02 INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS

Submit only ONE copy of this form **for each PI/PD and co-PI/PD** identified on the proposal. The form(s) should be attached to the original proposal as specified in GPG Section II.C.a. Submission of this information is voluntary and is not a precondition of award. This information will not be disclosed to external peer reviewers. ***DO NOT INCLUDE THIS FORM WITH ANY OF THE OTHER COPIES OF YOUR PROPOSAL AS THIS MAY COMPROMISE THE CONFIDENTIALITY OF THE INFORMATION.***

PI/PD Name: David T Sandwell

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☐

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

Ethnicity Definition:
Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.
Race Definitions:
American Indian or Alaska Native. A person having origins in any of the original peoples of North and South America (including Central America), and who maintains tribal affiliation or community attachment.
Asian. A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam.
Black or African American. A person having origins in any of the black racial groups of Africa.
Native Hawaiian or Other Pacific Islander. A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands.
White. A person having origins in any of the original peoples of Europe, the Middle East, or North Africa.

WHY THIS INFORMATION IS BEING REQUESTED:

The Federal Government has a continuing commitment to monitor the operation of its review and award processes to identify and address any inequities based on gender, race, ethnicity, or disability of its proposed PIs/PDs. To gather information needed for this important task, the proposer should submit a single copy of this form for each identified PI/PD with each proposal. Submission of the requested information is voluntary and will not affect the organization's eligibility for an award. However, information not submitted will seriously undermine the statistical validity, and therefore the usefulness, of information recieved from others. Any individual not wishing to submit some or all the information should check the box provided for this purpose. (The exceptions are the PI/PD name and the information about prior Federal support, the last question above.)

Collection of this information is authorized by the NSF Act of 1950, as amended, 42 U.S.C. 1861, et seq. Demographic data allows NSF to gauge whether our programs and other opportunities in science and technology are fairly reaching and benefiting everyone regardless of demographic category; to ensure that those in under-represented groups have the same knowledge of and access to programs and other research and educational oppurtunities; and to assess involvement of international investigators in work supported by NSF. The information may be disclosed to government contractors, experts, volunteers and researchers to complete assigned work; and to other government agencies in order to coordinate and assess programs. The information may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, NSF-50, "Principal Investigator/Proposal File and Associated Records", 63 Federal Register 267 (January 5, 1998), and NSF-51, "Reviewer/Proposal File and Associated Records", 63 Federal Register 268 (January 5, 1998).

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PI/PD Name: Dave Stegman

Gender: ☐ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)

- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
(Select one or more)

- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☒

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☐

Ethnicity Definition:
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Black or African American. A person having origins in any of the black racial groups of Africa.
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Collection of this information is authorized by the NSF Act of 1950, as amended, 42 U.S.C. 1861, et seq. Demographic data allows NSF to gauge whether our programs and other opportunities in science and technology are fairly reaching and benefiting everyone regardless of demographic category; to ensure that those in under-represented groups have the same knowledge of and access to programs and other research and educational oppurtunities; and to assess involvement of international investigators in work supported by NSF. The information may be disclosed to government contractors, experts, volunteers and researchers to complete assigned work; and to other government agencies in order to coordinate and assess programs. The information may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, NSF-50, "Principal Investigator/Proposal File and Associated Records", 63 Federal Register 267 (January 5, 1998), and NSF-51, "Reviewer/Proposal File and Associated Records", 63 Federal Register 268 (January 5, 1998).

List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:

Lee-Leung Fu - satellite altimetry
Steven Kirby - subduction processes
David McAdoo - NOAA - subduction and altimetry
Magali I. Billen - subduction
Joanne Stock - Marine Tectonics
Mark Behn - Marine Tectonics
Leigh Royden - Tectonics
Jonathan Nash - PO user of global bathymetry for mixing

REVIEWERS NOT TO INCLUDE:

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 11-1		FOR NSF USE ONLY
PD 98-1620	02/15/11	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)		
OCE - MARINE GEOLOGY AND GEOPHYSICS		

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				175104595	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)
956006144	☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
University of California-San Diego Scripps Inst of Oceanography	8602 La Jolla Shores Dr Univ of California-San Diego LA JOLLA, CA 92093-0210
AWARDEE ORGANIZATION CODE (IF KNOWN) 0013177010	
NAME OF PRIMARY PLACE OF PERF	ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE
University of California-San Diego Scripps Inst of Oceanography	University of California-San Diego Scripps Inst of Oceanography CA ,920930210 ,US.

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions) ☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS ☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **A Factor of 2 Improvement in Global Marine Gravity from Cryosat, Jason-1, and Envisat**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 458,375	48 months	09/01/11	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

- ☐ BEGINNING INVESTIGATOR (GPG I.G.2)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
- ☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date ________ PHS Animal Welfare Assurance Number ________
- ☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number ________ Exemption Subsection ____ or IRB App. Date ________
- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j) ________
- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
Inst. of Geophysics & Planetary Physics	8795 Biological Grade, Room 1104 La Jolla, CA 920930225 United States
PI/PD FAX NUMBER 858-534-2902	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME David T Sandwell	PhD	1980	858-534-7109	dsandwell@ucsd.edu
CO-PI/PD Dave Stegman	PhD	2003	858-822-0767	dstegman@ucsd.edu
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the Authorized Organizational Representative or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, lobbying activities (see below), responsible conduct of research, nondiscrimination, and flood hazard insurance (when applicable) as set forth in the NSF Proposal & Award Policies & Procedures Guide, Part I: the Grant Proposal Guide (GPG) (NSF 11-1). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

Conflict of Interest Certification

In addition, if the applicant institution employs more than fifty persons, by electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.A; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

Certification Regarding Lobbying

The following certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Certification Regarding Nondiscrimination

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative is providing the Certification Regarding Nondiscrimination contained in Exhibit II-6 of the Grant Proposal Guide.

Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:

(1) community in which that area is located participates in the national flood insurance program; and
(2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:

(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF Grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

Certification Regarding Responsible Conduct of Research (RCR)
(This certification is not applicable to proposals for conferences, symposia, and workshops.)

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research.
The undersigned shall require that the language of this certification be included in any award documents for all subawards at all tiers.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME		

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER

* EAGER - EArly-concept Grants for Exploratory Research
** RAPID - Grants for Rapid Response Research

PROJECT SUMMARY

Intellectual Merit

Over the next 3 to 5 years, a wealth of new marine gravity data will be provided by three currently operating satellite altimeters CryoSat, Jason-1, and Envisat. With careful processing of the data, in combination with data from past Geosat and ERS-1/GM altimeter missions, we propose to improve the accuracy of the global marine gravity field by at least a factor of two and in some areas a factor of four. One of the main benefits of an improved gravity field is the ability to resolve new structures on the ocean floor.

Our proposed research has 4 main components:

- Develop waveform retracking algorithms and computer codes for these new satellite altimeter data sets that are optimal for gravity field recovery.
- Develop global gravity grids at 1 minute resolution using the new altimeter data as it becomes available.
- Continue to develop global bathymetry grids at both 1 minute and 30 arc second resolutions.
- Use these new data to estimate the bending moments needed to support the trench and outer rise topography of all subduction zones. The higher resolution gravity may also reveal the characteristics of deep fractures on the outer trench walls where there is no multibeam bathymetry coverage. The bending moment measurements will be coupled to Benioff zone geometry and ultimately be used to infer the slab pull forces driving the plates.

Broader Impacts

Global bathymetry is used in many areas outside of the scientific community including: K-12 teaching of earth science and seafloor geography; undergraduate-level earth science and plate tectonics; law of the sea; US Naval operations; mineral exploration; planning of fiber-optic cable routing and general interest by the public. We will continue to work with Google to provide the global bathymetry and ancillary data, in the widely used Google Earth program. Funding will be used to support and educate graduate and undergraduate students.

Data Management Plan

All data will be freely available within one year after production. The gravity and bathymetry data will be distributed on line in three formats for three audiences: general public, general scientist, and power user through our web site topex.ucsd.edu. NOAA National Geophysical Data Center will provide the long-term archive for the global gravity and bathymetry grids.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.B.2.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

1. RESULTS FROM PRIOR NSF SUPPORT

HIGH-RESOLUTION MARINE GRAVITY, SEAFLOOR TOPOGRAPHY, AND SEAFLOOR ROUGHNESS; SANDWELL; OCE0326707; $367,567; 07/15/03 - 06/30/08, ACCOMPLISHMENT BASED RENEWAL OCE0825045; $166,505 09/01/2008 - 08/31/2011

Improved global gravity and bathymetry: Over the period of the investigation we have achieved nearly a factor of two improvement in the accuracy of the marine gravity field (Figure 1). Much of this improvement was due to retracking the raw radar altimeter waveform data from Geosat and ERS-1 altimeters using an algorithm that is optimized for gravity recovery [*Sandwell and Smith*, 2005; *Sandwell and Smith*, 2009]. In addition there has been a dramatic improvement in land gravity provided by the EGM2008 [*Pavlis et al.*, 2008]. These combined developments have resulted in a global marine gravity anomaly map having an accuracy of 3-5 mGal even in coastal areas. To complement the improvements in gravity we have constructed two new global bathymetry models by accumulating, and editing, available depth soundings [*Becker et al.*, 2009]. Our focus has been on compiling mostly single-beam echo-sounder data the remote deep ocean areas. There is little overlap between our efforts and the more detailed compilations of the Marine Geosciences Data System (http://www.marine-geo.org/portals/gmrt/) and we feel the two efforts are highly complementary. The 1-minute Mercator-projected bathymetry matches the global gravity grid so the pair is highly suitable for quantitative scientific investigations. We also developed a global 30-arc second grid to match the SRTM30 land topography format. This is called SRTM30_PLUS because it is SRTM30 [*Farr et al.*, 2007] PLUS the global bathymetry data. These bathymetry grids have a factor of two more soundings than were used in our previous 2-minute bathymetry [*Sandwell and Smith*, 1997]. The 30-arc second bathymetry grid also includes a matching grid of source identification number (SID) so the provenance of every depth pixel can be traced back to the original sounding or gravity prediction. New bathymetry contributions come from a variety of sources including previously proprietary shallow-water soundings from the National Geospatial Intellegence Agency (NGA) and GEBCO as well as multibeam data from JAMSTEC.

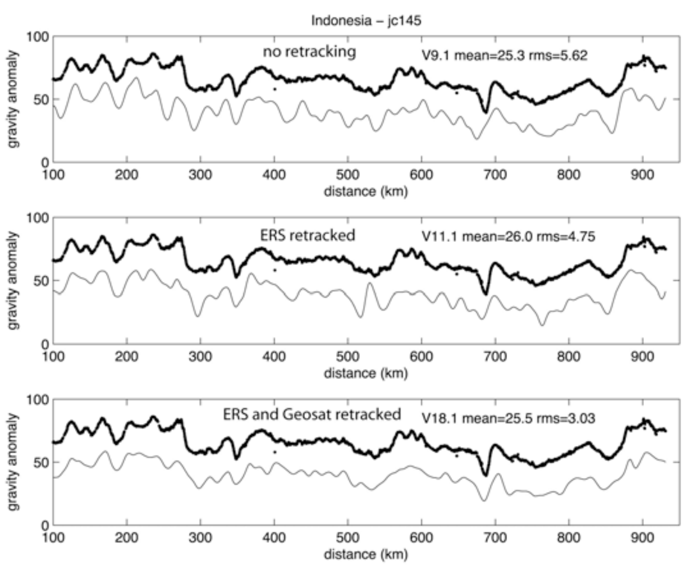


Figure 1. Comparison between satellite-derived gravity models (thin lines) and a shipboard gravity profile (points) across the Java Sea. (top) Gravity model version 9.1 does not use retracked altimeter data and has an rms misfit of 5.62 mGal. The mean difference of 25 mGal is due to a mean error commonly found in shipboard gravity [*Wessel and Watts*, 1988]. (middle) Gravity model version 11.1 uses retracked ERS-1 altimeter data but the Geosat data were not retracked; the rms misfit improved to 4.75 mGal. (bottom) Gravity model version 18.1 is based on both retracked ERS-1 and Geosat altimeter profiles. The rms is improved further to 3.03 mGal, which is a 46% reduction in rms.

Broader impacts through distribution of data products and student training: These gravity and bathymetry data are distributed on line in three formats for three audiences: general public, general scientist, and power user through our 15 year-old web site topex.ucsd.edu. Information for the general public is provided as jpegs, movies, and descriptive text. In collaboration with Paul Wessel at Univ. of Hawaii, we offer the global gravity and bathymetry in Google Earth KML-format as overlays to the standard bathymetry (SRTM30_PLUS V4.0) in their product. These overlays provide more quantitative information such as contour interval and ship tracklines; These Google Earth overlays were recently displayed on the cover of Science as an overview image of the Hawaiian Swell Seismic Experiment

[*Wolfe et al.*, 2009] (Figure 2). These overlays also provide the basis for a Seamount Discovery Tool that we hope will become a navigational aid on UNOLS and NOAA vessels [*Sandwell and Wessel*, 2010].

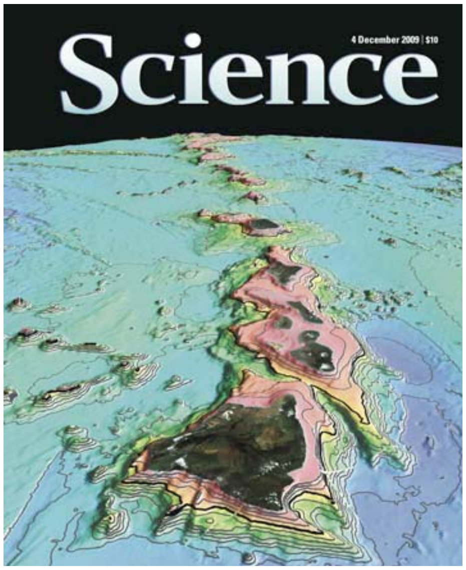


Figure 2. Seafloor depth based on ship soundings and satellite altimetry draped over matching seafloor in Google Earth (500 m contour interval) was used for the December 2009 cover of Science. The global kml-file is available at ftp://topex.ucsd.edu/pub/global_topo_1min/global_topo_1min_V13.1_terra.kmz

More quantitative data is distributed to scientific users either as user-selected ASCII xyz-files at 30 arc seconds or 1 minute resolution or as global grids. These data form the basis for a number of other global bathymetry grids such as GEBCO-08. In addition to the distribution of gridded data the raw altimetry or edited bathymetry are available to anyone who asks. The highest resolution available is 500 m so our compilations are complementary to the Marine Geosciences Data System [*Carbotte et al.*, 2004; *Ryan*, 2010] which distributes full resolution multibeam bathymetry data.

