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FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) OCE - MARINE GEOLOGY AND GEOPHYSICS	1536386

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TITLE OF PROPOSED PROJECT **Seafloor Geodesy Using Sidescan Sonar: Analysis of the NGDC Archive**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 222,474	24 months	09/01/15	

THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
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- ☐ 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)
- ☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date ____ PHS Animal Welfare Assurance Number ____
- ☒ FUNDING MECHANISM Research - other than RAPID or EAGER
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- ☒ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j) TW
- ☒ COLLABORATIVE STATUS Not a collaborative proposal

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

CERTIFICATION PAGE

Certification for Authorized Organizational Representative (or Equivalent) or Individual Applicant

By electronically signing and submitting this proposal, the Authorized Organizational Representative (AOR) 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 conflict of interest (when applicable), drug-free workplace, debarment and suspension, lobbying activities (see below), nondiscrimination, flood hazard insurance (when applicable), responsible conduct of research, organizational support, Federal tax obligations, unpaid Federal tax liability, and criminal convictions as set forth in the NSF Proposal & Award Policies & Procedures Guide,Part I: the Grant Proposal Guide (GPG). 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).

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The AOR is required to complete certifications stating that the organization has implemented and is enforcing a written policy on conflicts of interest (COI), consistent with the provisions of AAG Chapter IV.A.; that, to the best of his/her knowledge, all financial disclosures required by the conflict of interest policy were made; and that conflicts of interest, if any, were, or prior to the organization's expenditure of any funds under the award, will be, satisfactorily managed, reduced or eliminated in accordance with the organization's conflict of interest policy. Conflicts that cannot be satisfactorily managed, reduced or eliminated and research that proceeds without the imposition of conditions or restrictions when a conflict of interest exists, must be disclosed to NSF via use of the Notifications and Requests Module in FastLane.

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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 ☒

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This 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.

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

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By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) 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 Certification Pages, the Authorized Organizational Representative (or equivalent) 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 Certification Pages, the Authorized Organizational Representative 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 AOR shall require that the language of this certification be included in any award documents for all subawards at all tiers.

CERTIFICATION PAGE - CONTINUED

Certification Regarding Organizational Support

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that there is organizational support for the proposal as required by Section 526 of the America COMPETES Reauthorization Act of 2010. This support extends to the portion of the proposal developed to satisfy the Broader Impacts Review Criterion as well as the Intellectual Merit Review Criterion, and any additional review criteria specified in the solicitation. Organizational support will be made available, as described in the proposal, in order to address the broader impacts and intellectual merit activities to be undertaken.

Certification Regarding Federal Tax Obligations

When the proposal exceeds $5,000,000, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal tax obligations. By electronically signing the Certification pages, the Authorized Organizational Representative is certifying that, to the best of their knowledge and belief, the proposing organization:
(1) has filed all Federal tax returns required during the three years preceding this certification;
(2) has not been convicted of a criminal offense under the Internal Revenue Code of 1986; and
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AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Ann F Dunbar**	**Electronic Signature**	**Feb 12 2015 5:06PM**

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER
858-534-1293	**adunbar@ucsd.edu**	**858-534-9642**

Project Summary

Overview

The main objective of this proposal is to develop a method to use existing multibeam sonars, available on NSF-sponsored research vessels, to measure small displacements of the seafloor associated with rapid events such as earthquakes and landslides. The seafloor displacements are measured by differencing the location of a patch of seafloor surveyed at two times spanning an event. The published accuracy of this approach is currently tens of meters which severely limits the utility of the method. Our proposal would greatly improve the accuracy to better than 1 m by collecting data at a slow ship speed and navigating the repeat track to closely follow the reference track. This order of magnitude improvement in displacement accuracy would provide a valuable tool for assessing and understanding large and sometimes-destructive seafloor events.

Intellectual Merit

Active plate boundaries, especially subduction zones, pose significant hazards in the form of earthquakes and tsunamis, such as those associated with the 2011 M_ω 9.0 Tohoki-Oki earthquake (*Wilcock et al.*, 2012). However, our ability to monitor such areas and events are severely limited because current seafloor geodetic instruments are either too inaccurate or cost-prohibitive. Multibeam sonar, despite its relatively poor resolution, holds great potential as a cheap and effective geodetic tool due to its high spatial coverage, but the limits of its accuracy are still an active area of research. In a previous experiment at very low ship speed ($\sim$ 1 knot) we demonstrate that a patch of seafloor ($\sim$ 3000 m deep) can be re-positioned to an accuracy of better than 1 meter using the sidescan data from a 12 kHz multibeam sonar. In addition to the slow ship speed, the repeated surveys were performed within the critical baseline for interferometry. This displacement accuracy is at least 30 times better than has been achieved through repeated multibeam surveys at transit ship speed. We propose to analyze existing sidescan and multibeam data archived at NGDC to address some basic questions related to our preliminary analysis. These include how the displacement accuracy depends on: reference-to-repeat baseline offset; the ship speed; the sonar frequency/bandwidth; and variations in upper ocean sound velocity. Our approach will be to make modifications to the MB-System software to access the raw sidescan backscatter versus travel time and continue to develop spectral and spatial cross correlation methods to assess displacement accuracy versus system and geometric parameters. Our ultimate objective is to establish best practices for achieving sub-meter seafloor displacement accuracy using existing multibeam sonars. This research may help to guide future reference and repeat surveys of active plate boundaries.

Broader Impacts

Our proposal addresses one of the eight high-level science questions posed in the recent NRC Decadal Report (*NRC*, 2015) "How can risk be better characterized and the ability to forecast geohazards like mega-earthquakes, tsunamis, undersea landslides, and volcanic eruptions be improved?" The tools of GPS and InSAR are used to monitor the crustal deformation onshore of the Cascadia Subduction Zone but most of the locked part of the megathrust interface lies offshore. While our proposed method does not have sufficient accuracy to monitor interseismic motions, it can serve as a pre-event survey of the surface trace similar to the San Andreas Fault B-4 lidar survey (*Bevis et al.*, 2005). For example, a high resolution survey of the toe of the Cascade megathrust zone could serve as the reference benchmark for post-event surveys as well as provide high resolution imagery for paleoseismic analysis (*Goldfinger*, 2011). Funding will be used to train a graduate student in the methods of high-resolution sonar and seafloor geodesy.

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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

Synthetic Aperture Sonar for High Resolution Mapping and Change Detection; Sandwell; OCE0331549; $120,581; 08/01/2003 - 7/31/2004

Intellectual Merit - The development of interferometric synthetic aperture radar (InSAR) has revolutionized many areas of science and industry including crustal dynamics, glaciology, hydrology, and applications requiring high-resolution global topography. Is it possible to develop a comparable tool, based on sonar, to explore the deep ocean? Such a tool could be used for high-resolution imagery as well as change detection and crustal motion. There are no theoretical barriers to the development of interferometric synthetic aperture sonar (InSAS) but two important technical developments are required: 1) formation of a synthetic aperture sonar image (SAS) and 2) differencing the phase of the reference and repeat images to form a sonar interferogram (InSAS).

Broader Impacts - Development of a repeat-pass interferometric sonar capability would provide a transformative tool to investigate seafloor deformation associated with tectonics. The research supported a Masters Thesis for Davis Thomsen.

Accomplishments - To assess the possibility of developing a deep-ocean synthetic aperture sonar (SAS) capability, we carried out a 2 ship-day survey of the Juan de Fuca ridge ridge in co-ordination with an NSF funded seafloor geodesy program. The experiment aboard R/V Revelle was carried out between September 05 and September 22 of 2003 (Figure 1). David Chadwell was chief scientist for a well-developed seafloor geodesy program while David Sandwell was responsible for the SAS experiment. During this cruise we collected data to study the feasibility of performing SAS and InSAS using the Simrad EM120 multibeam system on the R/V Roger Revelle. The objectives of this survey were to collect raw hydrophone data at a speed of <1 knot at 3 km ocean depth using the Simrad EM-120 system while the 3-D ship motion is being tracked by multiple GPS receivers and inertial sensors to a precision of a few centimeters. Two concrete boxes were deployed in an area of low sonar backscatter to verify the resolution capabilities of the system. Funding for this experiment was provided by NSF through the Small Grant for Exploratory Research (SGER). During this cruise we achieved our experimental objectives and acquired all of the data needed to determine whether SAS is possible and feasible. The processing was done in collaboration with Enson Chang at Applied Signal Technology, Inc. While we were unable to achieve the SAS objectives, we have recently shown these data are highly suitable for standard image cross-correlation methods.

Publications - DeSanto, J., D. T. Sandwell. (2014), Meter Accuracy Seafloor Geodesy using Repeated Multibeam Surveys, presented at 2014, *Fall Meeting, AGU*, San Francisco, 15-19 December.

A Factor of 2-4 Improvement in Marine Gravity and Predicted Bathymetry from CryoSat, Jason-1, and Envisat Radar Altimetry; D. Sandwell, OCE1128801; $229,188; 02/1/12 – 01/31/16.

Intellectual Merit - We proposed 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. The proposal has 4 main components: (1) Develop waveform retracking algorithms and computer codes for these new satellite altimeter data sets that are optimal for gravity field recovery. (2) Develop global gravity grids at 1 minute resolution using the new altimeter data as it becomes available. (3) Continue to develop global bathymetry grids at both 1 minute and 30 arc second resolutions. (4) Use these new data to estimate the bending moments needed to support the trench and outer rise topography of all subduction zones.

