Contributions of mGal-Accuracy Gravity to Studies of Oceanic Spreading Centers and the RIDGE2000 Program

Donna K. Blackman, Scripps Institution of Oceanography

The RIDGE2000 program (R2K) is designed to further understanding of the geophysical, geochemical and geobiological causes and consequences of energy and material transfer, from the Earth's mantle to the hydrosphere and biosphere, along the globe-encircling mid-ocean ridge system. Three sites on the ridge are the focus of detailed R2K studies that will integrate information at various scales to determine how processes below the seafloor are linked to seawater circulation and life within and just above the uppermost crust. A key question is how the morphology of the spreading center axis is related to the supply of magma at depth and the vigor of hydrothermal circulation that vents at the seafloor. Several models suggest that axial morphology is a function of crustal structure and thickness- geophysical parameters that are reflected in the gravity field. The proposed higher resolution satellite gravity mission would provide new global constraints on how crustal production may vary along and between segments of the mid-ocean ridge system. Coverage on the young flanks of the ridge will enable temporal characterization of how crustal production and tectonism evolves over time at each segment. The global perspective of mGal-accuracy satellite gravity along the spreading centers and young flanks would provide key context within which the detailed R2K results are interpreted. In addition, the ~15 km resolution would allow first-order quantitative analyses to be made that address fundamental problems such as the origin of ridge segmentation and the time/length scale of variability in magma supply to spreading centers.

Determining the Structure of Hawaiian Submarine Rift Zones

Barry W. Eakins, U.S.G.S., Menlo Park, CA 94025; beakins@usgs.gov

The oceanic free-air gravity field (sea-surface slope measured by satellite altimetry) predominantly reflects seafloor topography and can be used to estimate that topography, assuming a spatially-uniform density profile of the oceanic crust. Alternatively, detailed knowledge of the bathymetry (obtained from multibeam sonar surveys) allows for inversion of the problem: spatial variations in crustal density can be observed by forward modeling of the bathymetric contribution to the free-air gravity field.

Multibeam bathymetry collected around the Hawaiian Islands, as part of a joint Japan Marine Science and Technology Center, U.S.G.S. and University of Hawaii 5-year collaborative program to investigate the deep, underwater flanks of Hawaiian volcanoes, forms the cornerstone of a bathymetric database that will be used to investigate the structure of Hawaiian submarine rift zones. Land gravity measurements have identified high-density magmatic cores within the subaerial rift zones of Hawaii. These high-density cores presumably extend down rift, to the deeper, submarine parts of the rift zones, and, as such, should contribute to the oceanic free-air gravity field, as well as the morphology and evolution of the rift zones.

Shipboard gravity measurements, while recording the short-wavelength (>5 km) gravity field, lie only along the various survey track lines, which sparsely sample the submarine rift zones. Satellite altimetry measurements of the free-air gravity field have the advantage of providing full spatial coverage of the rift zones and volcano flanks, though the current resolving wavelength (>25 km) is above the estimated 10- to 15-km wavelength signature of their deeper, high-density cores.

Barotropic/baroclinic Tidal Energy Conversion: Estimates from Altimetry and Models

Gary D. Egbert, College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, 97331-5503, egbert@coas.oregonstate.edu

Richard D. Ray, NASA Goddard Space Flight Center, Greenbelt, MD, 20771, richard.ray@gsfc.nasa.gov

Estimates of open ocean tidal elevations obtained from the TOPEX/POSEIDON (T/P) satellite altimeter are now sufficiently precise to map accurately the tidal dissipation rate throughout the world ocean. In recent publications (Egbert and Ray, 2000; 2001) we have presented global maps of barotropic dissipation for the M2 constituent. These estimates have been obtained as a balance between the rate of working by tidal forces and the barotropic energy flux divergence, computed using currents derived by least squares fitting of the altimeter data and the shallow water equations. Due to the high precision of the altimeter data area integrals of the energy balance are remarkably insensitive to dynamical assumptions required to compute tidal currents. Most of the 3.7 TW tidal energy dissipation in the ocean occurs in shallow seas, as has long been recognized. However, a significant fraction of the dissipation, perhaps 1 TW or more, occurs in the deep ocean, especially over major bathymetric features oriented perpendicular to tidal flows. The spatial pattern is qualitatively consistent with simple theories for topographic generation of internal tides. If this physical mechanism is responsible for the open ocean tidal dissipation, up to 1 TW of mechanical energy is available from the tides for deep-ocean mixing. Since it has been estimated that approximately 2 TW is required to maintain abyssal stratification and the meridional overturn circulation, tides may thus play a significant role in driving these climatically important processes.

Global computations with simplified physical models incorporating climatological ocean stratification from Levitus and deep-ocean bathymetry from Smith and Sandwell verify that open ocean barotropic dissipation estimated from the altimetry is quantitatively consistent with expected barotropic/baroclinic conversion rates, at least to zero order. However, there are some as yet unexplained anomalies. The simple models tend to underestimate dissipation over mid-ocean ridges, but slightly overestimate dissipation over island arcs and hotspot chains. This may result from differences in the spectral content of the bathymetric variations in the two cases. Over mid-ocean ridges higher wavenumbers, which are relatively poorly represented in current global bathymetric databases, have larger amplitudes and scatter a larger fraction of the barotropic energy into internal modes. Improved bathymetric data would help to resolve this issue, and allow better model estimates of internal wave generation.

Efforts to parameterize the baroclinic conversion as an additional drag coefficient in a high-resolution global tidal model will also be discussed. Significant improvements in purely hydrodynamic solutions are obtained when this refinement to the drag parameterization is incorporated. However there are probably limits to the effectiveness of simple internal wave radiation drag parameterizations, especially for time dependent flows. The simple physical models I will discuss show that the internal wave radiation stress would require a non-local (in space and time) operator, even in the case of linear dynamics. Improved open ocean bathymetry will ultimately be useful for improved parameterization of internal tide drag in coarse resolution models (e.g., those used for climate simulations). However, development of more realistic and physically based parameterizations of radiation drag will be required to take full advantage of these new data in ocean circulation models.

How Ocean Mixing Can Influence Global Sea Level

Sarah T. Gille, Scripps Institution of Oceanography and Department of Mechanical and
Aerospace Engineering, UCSD, La Jolla, CA, 92093-0230; sgille@ucsd.edu

Observations suggest that when tides flow over rough bathymetry, tidal energy is converted into vertically propagating internal waves. This internal wave energy appears to increase the local vertical diffusivity of the ocean. The possibility that vertical diffusivity varies spatially with bathymetric roughness has important implications for a number of aspects of ocean circulation and climate modeling, including prediction of sea level rise.

Global sea level is influenced by vertical mixing in two ways. First, high mixing rates allow heat and CO_2 to penetrate the deep ocean quickly. Previous modeling studies have indicated that large vertical diffusivities result in more rapid global sea level rise, due to the steric expansion of the deep ocean. Second, in the absence of heat input, vertical mixing can decrease sea level due to the nonlinearities in the equation of state. While the effect is comparatively small, it is comparable in magnitude to the uncertainties in the global sea level rise over the past 50 to 100 years. Improvements in spatially varying vertical diffusivities are likely to improve forecasts of future sea level rise.

Stochastic Modeling of Abyssal Hill Morphology

John A. Goff
University of Texas Institute for Geophysics, Austin, TX, goff@utig.ig.utexas.edu

Abyssal hills are the most pervasive landform on Earth. Like magnetic stripes, they are an indirect record of the seafloor spreading process, with morphology that relates to spreading rate, direction, segmentation and axial morphology. This presentation summarizes the findings of the analysis of stochastic properties of abyssal hills and their relationship to the mid ocean spreading ridges at which they were formed. Primary data sets include multibeam surveys from the flanks of the slow spreading

Mid-Atlantic Ridge, the fast spreading East Pacific Rise, and the intermediate spreading Southeast Indian Ridge. The latter area exhibits a transition between axial high and axial valley morphology without a significant change in spreading rate. These relationships provide observational constraints on models for axial faulting and volcanism. This presentation will also demonstrate visually changes in the texture of altimetry data that are likely related to changes in abyssal hill morphology. It is suggested that a quantifiable relationship may be discerned between altimetry texture and abyssal hill morphology.