These funds have been used to support both graduate and undergraduate students. Joseph Becker received his Ph.D. in 2009 by developing the tools for editing sparse sounding data as well as performing an investigation of tidally induced mixing in the deep ocean. Over the 7 years we have employed 6 undergraduate students to edit the raw sounding data and perform other types of research using these data (Scott Nelson, Breanna Binder, Seung-Hee Kim, Megan Jones, Adrienne Apabicle, and Adam Zona). These undergraduate students come from physics, math, and mechanical engineering departments at UCSD and work side-by-side with SIO graduate students and professors. Breanna, Seung-Hee, and Megan all moved on to graduate school.

Scientific results: Our group uses these data to perform research ranging from tidally induced mixing of the deep ocean [*Becker et al.*, 2009], to global seamount compensation studies [*Watts*, 2006], to estimation of global topographic stress [*Luttrell and Sandwell*, 2009]. The following publications were supported by this NSF grant:

Sandwell, D. T., and Y. Fialko, Warping and Cracking of the Pacific Plate by Thermal Contraction, *J. Geophys. Res.*, *109, B10411*, doi:10.1029/2004JB003091, 2004.

Sandwell, D. T., and W.H.F. Smith, Retracking ERS-1 Altimeter Waveforms for Optimal Gravity Field Recovery, *Geophys. J. Int., 163*, 79-89, 2005.

Lillibridge, J., W. H.F. Smith, D. Sandwell, R. Scharroo, F. Lemoine, and N. Zelensky, 20 Years of improvements to Geosat altimetry, paper presented at 15 Years of Progress in Radar Altimetry Symposium, European Space Agency, Venice Lido, Italy, 2006.

Watts, A. B., D. T. Sandwell, W. H. F. Smith, and P. Wessel, Global gravity, bathymetry, and the distribution of submarine volcanism through space and time, *J. Geophys. Res., 111*, B08408, 2006

Sandwell, D. T., W. H. F. Smith, S. Gille, E. Kappel, S. Jayne, K. Soofi, B. Coakley, and L. Geli, Bathymetry from Space: Rationale and requirements for a new, high-resolution altimetric mission, *Comptes Rendus de l'Académie des Sciences, 338, p. 1049-1062, 2006*.

Becker, J. J., D. T. Sandwell, Global Estimates Of Seafloor Slope From Single-Beam Ship Soundings, *J. Geophys. Res., 113,* C05028, doi:10.1029/2006JC003879 30 May 2008.

Sandwell, D. T., and W. H. F. Smith, Global marine gravity from retracked Geosat and ERS-1 altimetry: Ridge Segmentation versus spreading rate, *J. Geophys. Res.,* 114, B01411, doi:10.1029/2008JB006008, 2009.

Becker, J. J., D. T. Sandwell, W. H. F. Smith, J. Braud, B. Binder, J. Depner, D. Fabre3, J. Factor, S. Ingalls, S-H. Kim, R. Ladner, K. Marks, S. Nelson, A. Pharaoh, G. Sharman, R. Trimmer, J. VonRosenburg, G. Wallace, P. Weatherall., Global Bathymetry and Elevation Data at 30 Arc Seconds Resolution: SRTM30_PLUS, *Marine Geodesy,* 32:4, 355-371, October 8, 2009.

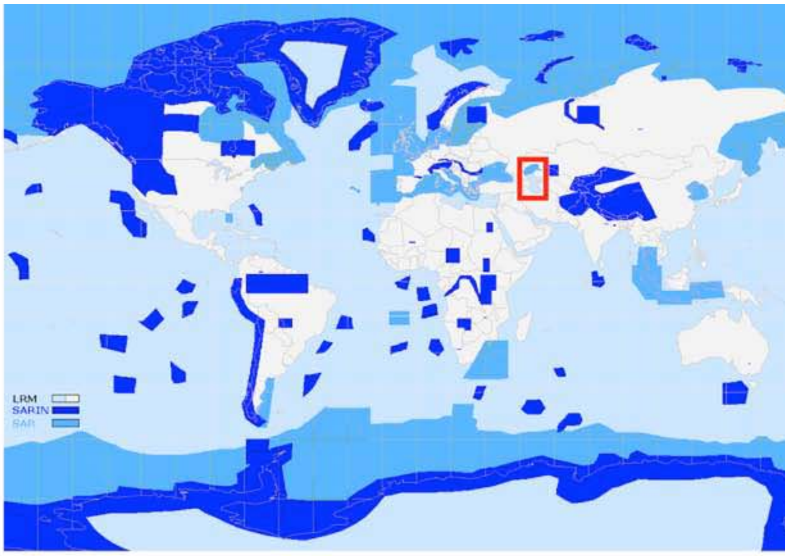
Sandwell, D. T., and P. Wessel, Seamount discovery tool aids navigation to uncharted seafloor features, *Oceanography, 23:1,* p. 34 - 36, 2010.
Marks, K. M., W. H. F. Smith, and D. T. Sandwell, Evolution of errors in the altimetric bathymetry model used by Google Earth and GEBCO, Mar. Geophys. Res., 31, p., 223-238, DOI 10.1007/s11001-010-9102-0, 2010.

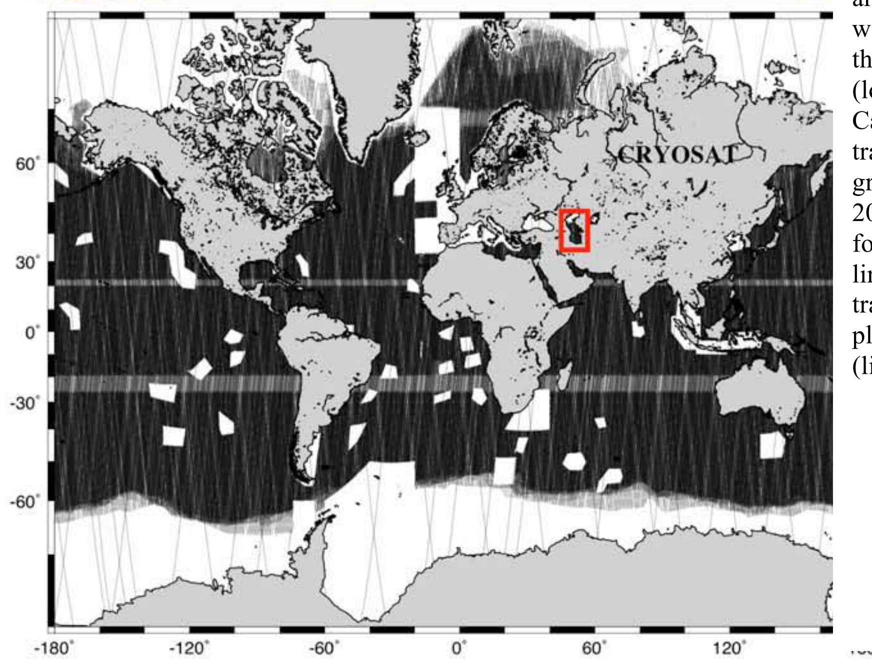
2. Project Description

2.1 Intellectual Merit

Over the next 3 to 5 years, a wealth of new marine gravity data will be provided by three currently operating satellite altimeters CryoSat, Jason-1, and Envisat. With careful processing of the data, in combination with data from past Geosat and ERS-1/GM altimeter missions, we propose to improve the accuracy of the global marine gravity field by at least a factor of two and in some areas a factor of four. Our proposed research has 4 main components. The first is to develop retracking algorithms and computer codes for analysis of data from these three radar altimeters. The second is to construct new global marine gravity models at 1 minute resolution extending to a latitude of 88 degrees north. The third is to update global bathymetry grids at both 1 minute and 30 arc second resolutions using the new gravity field information for interpolating areas where there are no ship soundings. These first three activities will be performed in collaboration with Walter H. F. Smith at NOAA (see letter of collaboration). The fourth is to use these new data to estimate the bending moments needed to support the trench and outer rise topography of all subduction zones. In addition, the higher resolution gravity may reveal the orientation and amplitude of outer trench wall fractures associated with this bending. These measurements will be coupled to Benioff zone geometry and ultimately be used to infer the slab pull forces driving the plates. This work will be performed in collaboration with Dave Stegman at SIO.

New Satellite Altimetry Data From CryoSat, Jason-1 and Envisat: The marine geophysics community has been waiting for 15 years for a new source of densely spaced radar altimeter measurements. Current gravity fields are based primarily on 18 months of Geosat/GM data collected in 1985-86 and 12 months of ERS-1/GM collected in 1995-96. Since then there have been several advances in radar altimeter technology but all the newer satellites have been placed in the repeat orbit configuration that is optimal for recovering changes in ocean surface height associated with currents and tides [*Fu and Cazenave*, 2001] but provide little new gravity information. The repeat orbit altimeters include Geosat/ERM 1986-1989, ERS-1 1991-1995, Topex/Poseidon 1992-2006, ERS-2 1995-2010, GFO 1998-present, Jason-1 2001-present, Envisat 2002-present, and Jason-2 2008-present. Over the past year there have been three developments related to radar altimeter missions with dense track spacing. First, CryoSat-2 was successfully launched in February of 2010 and has routinely collected altimetry data over ice, land, and ocean since July 2010 (Figure 3 - upper). Second, the Envisat satellite, which has been in continuous operation since 2002, is running low on the fuel needed for maintaining a repeating ground track. Beginning in October, 2010 the orbit has been allowed to drift while still collecting altimetry data. Envisat will remain in this drifting orbit at least until the 2013 launch of the replacement satellite Sentenel-1. Third the Jason-1 altimeter was replaced by Jason-2 in 2008 so to avoid a potential collision and to provide new gravity information, it will be maneuvered into an orbit with a 419-day repeat cycle (Figure 3 - lower) in early 2013 which is optimal for gravity field recovery [*Morrow et al.*, 2010]. In their normal operating modes all three of these “new” altimeter have range precision approximately the square root of two times better Geosat and ERS because they operate at 2 times higher pulse repetition frequencies of about 2000 Hz.





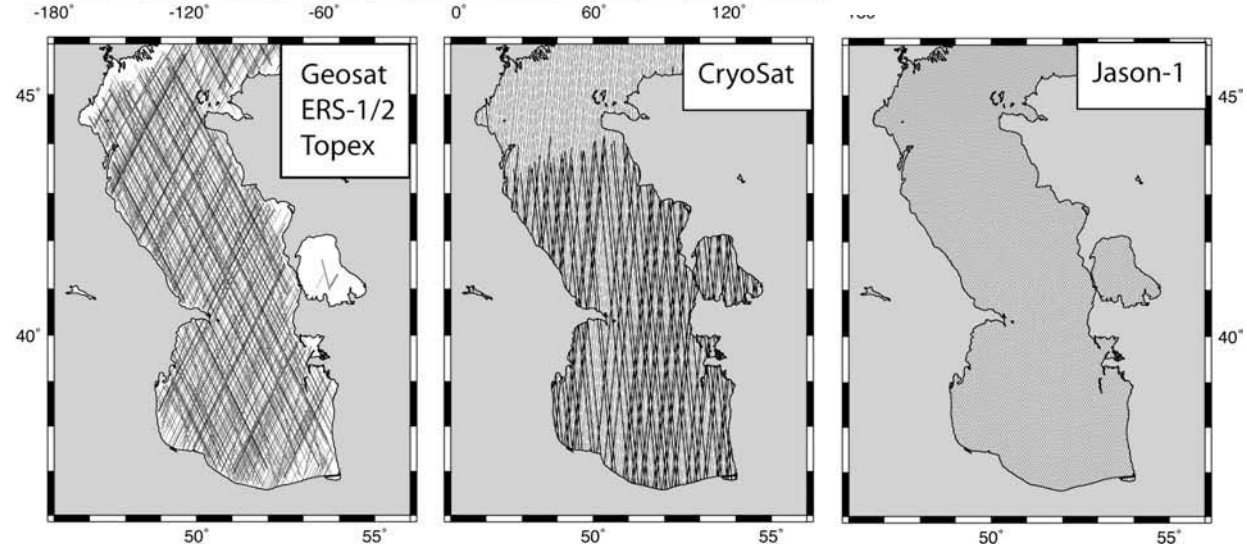


Figure 3. (upper) planned radar operating modes for CryoSat; LRM – standard mode used by all previous altimeters; SAR – synthetic aperture radar mode may provide 2-4 times better range precision. SARIN – uses two receive antennas to also measure cross-track slope over ice. We propose to process the data from all three modes for complete ocean coverage.
(middle) Actual CryoSat data collected in the LRM mode for the past 6 months basically follows the acquisition plan. Missing bands at +/- 22 latitude are due to calibration which will end in February, 2011 so these gaps will be filled.
(lower) Ground tracks for the Caspian Sea region. (left) actual tracks used in V18.2 global gravity [*Sandwell and Smith*, 2009]. (center) CryoSat tracks for the past 6 months (dark lines) as well as planned 1-year tracks (light lines). (right) planned Jason-1 tracklines (light lines).

More important, the CryoSat altimeter can also be operated in a synthetic aperture radar mode over the oceans to achieve a perhaps factor of 2-4 improvement in range precision [*Raney et al*., 2003; *Smith and Sandwell*, 2004; *Gilles et al*., 2010]. Figure 3 shows the planned modes of operation for CryoSat as well as the actual standard-mode (LRM) data collected for the past 6 months. A zoom of the Caspian Sea area shows existing coverage as well as planned coverage from CryoSat and Jason-1. The planned Jason-1 trackline is too dense to see individual tracks on this figure.

A preliminary analysis, discussed below, shows that CryoSat altimeter has better range precision than Geosat by a factor of 1.4. If CryoSat operated for 3 years or longer, then the combined gravity field improvement will be a nearly factor of 2 as shown in Figure 4. One negative feature of CryoSat is that the high orbital inclination results in mostly N-S track orientation so at low latitudes the E-W component will not be resolved as well as the N-S component. At low latitudes, the data from Jason-1 will be important for gravity field improvement. The tracks will be very dense if the satellite can operate for a full 419 day repeat cycle.