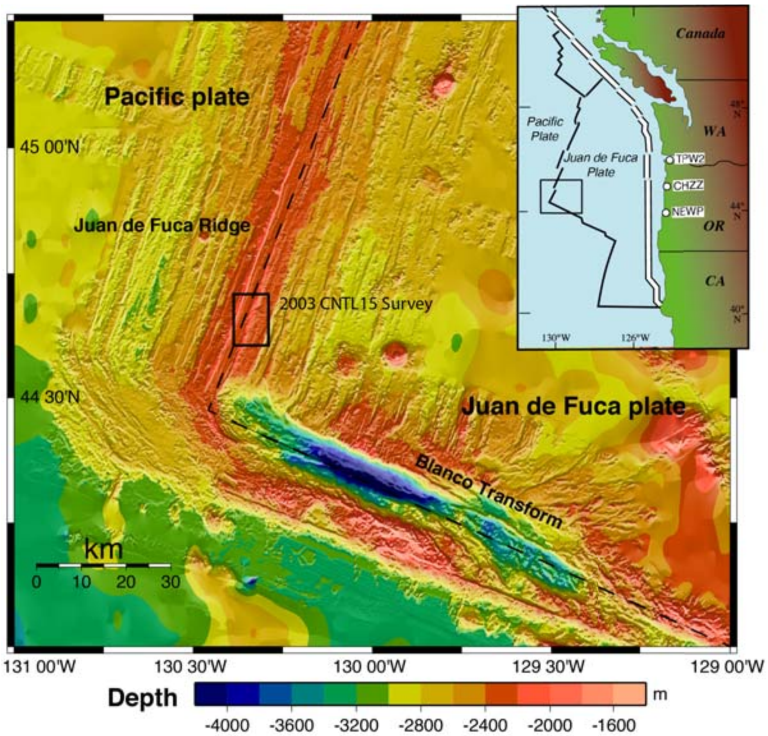

Figure 1: Bathymetry of the intersection between the Juan de Fuca Ridge and the Blanco Transform. The approximate location of the plate boundary between the Pacific and Juan de Fuca plates is denoted by the dotted line. The location of the repeated multibeam and sidescan data collected in the 2003 CNTL15RR survey by Sandwell and Chadwell has been boxed.

Broader Impacts - Global bathymetry and gravity 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 is being used to support and educate graduate student Emmanuel Garcia and undergraduate students Christopher Olson and Rachael Munda.

Accomplishments - We have completed the development of waveform retracking software and have retracked all the existing data (*Garcia et al.*, 2014). Using these data along with the Geosat and ERS-1 altimetry data we have published a new global gravity model (*Sandwell et al*, 2013; 2014). An updated global bathymetry model, based on this improved gravity, is being used in Google Earth.

Publications

Garcia, E., D. T. Sandwell, W. H. F. Smith. Retracking CryoSat-2, Envisat, and Jason-1 Radar Altimetry Waveforms for Improved Gravity Field Recovery, *Geophysical Journal International*, doi: 10.1093/gji/ggt469, 2014.

Sandwell, D., E. Garcia, K. Soofi, P. Wessel, M. Chandler, and W. H. F. Smith, Toward 1-mGal accuracy in global marine gravity from CryoSat-2, Envisat, and Jason-1, *The Leading Edge*,

32(8), 892–899. doi: 10.1190/tle32080892.1, 2013.
Sandwell, D. T., and W. H. F. Smith, Slope Correction for Ocean Radar Altimetry, Journal of Geodesy, doi: 10.1007/s00190-014-0720-1, 2013.
Sandwell, D. T., R. D. Müller, W. H. F. Smith, E. Garcia, R. Francis, New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure, *Science*, Vol. 346, no. 6205, pp. 65-67, doi: 10.1126/science.1258213, 2014.
Global gravity model available at: `http://topex.ucsd.edu/WWW_html/mar_grav.html`
Global bathymetry model available at: `http://topex.ucsd.edu/WWW_html/srtm30_plus.html`

GEOSPAR: A portable platform for GPS-Acoustic measurements of seafloor motion; Chadwell; OCE1130003; $688,188; 01/01/2012 - 12/31/2014.
Intellectual Merit - The purpose of this proposal was to lower the cost and operational barriers to measuring seafloor deformation by developing a portable platform to collect Global Positioning System - Acoustic (GPS-A) measurements. A Liquid Robotics Wave Glider, which uses mechanical wave motion for propulsion, solar arrays for electrical power and Iridium satellite communications for command/control from shore, was adapted as a GPS-A platform. Commercially available GPS/INS positioning systems and acoustic ranging systems form the basis of the measurement hardware. Adoption of commercial suppliers will allow a wider community of researchers to use this technology in the future.
Broader Impacts - Expanded seafloor geodetic measurements in the offshore region of the Cascadia subduction zone (as well as the Aleutians) can document better the potential great earthquake and tsunami hazards. This may eventually lead to better management of the societal risk when these events happen in the future. This project provides additional field evidence that Wave Gliders are useful sea going platforms for oceanographic observations.
Accomplishments - The system has been demonstrated in tests held in water depths of 100 m and 250 m offshore San Diego, and 3000 m offshore Oregon. It was launched nearshore and navigated remotely to seafloor transponder sites to collect the GPS-A data, thereby reducing significantly the cost of GPS-A data collection.
Publications
Chadwell, C. D., 2013, GPS-Acoustic Seafloor Geodesy using a Wave Glider, Abstract G14A-01 presented at 2013, *Fall Meeting, AGU*, San Francisco, CA, 9-13 December.

2 Intellectual Merit

2.1 Need for seafloor geodesy

There is a compelling need for accurate and economical tools to be used for seafloor geodetic applications (*Davis et al.* 2012, *Wilcock et al.* 2012). The vast majority of plate margins, specifically the subduction zones associated with megathrust earthquake and tsunami hazards, are distributed in marine environments unobservable via traditional satellite-based techniques (*Spiess*, 1985). Understanding the earthquake cycle along spreading ridges, transform faults, and subduction zones will require at least two types of geodetic measurements - point measurements to establish plate motions and spatially dense coverage to investigate moment accumulation rate of of locked patches at the plate margins. Figure 2 shows the characteristic length scales and deformation rates associated with various tectonic processes.

2.2 Geodetic methods: Land and ocean

On land, these tools are well developed. Point measurements from GPS networks provide mm-accuracy, vector displacement time series (*Wdowinski et al.*, 2001), and InSAR provides spatially dense snapshots of line-of-sight deformation (*Bürgmann et al.*, 2000). However, these techniques make use of electromagnetic radiation which cannot penetrate the deep ocean.

There are three main classes of seafloor geodetic measurements (*Bürgmann and Chadwell*, 2014). First, hybrid GPS-Acoustic (GPS-A) arrays measure the relative position between two or more seafloor transponders via acoustic ranging. The location of these transponders is monitored by a ship (or wave glider) whose position is in turn monitored in a global reference frame using GPS. Second, pressure sensors can be deployed to the seafloor to directly measure vertical deformation. Finally, the seafloor can be imaged using a multibeam sonar array or an active source seismic array. These data have geodetic applications when comparing repeated surveys.

GPS-A was first proposed by *Spiess* (1985), and has since been employed to measure tectonic motions of the Juan de Fuca plate (*Chadwell et al.* 1999, *Chadwell and Spiess* 2008). Analogous to terrestrial GPS, these systems can capture centimeter-scale motions at specific points, but GPS-A is hampered by the considerable expense of deploying and monitoring transponders as well as the significant ship time required to make the measurement. In contrast, multibeam sonar data are significantly cheaper to acquire and provide a denser spatial coverage like InSAR, but are significantly less accurate. Repeated multibeam surveys have mostly been used to detect large changes (>10 m) in bathymetry due to volcanic events (*Chadwick et al.* 1991, *Fox et al.* 1992, *Chadwick et al.* 1998, *Caress et al.* 2012). However, the *Fujiwara et al.* (2011) study showed that even the 10-m accuracy of the multibeam sonar was sufficient to provide important constraints on the very large displacement ($\sim$ 50 m) of the seafloor associated with the 2011 M_ω 9.0 Tohoku-Oki earthquake. These multibeam data were the critical for understanding why the tsunami had such large amplitude.

We are investigating methods for improving the accuracy of the seafloor displacement using pixel tracking of sonar backscatter data, a technique used to measure horizontal offsets. Pixel tracking has been used in InSAR studies to measure ice velocities and along-track offsets for co-seismic motions (*Joughin*, 2002). Our goal is to assess how the accuracy of the pixel tracking technique improves as the ship speed is reduced, as well as whether it is best applied to multibeam bathymetry or sidescan data.

2.3 Results from 2003 experiment

In 2003 we (Sandwell and Chadwell) collected repeated multibeam data above the Juan de Fuca ridge (Figure 1) at a very slow ship speed ($\sim$ 1 knot) and within the critical baseline for interferometry (see Appendix for definition of critical baseline). Since these tracks have a heading of 277°, the along-track direction is very nearly East-West and the across-track direction is very nearly North-South. The overlapping area of the tracks is approximately 7 km by 7 km in area. We use both the bathymetry and sidescan data from these tracks; the sum and difference of the repeated sidescan data is shown in Figure 3.