The necessity of Global bathymetric compilations: Examples from the Center for Coastal and Ocean Mapping/ Joint Hydrographic Center, University of New Hampshire

Martin Jakobsson and Larry Mayer

While modern acoustic and optical mapping systems are capable of full coverage bathymetry at unprecedented levels of resolution (often sub-meter pixels), the fundamental laws of physics constrain such surveys to very small areas. Thus while the goal of global ultra-high resolution bathymetric coverage is favorable, it is unrealistic to expect such data set without the investment of billions of dollars over decades or a revolutionary technological break through. In the mean time, the need for global bathymetric compilations gets greater as almost all aspects of oceanographic research, engineering, exploration, and resource exploitation require a fundamental spatial context.

At the Center for Coastal and Ocean Mapping/ Joint Hydrographic Center a number of recent projects have involved the use of bathymetric compilations on a global scale. One example is our study of Arctic Ocean volume and hypsometry [Jakobsson, 2001]. In this work the International Bathymetric Chart of the Arctic Ocean (IBCAO) has been used to estimate hypsometry and the volume of the entire Arctic Ocean and its constituent seas. However, IBCAO does not cover the full extent of the Arctic Ocean as the International Hydrographic Organization (IHO) [IHO, draft 4th edition, 2001] defines it (portions of Hudson Bay, Hudson and Davis Straits, and Norwegian and Island Seas falls outside the coverage). Therefore, the most recent version of the Global Seafloor Topography, first released by Smith and Sandwell 1997, was merged with IBCAO on a Lamberts Equal Area projection to supplement the mentioned areas. Subsequently, seafloor area and volume were calculated for different depths starting from present-day sea level and progressing in increments of 10 m to a depth of 500 m and in increments of 50 m from 550 m down to the deepest encountered depth. The results provided the oceanographic community with up-to-date area and volume estimates that could be used in a number of oceanographic applications such as chemical budget estimations. In addition, the hypsometry provides further insights to the glacial history of the broad shallow Arctic shelves, and indicates that the Arctic Ocean circulation ought to be highly sensitive for eustatic sea level variations.

A second example is our analysis of data relevant to a potential U.S. claim of extended continental margin under the United Nations Law of the Sea (UNCLOS) Article 76. The key bathymetric components set forth in Article 76 are the 2500-m isobath and the Foot Of the continental Slope (FOS). In the process of identifying critical areas for future bathymetric surveys where the 2500-m and the FOS needs to be accurately mapped we used ETOPO-2. We generated the 2500-m isobath from this data set and derived bathymetric profiles, which were used to locate the FOS. In addition, a seafloor gradient map derived from ETOPO-2 was used to identify a maximum zone of uncertainty within which the foot of slope should be located. Based on this information and trackline density, data gaps in the target zones were identified and surveying requirements defined. It is clear that the better the used regional compilation is, in this case ETOPO-2, the more precise the key bathymetric features can initially be located, which may save unnecessary data collection and large amount of resources for a country of the size of the U.S.

IHO (International Hydrographic Office), S-23 “Limits of Ocean and Seas”, draft 4th Edition, October 2001.

Jakobsson, M., 2002, Hypsometry and volume of the Arctic Ocean and its constituent’s seas, *Geochemistry Geophysics Geosystems*, v. 3, no. 2.

Smith, H.F.W., and D. T, Sandwell, 1997, Global Seafloor Topography from Satellite Altimetry and Ship Depth Soundings, Science, v. 277, p. 1956-1962.

Connections Between Ocean Bottom Topography and the Earth's Climate

Steven Jayne, Woods Hole Oceanographic Inst., Woods Hole, MA 02543-1541,
sjayne@whoi.edu

The seafloor is one of the key constraints determining the ocean's general circulation. Its influence comes through a variety of mechanisms, including, topographic steering of ocean currents, enhanced vertical mixing over rough and abrupt topography, and hydraulic control of water masses through narrow straits and over sills.

The influence of topographic roughness on the ocean's general circulation occurs through a series of connected processes. First, internal waves are generated by the barotropic tide flowing over topographic features in the presence of the stratification. Some portion of these waves are sufficiently non-linear that they immediately break creating locally enhanced vertical mixing. The majority of the internal waves radiate away from the source regions, and likely contribute to the background mixing observed in the ocean. The interaction of the background internal wave field with rough topography also leads to further enhanced mixing in locations where the topographic slope is equal to the internal wave's critical angle. The mixing supported by the dissipating internal wave energy influences the thermohaline structure of the deep ocean and provides buoyancy forcing for driving circulation in the abyss. These in turn have implications for the storage and transport of heat in the climate system.

None of the state-of-the-art ocean general circulation models take into account this tidally driven enhanced vertical mixing, and this lack of correct physics begs the question of how reliable these models are at predicting the present ocean circulation. These models are also an important part of climate models, and their ability to predict future climate change is brought into serious question. This highlights the need for improved parameterizations of mixing in ocean general circulation models used to study the Earth's climate. This talk addresses some of the outstanding questions concerning tidal dissipation, enhanced mixing over rough topography and its relation to the Earth's climate.

Global Bathymetry, Education, and Outreach

Sarah E. Kruse, Dept. of Geology, University of South Florida, Tampa, Florida, 33620;
skruse@chuma1.cas.usf.edu

A NASA-sponsored satellite gravity mission offers great promise for addressing the agency's ESE strategic goals for education and outreach. These broad objectives include, for example, "to increase public ... understanding of how the Earth functions as a system" and to "enable the use of Earth science information and results in teaching and learning...". Any proposal for an ABYSS-type mission should exploit the popular appeal of the unexplored seafloor as a platform for advancing general public and student understanding of Earth systems. At the same time a global bathymetry mission's education and outreach program must identify and address specific and timely educational needs. Such needs might include the growing desire for teacher training in Earth system science, as Earth science teaching at many levels evolves in response to national and state science teaching standards adopted in the last decade. In the informal education sector, the incredible public interest in NASA web sites (> 1 million hits/day on critical days of recent missions) promises wide avenues for dissemination of pedagogic tools.

To better support an ABYSS-like radar altimeter mission, we are seeking ideas from all workshop participants on:

- effective use of high-resolution global bathymetry data for informal education and public outreach in Earth system science (for example web sites, museum displays, videos, etc.), particularly applications of oceanography and climatology
- techniques that exploit present-day capabilities for managing and displaying large data sets, yet can be run on off-the-shelf moderately priced computers and hardware
- more general emerging, pervasive or systemic needs in Earth science education at K-12 or university levels.

A proposal for a high-resolution radar altimetry mission will be strengthened by an effective education plan that documents identified needs and generates creative, inspiring, and cost-efficient tools for learning.

The Role of Smallscale Topography for Internal Waves and Mixing

Eric Kunze, APL, U of Washington, 1013 NE 40th, Seattle, WA 98105-6698
phone: 206-543-8467; e-mail: kunze@ocean.washington.edu

The strength of the world ocean's meridional circulation is thought to be controlled by turbulent mixing of stratified waters. Mixing in the interior has consistently been found to be an order of magnitude too weak to account for bulk budgets so attention has moved to the boundaries, particularly the bottom boundary over rough topography where various flow/topography interaction mechanisms can produced elevated internal wave and turbulence levels. Evaluating these globally requires well-resolved topography on scales O(100-1000 m):

1. Critical reflection of internal waves to high wavenumber requires resolving slopes on scales of at most a few kilometers.

