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Ocean Mixing Studied Near Hawaiian Ridge

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The Hawaii Ocean Mixing Experiment (HOME) is a grassroots program to study turbulent mixing processes near the Hawaiian Ridge. The HOME is motivated by the desire to understand diffusive aspects of the advective-diffusive balance that mediates the general circulation of the oceans. HOME is focused on tidally driven mixing, given the ubiquity of the tide as a deep-sea energy source.

As the sea surface cools at high latitude, surface waters sink. subsidence rate is sufficient to fill the worlds ocean with cold bottom water in approximately 3,000 years. Diffusive processes that transfer heat into the abyssal ocean are required to maintain a steady-state thermal structure. An effective eddy diffusivity of order K_ρ=10^{-4} m^2 s^{-1}, 700 times the molecular diffusivity of heat, is necessary [*Munk*, 1966]. Such a diffusivity might be supported by either mechanical mixing (turbulent transport) or thermodynamic (so-called doubly diffusive) processes.

While both processes diffuse heat, these mechanisms affect the diapycnal transport of salt, nutrients, other scalars, and momentum quite differently.

Extensive measurements of pelagic turbulence, recently supported by direct tracer-release observations, suggest that the ocean interior is too calm for mechanical mixing to support the required flux. If turbulent transport is indeed important, it must occur at localized sites presumably associated with subsurface topography. But fundamental relationships gleaned from 3 decades of pelagic observations, showing that turbulent dissipation varies as the square of the buoyancy frequency, and that eddy diffusivity is roughly constant with depth, may not hold true for topographic mixing at these sites.

Observations of energetic mixing in the waters above the Mid-Atlantic Ridge and near-isolated seamounts strongly encourage further investigation. An organized, collaborative study of an energetic mixing site is appropriate, given the multi-scale nature and complex spatial geometry of the mixing process. Hence the establishment of HOME.

HOME Project s Establishment and Goals

HOME is focused on tidally driven mixing, given the ubiquity of the tide as a deep-sea energy source. The HOME hypothesis is that the surface tide interacts with the topography of the Hawaiian Ridge, generating both tidal and higher frequency internal waves. These propagate into the ocean interior and mix as they break. In centering on the tide, HOME can take advantage of the long history of global tidal studies and the notable, recent advances in tidal energetics stemming from satellite altimetry. Specific spatial and temporal patterns of tidal flows (Figure 1) suggest where mixing may occur. Recent observations of large internal tides radiating from the ridge [*Ray and Mitchum*, 1996], along with estimates that as much as 20 GW of barotropic M_2 energy are dissipated in the region, reinforce the tidal focus.

Informal planning meetings in 1997 and 1998 led to a group proposal to the National Science Foundation that was accepted for support in January 1999. Scientists from the University of Hawaii, University of Washington, the National Oceanic and Atmospheric Administration, Oregon State University, Woods Hole Oceanographic Institution, and Scripps Institution of Oceanography currently participate in the program.

HOME has three goals:

- To determine if mid-ocean sites such as Hawaii significantly contribute to global mixing. Is the tide a principal energy source?
- To create a simple, quantitative energy budget for tidal mixing in Hawaiian waters.

The proposed budget includes three terms: the energy lost from the M_2 barotropic tide, the energy radiated away in low-mode baroclinic waves, and the energy dissipation in the waters around the Hawaiian Ridge.

- To determine the principal mechanisms that transfer energy from large-scale flows to turbulent motions.

Do these mechanisms work differently in the deep sea and the upper ocean? How do the depth and lateral dependencies of mixing depend on topography and the tides? These findings will support generalization of HOME observations throughout the Hawaiian Ridge and the global ocean.