While there were only two surveys over the patch of seafloor, we estimated the displacement accuracy by injecting an artificial horizontal offset in the repeat data and comparing the estimated offset with the injected offset. This experiment was performed many times to establish the 2σ displacement accuracy. We estimated the offset by performing pixel tracking on these data using

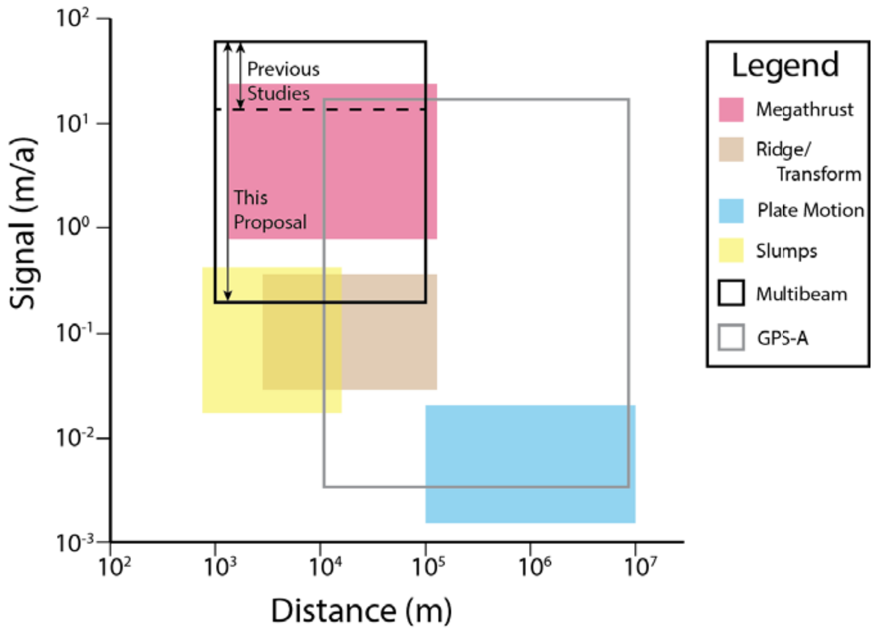

Figure 2: Schematic plot of the tectonic signal of various marine geologic processes, including megathrust earthquakes, ridge and transform earthquakes, average plate motion, and slumps/slope failures. The horizontal includes the upper and lower length scale for each process while the vertical scale bounds the amplitude of the motion per year. Also plotted is the estimated accuracy of repeated multibeam surveys (this proposal) and GPS-Acoustic arrays. The signal of a process is assumed to be a velocity or the amount of motion in a single event; in the latter case surveys are presumed to be separated by one year's time.

digital image correlation techniques. Two different methods were used (i.e., spectral and spatial) because we did not believe our initial results, which consistently returned horizontal seafloor displacements accurate to better than 1 meter. The details of the analysis are provided in the Appendix.

For comparison, we have analyzed multibeam data from the 2001 cruises DRFT03RR and DRFT05RR across the Cocos ridge. The repeated sections of these surveys were acquired at a high ship speed ($\sim$ 11 knots) and outside the critical baseline. To compensate, we consider a much larger area of overlapping data, approximately 220 km in the along-track direction by 10 km in the across-track direction. The heading of the ship in both surveys was very nearly North-South; thus the along-track direction is North-South and the across-track direction is East-West. Unfortunately, the sidescan data from these surveys is very nearly incoherent, thus we cannot use it for image correlation.

Results from both surveys using the cross spectral analysis and cross-correlation analysis are provided in Table 1. The displacement accuracy in the range direction is 0.28 m for the JDF sidescan data, 0.49 m for the JDF bathymetry, and 37.4 m for the Cocos bathymetry. Note there is a significant mean offset that should also be considered in the error budget. Range displacements are more accurate for the sidescan data, which is not surprising considering that this data also has the best resolution. The surprising result is that the displacement accuracies for the bathymetry is 50-75 times better for the slow ship speed compared to the fast ship speed, despite the speeds only

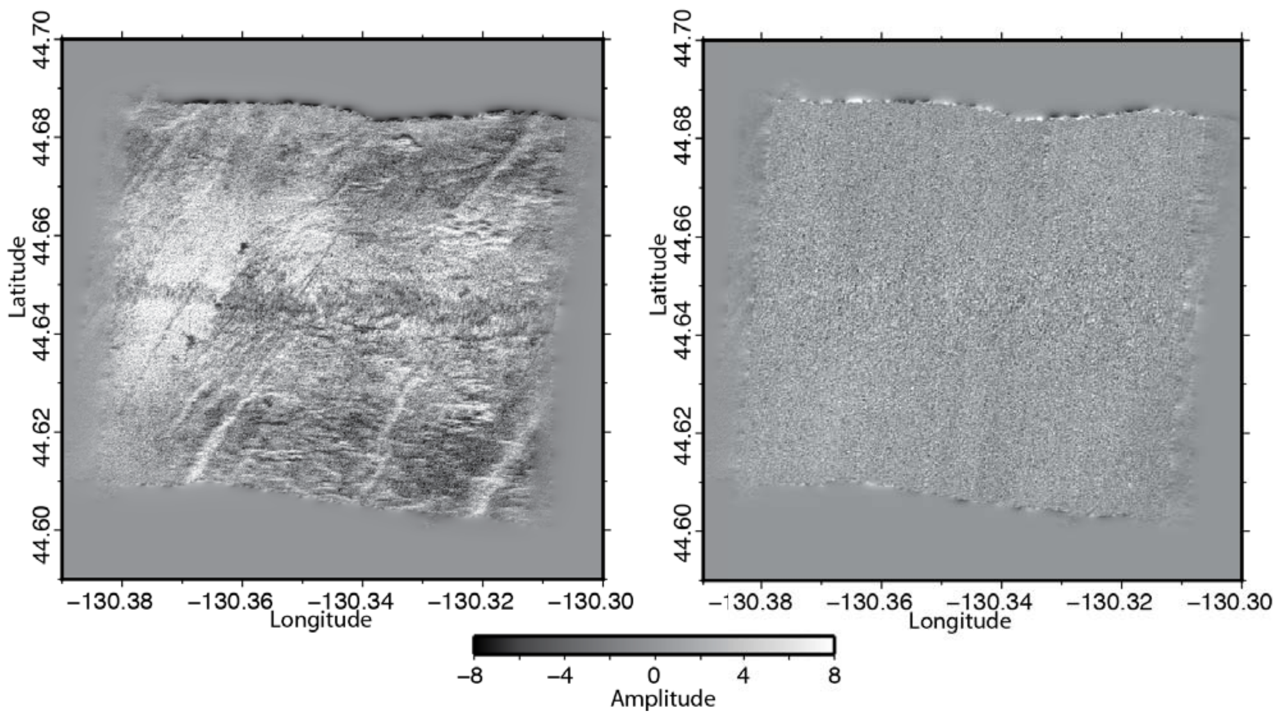

Figure 3: Sidescan image of repeated surveys in Juan de Fuca area. The sum of the two grids (left) shows the common signal while the difference (right) shows the noise. The noise is greatest directly beneath the ship track and decreases with increasing sonar look angle.

varying by a factor of 11. We do not understand whether this improvement is due to the slower ship speed, the shorter baseline, or a combination of both parameters. Hence, our key objective is to analyze repeated multibeam surveys at a variety of ship speeds, baselines, and other parameters to better understand the factors that control reference-to-repeat displacement accuracy. We feel an appropriate course of action is to evaluate data within the NGDC multibeam catalogue, which contains myriad repeat surveys.

3 Proposal

The main objectives of our proposed research are to determine the accuracy by which a patch of seafloor ($\sim$ 50 km^2) can be positioned using repeated sidescan sonar surveys from a surface ship. We envision using the same ship and multibeam sonar for the reference and repeat surveys to eliminate common errors associated with, for example, an incomplete knowledge of the phase center of the hydrophone array relative to the GPS receiver(s). In addition we expect that the best displacement accuracy will be achieved by having the same track line and heading on the repeated surveys. These were the conditions for our 2003 experiment where we achieved sub-meter displacement accuracy. We envision performing repeat surveys of two or more patches that span areas where the displacement could exceed 1 m over a decade such as a ridge axis, transform fault, or the toe of a megathrust zone.