2. Internal lee wave generation by subinertial flow ($f < kU < N$) over bottom roughness requires resolving topography on scales U/N (10 m) < _ < U/f (100 m) where _ $= k^{-1} =$ _/(2π) and the numerical values assume $U = 1$ cm/s, a typical abyssal buoyancy frequency $N = 10^{-3}$ rad/s and a midlatitude Coriolis frequency $f = 10^{-4}$ rad/s. Higher stratification at shallower depths would require even resolving even smaller scales to span the high end of the internal wave band.

3. Most importantly, tide/topography interactions generate linear internal waves (wrt the barotropic flow) with vertical scales in the range of the Garrett-Munk spectrum for $\frac{NH}{200□\sqrt{□^2 □ f^2}}(1\ km) < \ell < \frac{NH}{□\sqrt{□^2 □ f^2}}(200\ km)$ where assumed is a typical deep ocean $NH = 5$ _ 10^{-3} rad/s _ 2000 m, and $\sqrt{□^2 □ f^2} \sim f \sim 10^{□4}\ rad/s$ though much smaller values will be found near the critical latitude. Nonlinear internal lee waves and solitons which will be particularly prone to breaking will be found for
$kU >$ _, or _ $< U/$_ ~ 500 m.

Well-resolved topography may become increasingly important in shallow water on continental slopes and shelves as extremely strong turbulent mixing has been found in submarine canyons.

Ocean bathymetry and tidal conversion

Stefan Llewellyn Smith, Department of Mechanical and Aerospace Engineering, UCSD
William R. Young, UCSD

Tidal conversion is the process by which energy is converted from the barotropic tide to internal gravity waves via flow over ocean bathymetry. These internal gravity waves are known as the "internal tide".

The internal tide propagates at a fixed angle to the vertical determined by the three fundamental frequencies: (1) the tidal frequency, (2) the Coriolis frequency and (3) the buoyancy frequency. The ratio of this slope to the topographic slope determines the strength of the conversion process. For shallow topographic slopes, simple estimates of the conversion rate are easily made using Fourier techniques. The conversion occuring over steeper topography is not yet fully understood.

We examine the prospects for taking ocean measurements of bathymetry and using them to carry out forward tidal conversion calculations.

We discuss approaches and answers to some of the following questions:

* How relevant is the weak topographic approximation to the real ocean?
* Is a spectral characterization of ocean bathymetry sufficient to compute conversion?
* How much resolution is enough? What are the upper and lower limits?
* Is spectral extrapolation a good strategy?

Deformation and faulting of trench outer slopes

Massell, Christina, Scripps Institution of Oceanography, La Jolla, CA 92093-0225;
cmassell@ucsd.edu

The character and evolution of seafloor structural morphology at mid-ocean spreading ridges is well-established. Large scale features such as spreading ridges, fracture zones and off-axis volcanoes are identified on the basis of their free-air gravity signature. The orientation of abyssal hill faults can be deduced from those larger features and confirmed via more ambitious seafloor mapping campaigns. Seafloor structure remains relatively unchanged as it moves away from the vicinity of he spreading ridge across the abyssal plain and towards subduction zones. As the lithosphere approaches the subduction zone it is first flexed up into an outer rise, then down into the trench. It undergoes both elastic deformation and brittle failure of the outer slope demonstrated by the misfit between modeled flexural profiles and actual outer rise profiles around the Pacific.

The orientation of the bending stresses responsible for outer slope failure can be determined on the basis of plate boundary geometry and convergence direction. The response of the lithosphere to bending stress is dependent on the orientation of pre-existing features with respect to the bending stress. In regions where original abyssal hills strike less than 30° to the bending axis original abyssal hill faults are reactivated. In regions here abyssal hills strike greater than 30° to the bending axis, new faults are broken and crosscut original abyssal hills. At angle of ±30°, a combination of new faults and reactivated faults are observed.

The fault style varies between the two types of outer slope faults (reactivated vs. new). Scarps of reactivated abyssal hills are observed to be on the order of 150-300m in height and are primarily trench-facing. They present as a “step fault” morphology as adjacent blocks step down into the trench axis. Their linear extent may approach 60-80km, a characteristic which is seemingly a function of their original abyssal hill fault length. New, bending-induced faults develop 40-60km from the trench axis as horst and graben pairs. Their scarp heights increase to as great as 1400m, averaging 800-1000m. Bending axis parallel new faults average 100km in length. The graben features contribute to a mechanism by which large volumes of sediment could conceivably be carried down into a subduction zone.

Large, anomalously-oriented scarps are observed along some trench outer slopes and cannot be classified as reactivated abyssal hill faults or new, bending axis parallel faults. In the Arica Bight region of the Peru-Chile trench, where the trench axis changes orientation by nearly 60°, a series of sub-parallel scarps crosscut abyssal hills as well as the projected orientation of new faults. The large scarps measure 1300m in height. At the northern end of the Tonga Trench where the pate boundary turns abruptly westward by 90°active scarps as high as 500-800m extend 200km from the outer rise region. These anomalous scarps are proposed to be the result of the downgoing plate accommodating a large change in plate boundary geometry. In addition to along-axis changes in trench axis orientation, propagating spreading centers, failed rifts and seamounts complicate an otherwise straightforward characterization of the faulting on trench outer slopes.

Sensitivity of High Resolution Ocean Models to Topography

E. Joseph Metzger, Harley E. Hurlburt, Tamara L. Townsend, and Patrick J. Hogan, Naval Research Laboratory, Oceanography Division, Stennis Space Center, MS 39529-5004;
metzger@nrlssc.navy.mil

For approximately two decades, the Ocean Monitoring and Prediction System section at the Naval Research Laboratory (NRL) has been working toward the goal of a fully eddy-resolving data assimilative global ocean prediction system. This was achieved in September 2001 when the world’s first eddy-resolving nearly global ocean nowcast/forecast system was declared operational at the Naval Oceanographic Office (http://www.ocean.nrlssc.navy.mil/global_nlom). The system is based on the 1/16° NRL Layered Ocean Model (NLOM), which is scheduled to be upgraded to 1/32° horizontal resolution by FY04.

Before achieving this resolution on the global scale, basin-scale models of equally fine resolution have been developed. In the process of setting up such high resolution models, significant effort has been expended defining the coastlines (the 200 m isobath for NLOM) as the existing topographic databases are often filled with errors. This can be especially problematic in shallow regions rich with islands (e.g. the Philippines or Bahamas), in island chains (e.g. the Aleutians or the Antillean archipelago), or in small straits (e.g. Tsugaru Strait – the outflow of the Japan/East Sea). If existing topographic databases are simply interpolated to the model grid without any quality control efforts, the model solution (including the mean pathway of currents) may be in error.

Examples of such model sensitivities will be presented. These include the sensitivity of the mean pathway of the Kuroshio to coastline geometry as it enters the South China Sea at Luzon Strait, changes in volume transport distribution among the passages of the Intra-Americas Sea that are dependant upon the coastline configuration and the impact of seamounts on the pathway of the Kuroshio.

Toward automated calibration: merging shipboard archives with predicted bathymetry

Stephen P. Miller, Scripps Institution of Oceanography, La Jolla, CA, 92093-0220;
spmiller@ucsd.edu

No matter what satellite mission is accomplished, the information highway between altimetry observations and a global bathymetry model has a number of bumps, chicanes, detours, alternate routes, merging on-ramps and dangerous intersections. Along the way, the original altitude measurements undergo filtering, gravity modeling, and depth prediction, all based on certain assumptions and model parameters. Near the end of the road we approach a particularly critical intersection in which the predictions need to be calibrated by echo-soundings of the seafloor. No matter how hard we have worked along the road with altimetry processing, if the calibration data are faulty then the final map will be misleading, and the value of the overall project will be questioned.