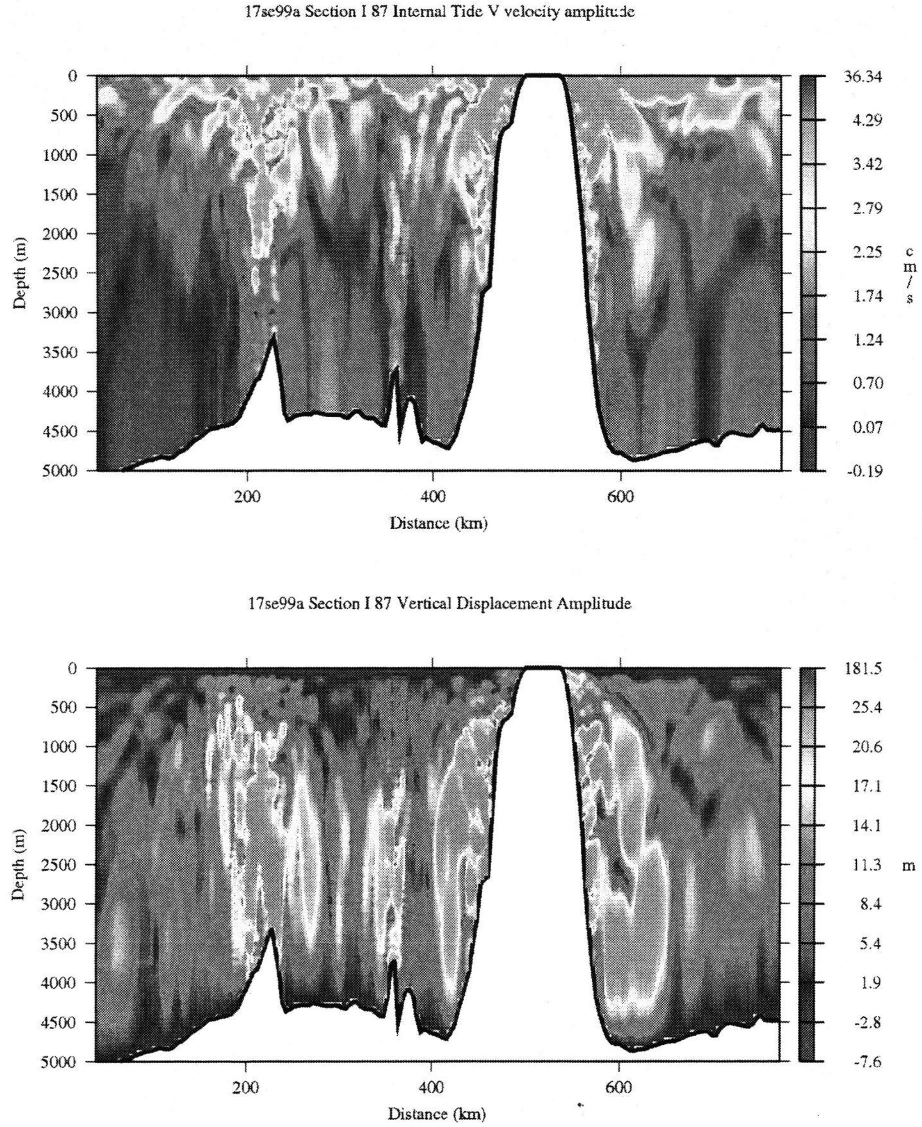

Fig. 1. A meridional section of M_2 baroclinic velocity magnitude (top) and vertical displacement (bottom) taken along 158 from 18 to 24 N, through the northwest flank of Oahu. This is a representative output of the Princeton Ocean Model, configured for Hawaiian topography by Mark Merrifield and Peter Holloway as an aspect of the HOME Modeling Program. The model resolves the first fifty baroclinic models (roughly 100-m vertical resolution). Verifying the basic spatial patterns predicted by this and other models is a central aspect of the HOME Survey. Original color image appears at the back of this volume.

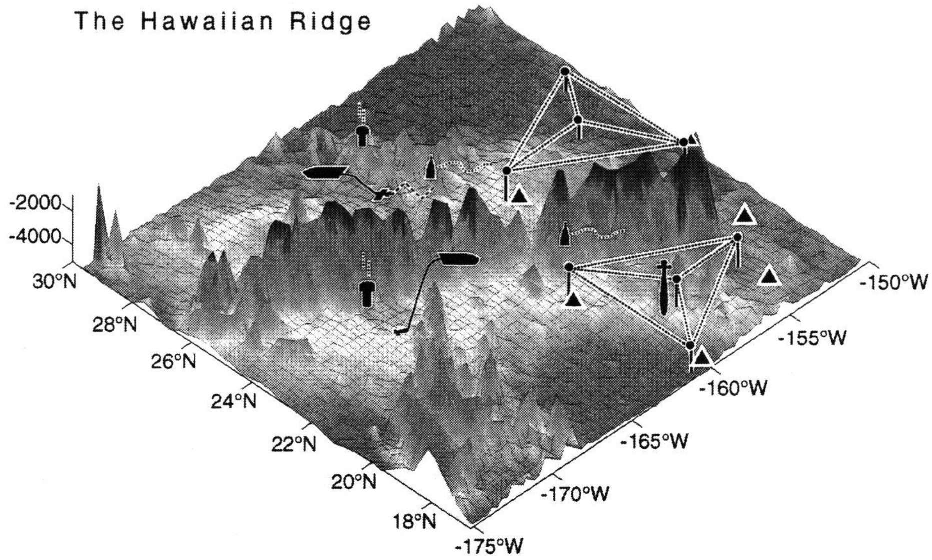

Fig. 2. Schematic illustration of the HOME experiment. The tomography arrays, bottom pressure, and electromagnetic sensors of the Farfield Program, shown on the right, quantify the barotropic tidal energy flux convergence at the ridge, as well as the flux divergence associated with low-mode internal tidal waves. The various towed, dropped, and drifting instruments of the HOME Survey Program, shown to the left, identify the dominant mixing processes active at the ridge and map their space-time variability. Based on survey findings, the Nearfield Program will document select mixing process in detail so that parameterizations appropriate for general application can be developed. Original color image appears at the back of this volume.