Our preliminary analysis used the standard MB-System tools (*Caress and Chayes* 1996, *Caress*

Survey Grids	Approx. Direction	Spectral		Correlation	
		μ (m)	2σ (m)	μ (m)	2σ (m)
JDF Bathymetry (~1 knot)	Along-track	-0.37	**0.55**	-1.66	0.72
	Range	-0.75	**0.49**	-0.20	1.21
JDF Sidescan (~1 knot)	Along-track	0.51	**0.75**	-0.21	0.57
	Range	0.10	**0.28**	-0.29	0.47
Cocos Bathymetry (~11 knots)	Along-track	-1.22	27.94	-3.75	29.01
	Range	-5.57	37.42	3.68	107.01

Table 1: Estimates of displacement accuracy for the Juan de Fuca (slow) and Cocos (fast) repeated surveys. The displacement accuracy is established in the range and along-track directions using two methods. The cross spectral analysis provides the best accuracy while the cross correlation analyses is slightly worse.

and Chayes 2015) to extract the raw sidescan data as longitude, latitude, depth, and backscatter. However this approach involves the development of a cross-track depth model for each ping using all the orientation and range information provided to the Simrad sonar. The first objective of our proposal will be to make modifications to the MB-System code to extract a less-processed sidescan product that has properties similar to spaceborne or aircraft radar. This work will be done in consultation with Dave Caress who is an author of the MB-System software (see letter of collaboration). We will work in a range and along-track coordinate system where range is the travel time (times an initially constant velocity) to a reflector. This raw measurement largely eliminates the need for beamforming and ship roll corrections except we will need to calculate the position of the phase center of the hydrophone array relative to the GPS. The other coordinate is called azimuth in the radar community but in our case it is distance along-track taken along a line connecting two points that best matches the ship trackline. For each ping, deviations of the actual trackline from the best track line will be used along with a flat-bottom model (i.e., same depth model for reference and repeat) to correct the range for cross-track deviation.

Changes in sound velocity of the upper ocean between the reference and repeat tracks will be a major error source in the range measurements (*Spiess and Hildebrand* 1995, *Spiess et al.* 1998). For a look angle of 45°, the two-way travel time can be different by about 0.4 m over time scales of 10 hours and perhaps 2-3 m over annual time scales (*Spiess* 1985, *Spiess et al.* 1998). One advantage of multibeam sonar over spaceborne SAR is that data are collected from both sides of the platform using differing sonar frequencies to discriminate between port and starboard returns. As demonstrated in the GPS-A studies (*Spiess et al.*, 1998) range perturbations on each side of the ship will be nearly the same because the sound velocity difference mainly depends on depth. Also the range perturbation will increase with increasing range due to the increase in upper ocean path length. During the processing we will apply a first-order range correction based on vertical sound velocity measurements from the XBT data collected during each cruise. This will stretch the repeat image in range relative to the reference image to improve the spatial cross correlation. Residual range errors from the port and starboard sides of the ship should largely cancel during the patch correlation. As in the case of spaceborne SAR, the along-track offsets are not affected by purely vertical velocity changes. Note that the vertical measurement of depth is affected in a first-order way from sound velocity errors and there is no port to starboard cancellation. Therefore we expect that this method will be most accurate for measuring horizontal displacements and much less accurate for vertical as is also the case for the GPS-A measurement.

A second smaller error source will be related to the accuracy of the standard shipboard GPS receiver. For example, the R/V Roger Revelle has a dual frequency receiver with P-code access for real-time accurate positioning. During our 2003 experiment, it was also outfitted with three additional dual frequency GPS receivers to monitor the position and orientation of the ship for the GPS-A experiment. We will compare these GPS data streams to establish the accuracy of the standard GPS. Other ships in the UNOLS fleet have similar standard GPS capability.

Once the raw sidescan data have been assembled in range and along-track coordinates, the image cross correlation will be performed as described in the Appendix. One additional change will be to apply a range-dependent weighting function to each image prior to cross correlation to deemphasize the near nadir data, which have poor geometry for the horizontal positioning measurement (Figure 3).

After determining the best practices for seafloor positioning using the sidescan data from the CNTL15RR survey, we will search the NGDC multibeam data archive for repeated tracks using the same ship and sonar. The main search criterion will be track lines that repeat to within 50-500 m, preferably inside critical baseline and at ship speeds ranging from 2 to 8 knots. Ideally the ship tracks should be parallel (not antiparallel) to minimize the horizontal uncertainty between the location of the GPS antenna and the phase center of the hydrophone array as well as possible differences between the port and starboard sonar. Initially we will analyze data from reflective and rugged seafloor at 3-4 km ocean depth to maximize the texture in the sonar imagery. Finally we will also investigate using a 30 kHz sonar to perhaps achieve higher range and along-track precision. In addition to analyzing archive data, graduate student John DeSanto recently had a UC Ship funds proposal approved to collect new sidescan data aboard R/V Revelle in January of 2016. (See attached letter of acceptance from Bruce Applegate.)

We have searched the NGDC archive for repeat tracks from the R/V Thompson in the region of the Juan de Fuca ridge; R/V Thompson has a 30 KHz sonar. The three-times higher frequency results in a smaller along-track footprint. In addition the range resolution is three times better which could result in more accurate patch positions assuming similar reflective texture at 30 kHz (5 cm wavelength) compared with 12 kHz (12.5 cm wavelength). Our preliminary assessment revealed multiple areas with overlapping ship tracks. We found two overlaps in the 2013 TN299 survey. The first occurs in the transit tracks, which repeat to within 30-35 m at a ship speed of $\sim$12 knots. The second occurs during the experiment, in which the tracks repeat to within 40 m at a ship speed of $\sim$2 knots. It is important to note that in both of these examples the ship tracks are oriented anti-parallel, and thus may have systematic errors associated with relative changes in the orientation of the phase center of the hydrophone array. Anti-parallel repeated tracks such as these are common in the NGDC archive, so it is especially critical to quantify this source of error.

4 Broader Impacts of the Proposed Work

The final outcome of our 2-year investigation will be a technical publication on the use of existing multibeam sonar data for measuring seafloor displacements between repeated surveys separated in time by years. We expect the displacement accuracy will depend on ship speed, baseline length, temporal variations in upper ocean sound velocity, seafloor reflective properties, and sonar frequency. Achieving sub-meter reference-to-repeat displacement accuracy using standard multibeam data opens two important areas of seafloor investigation. First, one could measure $\sim$1 m seafloor deformations in regions where there was a pre-survey having the required characteristics.

This could be accomplished by performing a suitable repeat survey using the same ship and sonar. Second, one could create seafloor "benchmarks" in areas where large horizontal deformations are expected such as the very high slip rate transform faults of the East Pacific Rise or across the Cascadia megathrust zone. Development of a new intermediate accuracy would greatly expand our tools for seafloor geodesy using existing UNOLS assets. This would address one of the eight high-level science questions posed in the recent NRC Decadal Report (*NRC*, 2015) "How can risk be better characterized and the ability to forecast geohazards like mega-earthquakes, tsunamis, undersea landslides, and volcanic eruptions be improved?" Funding for this proposal will be used to support an SIO Graduate Student in a Ph.D. investigation of seafloor geodesy.

5 Tasks and Timeline

Year 1 – Develop a model for the range change due to upper ocean sound velocity changes. Refine the MB-System software to export sidescan data in both range and along-track coordinates and geographic/depth coordinates with application of 1-D sound velocity corrections. Assess the accuracy of the standard GPS data on the Revelle, Thompson, and other appropriate platforms. Re-do the analysis of the low speed (CNTL15RR) and high speed (DRFT03-05RR) using velocity corrections and in the range/along-track coordinates. Develop an automated algorithm to search for repeat tracks in the NGDC archive including data from Revelle, Thompson, Melville, Knorr, Langseth, Ewing, and any other suitable platforms. Collect new sidescan data aboard R/V Revelle in January of 2016. Ship time will be provided by an approved UC Ship funds proposal.

Year 2 – Analyze sidescan data from >20 repeat surveys having a variety of ship speed, baseline length, temporal variation in upper ocean velocity, seafloor reflective properties, and sonar frequency. Publish results in a refereed, open-access, journal. Consider a follow-on proposal for a workshop or a seagoing experiment to further refine the methods and results.

6 Appendix: Sidescan and Multibeam

There are two types of data products from a multibeam array: sidescan and bathymetry. In this section we shall briefly address the theory and limits of resolution for these types of data. Much of the multibeam theory is similar to that of radar systems (*SeaBeam* 2000, *Curlander and McDonough* 1991). When evaluating the limits of resolution, we shall use the parameters of a Simrad EM120 multibeam array, as this is the system that was used aboard the R/V Roger Revelle to collect much of the data used in this study.

6.1 Sidescan Sonar

Sidescan sonar is truly analogous to radar, in that the technique involves measuring echoes from an area insonified with an acoustic pulse much like a radar satellite would for an electromagnetic pulse. The ground range resolution R_r of sidescan is a function of the pulse length τ, the wave speed c and the look angle θ:

$$R_r = \frac{c\tau}{2\sin\theta}$$

The speed of sound in seawater is on the order of 1500 m/s, and the EM120 system supports a 15 ms pulse length as well as a look angle of up to 75°. Thus, the range resolution is about 65 m for a look angle of 10°and 13 m for a look angle of 60°. Clearly, the ground range resolution is poorest directly beneath the array. We shall use a nominal sidescan range resolution of 16 m.

The along-track resolution is determined by the length of the seafloor illuminated by a single acoustic pulse, governed by Fraunhoffer diffraction. This is nominally a function of slant range ρ, sonar wavelength λ, and the length the transducer array L.

$$R_a = \frac{\rho\lambda}{L}$$

Using appropriate values yields an along-track resolution of about 100-150 m.