It was sobering to learn that a substantial fraction of the thousands worldwide ship tracks had to be rejected from the most recent Smith and Sandwell Global Topography calibration, due to errors of one sort or another. Unfortunately, the perils that echo-sounding data encounter between shipboard acquisition and the final intersection with altimetry predictions are largely due to errors in data handling or incorrect metadata, and are highly resistant to normal systematic approaches. Typical problems include navigation errors, inappropriate interpolation, typographic errors, bad sound velocity corrections, and misleading mgd77 header information.

However, the predicted depth model has been used as a very powerful quality control tool to segregate echosounding tracks into two categories: good and bad tracks, based on the mismatch statistics along the track. In the past, bad tracks were simply avoided but in the future it will be important to devise new methods to identify classes of problems and automate repair as much as possible, rather than proceed on a costly case-by-case basis. Efforts could be based on new automated methods for overall archive management that have been created to build a fully searchable digital library from the 822 SIO cruises in the Geological Data Center, along with related images, documents and global databases (http://SIOExplorer.ucsd.edu).

Additional sources of echosounding data are now available, beyond the set of conventional ship tracks. The highest quality, highest resolution information comes from multibeam swath mapping surveys, although quality control and proprietary holds remain as obstacles before data can be used widely beyond the collecting organization. A growing number of local and regional multibeam grids are available, although care needs to be taken to guarantee the geodetic accuracy of grid products. Shallow coastlines are particularly troublesome, since people know them so well from nautical charts, and coverage from conventional oceanographic track lines is so sparse. The importing of depths from public and commercial nautical chart databases needs to be carefully explored. Surveys for fiberoptic and pipeline routes are another untapped source for global data.

Altimetry and the Law of the Sea definition of the Continental Shelf

Dave Monahan, Director, Ocean Mapping , Canadian Hydrographic Service, Ottawa, Ontario,
Canada and Ocean Mapping Group , University of New Brunswick
Email monahand@DFO-mpo.gc.ca

One of the many objectives of the United Nations Convention on the Law of the Sea is to subdivide ocean space into zones under the jurisdiction of a Coastal State or of the International Seabed Authority. Although most of this subdivision is straightforward, delineating the Juridical Continental Shelf requires complying with the complex formula prescribed in Article 76 of the Convention. This paper examines the possible contribution that altimetric bathymetry can make to resolving one elements of the formula, namely the 2500 m isobath. Publications on altimetric bathymetry suggest that the technique should not work well in Continental Slope and Rise areas, where the 2500 m isobath most commonly lies, yet a comparison with two other world-scale bathymetric data shows that the 2500 m isobath from altimetric maps is within the zone of uncertainty of both. Comparison of all three with multibeam contours for the same area shows that the altimetric bathymetry is as close to the multibeam contour as are the other two. This suggests that altimetric bathymetry is sufficiently accurate warrant consideration for use in UNCLOS Article 76 Continental Shelf delineation.

Its earliest use is likely to be in a “desk –top studies” to determine the probable area to be included within a juridical Continental Shelf and in developing a plan for building the case to substantiate it. For this phase, altimetry can provide a good quality, long wavelength 2500 m isobath, help guide the interpolation between the sparse acoustic sounding tracks which are the prevalent data form over the continental slope, and assist in identifying erroneous sounding lines. Coastal States seeking to maximize the area of their Continental Shelves may wish to proceed to more detailed investigations, probably involving multibeam surveys. The comparison described here shows that multibeam contours will occasionally protrude seawards of the single beam and altimetric contours, and use of these protrusions by a Coastal State can maximize the area claimed. Altimetry can help focus the zone to be surveyed by multibeam through inference of morphologic trends between acoustic control lines.

Such uses of altimetric data is consistent with the view expressed by the Commission on the Limits of the Continental Shelf that altimetric data will be considered admissible as supporting information in a submission.

It is also likely that altimetry can contribute to the problem of determining the location of the Foot of the Slope.

Abyssal Recipes

Walter Munk, Scripps Institution of Oceanography, La Jolla, CA, 92093-0225;
wmunk@ucsd.edu

With 25 Sverdrups of bottom water formation the ocean would fill with 0 degree water in a few thousand years. I will review attempts for the last 40 years to explain why this is not so.

Visual comparison between multibeam data and predicted bathymetry along the Nazca Ridge and Easter Seamount Chain

David F. Naar, Brian T. Donahue, and Paul Wessel*
(College of Marine Science, USF, and *SOEST, University of Hawaii)

During Nov-Dec 2001, we collected Kongsberg Simrad EM 120 multibeam bathymetry and backscatter data using the R/V Revelle to map volcanoes and sample them along the Nazca Ridge and Easter Seamount Chain. The primary objective is to test the hypothesis of Steinberger and O'Connell (1998) that hotspots are migrating due to mantle flow. However, as a side-product of this work, we created a 3-D interactive view of multibeam bathymetry data superimposed on "predicted bathymetry data" using visualization software (Fledermaus), which dramatically shows the fits and misfits of the two data sets. We will present "underwater views" along the seafloor, along the broad Nazca Ridge, and along isolated seamounts that have small and large age differences with the seafloor they reside upon. Although these 3-D movies (and interactive fly-through options) do not provide quantitative measurements of misfits, they highlight patterns that dramatically demonstrate the need for higher resolution altimetry data. The 3-D visualizations can be shown on a laptop, but they would be best-suited for the Friday evening display of seafloor mapping technologies in the IGPP Visualization Lab as MPEG-2 movies (if possible).

Altimetry-Aided Plate Tectonic Reconstruction of the Pacific-Nazca System since 28 Ma

Doug Wilder, David F. Naar, Sarah F. Tebbens, and Sarah E. Kruse

We have used 2-D magnetic modeling, 2-minute predicted bathymetry (Smith and Sandwell, 1997), and Hellinger rotation programs and a GIS Package (ESRI ArcView3.2), to calculate 11 new finite and 13 new stage poles for the Pacific-Nazca (Farallon) plate system since 28 Ma. Several major ridge reorganization events during this time span (starting around 25 Ma) that includes the break-up of the Farallon plate and the initiation of several southward propagators and the formation of temporary microplates causing a complicated pattern of magentic anomalies and seafloor fabric.

The predicted bathymetry derived from altimetry data is instrumental in constraining the location of the rotation poles because otherwise unmapped intersections between identified magnetic anomalies and pseudofaults can be used as singular points which should rotate back together (assuming rigid plate tectonics). This integrated approach to deciphering the plate tectonic history of this ridge system since 28 Ma has proven effective, and with higher resolution altimetry data, could further refine plate boundary geometry over time in areas where pseudofaults and fracture zones are not visible in the present 2 minute predicted bathymetry. Furthermore, sufficiently increased resolution from a new altimetry mission may allow areas of slow (rough seafloor) and fast (smooth seafloor) spreading and even rotated abyssal hill fabric to be defined. Seafloor roughness patterns will be useful in data poor areas such as magnetic quiet zones, magnetic equator areas, and areas without marine magnetic or aeromagnetic data.

Further understanding of the Pacific-Nazca Ridge system is presently limited to the resolution of the existing altimetry data set and magnetic data collected over the southeast Pacific Basin. To improve our understanding of the tectonic history of these two fast moving plates (and other large plates), more magnetic and bathmetry data are needed. These data can either be obtained either by expensive and extremely time consuming shipboard bathymetry and magnetic surveys, or less expensive and more efficient aeromagnetic surveys combined with a higher resolution altimetry data set.