Implementation Plan

HOME is composed of five distinct complementary programs: Historic Data Analysis, Modeling, the Survey, the Nearfield Experiment, and the Farfield Experiment. The data analysis and modeling programs are being conducted to aid in planning the field studies. These efforts began in May 1999 and will continue throughout the HOME project, concluding in 2005 with a strong emphasis on data assimilation.

The survey of the ridge from 150 W to 165 W, both shallow and deep, will determine the principal phenomena involved in mixing and their geographic distribution (Figure 2). Transects by Along-Ridge Sea Soar, which obtains towed density, salinity, and temperature profiles to 400-m depth, and Doppler sonar, which provides ocean velocity profiles to 800-m depth, will be complemented by cross-ridge sections (0 1500 m) and deep-towed transects (1000 2000 m) of microstructure and fine-scale shear. The survey has been active since August and will continue until early December. Initial results are very encouraging.

Based on the Analysis/Modeling and Survey results, a specific site will be selected for detailed study. The site will be a contiguous section of topography extending from depths of less than 500 m to greater than 3000 m. The Nearfield program will examine mixing processes in detail in this region to better understand the mechanisms involved. It will quantify mixing rates, determine connections between the mixing site and the deep sea, and develop parameterizations of the dominant processes. Several moored arrays and a high-frequency radar system will be deployed for a full year to establish the long-term surface and sub-surface currents at the site.

During a 6-week Nearfield intensive period in fall 2002, numerous shipboard, towed, and profiling sensors will be used to document in detail mixing processes at the site, from the upper thermocline to full ocean depth.

HOME s Farfield component will quantify the barotropic M2 tidal flux convergence at the ridge and the baroclinic flux radiated back to the deep sea. The precision required for a conclusive result is daunting. A select mix of spatially integrating and in-situ sensors will be employed to meet the observational challenge.

The Farfield experiment will be implemented in two phases. Measurements will be made north of the ridge in spring 2001 and south of the ridge in fall 2001. Acoustic tomography, coupled with point measurements of seafloor pressure and barotropic current will be used to monitor barotropic energy losses and the mode-one scattered baroclinic tide. During the southern deployment, the RV *FLIP* will be moored near one of the tomography moorings to document the modal structure of the baroclinic tides.

Call for Participation

HOME invites interested researchers to participate in all aspects of the program. Biological observations and small-scale modeling efforts could enhance the value of our core effort significantly. For further information, visit the HOME Web site at http://chowder.ucsd.edu/ home, or contact HOME, Scripps Institution of Oceanography, La Jolla, Calif., 92093-0213 USA.

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Session Focuses on Subsurface Thermal Studies

