential to quantifying ocean uptake of climate-relevant tracers such as heat and carbon. Tracers are transported into the ocean by large-scale mean circulation, as well as by mesoscale and

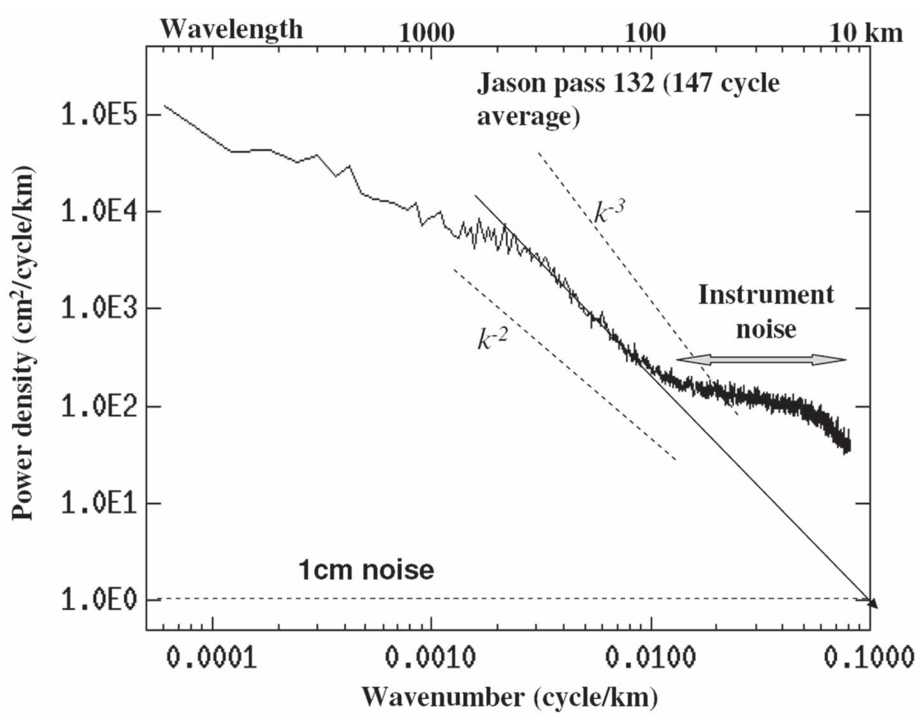

Fig. 1. Spectrum of sea surface height anomaly from Jason altimeter data (curve). The two slanted dashed lines represent two spectral power laws with k *as wavenumber. The horizontal dashed line represents the threshold of measurement noise at a 1-kilometer sampling rate. The slanted solid straight line represents a linear fit of the spectrum between 0.002 and 0.01 cycles per kilometer. It intersects with the threshold noise level at the 10-kilometer wavelength.*

submesoscale eddies. Traditional altimeters revealed the fundamental role of mesoscale eddies in the horizontal transport of tracers. Recent theoretical work suggests that submesoscale motions play a leading role in the vertical transport. Vertical velocities associated with the divergence and convergence of geostrophic motions on a 10-kilometer scale penetrate to a few hundred meters below the ocean surface. Hence, SWOT's spatial resolution will allow the computation of the exchange of properties between the ocean surface boundary layers and the deep ocean. Furthermore, these measurements will be fundamental to improving the skills of coupled climate models that are very sensitive to the exchange of properties between the ocean and the atmosphere. The information is also important for understanding the oceanic biological carbon pump and thus is of great value to biogeochemical studies of the ocean. Should the SWOT mission fly, our understanding of the ocean and its role in climate is likely to be radically advanced.

Acknowledgments

The research presented in this brief report was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA.

References

Alsdorf, D., L.-L. Fu, N. Mognard, A. Cazenave, E. Rodriguez, D. Chelton, and D. Lettenmaier (2007), Measuring global oceans and terrestrial freshwater from space, *Eos Trans. AGU, 88*(24), 253, 257.

Capet, X., J. C. McWilliams, M. J. Molemaker, and A. F. Shchepetkin (2008), Mesoscale to submesoscale transition in the California Current System: I. Flow structure, eddy flux, and observational tests, *J. Phys. Oceanogr., 38,* 29–43.