Satellite Altimetry and the EEZ's of Remote Islands

Gregory A. Neumann, Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139;
currently at Laboratory for Terrestrial Physics, NASA-Goddard Space Flight Center, Greenbelt, MD 20771; neumann@tharsis.gsfc.nasa.gov

Satellite altimetry/bathymetry will never replace the need for shipborne bathymetric mapping of the 200-nautical-mile Exclusive Economic Zones (EEZ) of many nations, but will guide the integration of traditional mapping techniques with remote sensing tools. In some cases, major features of EEZ's are missing from available bathymetric charts and have only been discovered via satellite. Figure 1 shows an unnamed, 2-km-high seamount that was first seen in the GEOSAT gravity field of Sandwell and Smith (1995) near the British island of Tristan da Cunha. The 300 inhabitants of this hot-spot volcanic island, continuously settled since 1816, maintain thriving fisheries but have no indication of a seamount rising to a depth of 500 m at 37.57°S, 12.75°W in their coastal navigational charts. Recently acquired multi-beam data from the Woods Hole Oceanographic Institution are now being processed to supplement their existing bathymetric maps.

Figure 2 shows the current bathymetry from satellite gravity, as incorporated into Etopo2. The unnamed seamount can barely be identified, and its depth appears greater than 2 km. It is apparent that better resolution is required to delineate significant features of the marine environment less than 20 miles from land. Its gravity signal is better resolved in the combined GEOSAT-ERS1 gravity map, owing to nonlinear response to large-amplitude topography.

Laser altimetry can contribute to mapping the gravity field of the oceans. The ICESAT mission, scheduled for launch this fall, will have a 183-day repeat orbit track with a 94° inclination polar orbit. Its Geoscience Laser Altimeter instrument will operate continuously at 40-Hz, with 70 m-diameter altimetric footprints. Averaging of multiple pulse waveforms along-track should determine sea surface slopes nearly as well as radar altimetry. The across-track spatial resolution of about 12 km at 37°S latitude, shown schematically in Figure 2, does not provide good constraints on the E-W deflections from vertical, but the short-wavelength N-S coverage holds promise for further improvements in satellite gravity. Achieving the important objective of 15-km-wavelength resolution using lasers would require a long-duration, low inclination, non-repeat orbit such as that envisioned for the currently dormant Vegetation Canopy Lidar Mission, but could easily be addressed with state-of-the-art radar altimetry.

File Name : tristanbw.ps
Title : GMT v3.3.6 Document from grdimage
Creator : GMT
CreationDate : Tue Oct 1 13:10:19 2002

Figure 1. Multibeam bathymetry in the Tristan da Cunha EEZ, 500 m contour intervals.

File Name : tristanetopo.ps
Title : GMT v3.4.1 Document from grdimage
Creator : GMT
CreationDate : Tue Oct 1 12:05:01 2002

Figure 2. Bathymetry from satellite altimetry does not resolve features such as the seamount shown in Figure 1. Sample tracks for ICESAT shown schematically by dashed lines.

Mixing in the Deep Ocean and Mid-Ocean Ridge Bathymetry

Kurt Polzin

The links between turbulent mixing in the deep ocean and mid-ocean ridge bathymetry are considered in this talk. Two mechanisms will discussed in detail: buoyancy driven flows within constrained passages (i.e. fracture zones and rift valleys) and internal wave generation/scattering from abyssal hills.

The major basins of the world ocean are typically separated by constrained passages. Such passages are often sites of energetic and highly sheared flow. The flow, in turn, appears to be in response to density contrasts between basins or along the passage itself. The turbulent mixing within such passages depends upon the detailed structure of the bathymetry. Relatively wide and gently sloping passages like the Vema Channel (aka Rio Grande Gap) are not sites of intense mixing. Narrow passages such as the Romanche and Vema Fracture Zones have intense mixing in hydraulic jumps associated with abrupt topographic features. Offset fractures and the rift valley of the Mid-Atlantic Ridge are a microcosm of such fracture zones.

In the internal wave problem, mixing results from vertical shear (the vertical derivative of horizontal velocity) within the internal wavefield. The vertical profile of turbulent intensity in this wave problem can be reduced to defining the dominant vertical length scale associated with internal wave shear, which in turn can be related to abyssal hill morphology using quasi-linear models of internal tide generation and internal wave scattering. In general, the dominant vertical length scale of wave shear is on the order 30 m, and implies corresponding horizontal scales of several hundred m. Predicting the internal wave shear associated with turbulent mixing thus requires resolving bathymetric features having horizontal wavelengths 2*pi*several hundred meters. This requires multi-beam data.

Ancillary wind speed and significant wave height from a bathymetric altimetry mission

David L. Porter, Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD 21218
R. Keith Raney, Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723

The primary measurement of an altimeter is the distance from the sensor to the sea surface below. However, there are two additional measurements the altimeter makes: 1) wind speed and 2) significant wave height (H_). These are important oceanographic parameters for forecasting and analysis. The wind speed is a function of the returned radar power. Stronger winds cause more capillary waves, which cause more diffuse scattering of the radar energy, and hence reduced power from the return signal in the specular direction at the altimeter. The significant wave height is a function of the shape of the returned signal caused by the radar energy reflecting off the crests of the waves first and the troughs last. Empirical relationships have been developed to accurately estimate the wind speed to ±1.5-1.7 m/s and significant wave height to ±0.2-0.3 m for conventional altimeters. These measurements have a footprint of about 2x6 km and can be assimilated into global forecasts in the same manner as microwave scatterometer data (ERS-2 and QUIKSCAT) with 50x50 km footprints. The Delay-Doppler altimeter (developed at the Johns Hopkins University Applied Physics Laboratory) can measure wind speed and significant wave height with approximately twice the accuracy of conventional altimeters. Not only does the Delay-Doppler altimeter have better accuracy, it also has a smaller footprint, 0.25x2km, and can get to less than five kilometers of shore. Implementing the Delay-Doppler altimeter as a geodetic mission, as proposed in the ABYSS system, has the added benefit of providing near-real-time wind and wave data. Thus the wind speed and significant wave height would arrive at the ground with a higher precision, smaller footprint, closer proximity to shore and at rate fast enough to make this an important contribution to forecasting ocean processes.

The Delay-Doppler Altimeter: More Precision and a Smaller Footprint

R. Keith Raney (1); W. H. F. Smith, NOAA (2)
(1) Johns Hopkins University Applied Physics Laboratory;
(2) NOAA Laboratory for Satellite Altimetry

The sea surface slope measurements provided by the Geosat radar altimeter (together with selected ERS-1 data) are the state-of-the-art for geodetic observations from space. However, those results fall significantly short of the potential resolution and sensitivity set by physical limits. Spaceborne radar data can approach these limits only if the instrument is substantially improved, and if the orbit is optimized. (Further information on the scientific goals, requirements, and benefits of improved data may be found in a companion paper by W. H. F. Smith at this meeting.)

A delay-Doppler radar altimeter can deliver the required height precision and spatial resolution. This innovative satellite altimeter uses signal processing strategies borrowed from synthetic aperture radar to improve height measurement precision by a factor of two, and to reduce along-track footprint size by a factor of five or more in marked contrast to a conventional radar altimeter. The signal processing can be performed on-board in real-time, resulting in a modest data downlink rate. The delay-Doppler altimeter has been built and flight-tested on NRL and NASA P-3 aircraft. The airborne instrument—the D2P altimeter—also included cross-track angle measurement using a pair of interferometric receive antennas. Results verify the predicted along-track resolution and delay-Doppler signal properties. In addition, it was demonstrated that angular offsets in the along-track (pitch) plane are measured uniquely in the Doppler domain, and that angular offsets in the cross-track (roll) plane are measured by the interferometer.

If a dedicated free-flying implementation were available, the orbit should be non-repeating, and have an inclination relatively near 55 degrees. From such an orbit, the required measurements would be completed in less than five years by a solo delay-Doppler radar altimeter satellite, or less than twenty months by a constellation of three co-planar satellites.