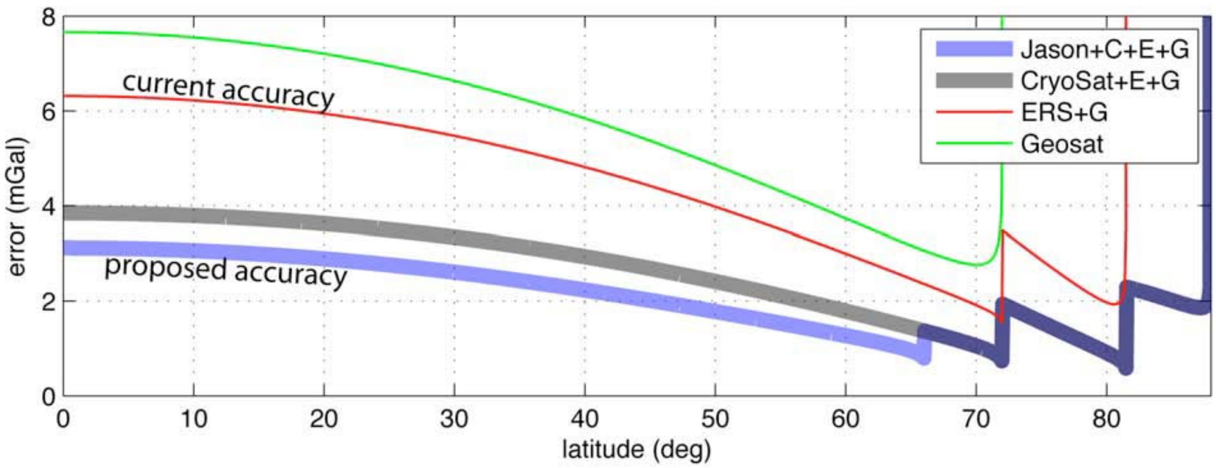


Figure 4. Theoretical gravity field accuracy versus latitude showing relative improvements as new altimeter data become available. Green curve shows gravity field accuracy based on retracked Geosat only which has a maximum latitude of 72˚. Accuracy improves with latitude to 72˚ as tracks become more orthogonal and track density increases. Red curve shows the present-day gravity accuracy from V18.1 [*Sandwell and Smith*, 2009], which also includes retracked ERS-1 data which has a maximum latitude of 81.5˚. The thick black and blue curves show improvements by adding CryoSat (3 years retracked) and Jason (1.15 year retracked).

Why Retracking is Essential for CryoSat and Jason-1: Satellite altimetry data are provided to the user community at different levels of processing. Most users begin with the level-2 products where the raw waveform data has been retracked and averaged into 1 Hz or 7 km along-track spacing. Standard waveform retracking estimates 3 to 5 parameters, the most important being arrival time, rise time, and the return amplitude [*Amarouche et al*., 2004; *Brown*, 1977]. Through calibration, these 3 parameters are transformed into sea surface height, significant wave height (SWH), and wind speed respectively. Most users of level-2 data, average these parameters for about 30 km in the along-track direction to further reduce noise. However, this standard processing is inadequate for optimal recovery of the marine gravity field. The marine gravity field is a measure of ocean surface slope so high range precision over the shortest possible along-track distance is needed.

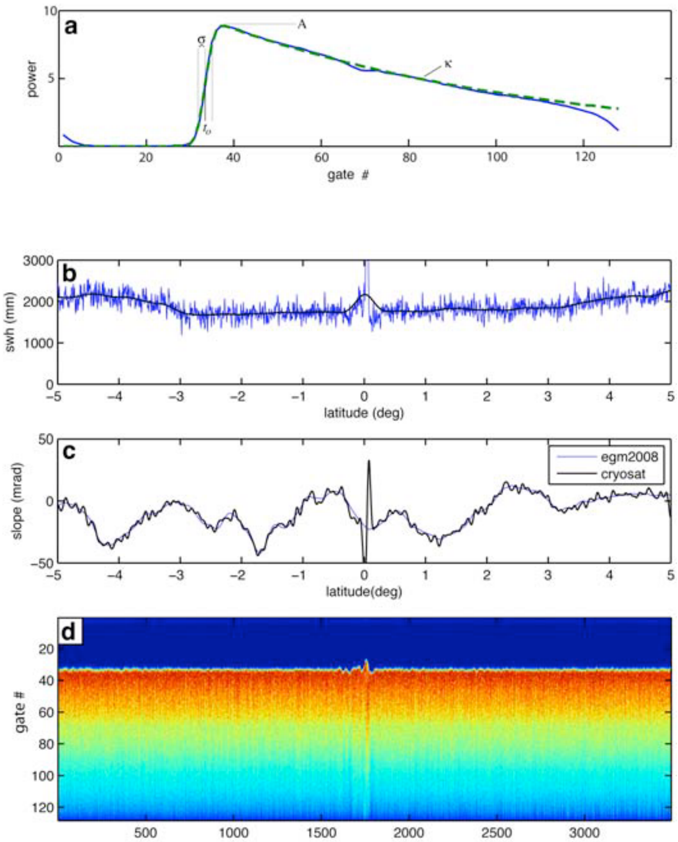


Figure 5. Short segment of a CryoSat LRM track across the Indian Ocean.
(a) Average of 27,000 CryoSat radar waveforms (solid) and a simplified model (dashed) with four adjustable parameters: *A*-amplitude, t_o – arrival time, σ – rise time, and κ – trailing edge decay.
(b) Significant wave height (SWH) derived from 4-parameter retracking model (blue curve) has unrealistic short wavelength jitter. Smoothed SWH (black curve) was provided to a 2-parameter retracker to constrain the shape of the leading edge of the waveform so the arrival time is more accurately estimated.
(c) Arrival time converted to along-track slope (black curve) compared with slope from the EGM2008 model (blue curve, essentially V18.1 gravity). Both were low-pass filtered at 18 km wavelength for direct comparison with a previous analyses of Geosat and ERS-1 data. The slope differences have a median absolute deviation of 2.48 microradian – part of this difference is gravity signal and part is altimeter noise.
(d) CryoSat waveforms used for the analysis. The anomaly at the equator is perhaps due to a rain cell. Further algorithm development is needed to identify and remove these bad data.

The accuracy of the recovered gravity field depends only on the accuracy of the arrival time parameter. One way of improving the gravity field is to retrack the raw altimeter waveform using an algorithm that is optimized for arrival time estimation. Arrival time error and SWH error are inherently correlated because of the noise characteristics of the return waveform [*Maus et al*., 1998; *Sandwell and Smith*, 2005]. Two previous studies have demonstrated up to 40% improvement in range precision by optimizing the retracking algorithm to achieve high range precision at the expense of recovering small spatial scale variations in significant wave height [*Maus et al*., 1998; *Sandwell and Smith*, 2005]. For this proposal, we have modified the ERS-1 retracking software to work with CryoSat LRM data. Our preliminary analysis based on 8 profiles across the Indian Ocean reveals the following (Figure 5). First the quality of the raw waveform data are excellent. The EGM2008 model was used to assess the accuracy of slope estimated from retracked CryoSat. The standard 3-parameter retracking has a median absolute deviation (MAD) of 3.14 μrad. The optimized 2-parameter retracking reduces the MAD to 2.48 μrad. A similar analysis using retracked Geosat and ERS-1 data shows MADs of 3.19 μrad and 3.56 μrad respectively. **We attribute the 1.4 reduction in noise level of CryoSat with respect to the previous altimeters to its 2 times higher pulse repetition frequency. This preliminary analysis suggests that a factor of 2 improvement of global marine gravity is feasible with 3 years of data and optimized waveform retracking.** The European Space Agency has no plans to retrack CryoSat data using this optimized approach. Our proposal is to develop optimal retracking methods for CryoSat, Jason-1, and Envisat. One year of CryoSat data has 500 million waveforms so the retracking algorithms must be computationally efficient.

How will improved gravity enable new science? One of the main drivers for an improved gravity field is the ability to resolve new structures on the ocean floor (Figure 6). The scientific rationale for such a mission is mature and a set of papers related to this topic was published in a special issue *Oceanography* [*Smith*, 2004], entitled *Bathymetry from Space*. The global ocean floor could be mapped to about 200 m horizontal resolution acoustically by ships carrying multi-beam echo-sounders, at an investment of around 200 years of ship time [*Carron et al*., 2001]. A global ocean mapping program by a satellite altimeter operated in SAR mode would be cheaper by an order of magnitude, but would also have a more limited resolution (about 6 km). This limitation is imposed by physical law (upward continuation of gravity anomalies from the sea floor to the sea surface) and not by altimeter technology. Several studies [*Smith*, 2005; Goff, 2010] found that an altimeter mapping sea surface slope to 1 microradian with a half-wavelength resolution of 6 km would be sufficient to resolve the abyssal hill fabric of the oceans. Although not as detailed as acoustic bathymetry, mapping to this resolution threshold would be a critical advance for a large number of basic science and practical applications, including: determining the effects of bathymetry and seafloor roughness on ocean circulation [*Gille et al.*, 2004], mixing [*Kunze and Llewellyn Smith*, 2004], climate [*Jayne et al.*, 2004], tides [*Arbic et al.*, 2004], and biological communities, habitats, and mobility [*Koslow*, 1997]; understanding the geologic processes responsible for ocean floor features, such as abyssal hills, seamounts, microplates, and propagating rifts [*Sandwell et al.*, 2001; *Sandwell et al.*, 2006]; improving tsunami hazard forecast accuracy by mapping the deep ocean topography that steers tsunami wave propagation [*Mofjeld et al.*, 2004]; assessing potential territorial claims to the seabed under the United Nations Convention on the Law of the Sea [*Monahan*, 2004].

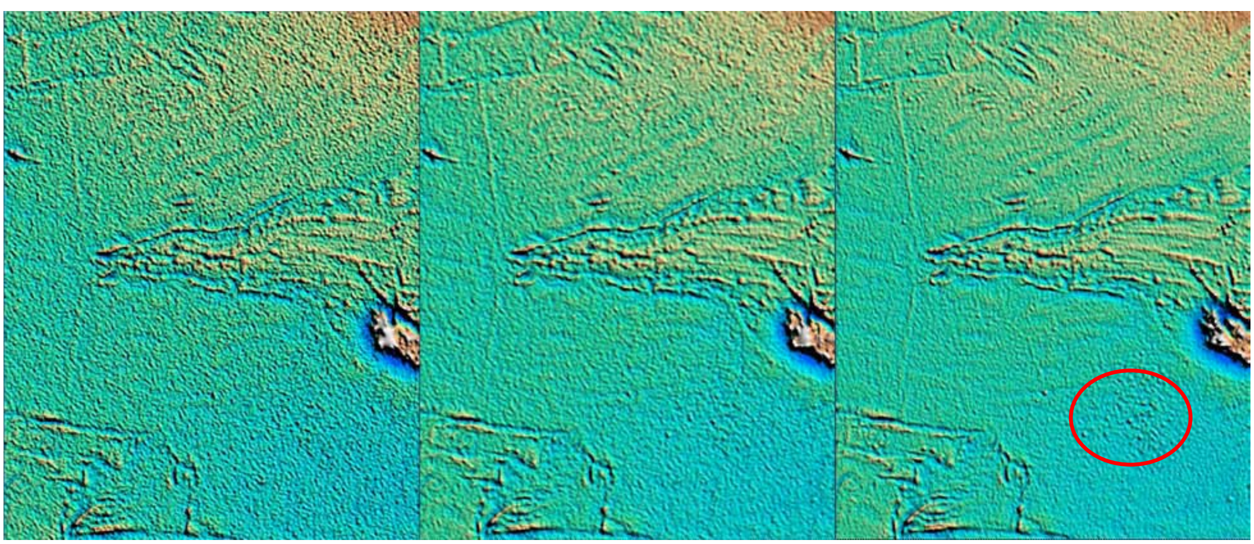


Figure 6 Shaded gravity anomaly for a large region in the Central Pacific Ocean centered at the Galapagos Triple Junction (latitude 11˚ to –8˚, longitude 255˚ to 270˚). Colors saturate at +/- 60 mGal. The visual noise level decreases as one moves from V9.1 (left) to V11.1 (center) to V18.1 (right). The axis of the East Pacific Rise is well defined in V18.1 but more difficult to trace in V9.1 because of the higher noise level. The red oval outlines a patch of small uncharted seamounts not apparent in V9.1. The evolution from V9.1 to V18.1 corresponds to a factor of 2 improvement in gravity field accuracy. **Our proposed investigation will improve the accuracy by another factor of 2. This will reveal significant unknown details in seafloor morphology.**

These studies of the new science are related to a gravity accuracy of better than 1 mGal. Note that 1 mGal accuracy in gravity translates into 1 microradian accuracy in ocean surface slope. Current gravity models have accuracies of 3-5 mGal over a 9 km length scale. With CryoSat we hope to reduce this error to 1.5-2.5 mGal over a 9 km length scale (Figure 4.). Achievement of better than 1 mGal over a 6 km length scale will require an altimeter operating in SAR mode. So we see CryoSat as an important milestone in demonstrating the ultimate accuracy and resolution threshold. Moreover, as shown in Figure 3, CryoSat will be operated in the SAR mode over the Arctic Ocean as well as some small test regions in the lower-latitude oceans. As part of this proposal we will assess the gravity improvement that can actually be achieved by operating in the SAR mode and will incorporate these SAR-mode data in our global gravity models.

Proposed tasks: We have an investigation, approved by the European Space Agency, to obtain all the CryoSat waveform data (LRM, SAR, and InSAR) over the oceans at no cost. These LRM data have similar characteristics to Geosat waveform data records WDR or the ERS waveform product (WAP). Our 4-year plan is:
Year 1 – We will modify our waveform retracking software and altimeter processing software to be used with the CryoSat waveform data product (LRM and SAR). We have obtained a few passes of CryoSat over ocean areas to evaluate the signal-to-noise characteristics of the multi-looked waveform data. Through comparisons with high-resolution geoid models we will refine waveform tracking algorithms that are optimized for the open ocean and sea ice areas. We expect that the algorithm development will continue into the second year of the investigation.
Year 2 - We will construct a new global gravity grid (1-minute resolution) based on all available satellite altimeter data. The methods and computer codes for constructing the vertical deflection, gravity anomaly, and geoid height grids are published in [*Sandwell and Smith*, 1997; 2009]. If we can automatically re-track CryoSat SAR data in areas of sea ice, we will extend the grid to +88˚ latitude. The gravity field construction will be repeated at 1-year intervals until the end of the CryoSat mission (3 – 5 years). The long-wavelength reference field for this grid will be based on the best available spherical-harmonic gravity models from CHAMP, GRACE, and GOCE. The altimeter-derived gravity models are most accurate between wavelengths of 20 km and 2000 km while the satellite-derived models are most accurate between wavelengths of 400 km and 40,000-km. The overlap part of the spectrum will be used to validate both approaches as well as to isolate the false gravity signals that will be apparent in the altimeter-derived gravity along the fronts of the major currents.
Years 3 and 4 – If Jason-1 is still operational after it is placed into a 419-day repeat cycle phase in mid-2012 we will develop a waveform retracker that is optimized for gravity recovery. We hope to receive 419 days of Jason-1 data from the planned Geodetic mission by mid-2014. We will add these data to the gravity field to improve the lower latitude gravity accuracy by another milligal. The major benefit of Jason-1 data will be to better constrain the E-W gravity field so N-S features such as the East Pacific Rise can be better resolved. In addition to Jason-1 we expect some new gravity information from the drifting phase of Envisat. However, the extent and duration of this drifting phase are not well known. ESA hopes to keep the envelope of the drifting Envisat tracks to less than 20 km so repeat-track InSAR and altimetry is still sometimes possible.