Much like in the case of satellite radar, we would like to improve the along-track resolution by forming a synthetic aperture. This involves integration of information from a spot on the seafloor over all of the pulses for which it is illuminated. This improves the along-track resolution to

$$R'_a = \frac{\lambda H}{2R_a \cos\theta} = \frac{L}{2}$$

The length of the transducer array L of the EM120 array is 7 m, so it is theoretically possible to achieve 3.5 m along-track resolution using sidescan sonar. However to avoid aliasing of the focused image, the along-track distance between successive out-going pulses should be less than half the length of the transducer array. For the EM120 array, this would be less than 3.5 m. Since the pulse repetition frequency of the EM120 array is 0.1 Hz, a well focused image requires a speed of <0.4 m/s, or about 0.8 knots. Though this technique is routine for satellite radar (referred to as *synthetic aperture radar* or SAR), it has yet to be implemented for a multibeam sonar system, and will not be implemented in this study.

If it were possible to focus the sidescan data into a single-look complex image (SLC) then one could construct an interferogram between a reference and repeat image as long as the distance between the repeated tracks is less than the critical baseline which is defined next.

The geometry of repeat-pass interferometry is shown in Figure 4. The largest contribution to the phase of the repeated sonar pulse with respect to the reference sonar pulse is due to the orientation of the surface of the earth with respect to the range vector. The change in phase with increasing range across the image is given by:

$$\frac{\partial\phi}{\partial\rho} = \frac{-4\pi B\cos(\theta-\alpha)}{\lambda\rho\tan\theta}$$

where $B_\perp = B\cos(\theta-\alpha)$ is the perpendicular component of the baseline. (Note for the ocean application, the reference and repeat tracks will be on nearly the same horizontal plane so $\alpha \sim 0$.) The reference and repeat images will be completely decorrelated if the phase changes by more than 2π across a single range pixel. The size of the range pixel is related to the pulse length of the radar $\Delta\rho = c\tau/2$. The fringe rate increases with increasing baseline length. The *critical baseline* where complete decorrelation occurs is

$$B_c = \frac{\lambda\rho\tan\theta}{c\tau\cos\theta} = \frac{\lambda H\tan\theta}{c\tau\cos^2\theta}$$

Note the critical baseline increases with increasing wavelength, increasing range, and decreasing pulse length. The critical baseline is also a function of the look angle. For a seafloor depth of 2.5 km, the critical baseline is 2.4 m for a look angle of 10°and 92.4 m for a look angle of 60°. For

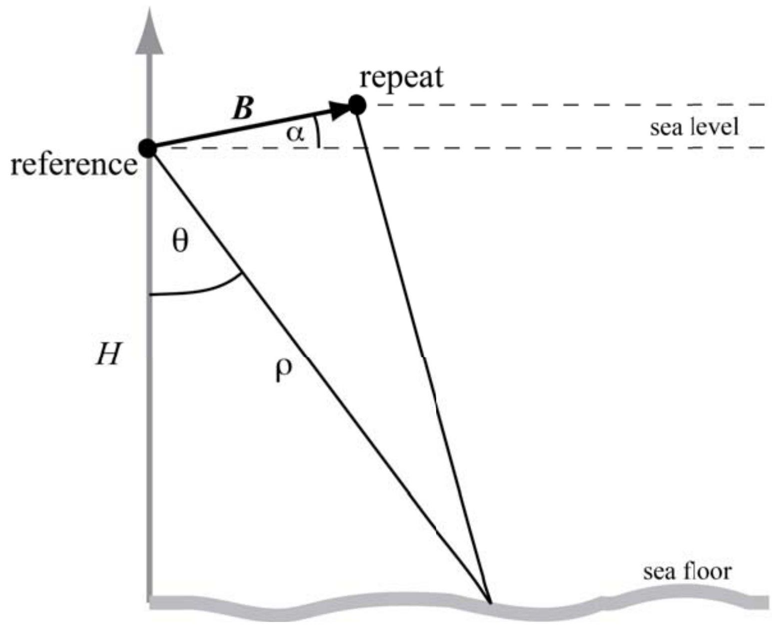

Figure 4: Geometry of a repeat pass multibeam survey where the direction of the reference and repeat tracks are parallel and into the page. They are displaced by a baseline B and the average ocean depth is H. Note this diagram is highly exaggerated because the range is more than 1000 times the baseline.

coherent change detection, the best interferometric pairs have baselines less than about 1/10 of the critical baseline.

For the purposes of this study, we shall not be focusing the data into synthetic aperture sonar (SAS) images. However, we still believe there may be value in observing some of the data collection requirements necessary to create SAS. In particular, collecting data at a slow ship speed and within the critical baseline should improve the coherence between successive ship tracks even if a SAS image cannot be formed.

6.2 Multibeam Bathymetry

The physics governing the multibeam bathymetry are not terribly different from those governing radar and sidescan sonar. The primary difference comes from the arrangement of a multibeam sonar array into a Mills-Cross formation. This formation is such that the transducers are placed in the along-track direction on the hull of the ship, which is perpendicular to a line of hydrophones in the across-track direction. The utility of this formation is that the transducers illuminate an area that is long in the across-track direction while the hydrophones are sensitive to an area long in the along-track direction. By taking advantage of a processing technique known as beam steering, in which a time delay is introduced to recorded data, the hydrophone array can be tuned to be sensitive to cross-track look angle. Thus, multibeam arrays can be used to survey much broader areas than other sonar systems.

The spatial resolution of the multibeam bathymetry is governed by Fraunhoffer diffraction in both the along-track and across-track directions. The along-track resolution (100-150 m) is equal to the wavelength times the range divided by the aperture length of the transducer array (7 m), while the across-track resolution (75-115 m) is analogously equal to the wavelength times the range divided by the aperture length of the hydrophone array (10 m) times the range.

6.3 Displacement Accuracy

We measure a seafloor displacement between repeated multibeam bathymetry or sidescan tracks using digital image correlation techniques. There are many ways to perform digital image correlation (*Pan et al.*, 2009); we describe the algorithms we use in a later section. Assuming that we have a large enough subset of pixels in each data set (perhaps 500-1000 in each of the range and along-track directions), we hope to be able to achieve accuracies on the order of $\frac{1}{20}$ of a pixel as in *Sjödahl and Benckert* (1993). This would correspond to displacement accuracies of approximately 0.8 m in the range direction for sidescan, 5 m for the along-track direction for sidescan, and 5 m in both the range and along-track directions for multibeam bathymetry. It is worth emphasizing that this is our goal for displacement accuracy rather than absolute position accuracy.

6.4 Data Preparation

We begin by extracting the bathymetry and sidescan data from the raw instrument products using the program MB-System. We create coregistered grid files using the Generic Mapping Tools (GMT) programs blockmedian and surface. In this process, blockmedian removes outliers, and surface creates the grid file using a cubic B-spline interpolation scheme that we control with a tension factor of 0.35 (*Smith and Wessel*, 1990). Before this process, we also shift the locations of one set of data points by a constant to simulate a lateral displacement of the seafloor. The multibeam bathymetry from the Juan de Fuca ridge surveys are gridded at 20 m by 50 m with the x-direction being very nearly along track and the y-direction nearly across track, while the sidescan amplitudes are gridded at 10 m by 10 m. The multibeam bathymetry from the Cocos plate surveys are gridded at 100 m by 100 m, but the orientation of these tracks is normal to the Juan de Fuca tracks, such that the x-direction is nearly across-track and vice versa. The grid dimensions are all parallel to longitude and latitude.

Finally, the grids have their means removed and are windowed such that the data distribution between grids is consistent. The window consists of a grid file that is one in locations where both data grids have data and zero otherwise. The window is low-pass filtered with a cutoff wavelength of 2 km to minimize the amount of common signal it may create when applied to both data grids.

6.5 Cross Spectral Analysis

One method of comparing the two data tracks is by taking their cross spectrum (*Chen et al.* 1993, *Sjödahl and Benckert* 1993). We perform this analysis in MATLAB using a multitaper scheme. Since the grid files are two-dimensional, we create a set of orthonormal 2D tapers by taking the outer product between orthonormal 1D tapers (*Hanssen*, 1997) generated using the MATLAB command dpss. Given two grid files $g_1(x, y)$ and $g_2(x, y)$ as well as an equally weighted set of N tapers $t_i(x, y)$, the multitaper cross spectrum estimate is given by

$$S_{12}(k_x, k_y) = \frac{1}{N}\sum_{i}^{N} \mathcal{F}[t_i g_1]\mathcal{F}[t_i g_2]^*$$

where $\mathcal{F}$ denotes the two-dimensional Fourier transform.

The three useful parameters of the cross spectrum are the amplitude, phase, and coherence, given by

$$A_{12} = \sqrt{|S_{12}|^2}$$
$$\Phi_{12} = \arctan\left(\frac{-\mathcal{I}[S_{12}]}{\mathcal{R}[S_{12}]}\right)$$
$$\gamma_{12}^2 = \frac{|S_{12}|^2}{S_{11}S_{22}}$$

When the coherence is low, the phase essentially random, but when the coherence is high, any displacement between the two grids will manifest itself as a phase ramp as per the Fourier shift theorem (Figure 5). Rather than inverse Fourier transform the cross spectrum to arrive at a correlation peak as in *Chen et al.* (1993) and *Sjödahl and Benckert* (1993), we estimate the displacement vector from the gradient of the phase ramp. This is done by least squares fit of a plane to the phase estimates where the coherence is greater than a prescribed threshold (e.g., 0.4). The threshold coherence of is chosen to maximize the data allowed in the least squares fit without allowing contamination from noisy estimates.