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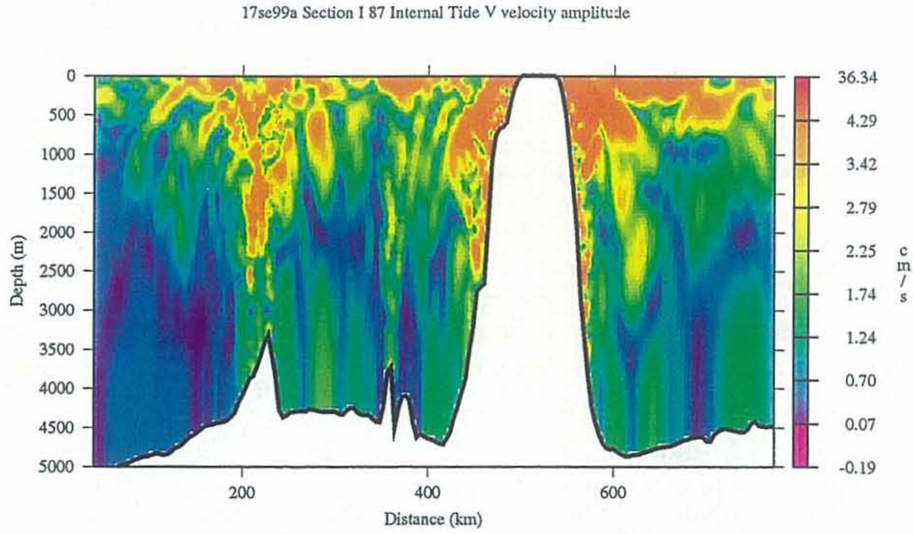
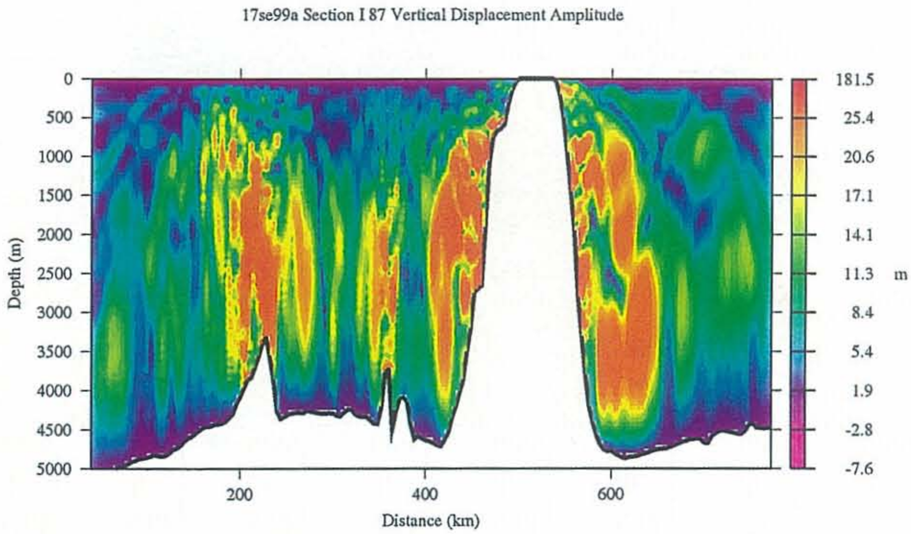
Temperature, along with pressure, is the most important parameter that governs the behavior of rock material. Deep in the Earth, the temperature field is controlled by the outflow of heat from depth. Thus, the emperature is stable and does not vary much locally. But in the shallow subsurface, temperature may be substantially disturbed.

Underground water migration and changes on the Earth s surface that diffuse into the subsurface may be two sources of such disturbances. The corresponding transient signal is detectable by precise temperature-depth measurements and can be separated from the steady-state geothermal gradient. Temperature measurements in boreholes and long-term near-surface temperature monitoring can be used as tracers in hydrology, atmospheric and ocean sciences, geothermics, seismology, and many other geophysical and geological disciplines.

Groundwater flow systems in sedimentary basins and fault zones and climate reconstructions inferred from borehole data and the submarine environment were topics discussed at the joint Hydrology and Ocean Sciences Section symposium at AGU s Western Pacific Geophysics Meeting in Tokyo on June 26 30, 2000.

The symposium confirmed very well that borehole T(z) data provide important additional information for completing paleoclimate proxies; namely, on recent global warming and its environmental components. Underground fluid flows considerably distort the general conductive subsurface heat transfer pattern, which may be of particular interest in various hydrogeological studies. Several interesting practical applications of thermal mapping in regional hydrology were presented. Such mapping is a powerful tool for determining the direction and rate of flow leakage across





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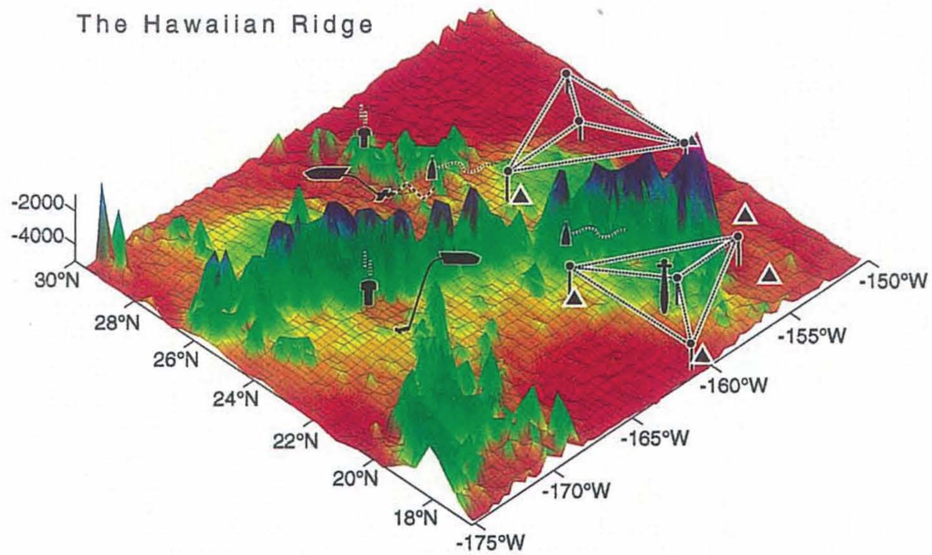

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