Refinement of Global Bathymetry: The third aspect of our proposed research is to continue the construction of global bathymetry models at 1-minute and 30-arc seconds. Our previous work is discussed above in the *Results from Prior NSF Support* section and also in the references cited so the approach will not be repeated here. The main points are that our global cleaned bathymetry data will be used with the improved CryoSat and Jason-derived gravity model to make a new global bathymetric prediction. The accuracy of the prediction degrades with distance to the nearest depth sounding [*Marks et al*., 2010] so our focus will be to locate existing data that will fill the largest data gaps. These "new" data do not come from the normal archives such as NGDC or the Marine Geosciences Data System. For example, the National Geospatial Agency has accumulated an archive of 1376 cruises that are not included in the NOAA GEODAS distribution [*Von Rosenberg*, 2006, personal communication]. In general the quality of these data are poor and unsuitable for constructing grids even at 1 minute resolution. Some of these tracks cover remote seafloor where there are large gaps. Approximately 50% of these sounding data have significant blunders in depth or navigation. Undergraduate students in our lab visually examine every trackline using a tool that displays the sounding depth along with the predicted depth. Blunders and questionable data are flagged and not used in the next update of the global bathymetry. This is an iterative process where a new global map is constructed, the source identifier of conflicting points is recorded and the trackline is re-edited. Over the past 7 years we have assembled and cleaned 6800 files of bathymetry data from perhaps 100 different sources. Some of these data are proprietary but most have no restrictions and have been provided to other investigators.

Multi-scale Modeling to Link Plate Curvature and Subduction Zone Geodynamics: The fourth aspect of this proposal is to use these new data to investigate the plate bending and fracturing on the outer trench wall of subduction zones globally. In terms of developing better understanding of multi-scale dynamics of the subduction system, bending near the trench represents a critical link between the integrated strength of oceanic lithosphere and mantle dynamics. The long-term dynamics can be investigated using numerical models but such efforts depend on adopting an appropriate plate rheology. Numerical models of subduction typically invoke a plate rheology derived from physics at the microscale (0.1-10 mm), based upon empirical relationships from rock deformation experiments that describe the composite effect of temperature-, stress-, volatile content, and grain-size dependent viscosity [*Billen*, 2008]. However, mature oceanic lithosphere is both much greater (~100 km) and deforming on a timescale much longer (~10^6 years) than laboratory experiments. Additionally the rheology must account for the tectonic fabric at the macroscale (~1-10 km), such as normal faulting and associated damage due to bending. One of the major unresolved issues in geodynamics is describing an appropriate strength of the lithosphere at the mesoscale (100 km) on timescales of subduction.

This mesoscale behavior of subducting plates has been previously described using a simplified rheology [*Ozbench et al*., 2008; *Stegman et al*., 2010; *Schellart et al.,* 2010] that, in essence, parameterizes the microphysics as well as the faulted, damaged, and/or hydrated tectonic fabric that composes oceanic lithosphere. This approach implements a rheologically-layered tectonic plate that represents the system of (sub-grid) normal faults embedded in the upper, brittle portion of the plate with a non-linear, viscoplastic rheology that yields when subjected to large stresses arising from plate bending. This is underlain by three linear-viscous layers with progressively decreasing viscosity that represent a discretization of the temperature-dependent viscosity structure, in which the strongest (coldest) layer acts as a stress guide between the sinking slab and trailing plate. *A key goal of the proposed work is to greatly improve upon describing the* *mesoscale rheology of subducting plates by better incorporating the macroscale aspects of fracturing due to bending as well as connecting across scales to the microscale physics*.

In order to further develop a more relevant description of the integrated strength of oceanic lithosphere, we intend to 1) provide new observations of subduction zones from both the macroscale (normal faulting) and mesoscale (plate flexure) that are global in coverage and 2) use numerical models of subduction to test new formulations of plate strength that utilize these new observations. The key parameter for analysis of plate flexure is the bending moment [*Turcotte and Schubert*, 2002]. Measuring the bending moment needed to support trench and outer rise topography is conceptually straightforward, however calculating a trench profile is rather difficult in practice because 90% of the seafloor is uncharted at a 1 minute resolution [*Becker et al*., 2009] and real seafloor topography has seamounts, plateaus, sediments, and thermal subsidence as seen in Figure 7. Using a small number of parameters, a flexural model is used to fit the shape of the bending topography indicated from pre-processed bathymetry data (e.g. age-corrected and median filtered to minimize the effects of small topographic features). The resultant topographic profile serves as a convenient and hopefully accurate parameterization of seafloor shape that can be integrated to estimate bending moment and differentiated to estimate outer rise plate curvature.

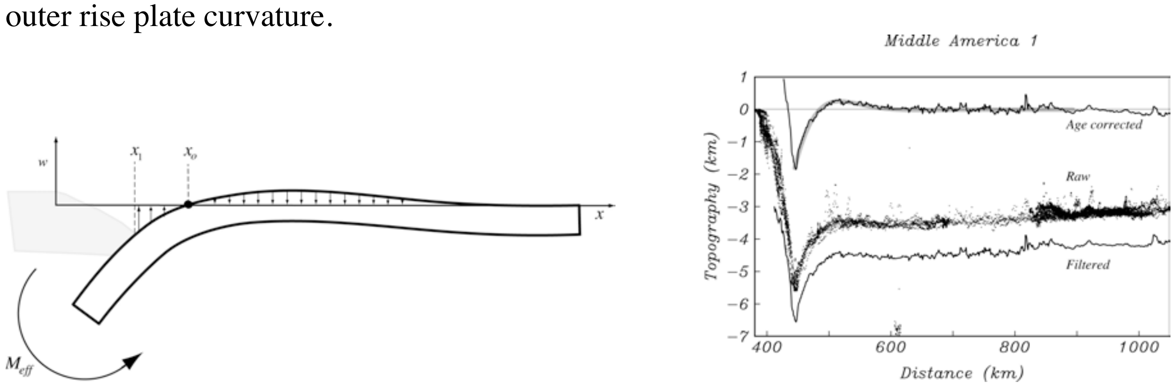


Figure 7. (left) Schematic diagram showing the effective bending moment M_{eff} per unit of trench length needed to support the trench and outer rise topography. The trench axis is at location x_1 and the first zero crossing seaward of the trench is at x_o. The overriding plate is shaded. (right) Raw, filtered, and age-corrected plots of a Middle America trench profile [*Levitt and Sandwell*, 1995]. One-kilometer window, median filtered data are shifted 1 km downward from raw data for presentation. The age-corrected data are displayed with reference to zero topography. Grey line shows best fit model.

Figure 7 also illustrates the basic physics where the moment per unit length of trench is the integral of the anomalous topography $w(x)$ times the density contrast between the mantle and ocean ρ times the acceleration of gravity g times the distance of the topography from the first zero crossing seaward of the trench axis x_o [*Goetze and Evans*, 1979].

$$M = g\rho \int_{x_1}^{\infty} w(x)(x - x_o)\,dx \qquad (1)$$

The main assumptions related to this calculation are that the plate or lithosphere is strong relative to the underlying mantle, the bending of the plate is 2-dimensional, and that the topography seaward of the trench axis is supported by membrane stresses within the plate. It is important to note that this method of estimating bending moment **does not depend on any type of model** (e.g. elastic or viscous bending). The estimated moment is highly sensitive to the location of x_o, since this determines where the topography goes to zero far from the trench axis. The gravity anomaly becomes important because it is used to help establish the location of the zero crossing point. Additionally, gravity is used to separate locally compensated topography (e.g. seamounts) from plate bending topography. *Levitt and Sandwell* [1995] performed such an analyses along discrete trench profiles and successfully fit both the topography and gravity data using an elastic model parameterization. However, the marine gravity model they used had errors of 10-30 mGal within 100 km of coastlines because of a Fourier edge effect in transforming geoid height to gravity anomaly. Besides the anticipated factor of 2 improvement in marine gravity, newer models such as EGM2008 have a much smaller gravity edge effect (< 5 mGal). We anticipate further improvement of this analysis to result from first assembling all the soundings and gravity measurements into a wider (100 km) trench-perpendicular transect extending from the trench axis to about 1000 km seaward of the trench.

New measurements of bending moment and curvature will comprise an essential geophysical dataset that is presently lacking. Recent compilations of subduction zone parameters provide global coverage along 207 trench-perpendicular transects of 24 distinct subduction zones [*Lallemand et al*., 2005; *Wu et al*., 2008]. The data compiled for each transect include plate age, subduction velocity, convergence azimuth, stress state of the upper plate, dip angle, radius of curvature based on Benioff Zone analyses, depth extent of the subducting slab and proximity to a slab edge (along-trench distance). Many aspects of the data remain unexplained both in terms of variations between subduction zones and along-trench variations within an individual subduction zone [*Heuret and Lallemand*, 2005; *Faccenna et al., 2007; Funiciello et al., 2008; Lallemand et al., 2008*]. The previous analysis of *Levitt and Sandwell* [1995] was only successful in determining the bending moment for 37 trench profiles, providing fairly sparse global coverage (only 6 out of 24 subductions zones). Additionally, no estimates of the bending moment exist for many of the more notable subduction zone systems, such as Cascadia, Tonga-Kermedec, Nankai-Ryukyu, or the 4400 km long Melanesia system (New Britain, San Cristobal and New Hebrides). Coverage along individual subduction systems is also quite poor, as only 2 observations exist along the entire length of the Sunda system (which includes the Andaman, Sumatra, and Java trenches) and only 6 observations exist along all of South America which exhibits large variations in dip angle and subducting plate age. New topographic profiles will coincide with the 207 subduction transects of previous studies [*Lallemand et al*., 2005; *Wu et al*., 2008]. Improvements in data quality and method of obtaining trench profiles will generate more accurate bending moments with significantly smaller uncertainties than those (unreported) uncertainties of *Levitt and Sandwell* [1995] .

The understanding for plate flexure within dynamical (not static) systems has already been developed and is largely built upon knowledge of the dynamics of thin viscous sheets *[Ribe, 2001; Ribe, 2002; Ribe, 2003; Buffett, 2006]* and the integrated strength of subducting plates [*Karato et al*., 2001; *Billen and Hirth*, 2005; *Morra et al*., 2006; *Ozbench et al*., 2008]. This analysis suggests a relationship between the bending rate (as derived from the subduction velocity) and the radius of curvature [*Ribe*, 2003; *Buffett and Rowley*, 2006; *Buffett*, 2006; *Ribe*, 2009] can provide an estimate for the strength of a plate in the bending region [*Buffett and Rowley*, 2006; *Wu et al*., 2008]. Bending moment and curvature measurements along the 207 proposed transects help connect the numerical models of subduction zones to those in nature at much smaller scales, such as for individual plates and discrete segments of individual plates.

In addition to estimating the bending moment, the proposed analysis provides an estimate of the plate curvature. Many previous studies have suggested that the plates are moment-saturated by the time they reach the trench axis [e.g., *McAdoo et al*., 1978; *Chapple and Forsyth*, 1979; *Judge and McNutt*, 1991]. The increasing curvature of the plate as it descends into the outer trench slope produces trench normal stresses that fracture the crust and shallow mantle (Figure 8) [*Massell*, 2002]. These fractures are observed in the bathymetry "step-faulted staircases with scarps consistently facing down the slope as well as horst-and-graben terrains [*Massell*, 2002]". An analysis of multibeam bathymetry along the outer trench wall of several major subduction zones reveals two types of fractures depending on the orientation of the abyssal hill fabric with respect to the trench axis. When the abyssal hills are oriented more than 30˚ from the trench axis new large amplitude bending induced faults are generated [*Masson*, 1991]. When the strike is less than 30˚, the original abyssal hill normal faults will become reactivated [*Massell*, 2002; *Mofjeld et al*., 2004]. Our 30-arc second global bathymetry includes a low resolution version of the available multibeam data. This combined with the improved resolution of the gravity field from CryoSat and the larger scale bending measurements may provide a more quantitative understanding of the generation of these normal faults and the perhaps larger-scale effects of the style of normal faulting on the style of subduction. This is a more exploratory aspect of our proposed investigation that will require high-resolution gravity and bathymetry data.

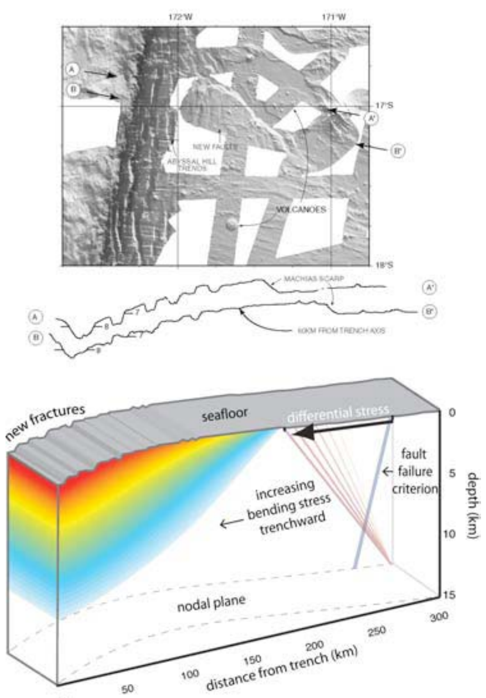


Figure 8. (upper) Formation of new outer rise fractures at the Tonga trench caused by plate bending [from *Massell*, 2002]. To the east of 172˚W the abyssal hill fabric is perpendicular to the trench axis so the abyssal fabric cannot be reactivated. The characteristic spacing of these new fractures is 18 km which is at the resolution limit of existing gravity models but perhaps could be resolved with 2 times better gravity.
(lower) model of the ratio of plate bending stress to frictional fault strength. Red zones have ratios greater than 1000 so large-offset faults are expected. Faults should extend to about 10 km depth at the trench axis. We proposed to refine these fracture models using new measurements and more realistic finite element models.