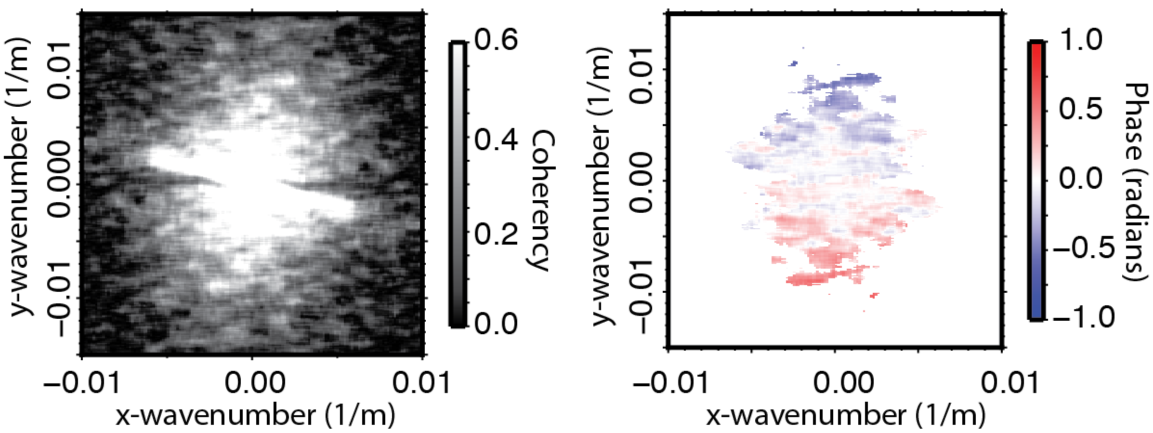

Figure 5: Coherence (left) and phase (right) spectra of the Juan de Fuca sidescan data. The data have a relative displacement of 0.5 m in the y-direction, which is evident in the phase ramp.

6.6 Cross Correlation Analysis

An alternative is to perform a direct analysis in the spatial domain. We choose to calculate the normalized cross-correlation, which has been shown to be more stable and accurate than other correlation metrics in pixel-tracking experiments (*Tong*, 2005). The normalized cross-correlation, assuming some displacement $\vec{u}$ between the grids, is written as

$$\rho(\vec{u}) = \frac{(g_1(\vec{x}) - \bar{g_1}) * (g_2(\vec{x} - \vec{u}) - \bar{g_2})}{\sqrt{V[g_1]V[g_2]}}$$

where $\bar{g}_i$ and $V[g_i]$ denote the mean and variance. Written numerically,

$$\rho(u_x, u_v) = \frac{\sum_{x,y}(g_1(x,y) - \bar{g_1})(g_2(x - u_x, y - u_y) - \bar{g_2})}{\left(\sum_{x,y}(g_1(x,y) - \bar{g_1})^2 \sum_{i,j}(g_2(i,j) - \bar{g_2})^2\right)^{1/2}}$$

This operation produces a peak ideally centered at the applied displacement between grids. We solve for the peak location by performing a least-squares fit on the peak of a parabola of the form

$$f(x, y) = Ax^2 + Bx + Cy^2 + Dy + Exy + F$$

Since this formulation assumes a Taylor approximation, it is only good when the fit considers points near the peak.

This formulation is susceptible to systematic errors dependent upon pixel offset, which manifest themselves as a sine wave with a 2-pixel wavelength. We address this by performing a low-pass filter on both grids before the cross-correlation (*Schreier et al.*, 2000), which is analogous to applying a cutoff coherency in the Fourier domain.

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Tong, X., D. Sandwell, K. Luttrell, B. Brooks, M. Bevis, M. Shimada, J. Foster, R. Smalley Jr., H. Parra, J. C. Báez Soto, M. Blanco, E. Kendrick, J. Genrich, and D. J. Caccamise II, The 2010 Maule, Chile earthquake: Downdip rupture limit revealed by space geodesy, *Geophys. Res. Lett., 37*, L24311, doi:10.1029/2010GL045805, 2010.

Tong, X., D. T. Sandwell, and B. Smith-Konter, High-resolution interseismic velocity data along the San Andreas Fault from GPS and InSAR, *J. Geophys. Res.; Solid Earth, 118*, doi:10.1029/2012JB009442, 2013.

Sandwell, D. ., R. . Mellors, X. Tong, M. Wei, and P. Wessel, Open radar interferometry software for mapping surface deformation, *Eos Trans. AGU, 92(28)*, doi:10.1029/2011EO280002, 2011.

Five Significant:

Sandwell, D. T., Biharmonic Spline Interpolation of GEOS-3 and SEASAT Altimeter Data, *Geophys. Res. Lett., 14*, 139-142, 1987.

Sandwell, D. T., E.L. Winterer, J. Mammerickx, R. A. Duncan, M. A. Lynch, D. A. Levitt, and C. L. Johnson, Evidence for diffuse extension of the Pacific plate from Pukapuka ridges and crossgrain gravity lineations, *J. Geophys. Res.*, *100*, 15087-15099, 1995.

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

Sandwell, D. T., D. Myer, R. Mellors, M. Shimada, B. Brooks, and J. Foster, Accuracy and resolution of ALOS interferometry: Vector deformation maps of the Father's Day Intrusion at Kilauea, *IEEE Trans. Geosciences and Remote Sensing,* 46, 3524-3534, 2008.

Sandwell, D. T., R. D. Müller, W. H. F. Smith, E. Garcia, R. Francis, New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure*, Science, Vol. 346,* no. *6205*, pp. 65-67, doi: 10.1126/science.1258213, 2014.

SYNERGISTIC ACTIVITIES:

Provide global bathymetry SRTM30_PLUS currently used in Google Earth and Maps.

Teach graduate classes: *Geodynamics; Satellite Remote Sensing; Synthetic Aperture Radar.*

Developed and distribute global gravity and topography data for research and education: http://topex.ucsd.edu

Developed and distribute GNU free InSAR processing package based on GMT http://topex.ucsd.edu/gmtsar.

COLLABORATORS AND OTHER AFFILIATIONS:

Benjamin Brooks (Univ. of Hawaii)
Yuri Fialko (SIO/UCSD)
Graham Kent (Univ. of Nevada, Reno)
Bridget Konter (UT El Paso)
Karen Marks (NOAA, Laboratory for Satellite Altimetry)
Rob Mellors (LLNL)
Peter Shearer (SIO/UCSD)
Walter Smith (NOAA, Laboratory for Satellite Altimetry)
Paul Wessel (Univ. of Hawaii)
Ed Zaron (Portland State University)

GRADUATE AND POSTDOC ADVISORS

Bruce Douglas (retired)
Gerald Schubert (UCLA)

STUDENTS AND POSTDOCS:

Y. John Chen (Peking University)
Joseph Becker (Naval Oceanographic Office, Stennis)
Catherine Johnson (Univ. of British Columbia)
Bridget Konter-Smith (UT El Paso)
Dan Levitt (lost contact)
Karen Luttrell (USGS, Menlo Park)
Suzanne Lyons (US Navy)
Bill Moore (UCLA)
Dietmar Mueller (Univ of Sidney)
Evelyn Price (UT Austin)
Jean-Yves Royer (CNRS)
Lydie Sichox (University of French Polynesia, Tahiti)
Xiaopeng Tong (University of Washington)
Meng Wei (WHOI)

BIOGRAPHICAL SKETCH

C. David Chadwell

PROFESSIONAL PREPARATION:

The Ohio State University,	Surveying	B.S., 1985
The Ohio State University	Civil Engineering	B.S., 1985
The Ohio State University	Geodesy	M.S., 1989
The Ohio State University	Geodesy	Ph.D., 1995
Scripps Institution of Oceanography,	UCSD	Post-doc., 1994-1997

APPOINTMENTS:

2009–present Research Geophysicist, Marine Physical Laboratory (MPL), Scripps Institution of Oceanography (SIO), University of California, San Diego (UCSD)
2005–2009 Associate Research Geophysicist, MPL,SIO, UCSD
2003-2005 Assistant Research Geophysicist, MPL, SIO, UCSD
1997-2003 Assistant Project Scientist, MPL, SIO, UCSD
1994-1997 Post-Graduate Research Geophysicist, MPL, SIO, UCSD
1992-1994 Graduate Research and Teaching Associate, Department of Geodetic Science and Surveying (DOGSS), OSU
1990-1992 Graduate Research Associate, Byrd Polar Research Center (BPRC), OSU
1990 Civil Engineering Assistant, P & L System Ltd., Columbus, Ohio
1987 GPS Surveyor, Trimble Navigation Ltd., Sunnyvale, California
1986-1990 Graduate Research and Teaching Associate, DOGSS, OSU
1985 Surveyor, Franklin County Engineers Office, Columbus, Ohio
1983-1984 Undergraduate Research Assistant, BPRC, OSU
1982 Surveyor, U.S. Army Corps of Engineers, Huntington, West Virginia
1982 Civil Engineering Intern, Ohio Department of Transportation, Delaware, Ohio

SELECTED PUBLICATIONS:

Burgmann R. and Chadwell, C.D.,. (2014) Seafloor Geodesy, Annu. Rev. Earth Planet. Sci. 42:509-534, doi:10.116/annurev-earth-060313-054953.