As an alternative, the International Space Station (ISS) is also a candidate. The ISS has a non-repeating orbit at an inclination of 51.6 degrees. Although its orbit is nearly optimal, the angular motions of the ISS could disqualify it as a host platform. On the ISS, a D2P-style altimeter could be mounted on a mechanical gimbal. Angle measurements from the altimeter could be used to servo-steer the gimbal to maintain nadir pointing, regardless of the attitude of the ISS. The ISS was the nominal satellite of choice in the ABYSS ESSP project recently proposed to NASA. Further details are at http://fermi.jhuapl.edu/abyss and http://fermi.jhuapl.edu/d2p

Using the Wide-Swath Ocean Altimeter to Map the Geoid

Ernesto Rodriguez, Jet Propulsion Laboratory, California Institute of Technology,
ernesto.rodriguez@jpl.nasa.gov

The Wide-Swath Ocean Altimeter (WSOA) is an instrument that has been proposed for demonstration as part of the NASA Ocean Surface Topography Mission (OSTM, also known as Jason-2). The WSOA was designed to measure ocean topography over a 200 km swath, with height postings every 15 km and a height accuracy better than 5 cm. The instrument has a repeat cycle of ten days, which leads to near complete global coverage for mid-latitudes and higher, but coverage gaps near the equator can lead to coverage loss of up to 40%, for the worst cases.

These measurement characteristics were selected to sample ocean mesoscale phenomena and tides. In practice, the intrinsinc data resolution is higher. The real aperture size, which, in the absence of more sophisticated processing, limits the spatial resolution, is about 12 km in the along-track direction and about 500 m in the cross-track direction. However, significant overlap exists between footprints in the along-track direction, since a data point is collected approximately every 650 m. This oversampling of the along-track footprints allows for the use of super-resolution algorithms, such as have been used to improve the resolution of spaceborne scatterometer instruments. In this paper, we examine the resolution capabilities of the WSOA and the implications for measurements of the geoid, given the mission scenario proposed for the WSOA mission.

Bathymetry from Space

David T. Sandwell, Scripps Institution of Oceanography, La Jolla, CA, 92093-0225; dsandwell@ucsd.edu
Walter H. F. Smith, Laboratory for Satellite Altimetry, NOAA, Silver Spring Maryland, 20910-3282; walter@raptor.grdl.noaa.gov
Sarah T. Gille, Scripps Institution of Oceanography and Department of Mechanical and Aerospace Engineering, UCSD, La Jolla, CA, 92093-0230; sgille@ucsd.edu
Steven Jayne, Woods Hole Oceanographic Inst., Woods Hole, MA 02543-1541; sjayne@whoi.edu
Khalid Soofi, ConocoPhillips Inc., 600 North Dairy Ashford, Houston, TX, 77252-2197; Khalid.A.Soofi@conoco.com
Bernard Coakley, Geophysical Institute, University of Alaska Fairbanks, 900 Yukon Drive, Fairbanks, Alaska 99775-5780, Bernard.Coakley@gi.alaska.edu

One of the more important ocean science observations in the last two decades was provided by the Geosat radar altimeter during its 18-month geodetic mission (1985-86) and the ERS-1 geodetic mission (1994-95). The availability of these data in July of 1995 set off a flurry of activity in basic research, industrial research/development, and public interest. While these data fill a huge gap in our understanding of the ocean basins, they also triggered a thirst for more. We review: i) current scientific applications of ocean bathymetry and gravity; ii) fundamental physical limitations for recovering seafloor topography from measurements of ocean surface slope; and iii) the altimetric requirements needed to achieve significant improvements in accuracy and spatial resolution. Several applications cannot be addressed using the current measurements from Geosat and ERS-1 because their spatial resolution is limited to about 25 km. These include:

- resolving the fine-scale (~15 km wavelength) tectonic structure of the deep ocean floor in areas that have not been surveyed by ships (e.g., abyssal hills, microplates, propagating rifts, seamounts, meteorite impacts, . . .);

- measuring the roughness spectra (15-100 km wavelength) of the seafloor on a global basis to better constrain models of tidal dissipation, vertical mixing, and mesoscale circulation of the oceans;
- and resolving the fine-scale (~15 km wavelength) gravity field of the continental margins for basic research and petroleum exploration.

Altimeter requirements to achieve 15-km wavelength resolution are much less stringent and less costly than physical oceanography requirements. Long-term sea-surface height accuracy is not needed; the fundamental measurement is the slope of the ocean surface to an accuracy of ~1 microradian. This can be achieved without application of the usual environmental corrections. The main requirements are high range precision, dense coverage (< 7-km cross-track spacing), and a long-duration to reduce the noise from ocean waves, coastal tides, and mesoscale ocean variability. A low inclination orbit (50-65˚) is best for recovery of the low-latitude gravity field since the E-W slopes are poorly constrained by the Geosat and ERS altimeters. Existing and planned repeat-orbit altimeters will not achieve these objectives. Moreover, the satellite gravity missions, CHAMP, GRACE, and GOCE will recover sea surface slope at wavelengths greater than about 200 km but because of upward continuation, they cannot recover the shorter wavelengths. The complete white paper on this topic can be found at:
http://topex.ucsd.edu/marine_grav/white_paper.pdf

MARGINS Interests in Improved Resolution Satellite Derived Gravity Observations

Dale Sawyer, Dept. of Earth Science, Rice University, Houston, TX, dale@rice.edu.

The MARGINS Initiative seeks to understand the complex interplay of processes that govern continental margin evolution. The objective is to develop a self-consistent understanding of the processes that are fundamental to margin formation and evolution. The MARGINS approach involves concentration on several study areas targeted for intense, multidisciplinary programs of research in which an ongoing dialogue among field experiment, numerical simulation and laboratory analysis researchers is axiomatic. The plan is to investigate active systems as a whole, viewing a margin not so much as a “geological” entity of divergent, translational or convergent type, but more in terms of a complex physical, chemical and biological system, subject to a variety of influences. The processes that fundamentally govern the evolution of margins include lithospheric deformation, magmatism and mass fluxes, sedimentation, and fluid flow.

MARGINS scientists are pursuing these goals through 4 major efforts:

Rupturing Continental Lithosphere, a program to study the processes associated with the rifting of lithosphere and the formation of new oceans, with focus areas in the Gulf of California and the northern Red Sea.

Source-to-Sink, a program to study the processes of sediment generation, transport, and deposition on continental margins, with focus areas in New Zealand, New Guinea, and SE Alaska.

The Subduction Factory, a program to study the processes of mass transport and chemical alteration in subduction, island arc, and back arc settings, with focus areas in the Central American and Izu-Bonin-Mariana Arcs.

The Seismogenic Zone Experiment (SEIZE), a program to study the conditions and processes that control the distribution of large earthquakes at subducting margins, with focus areas in Japan and Central America.

Increased resolution satellite derived geoid and gravity data will benefit all of the MARGINS programs. I will try to identify a few examples of problems that may be better addressed by the ability to resolve crustal features at the 15 km scale envisioned for the improved resolution dataset.

Bathymetry and the National Geophysical Data Center

George F. Sharman, David L. Divins, and John G. Campagnoli, Marine Geology and Geophysics
Division, National Geophysical Data Center, Boulder CO, 80305-3328;
George.F.Sharman@noaa.gov, David.Divins@noaa.gov, John.G.Campagnoli@noaa.gov

The National Geophysical Data Center (NGDC) has been actively working with trackline geophysical data in significant quantities since 1977, when it hosted the meeting to define an exchange format for trackline data. The result was MGD77, a consensus-built, standard, exchange format and the GEOphysical DAta System, GEODAS, designed to manage trackline data. GEODAS continues to grow and evolve. Today the system manages not only trackline data, but survey, gridded, and coastline data, as well as horizontal datum transformations.