Ducet, N., P. Y. Le Traon, and G. Reverdin (2000), Global high-resolution mapping of ocean circulation from TOPEX/Poseidon and ERS-1 and -2, *J. Geophys. Res., 105*(C8), 19,477–19,498.

Fu, L.-L., and E. Rodriguez (2004), High-resolution measurement of ocean surface topography by radar interferometry for oceanographic and geophysical applications, in *The State of the Planet: Frontiers and Challenges in Geophysics, Geophys. Monogr. Ser.,* vol. 150, edited by R. S. J. Sparks and C. J. Hawkesworth, pp. 209–224, AGU, Washington, D. C.

—Lee-Lueng Fu, Jet Propulsion Laboratory, California Institute of Technology, Pasadena; E-mail: llf@jpl.nasa.gov; and Raffaele Ferrari, Massachusetts Institute of Technology, Cambridge

NEWS

In Brief

PAGE 489

Atmospheric brown cloud report The combined effects of human-made atmospheric brown clouds (ABCs) and greenhouse gases in the atmosphere are having broad-based impacts, including causing some cities to get darker, contributing to faster melting of some glaciers, masking the effects of climate change, and having negative effects on agriculture and air quality, according to a 13 November report released by the United Nations Environment Programme (UNEP). "We believe today's report brings ever more clarity to the ABC phenomena and in doing so must trigger an international response, one that tackles the twin threats of greenhouse gases and brown clouds and the unsustainable development that underpins both," said Veerabhadran Ramanathan, head of the UNEP scientific panel carrying out the research and a professor at the Scripps Institution of Oceanography, La Jolla, Calif. The report, "Atmospheric brown clouds: Regional assessment report with focus on Asia," can be found at http://www.unep.org.

Deep-sea observatory The first deep-sea ocean observatory offshore of the continental United States has begun operating in the waters off central California. The remotely operated Monterey Accelerated Research System (MARS) will allow scientists to monitor the deep sea continuously. Among the first devices to be hooked up to the observatory are instruments to monitor earthquakes, videotape deep-sea animals, and study the effects of acidification on seafloor animals. "Some day we may look back at the first packets of data streaming in from the MARS observatory as the equivalent of those first words spoken by Alexander Graham Bell: 'Watson, come here, I need you!'," commented Marcia McNutt, president and CEO of the Monterey Bay Aquarium Research Institute, which coordinated construction of the observatory. For more information, see http://www.mbari.org/news/news_releases/2008/mars-live/mars-live.html.

Science teaching certificate More than 200 educators will receive fellowships over the next 5 years to participate in NASA's Endeavor Science Teaching Certificate Project, the agency announced on 14 November. Through workshops, online and on-site graduate courses, and NASA educational materials, the project will expose educators to NASA science and engineering and support them in translating the information for use in classrooms. "Through the program, educators will learn to deliver cutting-edge science into the classroom, promoting science, technology, engineering, and mathematics education," according to Joyce Winterton, assistant administrator for education at NASA Headquarters, in Washington, D. C. Project fellows will earn a certificate from Teachers College Innovations at Teachers College, Columbia University, New York, and graduate credit from other institutional partners. For more information, visit http://education.nasa.gov/home/index.html.

Mount Wilson centennial The 60-inch reflecting telescope at Mount Wilson Observatory, in southern California, which helped scientists measure the Milky Way and determine our solar system's position within it, celebrates its 100th anniversary in December. "The 60-inch continued the Copernican Revolution by dethroning the Sun from the center of our galaxy," noted observatory director Harold McAlister. The telescope, with its silver-on-glass reflectors, also established the basic design for observatory telescopes on Earth. Capable of operating in several different optical configurations, the telescope was the first one built primarily for photographic and spectrographic use. With its 5-foot-diameter mirror, the telescope was the largest in the world until 1917. The telescope is retired from active science but is made available to groups for viewing astronomical objects. The observatory was founded by astronomer George Ellery Hale under the auspices of the Carnegie Institution of Washington. For more information, visit http://www.mtwilson.edu.

—Randy Showstack, Staff Writer