Chadwell, C. D. and A. D. Sweeney (2010), Acoustic Ray-Trace Equations for Seafloor Geodesy, *Marine Geodesy*, 33, 164-186.

Chadwell, C. D. and F. N. Spiess (2008), Plate motion at the ridge-transform boundary of the south Cleft segment of the Juan de Fuca Ridge from GPS-Acoustic data, *J. Geophys. Res.*, 113, B04415,doi:10.1029/2007JB004936.

Gagnon, K., **C.D. Chadwell**, (2007) Relocation of a seafloor transponder – Sustaining the GPS-Acoustic technique, *Earth Planets Space*, 59, pp. 327-336.

Gagnon, K., **C. D. Chadwell**, E. Norabuena (2005), Measuring the onset of locking in the Peru-Chile trench with GPS and acoustic measurements, *Nature*, 434, pp. 205-208.

Chadwell, C. D. (2002) Shipboard Towers for Global Positioning System Antennas, *Ocean Engineering*, Vol. 30, 1467-1487.

Chadwell, C.D., Y. Bock. (2001) Direct estimation of absolute precipitable water in oceanic regions by GPS tracking of coastal buoy, *Geophys. Res. Letts*., 28(19), 3701-3704.

Spiess, F.N., **C.D. Chadwell**, J.A. Hildebrand, L.E. Young, G.H. Purcell, Jr, and H. Dragert (1998). Precise GPS/acoustic positioning of seafloor reference points for tectonic studies. *Physics of the Earth and Planetary Interiors***,** 108, 101-112.

SYNERGISTIC ACTIVITIES:

Co-supervised PhD student (Sweeney) and supervised PhD students (Phillips, Gagnon) and MS student (Kussat) working on a variety of seafloor geodesy/geophysics projects. Support one summer undergraduate intern each summer. Acted as Chief or Co-Chief Scientist aboard ~15 cruises during the past 10 years. Have included aboard the cruises intern, 2-3 volunteers from the Stephen Birch Aquarium, 2-3 undergraduate science students and occasionally international scientists (Peru) to expose them to sea-going research. Provide guidance and build equipment for researchers in Japan and France to conduct seafloor geodetic research. Serve on SIO Marine Operations Committee and Marine Sciences Physical Planning Committee. Served as Chair of the IEEE-Ocean Engineering Society Technical Committee on Communications, Navigation and Positioning from 2002 to 2007. Co-teach SIO 226 – Introduction to Marine Geophysics.

COLLABORATORS AND OTHER AFFILIATIONS

Collaborators and Co-Editors (last four years): H. Fujimoto, S. Miura, S. Webb, S. Nooner

Graduate/Post-graduate Advisor:
Fred N. Spiess (Post-doctoral, SIO)
Clyde C. Goad (Ph.D, The Ohio State University)

Graduate Student Advisor:
Aaron Sweeney Ph.D (2001) , Neil Kussat M.S. (2004, Chair), Kathleen Phillips PhD. (2006, Co-Chair), Katie Gagnon PhD. (2007, Chair).

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 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. C. David Chadwell - Res. Geophysicist	1.00	0.00	0.00	15,565	
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	1.00	0.00	0.00	15,565	
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				30,095	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (2) OTHER				7,376	
TOTAL SALARIES AND WAGES (A + B)				53,036	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				23,373	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				76,409	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				2,026	
2. FOREIGN				2,092	
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				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				3,312	
5. SUBAWARDS				0	
6. OTHER				250	
TOTAL OTHER DIRECT COSTS				3,562	
H. TOTAL DIRECT COSTS (A THROUGH G)				84,089	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC (Rate: 55.0000, Base: 41577) (Cont. on Comments Page)					
TOTAL INDIRECT COSTS (F&A)				26,312	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				110,401	
K. SMALL BUSINESS FEE				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				110,401	
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

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

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

**** I- Indirect Costs**
MTDC - MPL (Rate: 18.0000, Base 19139)

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 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. **C. David Chadwell - Res. Geophysicist**	1.00	0.00	0.00	16,577	
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	1.00	0.00	0.00	16,577	
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				30,698	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (2) OTHER				7,717	
TOTAL SALARIES AND WAGES (A + B)				54,992	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				25,713	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				80,705	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				2,026	
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				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				3,312	
5. SUBAWARDS				0	
6. OTHER				250	
TOTAL OTHER DIRECT COSTS				3,562	
H. TOTAL DIRECT COSTS (A THROUGH G)				86,293	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 55.0000, Base: 40206) (Cont. on Comments Page)**					
TOTAL INDIRECT COSTS (F&A)				25,780	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				112,073	
K. SMALL BUSINESS FEE				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				112,073	

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

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

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET COMMENTS - Year 2

** I- Indirect Costs
MTDC - MPL (Rate: 18.0000, Base 20374)

SUMMARY PROPOSAL BUDGET

Cumulative

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 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. **C. David Chadwell - Res. Geophysicist**	2.00	0.00	0.00	**32,142**	
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**1**) TOTAL SENIOR PERSONNEL (1 - 6)	2.00	0.00	0.00	**32,142**	
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. (**2**) GRADUATE STUDENTS				**60,793**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**4**) OTHER				**15,093**	
TOTAL SALARIES AND WAGES (A + B)				**108,028**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**49,086**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**157,114**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				**4,052**	
2. FOREIGN				**2,092**	
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				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**6,624**	
5. SUBAWARDS				**0**	
6. OTHER				**500**	
TOTAL OTHER DIRECT COSTS				**7,124**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**170,382**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**52,092**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**222,474**	
K. SMALL BUSINESS FEE				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				**222,474**	
M. COST SHARING PROPOSED LEVEL $ **0**	AGREED LEVEL IF DIFFERENT $				

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

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

BUDGET JUSTIFICATION

Personnel

We request 1 month of salary support per year for David Chadwell (MPL). Chadwell will work with Sandwell and DeSanto on all aspects of the research.
MPL's Labor costs are calculated on an individual basis and recharged on a direct hours worked basis. Included in each individual's rate are the costs for their individual benefit costs such as health, dental, vision, and life insurance, retirement, workman's compensation, unemployment, holiday, vacation, etc

Funds for MPL laboratory support services are also included. Laboratory support services is a combined rate, currently 22%, which includes support for laboratory supplies and expense and laboratory administrative salaries and benefits. Laboratory Supplies and Expense provides for the equitable assignment of those costs which, although allowable as direct charges to a contract or grant, are difficult or impractical to apportion by other means. Examples include charges for janitorial services, administrative telephones, payments in accordance with the terms of the tenancy agreement with the Space and Naval Warfare Systems Center for guard and fire protection services, buildings and ground maintenance, and fees for utility usage. These costs are prorated to individual projects in accordance with the salary related costs incurred by the project. The MPL's indirect cost rate has been reduced to compensate for the direct charging of laboratory contract and grant administration.

Salary and Tuition Remission funds are requested for Graduate Student John DeSanto.

Salary support is also requested for a Research Project Assistant (0.5 mo./yr) 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 researching and procuring project materials, making travel arrangements and coordination of efforts between project participants.

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.

Travel

Foreign travel funds are requested in year one for graduate student John DeSanto to travel to Taiwan to participate in a 4-day cruise on the *R/V Revelle*.

Domestic travel funds are requested each year for one person to attend Fall AGU in San Francisco.

Other Direct Costs

Computer Services - We 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.

Communication Charges - Project specific costs that include telephone tolls, voice and data communication charges, photocopying, faxing, postage are also requested. UCSD applies a direct charge equivalent exclusion calculating the D.A. indirect costs.

Indirect Costs - The date of the most recent indirect cost agreement was 5/12/10. The cognizant agency for the University is the Department of Health and Human Services. The contact is Arif Karim located at DHHS OIG Western Field Office, 90 7th Street, Suite 4-600, San Francisco, CA 94103.