The Marine Geology and Geophysics (MGG) Division of the NGDC holds over 14 million trackline nautical miles (n.m.) of bathymetry. Most of this has been collected with single beam systems over the past 60 years, although the Center has assimilated over a million n.m. of multibeam data. The 14.5 million n.m. of bathymetry currently in the public domain provide but 10% ensonfication of the seafloor. Historical trends of collection show a sharp and continuing decline in collection rates since a peak in the early 70's. The U.S. Naval Oceanographic Office hosted a Global Ocean Mapping (GOMAP) conference in June of 2000 to describe and build support for the concept of 100% echosounding coverage of the seafloor. NGDC's evaluation of this task estimated a thousand ship-year effort resulting in three petabytes of data.

Despite declines in collection rate, bathymetry remains the high-demand data set in MGG. As a fundamental underpinning for imagery and modeling and the essential framework for support of other oceanographic data, the need and desire for more complete and accurate bathymetry grows exponentially with new users and applications. NGDC has responded to the coastal communities with the development of the Coastal Relief Model (CRM). The CRM is a new, integrated, GIS-friendly, grid of topography and bathymetry in the U.S. coastal zone, joining the cultures of terrestrial and marine surveying into a single 3 arc-second grid of the earth's surface above and below sea level. This departure from distributing fundamental or original data is our response to customer and client demand for more directly useful products as well as more complete and accurate bathymetry.

Most of the seafloor remains poorly mapped. NGDC's current world digital elevation model, ETOPO2, is a 2 arc minute grid of global relief. It relies heavily on the pioneering work of Smith and Sandwell,(1997) in estimating seafloor bathymetry between 72° north and south. Their work is the best, unclassified, portrayal of overall bathymetry available. The satellite-altimetry-derived gravity must be matched with high-quality, accurate, acoustically measured bathymetry in order to calibrate the regional relationship between gravity and bathymetry. NGDC welcomes the critical review of our bathymetric holdings, especially in this context, in order to improve and quantify the quality of our bathymetric data. The overall technique has explicit theoretical limits to the resolution and accuracy of the result. Those limits should be pursued to complete our description of the seafloor to the best of our current abilities. Prospects for a better alternative, *e.g.* 100% acoustic coverage of the seafloor, are dim at best.

Potential Role of Mixing and Diffusion on 20th Century Global Sea Level Rise

C.K. Shum, Chung-yen Kuo, Alexander Braun[1], Laboratory for Space Geodesy and Remote
Sensing Research, Ohio State University, Columbus, Ohio 43210, U.S.A. emails:
ckshum@osu.edu, kuo.70@osu.edu, braun.118@osu.edu
[1]Also at Byrd Polar Research Center, Ohio State University, Columbus, Ohio 43210, U.S.A.

Global sea level rise has been widely recognized as one of the consequences of possible anthropogenic (human-induced) effect on global climate change. The recently published 20th century sea level rise rate of 1.84±0.35 mm/yr [Douglas, 2001; Peltier, 2001] is not fully explained by up to one half [e.g., Munk, 2002], compared with the IPCC estimate of 1.1 mm/yr (0.6 mm/yr from melt water, and 0.5 mm/yr from steric effect) [Church et al., 2001]. Recent studies [Cabanes et al., 2001; Gille, 2001; Shum et al., 2001] indicate significantly more upper-ocean (above 500 m) warming in the Southern Ocean, and imply significant geographical variations in both the thermal [Shum et al., 2001] and the "self-gravitational" sea level signal as result of present-day ice melt [Mitrovica et al., 2001] which limits tide gauge determination of the 20th century sea level rise. It is speculated that that a portion of sea level rise budget could be associated with the mixing (thermal, salinity, tidal) and diffusion in the abyss ocean. The multi-mission radar altimeter observed sea level trend estimates (1985-2001), though dominated at present by interannual variability and instrument errors, provide insights of causes of sea level change in the decadal time scale when compared with tide gauges and steric sea level inferred using the NODC salinity and thermal data (1955-2001) [Levitus, 1998]. In this contribution, we provide an assessment of sea level rise measurement using tide gauges and radar altimeter, the known causes and the associated budget for sea level rise during the last century and speculate the potential effect of mixing and diffusion on the signal.

Summary of Petroleum Exploration

Khalid A. Soofi, Conoco

The Altimeter derived Global Free Air Gravity Anomaly and Bathymetry data are used routinely by oil industry for hydrocarbon exploration in frontier areas.

These data provide a pair of uniform baseline grids around the world, which are useful at many levels. For example, it allows easy identification and comparison of major offshore basins around the world. In absence of detailed seismic data, the combination of bathymetry and Free Air Gravity Anomaly are sometimes the only source to test different geologic hypothesis. For example, one can calculate a gravity response of simple geologic model, and then compare the results with the measured free air gravity to test how valid the initial geologic model was. Because of its uniform global nature, this exercise can be done anywhere in the world and compared with well-known producing basins.

The altimeter derived bathymetry data has proven to be an excellent tool for geomorphic analysis of sea floor. One can easily identify paleo submarine canyons, which might have transported the sediments to the deep-water basins. The fracture zones reveal their affect on complex geometry of the basins etc. The bathymetry data are also useful for logistics and engineering applications, such as ideal pipeline routes and design of seismic surveys etc.

Despite its usefulness, these data do have limits. The altimeter derived bathymetry and Free Air Gravity Anomaly have nominal resolution of 40 and 25 km respectively. This is roughly equivalent to regional seismic grids with 10 km spacing. As hydrocarbon exploration moves into smaller basins into deeper waters, it would be useful to have a Global Free Air Gravity Anomaly at a nominal wavelength of 20 km and bathymetry at 5-10 km.

The Application of Bathymetric Data in Calculations of Internal Tides and Mixing

Louis St. Laurent
Department of Oceanography, Florida State University
lous@ocean.fsu.edu
http://turbulence.ocean.fsu.edu

Internal waves have been implicated as the major source of mechanical energy for mixing in the ocean interior. In particular, internal waves generated by tidal forcing, the "internal tides," have been directly associated with mixing in numerous observational studies. The physical mechanisms controlling the transfer of energy from internal tides to turbulent mixing are complicated, though models based on wave-wave interactions have been formulated (Polzin, 2002). A basic metric for estimating turbulent mixing rates is provided by the energy flux of the internal tides. This quantity measures the rate at which energy is transferred from tidal currents into internal waves. All of this energy is assumed to dissipate as turbulence somewhere in the ocean.

St. Laurent and Garrett (2002) present energy flux estimates for the internal tides generated at mid-ocean ridge topography. The properties of the generated spectrum of waves are considered, and the efficiencies of various wave instability mechanisms are assessed. In general, low-mode internal waves with spatial scales of 20 to 100 km carry much of the energy flux. These low-mode waves radiate energy away from generation regions. Higher mode waves with spatial scales of 20 km or less are generated by fine-scale bathymetric roughness. These waves dissipate their energy close to the generation site, leading to enhanced levels of turbulent mixing.

A new bathymetric altimeter mission should resolve bathymetry in the spectral bandwidth between 10 and 30 km. This bandwidth captures the spatial scale of the dominant wave energy at mid-ocean ridge topography. The transition to the fractal regime of bathymetric roughness is also resolved. At present, calculations of internal-tide energy must be based entirely on multibeam data. In the future, internal tide calculations will be based on bathymetry measured by altimetry and a fractal model for fine-scale roughness.