Preferential reactivation or initiation of new faults has previously been examined in a global data set under the framework of applying the Mohr-Coulomb brittle failure criterion for rocks [*Billen et al*., 2007]. They conclude that the applicable values for the coefficient of friction on these faults are in line with Byerlee's law, but analysis of seismic reflection surveys at the Middle America trench [*Ranero et al*., 2003] has led to the interpretation that serpentinization is occurring at such outer rise faults. Along with the serpentinization that can change these faults' frictional properties, the seismic images seem to show that these faults penetrate as deep as 20 km into the lithosphere, and thus possibly serves as a pathway for water entering the upper mantle. Results of numerical simulations of strain rate in a freely subducting slab [*Faccenda et al*., 2009] demonstrate the feasibility of the transport of water along newly formed fractures, and could allow the formation of hydrous mineral phases. A relationship between fault formation and slab hydration has also been inferred from studies of seismic wave properties such as anisotropy [*Contreras-Reyes et al.,* 2008, *Faccenda et al.,* 2008], Poisson's ratio, [*Contreras-Reyes et al.,* 2007] and the ratio of compressional to shear wave velocities [*Green et al*., 2010]. Apart from these remote measurements, data from heat flow surveys [*Grevemeyer et al.,* 2005] have been used to associate hydrothermal circulation with these faults. These features are pervasive across the entire trench slope and could thus present consequences not only for the hydration of the upper mantle but also the strength of the subducting slab.

Using our new compilation of outer rise curvature and fractures, we propose to investigate the mechanics of the formation of these outer rise faults by relating the fracturing to the prevailing stresses due to bending. The local curvature of the plate increases from the outer rise towards the trench, and as it does, the theoretical extensional stress for a bending plate also becomes greater. However, in the oceanic lithosphere these stresses are likely limited by the brittle behavior of the upper portion of the slab. Still, the estimates of the bending stress could be used in a formulation that prescribes a range of behavior for the system of outer rise faults, such as values for the depth up to which they exist in the upper plate, the fault offsets on the seafloor, and the spacing between the scarps of adjacent faults. *The latter is an observable that may be resolved better using improved gravity anomalies*.

Interpretation of Bending Moments at Subduction Zones: The new measurements of the bending moment will actually represent the effective bending moment M_{eff}, consisting of several contributions (discussed next) arising from the particular dynamics of the system

$$M_{eff} = M_{slab} + M_{upper} - M_{cf} - M_{lm} - M_{eoc} \qquad (2)$$

where (M_{slab}) is the contribution from the negative buoyancy of the slab, (M_{upper}) is the moment supplied by the overriding plate, (M_{cf}) is the moment induced by corner flow in the asthenosphere, (M_{lm}) is the moment caused by the slab penetration of the more viscous lower mantle, and (M_{eoc}) is the negative moment contribution from thickened crust. Numerical models will be used to systematically understand each contribution to the total effective moment.

The weight of the slab is the main source of bending moment (M_{slab}) applied to the subduction hinge, and depends on integrating the net density contrast (accounting for thermal effects as well as compositional effects from oceanic crust, $\Delta\rho_c$) at a particular length (l) along the entire length of the slab (L), for example:

$$M_{slab} = \int_0^L g\left(2\sqrt{\frac{\kappa A_s(l)}{\pi}}\rho_m \alpha \Delta T - \Delta\rho_c\right) l dl \qquad (3)$$

The density from thermal contraction is estimated from assuming a lithospheric temperature drop (ΔT) of about 1200 K and reasonable values for material properties. The thickness of the lithosphere is obtained using the age of the plate at the time of subduction (A_s) and maximum depth (D) the slab extends into the upper mantle, both of which have already been compiled [*Lallemand et al.*, 2005]. The total length of the slab (L) can be obtained through a simple relation with the dip angle and slab depth (D). The upper plate can, in some cases, apply a bending moment from above (M_{upper}), along the contact region between the subducting and overriding plates. This would be much larger in places where a plate is subducting underneath relatively strong continental lithosphere (Peru-Chile, Sumatra, Japan) and insignificant in regions where the upper plate is very thin oceanic lithosphere with back-arc spreading (Tonga, Mariana, Scotia). There are two physical mechanisms that reduce the applied moment, both of which originate from deeper sources within the mantle and can represented as equivalent moments. The first, (M_{lm}) applies to when the length of the slab has reached the transition zone (> 600 km depth), and is viscously supported through interaction with the increased viscosity of the lower mantle (approximately 30-100 times more viscous than the upper mantle). The second, (M_{cf}), the shallow portion of the slab can be supported through hydrodynamic lift resulting from a cornerflow circulation within the mantle wedge [*Batchelor*, 1967; *McKenzie*, 1969; *Turcotte and Schubert*, 2002]. The lift is generated by low dynamic pressure developing over the slab from the cornerflow: a faster circulation within the mantle wedge produces a larger suction between the subducting and overriding plates and correspondingly greater lift. Alternatively, either a constricted wedge resulting from a deeper continental lithosphere or a larger mantle viscosity within the wedge would both result in similarly increased lift. However, because subducted slabs are finite in lateral extent, there is also an important toroidal flow around slab edges [*Griffiths et al.*, 1995; *Guillou-Frottier et al.*, 1995; *Funiciello et al.*, 2003b; *Kincaid and Griffiths*, 2003; *Schellart*, 2004a; *Stegman et al.*, 2006] and this component of flow will dramatically reduce the suction arising from poloidal flow [*Dvorkin*, 1993]. These are complicated flow patterns that result from the particulars of the tectonic setting and viscosity variations within the vicinity of the mantle wedge. The nature and extent of such variations should be readily expressed in the modifications to the bending moment, and quantitatively describing these contributions will further both our understanding of subduction zone geodynamics as well as mantle rheology. As an example, the distance from the slab edge over which the cornerflow is diminished has never been quantified.

Modeling Subduction Zone Geodynamics: By exploiting the fact that the estimated bending moments are independent of assuming elastic or viscous bending, the resulting observations can be compared to the bending moments in numerical models of subduction. Over the past decade, both analogue and numerical models of "free subduction" have been developed which consider the dynamics of a viscous/viscoplastic plate sinking under its own negative buoyancy into a passive upper mantle [*Faccenna et al.*, 2001; *Funiciello et al.*, 2003a; *Schellart*, 2004b; *Morra et al.*, 2006; *Royden and Husson*, 2006; *Stegman et al.*, 2006; *Billen*, 2008]. These models offer a novel way to investigate aspects of plate tectonics and mantle convection through single-sided, asymmetric subduction with a coupled lithosphere-mantle system, but are restricted to the upper 660-1000 km of the mantle and 30-50 million years of progressive time-evolution. The subducting plate and the sinking slab are coupled through a stress guide in the middle of the subducting plate (the strong core) as well as by virtue of poloidal and toroidal flows induced in the surrounding mantle. These models have proved quite useful for investigating aspects of plate tectonics such as the development of trench curvature [*Stegman et al.*, 2006; *Schellart et al.*, 2007], how the subduction rate is partitioned between forward plate advance and slab rollback [*Schellart et al.*, 2010], and how slab morphologies in the upper mantle are a product of these plate and trench motions [*Stegman et al*., 2010a]. Additionally, *Stegman et al*., [2010b] demonstrated the bending moment was easily quantified in a suite of 25 numerical experiments.

Recently, these models have been extended to include an overriding plate [*Capitanio et al*., 2011], which will allow a much more direct comparison between the numerical models and natural subduction zones. Continued development of these numerical models will significantly advance our understanding of how the mesoscale strength of the lithosphere responds to various contributions to the bending moment because all of the individual components can be measured independently. Many of these aspects have been studied previously with regional mantle convection models, even with some in 3-D geometry, however no such investigations have been performed with models of free subduction. These models require significant computational resources that will be acquired through a current project supported by NSF TeraGrid as well as from resources available at the San Diego Supercomputing Center.

Proposed Tasks:
Years 1 – 4 PIs Sandwell, Stegman, and a graduate student will develop methods for measuring moments at trench outer rise and trench curvature as well as their uncertainties.
Year 2 – Stegman and graduate research assistant will perform 3-D numerical experiments of subduction with an overriding plate to systematically investigate contributions to the resultant bending moment in numerical models. The mantle viscosity will be assumed linear such that simple scaling analyses will be derived to explain the results.
Year 3 - Stegman and graduate research assistant will perform a further suite of 3-D experiments that characterize the influences of shape, viscosity, and level of dehydration of the mantle wedge on bending stresses in the outer rise. The first higher resolution gravity maps will be available and a global survey will be conducted to investigate patterns of outer rise faulting. We will update the global compilation of subduction zone parameters with new observations. Results from Year 2 will be prepared and submitted for publication.
Year 4 - Stegman and graduate research assistant will build on the results from previous years to forward model specific subduction systems in an attempt to provide best fit models that explain trench-parallel variations in the newly obtained global data set of bending moments and outer rise faulting. These models will lead to proposing a new global classification of subduction zones based solely on the temporal evolution of fully-dynamic 3-D models. Results of Years 3 and 4 will be prepared and submitted for publication.

2.2 Broader Impacts

This work will support the training of a graduate student and 2 - 3 undergraduate students. While there is no specific budget line for outreach activities outside of UCSD/SIO, we will continue to: participate in media activities, give talks at Museums and Science Centers, and give presentations at local schools. In addition we will continue to distribute our data products and scientific results at our web site http://topex.ucsd.edu. To determine the effectiveness of our web outreach activities, one could Google search on the following keywords and our web site topex.ucsd.edu will be near the top of the sites listed: *marine gravity* (1st/6.4 million), *global topography* (2nd/8.6 million), *bathymetry* (4th/0.3 million), *seafloor* (3rd/0.8 million). The key to the success of these pages is long-term stability and consistency. The gravity and bathymetry data are distributed at three levels to help fill the needs of expert, intermediate, and novice users as described in the section Data Management Plan.

4. REFERENCES

Amarouche, L. et al. (2004), Improving the Jason-1 ground retracking to better account for attitude effects. Marine Geodesy, 27: 171-197.

Arbic, B. K., S. T. Garnerb, R. W. Hallbergb, and H. L. Simmons (2004), The accuracy of surface elevations in forward global barotropic and baroclinic tide models, Deep Sea Research Part II: Topical Studies in Oceanography, 51(25-26), 3069 - 3101.

Batchelor, G. K. (1967), An introduction to fluid mechanics, Cambridge University Press Cambridge.

Becker, J. J., D. T. Sandwell, W. H. F. Smith, J. B. c, B. Binder, J. Depner, D. Fabre, J. Factor, S. Ingalls, S.-H. Kim, R. Ladner, K. Marks, S. Nelson, A. Pharaoh, R. Trimmer, J. V. Rosenberg, G. Wallace, and P. Weatherall (2009), Global Bathymetry and Elevation Data at 30 Arc Seconds Resolution: SRTM30_PLUS, Marine Geodesy, 32(4), 355-371.

Brown, G.S. (1977), The average impulse response of a rough surface and its application. IEEE Transactions on Antenna and Propagation, AP-25(1): 67-74.

Billen,M., E. Cowgill, and E. Buer, (2007) Determination of fault friction from reactivation of abyssal-hill faults in subduction zones, Geology, 35:9, pp. 819–822.

Billen, M. I., and G. Hirth (2005), Newtonian versus non-Newtonian upper mantle viscosity: Implications for subduction initiation, Geophysical Research Letters, 32, L19304.

Billen, M. I. (2008), Modeling the Dynamics of Subducting Slabs, Annual Review of Earth and Planetary Sciences, 36, 325-356.

Buffett, B. A. (2006), Plate force due to bending at subduction zones, Journal of Geophysical Research (Solid Earth), 111(B10), 9405-+.

Buffett, B. A., and D. B. Rowley (2006), Plate bending at subduction zones: Consequences for the direction of plate motions, Earth and Planetary Science Letters, 245, 359-364.

Capitanio, F.A., C. Faccenna, S. Zlotnik, and D. R. Stegman. "Subduction dynamics and the origin of Andean orogeny and Bolivian Orocline", Nature, (in review) 2011.

Carbotte, S. M., R. Arko, D. N. Chayes, W. Haxby, K. Lehnert, S. O'Hara, W. B. F. Ryan, R. A. Weissel, T. Shipley, L. Gahagan, K. Johnson, and T. Shank (2004), New Integrated Data Management System for Ridge2000 and MARGINS Research, Eos Trans. AGU, 85(51), 553.

Carron, M. J., P. R. Vogt, and W.-Y. Jung (2001), A proposed international long-term project to systematically map the world's ocean floors from beach to trench: GOMaP (Global Ocean Mapping Program), Inter. Hydr. Rev., 2(3), 49-50.

Chapple, W. M., and D. W. Forsyth (1079), Earthquakes and bending of plates at trenches, J. Geophys. Res., 84(12), 6729 - 6749.

Contreras-Reyes E., I. Grevemeyer, E. R. Flueh, M. Scherwath, and M. Heesemann (2007), Alteration of the subducting oceanic lithosphere at the southern central Chile trench–outer rise, Geochem. Geophys. Geosyst., 8, Q07003, doi:10.1029/2007GC001632.

Contreras-Reyes, E., I. Grevemeyer, E.R. Flueh, M. Scherwath, and J. Bialas, (2008), Effect of trench-outer rise bending-related faulting on seismic Poisson's ratio and mantle anisotropy: a case study offshore of Southern Central Chile, Geophys. Journ. Int., 173(3):142-156.

Dvorkin, J. (1993), Narrow subducting slabs and the origin of backarc basins, Tectonophysics, 227, 63-79.

Faccenda, M., L. Burlini, T. V. Gerya and D. Mainprice, (2008), Fault-induced seismic anisotropy by hydration in subducting oceanic plates, Nature 455:1097-1100.

Faccenna, C., F. Funiciello, D. Giardini, and P. Lucente (2001), Episodic back-arc extension during restricted mantle convection in the Central Mediterranean, Earth Planet. Sci. Lett., 187, 105-116.

Faccenda, M., T. V. Gerya, and L. Burlini, (2009), Deep slab hydration induced by bending-related variations in tectonic pressure, Nature Geoscience, 2, pp. 790 – 793.

Faccenna, C., A. Heuret, F. Funiciello, S. Lallemand, and T. W. Becker (2007), Predicting trench and plate motion from the dynamics of a strong slab, Earth and Planetary Science Letters, 257, 29-36.