Current and Pending Support
Investigator: David Sandwell

CURRENT

Title: Study of Postseismic Deformation Due to the 2010 M7.2 El Mayor (Mexico) Earthquake (Y. Fialko, PI)
Source of Support: NSF EAR 1053627
Total Award Amount: $418789
Total Award Period: 05/01/11-04/30/15* (NCE)
Location of Project: SIO
Person-Months on Project: 0

Title: Cryosat Altimetry, Arctic Gravity Enhancements, Investigation of Ice Freeboard Measurements, and InSAR Code Development
Source of Support: ConocoPhillips
Total Award Amount: $240,000
Total Award Period: 03/01/11-02/28/17
Person-Months on Project: 0

Title: A Factor of 2-4 Improvement in Marine Gravity and Predicted Bathymetry from Cryosat, Jason-1, and Envisat Radar Altimetry: Arctic and Coastal Regions
Source of Support: ONR N00014-12-1-0111
Total Award Amount: $157,071
Total Award Period: 10/01/11-09/30/15
Location of Project: SIO
Person-Months on Project: 0

Title: A Factor of 2 Improvement in Global Marine Gravity from Cryosat, Jason-1, and Envisat
Source of Support: NSF OCE 1128801
Total Award Amount: $229,188
Total Award Period: 02/15/12-01/31/16
Location of Project: SIO
Person-Months on Project: 0

Title: Collaborative Research: Strain Rate and Moment Accumulation Rate Along the San Andreas Fault from InSAR and GPS
Source of Support: NSF EAR 1147435
Total Award Amount: $220,015
Total Award Period: 06/15/12-5/31/15
Location of Project: SIO
Person-Months on Project: 0

Title: Improving Coastal Marine Gravity
Source of Support: NGA HM0177-13-1-0008
Total Award Amount: $447,487
Total Award Period: 02/11/13-02/10/16
Location of Project: SIO/PSU
Person-Months on Project: 0

Title: Global Predicted Bathymetry for Google Earth and Beyond
Source of Support: Google PO#204922
Total Award Amount: $94,000
Total Award Period: 10/1/13-indef
Location of Project: SIO
Person-Months on Project: 0

Title: Collaborative Research: Improving the Generic Mapping Tools for Seismology, Geodesy, Geodynamics and Geology
Source of Support: NSF EAR-1347204
Total Award Amount: $97,845
Total Award Period: 05/01/14-4/30/17
Location of Project: SIO
Person-Months on Project: 0

Title: Improving the Community Geodetic Model with GPS and InSAR
Source of Support: SCEC
Total Award Amount: $20,000
Total Award Period: 02/01/14-01/31/16
Location of Project: SIO
Person-Months on Project: 0

PENDING

Title: Improving the Community Geodetic Model with GPS and InSAR
Source of Support: SCEC
Total Award Amount: $20,000
Total Award Period: 02/01/15-01/31/16
Location of Project: SIO
Person-Months on Project: 0

Title: Seafloor Geodesy Using Sidescan Sonar: Analysis of the NGDC Archive
Source of Support: NSF MG&G
Total Award Amount: $222,474
Total Award Period: 09/01/15-08/31/17
Location of Project: SIO
Person-Months on Project: 0

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

Investigator: **C. David Chadwell**

Other agencies (including NSF) to which th

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support
Project/Proposal Title: **Constraining Slip Distribution of the Cascadia Subduction Zone Offshore Central Oregon**
Source of Support: **NSF OCE-1249876**
Total Award Amount: **$421,567** Location of Project: **SIO/UCSD**
Total Award Period Covered: **3/1/13 - 2/29/16**
Avg Person-Months/Yr Committed: Cal: **2.0** Acad: **0** Sumr: **0**

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support
Project/Proposal Title: **Advances in Measuring Seafloor Motion With Space Geodesy**
Source of Support: **NASA NNX12AK22G**
Total Award Amount: **$128,934** Location of Project: **SIO/UCSD**
Total Award Period Covered: **7/1/12-6/30/15**
Avg Person-Months/Yr Committed: Cal: **3.0** Acad: **0** Sumr: **0**

Support: [ ] Current [X] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support
Project/Proposal Title: **Constraining Slip Distribution of the Cascadia Subduction Zone Offshore Central Oregon**
Source of Support: **NSF OCE-1249876**
Total Award Amount: **$121,970** Location of Project: **SIO/UCSD**
Total Award Period Covered: **3/1/15 - 2/29/16**
Avg Person-Months/Yr Committed: Cal: **2.0** Acad: **0** Sumr: **0**

Support: [ ] Current [X] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support
Project/Proposal Title: **A Low-Power GPS-Acoustic Payload for Seafloor Geodesy**
Source of Support: **UCSD 2015 0212**
Total Award Amount: **$176,240** Location of Project: **SIO/UCSD**
Total Award Period Covered: **9/1/15-8/31/16**
Avg Person-Months/Yr Committed: Cal: **2.0** Acad: **0** Sumr: **0**

Support: [ ] Current [X] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support
Project/Proposal Title: **Seafloor Geodesy Using Sidescan Sonar: Analysis of the NGDC Archive**
Source of Support: **UCSD 20153257 (Co-I w/t Principal Investigator David Sandwell, SIO) - This Proposal**
Total Award Amount: **$222,474** Location of Project: **SIO/UCSD**
Total Award Period Covered: **09/01/15-08/31/17**
Avg Person-Months/Yr Committed: Cal: **1.0** Acad: **0** Sumr: **0**

FACILITIES, EQUIPMENT, AND OTHER RESOURCES

Software and Data –We have developed a full InSAR processing system called GMTSAR (http://topex.ucsd.edu/gmtsar). This freely-available, open-source software comes with complete documentation to describe the algorithms processing methods. Parts of this software can be directly applied to pixel tracking of sidescan sonar data. We maintain a local copy of all the multibeam bathymetry data at NGDC as well as numerous additional data sets used to construct global bathymetry grids.

General Computing Equipment - Our lab maintains state-of-the-art workstations, tape drives, and disk facilities for processing bathymetry, SAR, satellite altimetry data.

Data Management Plan

This proposal will use data that is freely available at the US National Geophysical Data Center (NGDC). We will reprocess these data into geodetic products to be provided in publications and on our ftp site http://topex.ucsd.edu . The most important output of the proposal will be modifications to the MB-System software to output the raw sidescan data in the range and azimuth coordinates needed for the seafloor positioning analysis. Any significant software enhancements will be freely distributed as part of the MB-System software under a GPL license for free and open distribution.

Currently we distribute global bathymetry and gravity grids using our web site http://topex.ucsd.edu . There are no restrictions on this site and no requirements for registration or identification. Critical data sets are stored in a long-term archive at NGDC.

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TEL: 858.534.2220

02 February 2015

John DeSanto
Scripps Institution of Oceanography
La Jolla, CA 92093

Dear Mr DeSanto:

Congratulations, your UC Ship Funds Program proposal "*Assessment of parameters that affect the accuracy of seafloor displacements observable by a multibeam sonar*" will be supported. Your award is for a one-day program aboard ROGER REVELLE that will be conducted according to the following conditions.

The following conditions apply:

1. Based on the current schedule for ROGER REVELLE, the next availability for this project will be during a four-day shakedown cruise following the ship's departure from a shipyard period in Taiwan mid-January 2016.
2. On that cruise, the Chief Scientist will be Dr Bruce Appelgate. Other cruise activities will include tests of overboard handling equipment, and calibration of the EM-122 multibeam echosounder.
3. The ship time must be used in the calendar year for which it was awarded. Days not used cannot be deferred into a later year without the written consent of the Associate Director.
4. A cruise report is required within one week of your cruise completion, and a complete final project report, with analysis and results, is required within six months of cruise completion.
5. You may be asked to accommodate SIO Communications or SIO Development to take advantage of opportunities for outreach on this cruise, and you should comply if you are able.

Please follow up now on two important tasks:

1. Contact Liz Brenner in SIO Ship Scheduling to begin the process of scheduling your cruise.

2. Contact Lee Ellett in Shipboard Technical Support to discuss your scientific program, instrumentation and survey/sampling needs so we can be ready to support you.

This project requires foreign travel. The UC Ship Funds Program is intended to fund ship time. Other expenses, such as travel, shipping, data processing and analysis, are not intended to be paid using UC Ship funds, and you should discuss these needs with your advisor and/or department chair. If this poses a hardship, please contact me to discuss alternative funding sources.

If you have other questions, please feel free to contact me.

I wish you the very best for a successful and productive program at sea.

Regards,

Bruce Appelgate

MONTEREY BAY AQUARIUM RESEARCH INSTITUTE

David T. Sandwell
Institute for Geophysics and Planetary Physics
Scripps Institution of Oceanography
La Jolla CA 92093-0225

Dear David,

I would like to express my support for your NSF proposal *Seafloor Geodesy Using Sidescan Sonar: Analysis of the NGDC Archive* and to confirm my commitment to collaborate with you in this effort.

The tools of seafloor geodesy are increasingly important tool for monitoring changes on the seafloor associated with tectonic activity as well as changes in sea life. At MBARI we are using repeated AUV-based 200 kHz to 400 kHz multibeam surveys to monitor small-scale changes on the seafloor associated with the volcanic inflation of Axial Seamount on the Juan de Fuca Ridge. Hull-mounted, 12 kHz to 30 kHz multibeam bathymetry have also been used to detect seafloor changes, but only at scales of 10’s of meters or more. Your concept to apply synthetic aperture radar computational techniques to the full resolution backscatter produced by current generation multibeam sonars is exciting because of the potential to achieve sub-meter precision in seafloor change detection using data that are readily available from existing platforms (e.g. most of the ocean class UNOLS vessels).

Dale Chayes and I are funded by NSF-OCE to ensure that the MB-System software package for processing seafloor mapping data works with multibeam data from all of the UNOLS vessels and NDSF vehicles (and it does). As the primary author of MB-System, I will work with you to define and implement software changes as needed to support this investigation. Your effort will require enhancements that are consistent with our planned development for the next major MB-System release.

As you point out, and plan to exploit, there are likely relevant datasets already existing within the NGDC multibeam data archives. I recommend that you look closely at 3D seismic reflection surveys conducted from R/V Langseth, as the slow speed and tight line spacing may result in data suitable for your method. I also suggest that you investigate surveys done in recent years on R/V Falkor and R/V Nautilus. These are not UNOLS vessels, but they are excellent sonar platforms from which most datasets are openly available.

Sincerely,

David W. Caress

David W. Caress
Software Engineer
Monterey Bay Aquarium Research Institute

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