BEYOND TOPOGRAPHIC VARIANCE (THE NEED FOR ACCURATE HIGH-RESOLUTION BATHYMETRIC DATA IN PHYSICAL OCEANOGRAPHY)

Andreas M. Thurnherr, Florida State University, A.Thurnherr@ocean.fsu.edu

It is commonly observed in hydrographic sections crossing mid-ocean ridges that the isopycnals on the ridge flanks slope downward toward the crests, an effect that is presumed to be associated with boundary mixing. The resulting cross-flank pressure gradients are usually inferred to be associated with geostrophic along-flank flows, equatorward on the western flanks and poleward on the eastern flanks of meridional ridge slopes. Model results imply that the transports of the along-flank flows can be of the same order as DWBCs (Thompson and Johnson, DSR, 1996; Huang and Jin, JPO, 2002), i.e. they are of large-scale significance. The isopycnal surfaces over the Mid-Atlantic Ridge (MAR) in the South Atlantic, where high levels of dissipation have been observed in microstructure data (Polzin et al., Science, 1997) and tracer advection (Ledwell et al., Nature, 2000) are consistent with this conceptual picture. Observations of southward flow along the western ridge flank near 20S in the Brazil Basin (Hogg and Owens, DSR, 1999; Ledwell et al., Cruise Report, 2001), on the other hand, are not.

We have analyzed available hydrography from the MAR in the South Atlantic in detail (Thurnherr and Speer, JPO, in press). When geostrophic velocities are calculated without taking the topographic context into account erroneous along-ridge transports of up to 3Sv result, because topographic blocking in cross-flank canyons is ignored. When only the local water depths at hydrographic stations are considered it appears that the effects of mixing extend significantly above the topography, while they are in reality largely confined below the peak depths of the canyon walls. This has potentially important consequences for the processes inferred to be causing the mixing. In particular, we suggest that the topographic organization on the ridge flanks may related to the high observed dissipation levels, in which case it will not be appropriate to parameterize mixing rates from topographic variance of the sea floor. None of these inferences could have been drawn without the Smith and Sandwell (Science, 1997) seafloor topography. The study also illustrates some limitations of these data: (i) there are regions of systematic biases of >100m, (ii) there are large (several 10s of km horizontal extents) false apparent topographic highs extending up to 500m from the true sea floor, and (iii) some of the first-order topographic structures that control the hydrographic characteristics are too small to be resolved.

Global Ocean Models and Bathymetry

Robin Tokmakian

This paper discusses various aspects of global ocean models and their use or potential use of bathymetric data sets. Following an introduction of how ocean models of differing varieties incorporate bathymetric maps onto their domain space, the impact of the bathymetry on the flow dynamics is discussed. Several examples are shown to illustrate how bathymetry, and modifications to it, may be influencing differences in the flow itself. Examples include the Indonesian Throughflow, flow around New Zealand, western boundary areas, areas of strong, narrow flows, and deep flows. The lack of measurements at depth, make it difficult to quantify the accuracy of the deep flows. Possible model improvements as related to bathymetry will be discussed as related to code improvements, data improvements, and in better understanding of the physics.

The Impact of Satellite Altimetry on Plate Tectonics and Geodynamics: Past and Future

Paul Wessel, Department of Geology and Geophysics, School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu, HI 96822; pwessel@hawaii.edu

Satellite altimetry was initiated in the 1970s with the Skylab and GEOS-3 missions, followed by the brief, but highly successful Seasat mission of 1978. Having much higher precision than its predecessors, the gravity anomalies derived from Seasat altimetry gave scientists a comprehensive global view of the Earth's gravity field over the oceans, perhaps best represented by Bill Haxby's maps of the early 1980s. Although first-order bathymetric features were well defined, the large spacing between adjacent tracks made the detection and characterization of smaller features challenging. Matters improved dramatically with the launch of the Geosat (1985-1989) mission and the first European ERS-1 (1991-1996) mission. The dense coverage of these combined tracks provided the basis for the 1997 gridded gravity anomaly solution of Sandwell and Smith. This global grid has a precision of about 5 mGal and a spatial resolution of about 25-30 km; it has been extensively used by marine geophysicists in a wide range of studies.

The earlier missions helped constrain the long-wavelength geoid used to demonstrate the isostatic character of broad features such as continental margins, oceanic plateaus, mid-ocean ridges, and hotspot swells. The results are now textbook material: the passive continental margins and oceanic plateaus largely follow the Airy compensation scheme, whereas the mid-ocean ridges and hotspot swells exhibit Pratt-like thermal isostasy. Intermediate wavelengths were studied in more detail once the Seasat data became available. In particular, investigations into the thermo-mechanical properties and evolution of the oceanic lithosphere relied heavily on the Seasat data. For these intermediate wavelengths, flexural compensation is significant. The evidence for flexure came predominantly from gravity anomalies over seamounts and fracture zones. In particular, the flexural rigidity (or elastic thickness) of the oceanic lithosphere beneath seamounts was shown to be a function of plate age at the time of loading, and revealed a monotonically increasing plate strength with age. These results were naturally interpreted in the context of cooling plate or half space models. Interpretations of geoid profiles across fracture zones corroborated these results.

The gravimetric signature of seamounts has also proven useful in other contexts. For instance, it was realized early on that the signatures over seamounts formed on young and old lithosphere differed markedly. This difference allows a classification of seamounts according to their origins of formation (“on-ridge” or “off-ridge”). Other studies of seamounts have focused on mapping their spatial distribution. Pioneering studies relied on individual Seasat tracks but were hampered by the coarse track spacing: large diamond-shaped areas between the tracks were not mapped. Later studies employed the Geosat/ERS-1 global grid which provided an opportunity to catalog the global seamount distribution. Seamount distributions provide vital information regarding the intraplate volcanic budget in time and space, and delineate hotspot chains whose geometry constrains absolute plate motion models. Finally, the on/off-ridge classification may be extended to allow for approximate age predictions for individual seamounts.

Intermediate-wavelength geoid undulations oriented approximately parallel to absolute plate motions were identified by Haxby and Weissel and have been a source of much debate. Originally attributed to small-scale convection, more recent interpretations and modeling have favored “extensional volcanism”, in part following the discovery of narrow volcanic ridges in the troughs of the geoid undulations. Longer-wavelength undulations, also parallel to plate motion directions, appear to be related to mantle convection realigned into rolls by the motion of the over-riding plate. Numerous linear volcanic ridges, in particular in the Pacific Ocean basin, have been identified in the satellite altimetry images. Features such as Hollister and Sojourn ridges, as well as larger (and previously identified) ridges such as Necker ridge and an unnamed ridge trending SW from the Tuamoto plateau are still poorly understood but are thought to have extensional origins, possibly related to changes in plate motion. Likewise, features such as the V-shaped anomalies on the Reykjanes ridge may reflect temporal and spatial variations in the interactions between spreading center and pulsating hotspot.

Plate tectonics reconstructions have greatly improved following the availability of the high resolution gravity grids. Fracture zones, propagating rifts, abandoned spreading centers, paleo-microplates, and conjugate rift features stand out in the altimetry-derived gravity images, providing unprecedented geometric and kinematic control for the reconstructions. This improvement has forced the re-examination of the rigid plate assumption central to the plate tectonic hypothesis, leading to several new plates being defined.

The abyssal hill fabric created at the mid-ocean ridges exhibits a range of magnitudes. Using altimeter data, Small and Sandwell discovered that the gravity "roughness" decreases with increasing spreading rate up to an intermediate rate of 60-80 mm/yr, with almost no change at higher rates. This threshold appears to correspond to the transition from axial trough to axial high along the mid-ocean ridge system. Their discovery led to models that have sought to explain this transition in terms of a spreading-rate dependence on rheology.

Future altimetry missions with state-of-the-art instruments may achieve a 5-fold improvement in precision (1 mGal) while resolving features less than half the size (12 km full wavelength) of what we can now. While all the areas of research discussed above stand to gain from improved data, the ones that will benefit the most would be those investigating features of short wavelength and low amplitude. In particular, studies that seek to delineate plate tectonic fabric (fracture zones, pseudo faults, propagating rifts etc.), map linear volcanic ridges, mid-ocean ridge dynamics, and characterize seamount signatures and their distributions would make rapid progress. Significant improvements in both absolute and in particular relative plate motions are likely to result following the general availability of the Next Generation altimetry data.