Farr, T. G., P. A. Rosen, E. Caro, R. Crippen, R. Duren, S. Hensley, M. Kobrick, M. Paller, E. Rodrigues, L. Roth, D. Seal, S. Shaffer, J. Shimada, J. Umland, M. Werner, M. Oskin, D. Burbank, D. Alsdorf, P. A. R. Tom G. Farr, 1 Edward Caro,1 Robert Crippen,1 Riley Duren,1 Scott Hensley,1, M. P. Michael Kobrick, 1 Ernesto Rodriguez,1 Ladislav Roth,1 David Seal,1, J. S. Scott Shaffer, 1 Jeffrey Umland,1 Marian Werner,2 Michael Oskin,3, and a. D. A. Douglas Burbank (2007), The Shuttle radar topography mission, Reviews of Geophysics, 45(RG2004).

Fu, L.-L., and A. Cazenave (2001), Satellite Altimetry and Earth Sciences: A Handbook of Techniques and Applications, 463 pp., Academ1c Press, San Diego.

Funiciello, F., C. Faccenna, D. Giardini, and K. Regenauer-Lieb (2003a), Dynamics of retreating slabs: 2. Insights from three-dimensional laboratory experiments, Journal of geophysical research, 108(B4), 2207.

Funiciello, F., G. Morra, K. Regenauer-Lieb, and D. Giardini (2003b), Dynamics of retreating slabs: 1. Insights from two-dimensional numerical experiments, Journal of Geophysical Research (Solid Earth), 108, 2206-+.

Funiciello, F., C. Faccenna, A. Heuret, S. Lallemand, E. di Giuseppe, and T. W. Becker (2008), Trench migration, net rotation and slab mantle coupling, Earth and Planetary Science Letters, 271, 233-240.

Gille, S. T., E. J. Metzger, and R. Tokmakian (2004), Seafloor topography and ocean circulation, Oceanography, 17(1), 47-54.

Gilles, L., J.-Y. Royer, D. Rouxel, L. Geli, M. Maia, and M. Failot (2010), Ocean Gravity Models from Future Satellite Missions, in EOS Trans. AGU, edited, p. 3, Amer. Geophys. Un.

Goetze, C., and B. Evans (1979), Stress and temperature in the bending lithosphere as constrained by experimental rock mechanics, Geophys. J. R. astr. Soc., 59, 463-478.

Goff, J. A. (2010), Global prediction of abyssal hill root-mean- square heights from small- scale altimetric gravity variability, J. Geophys. Res., 115, B12104, doi:10.1029/2010JB007867.

Green II, H. W., W. P. Chen, and M. R. Brudzinski (2010), Seismic evidence of negligible water carried below 400-km depth in subducting lithosphere, Nature 467:828–831.

Griffiths, R. W., R. I. Hackney, and R. D. van der Hilst (1995), A laboratory investigation of effects of trench migration on the descent of subducted slabs, Earth and Planetary Science Letters, 133(1-2), 1-17.

Grevemeyer, I., N. Kaul, J. L. Diaz-Naveas, H. W. Villinger, C. R. Ranero, and C. Reichert (2005), Heat flow and bending-related faulting at subduction trenches: Case studies offshore of Nicaragua and Central Chile. *Earth Planet. Sci. Lett.* 236: 238–248.

Guillou-Frottier, L., J. Buttles, and P. Olson (1995), Laboratory experiments on the structure of subducted lithosphere, Earth and Planetary Science Letters, 133, 19-34.

Heuret, A., and S. Lallemand (2005), Plate motions, slab dynamics and back-arc deformation, Physics of the Earth and Planetary Interiors, 149, 31-51.

Jarrard, R. D. (1986), Relations among subduction parameters, Rev. Geophys, 24(2), 217-284.

Jayne, S. R., L. C. St. Laurent, and S. T. Gille (2004), Connections between ocean bottom topography and the Earth's Climate, Oceanography, 17(1), 65 - 74.

Judge, A. V., and M. K. McNutt (1991), The relationship between plate convergence and elastic plate thickness: A study of the Peru-Chile trench, J. Geophys. Res., 96, 16625 - 16639.

Karato, S.-i., M. R. Riedel, and D. A. Yuen (2001), Rheological structure and deformation of subducted slabs in the mantle transition zone: implications for mantle circulation and deep earthquakes, Physics of the Earth and Planetary Interiors, 127, 83-108.

Kincaid, C., and R. W. Griffiths (2003), Laboratory models of the thermal evolution of the mantle during rollback subduction, Nature, 425, 58-62.

Koslow, J. S. (1997), Seamounts and the ecology of deep-sea fisheries, Am. Sci., 85, 168-176.

Kunze, E., and S. G. Llewellyn Smith (2004), The role of small-scale topography in turbulent mixing of the global ocean, Oceanography, 17(1), 55 - 64.

Lallemand, S., A. Heuret, and D. Boutelier (2005), On the relationships between slab dip, back-arc stress, upper plate absolute motion, and crustal nature in subduction zones., Geochemistry Geophysics Geosystems, 6(9), Q09006.

Lallemand,S., A. Heuret, C. Faccenna, and F. Funiciello (2008), Tectonics, 27, TC3014, doi:10.1029/2007TC002212.

Levitt, D. A., and D. T. Sandwell (1995), Lithospheric bending at subduction zones based on depth soundings and satellite gravity, J. Geophys. Res. (Solid Earth), 100, 379-400.

Luttrell, K., and D. T. Sandwell (2009), Estimates of the minimum 3-D stress in the lithosphere needed to support global topography, paper presented at EOS Trans. AGU, AGU, San Francisco, CA.

Marks, K. M., W. H. F. Smith, and D. T. Sandwell (2010), Error Analysis of the Altimetric Bathymetry Models used by GEBCO and Google Earth, Mar. Geophys. Res., 31, p., 223-238, DOI 10.1007/s11001-010-9102-0

Massell, C. G. (2002), Large Scale Structural Variation of Trench Outer Slopes and Rises, Ph.D. thesis, University of California at San Diego, La Jolla.

Masson, D. G. (1991), Fault patterns on outer trench walls, Mar. Geophys. Res., 13, 209 - 225.

Maus, S., Green, C.M. & Fairhead, J.D., (1998) Improved ocean-geoid resolution from retracked ERS-1 satellite altimeter waveforms. Geophys. J. Int., 134(N1): 243-253.

McAdoo, D. C., J. G. Caldwell, and D. L. Turcotte (1978), On the elastic-perfectly plastic bending of the lithosphere under generalized loading with application to the Kurile Trench, Geophys J. R. astr. Soc., 54, 11-26.

McKenzie, D. (1969), Speculations on consequences and causes of plate motions, Geophysical Journal International, 18, 1-32.

Mofjeld, H. O., C. Massell-Symons, P. Lonsdale, F. I. Gonzalez, and V. V. Titiv (2004), Tsunami scattering and earthquake faults in the deep Pacific Ocean, Oceanography, 17(1), 38-46.

Monahan, D. (2004), Altimetry applications to continental shelf delineation under the United Nations Convention on the Law of the Sea, Oceanography, 17(1), 75-82.

Morra, G., K. Regenauer-Lieb, and D. Giardini (2006), Curvature of oceanic arcs, Geology, 34(10), 877-880.

Morrow, R. et al., (2010), Report of the 2010 Ocean Surface Topography Science Team (OSTST) Meeting, OSTST Meeting, October 18-22, Lisbon, Portugal http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2010/oral/final%20report/10_lisbon_OSTST_meeting_report.pdf

Ozbench, M., K. Regenauer-Lieb, D. R. Stegman, G. Morra, R. Farrington, A. Hale, D. A. May, J. Freeman, L. Bourgouin, H. Mühlhaus, and L. Moresi (2008), A model comparison study of large-scale mantle-lithosphere dynamics driven by subduction, Physics of the Earth and Planetary Interiors, 171, 224-234.

Pavlis, N. K., S. A. Holmes, S. C. Kenyon, and J. K. Factor (2008), An Earth Gravitational Model to Degree 2160: EGM2008, paper presented at General Assembly of the European Geosciences Union, Vienna, Austria.

Ranero, C. R., J. Phipps Morgan, K. McIntosh, and C. Reichert (2003), Bending, faulting, and mantle serpentinization at the Middle America trench, Nature, 425:367–373.

Raney, R. K., W. H. F. Smith, D. T. Sandwell, J. R. Jensen, D. L. Porter, and E. Reynolds (2003), Abyss-Lite: Improved bathymetry from a dedicated small satellite delay-Doppler radar altimeter, paper presented at Proceedings of the International Geoscience and Remote Sensing Symposium IGARSS2003, IEEE, Toulouse, France.

Ribe, N. M. (2001), Bending and stretching of thin viscous sheets, Journal of Fluid Mechanics, 433, 135-160.

Ribe, N. M. (2003), Periodic folding of viscous sheets, Physical Review E, 68(3), 036305-+.
Ribe, N. M. (2009), Bending Mechanics and Mode Selection in Free Subduction: a Thin-Sheet Analysis, Geophys. J. Int., submitted.
Royden, L. H., and L. Husson (2006), Trench motion, slab geometry and viscous stresses in subduction systems, Geophysical Journal International, 167, 881-905.
Ryan, W. B. F., S.M. Carbotte, J. Coplan, S. O'Hara, A. Melkonian, R. Arko, R.A. Weissel, V. Ferrini, A. Goodwillie, F. Nitsche, J. Bonczkowski, and R. Zemsky (2010), Global Multi-Resolution Topography (GMRT) synthesis data set, Geochem. Geophys. Geosyst., 10(Q03014).
Sandwell, D., and P. Wessel (2010), Seamount discovery tool aids navigation to uncharted seafloor features, Oceanography, 23:1, p. 34 - 36, 2010.
Sandwell, D. T., and W. H. F. Smith (1997), Marine gravity anomaly from Geosat and ERS-1 satellite altimetry, J. Geophys. Res., 102(B5), 10039-10054.
Sandwell, D. T., W. H. F. Smith, S. Gille, S. Jayne, K. Soofi, and B. Coakley (2001), Bathymetry from Space, 87 - 108 pp, Oregon State University, Corvallis.
Sandwell, D. T., and W. H. F. Smith (2005), Retracking ERS-1 Altimeter Waveforms for Optimal Gravity Field Recovery, Geophys. J. Int., 163, 79-89.
Sandwell, D. T., W. H. F. Smith, S. Gille, K. E., J. S., S. K., C. B., and L. Geli (2006), Bathymetry from Space: Rationale and requirements for a new, high-resolution altimetric mission, Comptes Rendus de l'Académie des Sciences, 338, 1049-1062.
Sandwell, D. T., and W. H. F. Smith (2009), Global marine gravity from retracked Geosat and ERS-1 altimetry: Ridge segmentation versus spreading rate, J. Geophys. Res., 114(B01411), 1-18.
Schellart, W. P. (2004a), Kinematics of subduction and subduction-induced flow in the upper mantle., Journal of geophysical research, 109, B07401.
Schellart, W. P. (2004b), Quantifying net slab pull force as a driving mechanism for plate tectonics., Geophysical Research Letters, 31, L07611.
Schellart, W. P., J. Freeman, D. R. Stegman, L. Moresi, and D. May (2007), Evolution and diversity of subduction zones controlled by slab width, Nature, 446, 308-311.
Schellart, W. P., D. R. Stegman, R. Farrington, J. Freeman, and L. Moresi (2010), Lateral Slab edge control on plate velocity, trench velocity and subduction partitioning, Nature, in review.
Smith, W. H. et al., (2005), ABYSS-Lite: A radar altimeter for bathymetry, geodesy and mesoscale oceanography, http://topex.ucsd.edu/concept/
Smith, W. H. F. (2003), Introduction to This Special Issue on Bathymetry from Space, Oceanography, 17(1), 6 - 7.
Smith, W. H. F., and D. T. Sandwell (2004), Conventional Bathymetry, Bathymetry from Space, and Geodetic Altimetry, Oceanography, 17(1), 8-23.
Stegman, D. R., J. Freeman, W. P. Schellart, L. Moresi, and D. May (2006), Influence of trench width on subduction hinge retreat rates in 3-D models of slab rollback, Geochemistry Geophysics Geosystems, 7(3), 1-22.
Stegman, D. R., R. Farrington, F. A. Capitanio, and W. P. Schellart (2010a), A regime diagram for subduction styles from 3-D numerical models of free subduction, Tectonophysics, in press.
Stegman, D. R., W. P. Schellart, and J. Freeman (2010b), Competing influences of plate width and far-field boundary conditions on trench migration and morphology of subducted slabs in the upper mantle, Tectonophysics, in press.
Turcotte, D. L., and G. Schubert (2002), Geodynamics: Second Edition, 456 pp., Cambridge University Press, Cambridge, UK.
Watts, A. B., D. T. Sandwell, W. H. F. Smith, and P. Wessel (2006), Global gravity, bathymetry, and the distribution of submarine volcanism through space and time, J. Geophys. Res., 111.
Wessel, P. and A. B. Watts, (1988), On the accuracy of marine gravity measurements, J.Geophys. Res., 93, 393–413.

Wolfe, C. J., S. C. Solomon, G. Laske, J. A. Collins, R. S. Detrick, J. A. Orcutt, D. Bercovici, and E. H. Hauri (2009), Mantle Shear-Wave Velocity Structure Beneath the Hawaiian Hot Spot, Science, 326(5958), 1388-1390.

Wu, B., C. P. Conrad, A. Heuret, C. Lithgow-Bertelloni, and S. Lallemand (2008), Reconciling strong slab pull and weak plate bending: The plate motion constraint on the strength of mantle slabs, Earth and Planetary Science Letters, 272, 412-421.

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1982 – 85	National Geodetic Survey, Research Geophysicist

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1/09 -	Member of NRC Committee on Seismology and Geodynamics
1/08 -	President Geodesy Section of the AGU
1/07 - 1/09	Chair of Western North America InSAR Consortium (WInSAR)
5/05 - 9/05	Member of committee to review ESA's Earth Observation Envelope Programme
6/03 - 7/04	Member of NASA Jupiter Orbiter Icy Moons Science Definition Team
6/01 - 4/04	Associate Editor of *Journal of Geophysical Research*
2/01 - 12/03	Member of NRC U.S. National Committee to the IUGG
10/99 - 7/02	Chair of Western North America InSAR Consortium (WInSAR)
9/98 - 6/01	Member of NRC Space Studies Board, Committee on Earth Studies
5/95 - 12/96	Member of NRC, US Committee on Geodynamics
9/94 - 5/96	SIO Representative to UCSD Academic Senate
9/93 - 8/94	Chair of UCSD Academic Senate Committee on Computing
2/92 - 12/95	Office of Technology Assessment panel on Earth Observing Systems
6/90 - 1/95	Member of National Research Council, Committee on Geodesy
12/86 - 1/91	Science steering group member for NASA's satellite gravity program
1/87 - 12/90	Associate Editor, *Reviews of Geophysics and Space Physics*
2/85 - 1/89	Associate Editor, *Journal of Geophysical Research*

Recent Research Funding:

12/08-12/11	NASA Geodetic Imaging and Modeling of the San Andreas Fault System
7/08 - 6/11	NSF Observations and Modeling of Shallow Fault Creep
10/05- 9/08	ONR Predicted Bathymetry for Naval Operations and Scientific Applications
6/03 - 6/10	NSF/NASA Marine Gravity, Seafloor Topography and Seafloor Roughness

Cruise Participation:

9/03	Co-chief on R/V Revelle to test feasibility of Synthetic Aperture Sonar
2/97	Participant in expedition to Foundation Seamounts, South Pacific
1/94	Co-chief scientist on R/V Melville to map Eltanin and Udintsev Fracture Zones
1/93	Chief scientist on R/V Melville to map Pukapuka En-Echelon Ridges
2/89	Assistant scientist on R/V Surveyor to map the Shackleton Fracture Zone
3/87	Assistant chief scientist on R/V Washington to explore Seasat gravity lineations
5/83	Participating scientist on Bermuda Swell heat flow experiment

Awards and Memberships:

4/08	Fellow of the American Academy of Arts and Sciences
11/04	George P. Woollard Award and Fellow of the Geological Society of America
12/97	Fellow of the American Geophysical Union
12/95	Bowie Lecture American Geophysical Union
9/98	Society for Exploration Geophysics
6/77	American Geophysical Union
6/80	International Association of Geodesy

(5) Related and (5) Significant Publications:

Levitt, D. A. and D. T. Sandwell, Lithospheric bending at subduction zones based on depth soundings and satellite gravity, *J. Geophys. Res.*, *100*, 379-400, 1995.

Sandwell, D. T. and W. H. F. Smith, Marine Gravity from Geosat and ERS-1 Altimetry, *J. Geophys. Res.*, 102, 10039-10054, 1997.

Smith, W. H. F. and D. Sandwell, Global seafloor topography from satellite altimetry and ship depth soundings, *Science, 277*, p.1956-1962, 1997.

Watts, A. B., D. T. Sandwell, W. H. F. Smith, and P. Wessel, Global gravity, bathymetry, and the distribution of submarine volcanism through space and time, *J. Geophys. Res., 111*, B08408, 2006.

Sandwell, D. T., Smith, W. H. F., S. Gille, S., Kappel E., Jayne S., Soofi K. , Coakley B., and L. Geli, Bathymetry from Space: Rationale and requirements for a new, high-resolution altimetric mission, *Comptes Rendus de l'Académie des Sciences, 338, p. 1049-1062, 2006*.

Becker, J. J., D. T. Sandwell, Global Estimates Of Seafloor Slope From Single-Beam Ship Soundings, *J. Geophys. Res., 113,* C05028, doi:10.1029/2006JC003879 30 May 2008

Sandwell, D. T., and W. H. F. Smith, Global marine gravity from retracked Geosat and ERS-1 altimetry: Ridge Segmentation versus spreading rate, *J. Geophys. Res.,* 114, B01411, doi:10.1029/2008JB006008, 2009.

Becker, J. J., D. T. Sandwell, W. H. F. Smith, J. Braud, B. Binder, J. Depner, D. Fabre3, J. Factor, S. Ingalls, S-H. Kim, R. Ladner, K. Marks, S. Nelson, A. Pharaoh, G. Sharman, R. Trimmer, J. VonRosenburg, G. Wallace, P. Weatherall., Global Bathymetry and Elevation Data at 30 Arc Seconds Resolution: SRTM30_PLUS, *Marine Geodesy,* 32:4, 355-371, October 8, 2009.

Wessel, P., D. T. Sandwell and S-S. Kim, The global seamount census, *Oceanography, 23:1,* p. 24 - 33, 2010.

Sandwell, D. T., and P. Wessel, Seamount discovery tool aids navigation to uncharted seafloor features, *Oceanography, 23:1,* p. 34 - 36, 2010.

Synergistic Activities:

Teach graduate classes: *Geodynamics; Satellite Remote Sensing; Synthetic Aperture Radar*.
Distribute global gravity and topography data for research and education: http://topex.ucsd.edu

Collaborators and other affiliations:

Duncan Agnew
Gidi Baer
Yehuda Bock
Robert Cheney
Yuri Fialko
Sarah Gille
Graham Kent
Larry Lawver
Rob Mellors
Bernard Minster
John Orcutt
Paul Rosen
Peter Shearer
Walter Smith

Graduate and Postdoctoral Advisors:

Bruce Douglas
Gerald Schubert

Students and post docs:

Y. John Chen
Joseph Becker
Catherine Johnson
Bridget Konter-Smith
Dan Levitt
Karen Luttrell
Suzanne Lyons
Bill Moore
Dietmar Mueller
Evelyn Price
Jean-Yves Royer
Lydie Sichoix
Meng Wei

Dave Robert Stegman

Professional Preparation

• Bowdoin College	Physics (with Honors)	Magna Cum Laude	B.A.	*1996*
• Univ. of California, Berkeley	Earth & Planetary Science		Ph.D.	*2003*
• Monash University	Geophysics			*2003-2008*
• University of Melbourne	Geophysics			*2008-2009*

Appointments

- Assistant Professor, Scripps Institution of Oceanography, UC San Diego *2009-present*
- Centenary Research Fellow, University of Melbourne, School of Earth Sciences *2008-2009*
- ARC Australian Postdoctoral Fellow, Monash University *2005-2008*
- Research Fellow, Monash University, School of Mathematical Sciences *2003-2005*
- Graduate Research Assistant , UC Berkeley, Dept. of Earth and Planetary Science *1996-2003*
- Undergraduate Researcher, NASA Planetary Geology & Geophysics Program *Summer 1995*
- Undergraduate Researcher, UC Irvine, Department of Physics *Summer 1994*

Relevant Publications

1. Schellart, W.P., **D.R. Stegman**, R.J. Farrington, J. Freeman, and L. Moresi. "Cenozoic Tectonics of Western North America Controlled by Evolving Width of Farallon Slab", *Science*, 329, 5989, 316-319, doi: 10.1126/science.1190366, 2010.
2. **Stegman, D.R.**, R. Farrington, F.A. Capitanio, and W.P. Schellart. "A regime diagram for subduction styles from 3-D numerical models of free subduction," *Tectonophysics*, doi:10.1016/j.tecto.2009.08.041, 483, 29-45, 2010.
3. Capitanio, F.A., **D.R. Stegman,** L. Moresi and W. Sharples. "Upper plate controls on deep subduction, trench migrations and deformations at convergent margins", *Tectonophysics*, doi:10.1016/j.tecto.2009.08.020, 483, 80-92, 2010.
4. **Stegman, D.R.**, W.P. Schellart, and J. Freeman. "Competing influences of plate width and far-field boundary conditions on trench migration and morphology of subducted slabs in the upper mantle," *Tectonophysics*, doi:10.1016/j.tecto.2009.08.026, 483, 46-57, 2010.
5. Schellart, W.P., J. Freeman, **D.R. Stegman**, L. Moresi, and D. A. May. "Evolution and diversity of subduction zones controlled by slab width," *Nature*, 446:308–311, 2007.

Other Significant Publications

1. R. Farrington, **D.R. Stegman,** L. Moresi, M. Sandiford and D.A. May. "Interactions of 3D Mantle Flow and Continental Lithosphere near Passive Margins," *Tectonophysics*, 483, 20-28, 2010.
2. **Stegman, D.R.**, J. Freeman and D.A. May. "Origin of ice diapirism, true polar wander, subsurface ocean, and tiger stripes of Enceladus driven by compositional convection," *Icarus*, 202, 669-680, doi:10.1016/j.icarus.2009.03.017, 2009.
3. Schellart, W.P., **D.R. Stegman**, and J. Freeman. "Global trench migration velocities and slab rollback-induced mantle fluxes: Constraints to find an absolute Earth reference frame based on minimizing viscous dissipation," *Earth Sci. Rev.*, doi:10.1016/j.earscirev.2008.01.005, 2008.
4. **Stegman, D.R.**, J. Freeman, W.P. Schellart, L-N. Moresi, and D.A. May "Influence of trench width on subduction hinge retreat rates in 3-D models of slab rollback," *Geochemistry Geophysics Geosystems*, **7**, Q03012, 2006.
5. **Stegman, D.R.**, A.M. Jellinek, S.A. Zatman, J.R. Baumgardner, and M.A. Richards. "An early lunar core dynamo driven by thermochemical mantle convection," *Nature*, **421**, 143-146, 2003.

Synergistic Activities

- Convener of NSF-supported conference: Geodynamics of the Lithosphere and Deep Earth (GLADE) , San Diego, *July 26-29, 2010*
- Convener of International Workshop on Subduction Dynamics, Melbourne, *July 13-15, 2009*
- Member, Simulation & Modeling working group, NCRIS capability 5.13 (Auscope) *2007-2008*

- Session Co-convener, *3-D Aspects of Subduction*, 33rd Intl. Geological Congress, *August 2008*
- Member, Australian Partnership for Advanced Computing, National Facility 5 year plan

Collaborators and Other Affiliations

Collaborators and Co-Editors (last 48 months):

- Dr. Fabio Capitanio (Monash University)
- Prof. Mike Sandiford (University of Melbourne)
- Dr. Stuart Clark (Simula, Norway)
- Rebecca Farrington (Monash University)
- Dr. David May (ETH-Zurich)
- Dr. Justin Freeman (Bureau of Meterology, Australia)
- Prof. Louis Moresi (Monash University)
- Dr. Gabrielle Morra (University of Sydney)
- Prof. Dietmar Müller (University of Sydney)
- Prof. Klaus Regenaur-Lieb (University of Western Australia)
- Dr. Wouter Schellart (Monash University)
- Dr. Takatoshi Yanagisawa (JAMSTEC)
- Dr. Yasuko Yamagishi (JAMSTEC)
- Dr. Yozo Hamano (JAMSTEC)

Graduate Advisors and Postdoctoral Sponsors:

- Prof. Mark Richards (UC Berkeley)
- Prof. Louis Moresi (Monash University)
- Prof. Mike Sandiford (University of Melbourne)

Thesis Advisor and Postgraduate-Scholar Sponsors:

Total number of graduate students advised: 3 *postdoctoral scholars sponsored:* 2

- Robert Petersen, Ph.D. Student, U.C. San Diego, Directed Research, *2009-present*
- Dr. Lijun Liu, Postdoctoral Scholar, U.C. San Diego, *July 2010-present*
- Dr. Derrick Hasterok, Postdoctoral Scholar, U.C. San Diego, *July 2010-present*
- Rebecca Farrington, Ph.D. Student, Monash University, Directed Research, *2007-2010*
- Dr. Stuart Clark, Ph.D. Student, University of Sydney, Directed Research, *2006-2007*
- Dr. Sergio Zlotnik, Postdoctoral Scholar, Monash University, *2008-2009*
- Dr. Margaret Jadamec, Postdoctoral Scholar, Monash University, *2008-2009*

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION: University of California-San Diego Scripps Inst of Oceanography			FOR NSF USE ONLY		
			PROPOSAL NO.	DURATION (months)	
				Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: David T Sandwell			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. David T Sandwell - Professor	0.00	0.00	0.00	$ 0	$
2. Dave Stegman - Asst. Professor	0.00	0.00	0.50	4,039	
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.50	4,039	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				26,715	
4. (1) UNDERGRADUATE STUDENTS				5,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (1) OTHER				6,245	
TOTAL SALARIES AND WAGES (A + B)				41,999	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				21,996	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				63,995	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
Desktop computer with 16GM memory and 8TB disk $ 8,000					
TOTAL EQUIPMENT				8,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				4,060	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				4,080	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				4,080	
H. TOTAL DIRECT COSTS (A THROUGH G)				80,135	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
DC (Rate: 55.0000, Base: 9690) (Cont. on Comments Page)					
TOTAL INDIRECT COSTS (F&A)				31,735	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				111,870	
K. RESIDUAL FUNDS				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 111,870	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME: David T Sandwell	FOR NSF USE ONLY		
	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

** I- Indirect Costs
MTDC (Rate: 54.5000, Base 48449)

SUMMARY PROPOSAL BUDGET

YEAR 2

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION

University of California-San Diego Scripps Inst of Oceanography

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR

David T Sandwell

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **David T Sandwell - Professor**	0.00	0.00	0.00	$ **0**	$
2. **Dave Stegman - Asst. Professor**	0.00	0.00	0.50	**4,241**	
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**2**) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.50	**4,241**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	**0**	
3. (**1**) GRADUATE STUDENTS				**28,052**	
4. (**1**) UNDERGRADUATE STUDENTS				**5,000**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**1**) OTHER				**6,557**	
TOTAL SALARIES AND WAGES (A + B)				**43,850**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**25,299**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**69,149**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**1,900**	
2. FOREIGN				**3,500**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**4,080**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**4,080**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**78,629**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 55.0000, Base: 53330)**					
TOTAL INDIRECT COSTS (F&A)				**29,332**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**107,961**	
K. RESIDUAL FUNDS				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **107,961**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME

David T Sandwell

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 3

ORGANIZATION **University of California-San Diego Scripps Inst of Oceanography**		FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **David T Sandwell**		AWARD NO.			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **David T Sandwell - Professor**	0.00	0.00	0.00	$ **0**	$
2. **Dave Stegman - Asst. Professor**	0.00	0.00	0.50	**4,453**	
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**2**) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.50	**4,453**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	**0**	
3. (**1**) GRADUATE STUDENTS				**29,453**	
4. (**1**) UNDERGRADUATE STUDENTS				**5,000**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**1**) OTHER				**6,885**	
TOTAL SALARIES AND WAGES (A + B)				**45,791**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**29,097**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**74,888**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**4,060**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ **0** 2. TRAVEL **0** 3. SUBSISTENCE **0** 4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**4,080**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**2,300**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**6,380**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**85,328**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 55.0000, Base: 56231)**					
TOTAL INDIRECT COSTS (F&A)				**30,927**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**116,255**	
K. RESIDUAL FUNDS				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **116,255**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME **David T Sandwell**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

YEAR 4

FOR NSF USE ONLY			
PROPOSAL NO.	DURATION (months)		
	Proposed	Granted	
AWARD NO.			

ORGANIZATION
University of California-San Diego Scripps Inst of Oceanography

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
David T Sandwell

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. David T Sandwell - Professor	0.00	0.00	0.00	$ 0	$
2. Dave Stegman - Asst. Professor	0.00	0.00	0.50	4,675	
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.50	4,675	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				30,924	
4. (1) UNDERGRADUATE STUDENTS				5,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (1) OTHER				7,229	
TOTAL SALARIES AND WAGES (A + B)				47,828	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				33,462	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				81,290	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				1,900	
2. FOREIGN				3,500	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				4,080	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				4,080	
H. TOTAL DIRECT COSTS (A THROUGH G)				90,770	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC (Rate: 55.0000, Base: 57308)					
TOTAL INDIRECT COSTS (F&A)				31,519	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				122,289	
K. RESIDUAL FUNDS				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 122,289	$

M. COST SHARING PROPOSED LEVEL $ 0 | AGREED LEVEL IF DIFFERENT $

PI/PD NAME
David T Sandwell

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION: **University of California-San Diego Scripps Inst of Oceanography**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **David T Sandwell**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. David T Sandwell - Professor	0.00	0.00	0.00	$ 0	$
2. Dave Stegman - Asst. Professor	0.00	0.00	2.00	17,408	
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	17,408	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (4) GRADUATE STUDENTS				115,144	
4. (4) UNDERGRADUATE STUDENTS				20,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (4) OTHER				26,916	
TOTAL SALARIES AND WAGES (A + B)				179,468	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				109,854	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				289,322	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ 8,000					
TOTAL EQUIPMENT				8,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				11,920	
2. FOREIGN				7,000	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				16,320	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,300	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				18,620	
H. TOTAL DIRECT COSTS (A THROUGH G)				334,862	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				123,513	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				458,375	
K. RESIDUAL FUNDS				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 458,375	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **David T Sandwell**

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

BUDGET JUSTIFICATION

We request salary support for .5 mo./year for David Stegman for model development, salary and tuition for a graduate student, 1 mo./year support for a Research Project Assistant, and $5k/year for an undergraduate student to participate in the research and update the web pages.

Salary recharge rates are calculated for actual productive time only (except for non-faculty sick leave, which is charged as direct). The rates include components for employee benefits, provisions for applicable merit increases and range adjustments in accordance with University policy.

Salaries for Research Project Assistant are for tasks that will specifically benefit this project, will be assigned by the Principal Investigator, charged on a time reported basis, and will not exceed the percent of effort requested. These tasks normally include library searches, data entry, copying project literature, researching and procuring project materials, making travel arrangements, computer file maintenance, computer searches, preparation of camera-ready manuscripts and coordination of efforts between project participants.

The travel budget includes one trip/year for one of the researchers to attend the Fall AGU meeting. Budgets for years 1 and 3 include expenses for Sandwell to travel to NOAA to work with research collaborator. Budgets for years 2 and 4 include travel for Sandwell to attend the CryoSat PI meeting in Italy.

We request funding to purchase a desktop computer in year 1 for processing the CryoSat waveform data.

Project specific costs that include telephone tolls, voice and data communication charges, photocopying, faxing, postage are also requested. We also request funds each year for computer and networking services which are for expenses that specifically benefit this project and are reasonable and necessary for performance of this project. UCSD applies a direct charge equivalent exclusion calculating the D.A. indirect costs, as required in the draft interpretations of A-21 section F.6.b.

Funds are also requested for Publication charges in year three of the project.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: David Sandwell

Other agencies (including NSF) to which this proposal has been/will be submitted: none

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Observations and Modeling of Shallow Fault Creep Along the San Andreas
UCSD 2008-1732
Source of Support: NSF EAR 0811772
Total Award Amount: $298,000 Total Award Period Covered: 07/01/08-06/30/11
Location of Project: SIO
Person-Months Per Year Committed to the Project. Cal: 0 Acad: Sumr:

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Geodetic Imaging and Modeling of the San Andreas Fault System
UCSD 2008-1269
Source of Support: NASA NNX09AD12G
Total Award Amount: $386,471 Total Award Period Covered: 12/15/08-12/14/11
Location of Project: SIO
Person-Months Per Year Committed to the Project Cal: 0 Acad: Sumr:

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: High-Resolution Gravity, Topography, and Seafloor Roughness
UCSD 2008-2549
Source of Support: NSF OCE 0825045
Total Award Amount: $166,505 Total Award Period Covered: 09/01/08-08/31/10*
Location of Project: SIO *NCE thru 8/31/11
Person-Months Per Year Committed to the Project Cal: 0 Acad: Sumr:

Support: X Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: GPS and CHIRP Surveys of the Imperial and Cerra Prieto Faults, Mexico
UCSD 2010-3965
Source of Support: USC/SCEC
Total Award Amount: $10,000 Total Award Period Covered: 02/01/10-01/31/11
Location of Project: SIO
Person-Months Per Year Committed to the Project Cal: 0 Acad: Sumr:

Support: X Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Deformation Models for Use in UCERF3
UCSD 2011-0693
Source of Support: USC/SCEC PO#149731
Total Award Amount: $12,000 Total Award Period Covered: 07/01/10-12/31/11
Location of Project: SIO
Person-Months Per Year Committed to the Project Cal: 0 Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: David Sandwell

Other agencies (including NSF) to which this proposal has been/will be submitted: none

Support: Current X Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: SGRUMB: Studying Gravity Rolls Using Magnetotellurics and Bathymetry

Source of Support: NSF
Total Award Amount: $563,866 Total Award Period Covered: 01/01/11-12/31/13
Location of Project: SIO
Person-Months Per Year Committed to the Project. Cal: 0 Acad: Sumr:

Support: Current X Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Incorporating Geodetic Surface Data into UCERF3: Strain Rate

Source of Support: USC/SCEC
Total Award Amount: $15,000 Total Award Period Covered: 02/01/11-01/31/12
Location of Project: SIO
Person-Months Per Year Committed to the Project Cal: 0 Acad: Sumr:

Support: Current X Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Study of postseismic deformation due to the 2010 M7.2 El Mayor (Mexico)
UCSD 2011-0112
Source of Support: NSF
Total Award Amount: $440,830 Total Award Period Covered: 03/01/11-02/28/14
Location of Project: SIO
Person-Months Per Year Committed to the Project Cal: 0 Acad: Sumr:

Support: Current X Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: A Factor of 2 Improvement in Global Marine Gravity from Cryosat, Jason-1, and Envisat THIS PROPOSAL
Source of Support: NSF
Total Award Amount: $458,375 Total Award Period Covered: 09/01/11-08/31/15
Location of Project: SIO
Person-Months Per Year Committed to the Project Cal: 0 Acad: Sumr:

Support: Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:
Source of Support:
Total Award Amount: Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

1.1 Dave Stegman (PI)

Current Support:

Agency: NSF/EAR Geophysics
Contact: Benjamin R. Phillips, (703) 292-4467
Title: GLADE Workshop: July 26-29, 2010 at Scripps, UCSD
Amount: $30,000
Period: 07/15/10-06/30/11
Annual Effort: 0
Location: UCSD/SIO

Agency: Australian Research Council Discovery Projects
Title: 3D subduction models of overriding plate deformation and mantle flow using laboratory and numerical methods
Amount: $0
Period: 01/01/11- 12/31/13
Annual Effort: 10% academic (0.9 months summer) NOTE: Stegman is partner investigator on this proposal and his commitment is the complement of a corresponding proposal submitted to NSF/EAR
Location: UCSD/SIO

Pending Support:

Agency: American Chemical Society/ PRF# 51166-DNI8
Contact: Dean A. Dunn (202) 872-4481
Title: Evaluating the Plume-push Force as a Driver of Plate Motions and Passive Margin Evolution
Amount: $100,000
Period: 09/01/11-08/31/13
Annual Effort: 1 mo summer
Location: UCSD/SIO

Agency: NASA Mars Data Analysis Program
Contact: Robert Fogel (202) 358-2289
Title: Investigating the Dynamic Causes for Morphologic Dichotomy of the Olympus Mons and Alba Patera Structures Using Gravity and Surface Geology Data
Amount: $462,994
Period: 04/01/11- 3/31/14
Annual Effort: 1 mo. summer
Location: UCSD/SIO

Agency: NSF/EAR Ocean Sciences **(THIS PROPOSAL)**
Title: A Factor of 2 Improvement in Global Marine Gravity from Cryosat, Jason-1, and Envisat
Amount: $458,375
Period: 09/01/11-08/31/15
Annual Effort: 0.5 mo summer
Location: UCSD/SIO

Facilities, Equipment, and Other Resources

Software and Data – Over the past 18 years, Sandwell and Smith have developed specialized software for processing of radar altimeter profiles, computing gravity anomalies from spherical harmonic models and residual sea surface slopes, and predicting seafloor depth from marine gravity and ship soundings. In addition, we have assembled global depth soundings from a variety of sources and have converted all the data to a common format for the construction of global bathymetry models.

General Computing Equipment - Our lab maintains state-of-the-art workstations, tape drives, and disk facilities for processing bathymetry and satellite altimetry data. We have access to a 30-terabyte mass storage system for backup and archival of results. Additionally, IGPP houses the Visualization Center at Scripps that comprises high-end immersive environments and graphics cluster systems, along with commodity graphics systems such as the Geowall-II and the iCluster (see http://siovizcenter.ucsd.edu).

DATA MANAGEMENT PLAN

The raw altimeter waveform data from CryoSat and Envisat are freely available from the European Space agency while the raw altimeter waveform data from Jason-1 are freely available from the NASA Physical Oceanography DAAC (PODAAC). Thus we do not propose to distribute the original data. Retracked altimeter data created under this investigation will be available to anyone on request and the retracking software and publications will be made available on our web site topex.ucsd.edu.

All data will be freely available within one year after production. The higher level products of gravity and bathymetry data will be distributed on line in three formats for three audiences: general public, general scientist, and power user through our 15 year-old web site topex.ucsd.edu. The expert users want global grids of gravity, topography, geoid height, and seafloor roughness. These will be available by anonymous ftp to topex.ucsd.edu. The intermediate users usually prefer ascii files of sub areas derived from these grids. The interface is found at http://topex.ucsd.edu/cgi-bin/get_data.cgi . Finally the novice users want fully digested information for education or enjoyment. This information for the general public will be provided as jpegs, movies, and descriptive text. In collaboration with Paul Wessel at Univ. of Hawaii, we offer the global gravity and bathymetry in Google Earth KML-format as overlays to the standard bathymetry (SRTM30_PLUS V4.0) in their product. These overlays provide more quantitative information such as contour interval and ship tracklines.

NOAA National Geophysical Data Center will provide the long-term archive for the global gravity and bathymetry grids.

Scripps will host the next GEBCO meeting in October 3-7, 2011 where the larger group will discuss combining all edited bathymetric, compiled by groups around the world, and providing free and open access to these combined data.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL ENVIRONMENTAL SATELLITE, DATA
AND INFORMATION SERVICE
Silver Spring, Maryland 20910

Laboratory for Satellite Altimetry
NOAA mail code E/RA-31

7 January 2011

Prof. Dr. David T. Sandwell
IGPP UCSD SIO code 0225
La Jolla CA 92093-0225

Re: NSF Proposal "A Factor of 2 Improvement in Global Marine Gravity from Cryosat, Jason-1, and Envisat"

Dear David,

I am writing to express my enthusiastic support for your NSF Proposal. I will be delighted to continue our collaboration on marine gravity fields from satellite altimetry.

I can provide access to data through our collaboration. I am a PI on the European Space Agency's Gravity and Ocean Circulation Explorer (GOCE) and CryoSat-2 missions, and on the French and Indian SARAL/AltiKa mission. I am a co-I on the NASA Ocean Surface Topography Science Team, with access to Topex/Poseidon, Jason-1 and Jason-2 data. NOAA has operational responsibility for Jason-2 and international and inter-agency data share agreements by which my shop accesses the above and also ERS-1, ERS-2 and EnviSat data. We make Geophysical Data Records for several of these missions.

There have been many exciting developments in the last year. GOCE data have been combined with GRACE to improve the long-wavelength gravity field significantly. However satellite altimetry is still required to resolve the shorter wavelengths, where most of the tectonic signal is revealed. CryoSat-2 launched in the last year, and we now have data arriving from it. Results are preliminary, but the altimeter seems to function well.

Also over the last year there has been a Jason-1 "End-of-Life" (EoL) study made by CNES, NASA, NOAA and Eumetsat, in consultation with OSTST. I took the lead on the NOAA side. It has been decided that Jason-1 shall be put in a geodetic orbit at the earliest occurrence of any one of the following: (1) launch of AltiKa, (2) increased collision risk, or (3) failure of a system (radiometer, C band altimeter) desired by the operational ocean forecast community but not needed for marine gravity and geodesy.

I am currently investigating whether CryoSat-2 in Synthetic Aperture Radar mode gives gravity anomaly recovery that is superior to a conventional altimeter. Through my work with the U.S. Navy's Submarine Navigation Improvement Program I am also interested in the hunt for uncharted seamounts. These investigations dovetail nicely with your plans in this proposal.

My time on all these investigations will be contributed by NOAA. It will be helpful if you can ask NSF to fund some travel between our institutions to facilitate our collaboration.

Highest regards,

Walter H. F. Smith

Prof. David T. Sandwell
IGPP 0225
Scripps Institution of Oceanography
La Jolla CA 92093-0225
United States

Dr.Tommaso Parrinello
ESA-ESRIN
Via G. Galilei cp. 64
00044 Frascati – Roma -
Italy

Our ref.: EOP-G/TP/080202/cs

Frascati, 08 February, 2011

Subject: **NSF Proposal "A Factor of 2 Improvement in Global Marine Gravity from CryoSat, Jason-1 and Envisat**

Dear David,

This letter is to confirm that ESA CryoSat Mission will provide altimeter data over all ocean areas to support your proposed investigation in accordance to our Earth Explorer Data Policy.

The CryoSat mission is designed to monitor changes in sea ice thickness in the Arctic Ocean and also the volumes of the ice sheets (e.g., Greenland and Antarctica) as well as mountain glaciers. CryoSat has an advanced radar that operates in three modes to support these diverse applications. Although the marine gravity application outlined in your proposal is not a primary mission objective, the altimeter will provide global coverage for gravity field recovery according to the mission geographical mask.

ESA will support your proposal with both access to the full on-line data sets and support to technical queries related to data quality, data usage and product contents, throughout our online EO Helpdesk. Our level 2 processing of the waveform data is not optimized for your marine gravity application so we encourage the development of the new waveform retracker algorithms for both the standard and SAR waveform products. We hope that you will contribute you findings at CryoSat investigator meetings and other scientific venues.

I hope that your proposal is successful and that you and your co-investigators will be able to participate in the exploitation of these CryoSat data.

Sincerely,

Tommaso Parrinello
CryoSat Mission Manager