Project Description: High-Resolution Marine Gravity, Seafloor Topography, for Google Earth

We propose to refine global marine gravity and topography grids at 30-second resolution (~ 1 km), deliver these to Google, and to perform scientific investigations using these new data (http://topex.ucsd.edu). Seafloor topography is derived from sparse ship soundings and dense satellite altimeter measurements of the marine gravity field. The basic approach, developed at Scripps Institution of Oceanography by Walter Smith (now at NOAA) and David Sandwell [*Smith and Sandwell* 1994; 1997; *Sandwell and Smith* 2001] is to filter the satellite gravity data over the 16- to 160-km wavelength band and downward continue the filtered gravity to the mean seafloor depth. The local relationship between seafloor gravity and sparse ship soundings is used to map gravity into topography. Finally the global predicted topography grid is refined using the available soundings. Since only 24% of the seafloor has been mapped by ships at 1-minute resolution, the topography predicted satellite from gravity is essential for constructing a global grid (Figure 1). The latest examples include version V11.1 global topography/bathymetry at 1-minute resolution as well as V18.1 global gravity. In addition, we constructed V5.0 of a global topography/bathymetry on a 30 second grid called SRTM30_PLUS, which adds ocean bathymetry data to the Shuttle Radar Topography grids (SRTM30) [*Farr et al.,* 2007; *Becker et al.,* 2008]. Google Earth currently uses version 1.0 of the SRTM30_PLUS to provided shaded relief over the ocean areas (Figure 2). Since our grids are available by ftp they have been copied, enhanced, reformatted, and repackaged into derivative products such as ETOPO2, ETOPO1, and GeoMapApp. We encourage the widest possible distribution of these data but also want to keep track of the grid as it is copied through the community; positive identification is achieved by a small signature imbedded in the grid (Figure 2). The part of the grid that is unique to SIO is the predicted depth, which makes up 76% of the ocean floor. The land data and ship soundings come from mostly open sources. Our lab has spent 3 student-years editing the raw sounding data. Most of these cleaned sounding data will be placed in the public domain under a memorandum of agreement (MOA) between NOAA, NAVO, and NGA. The SRTM30_PLUS depth grid has a matching grid of source identification number that can be used to highlight the locations of actual ship soundings and moreover identify the source of the data as well as provide a link to other metadata (e.g., which expedition and chief scientist collected the soundings).

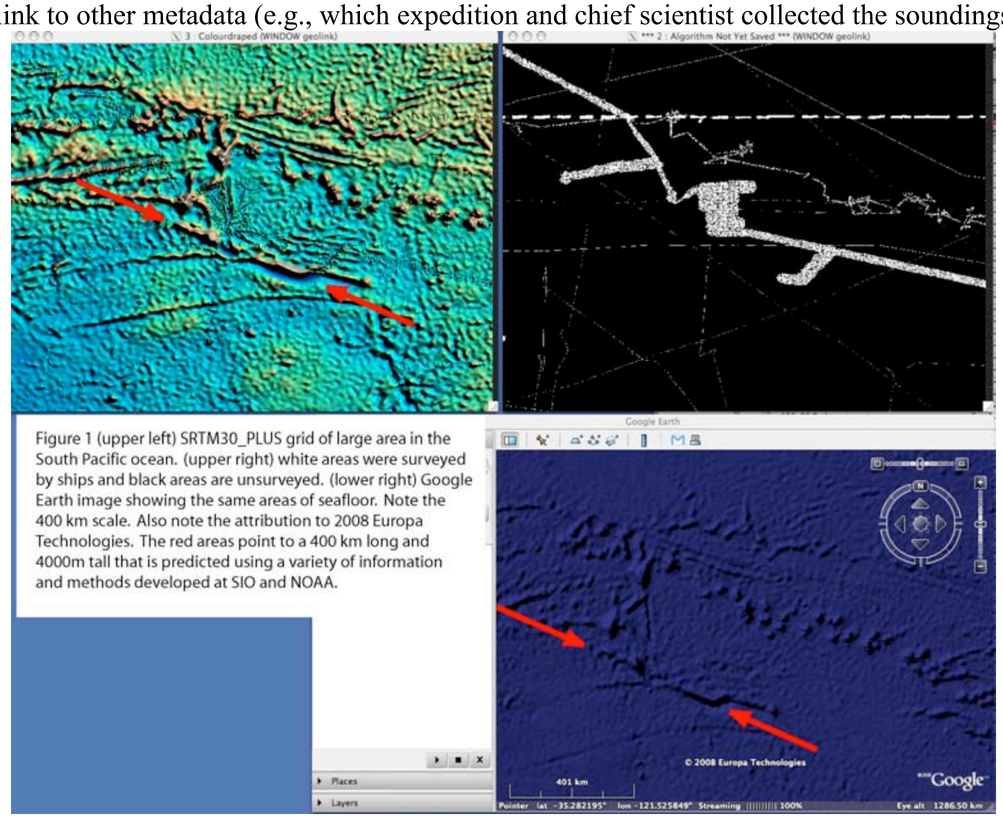
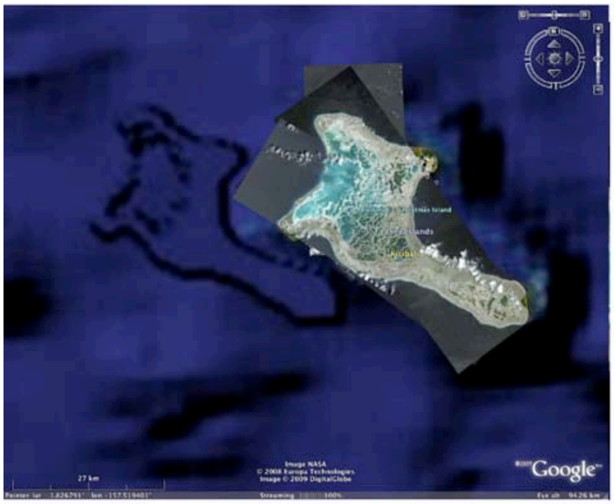


Figure 1 (upper left) SRTM30_PLUS grid of large area in the South Pacific ocean. (upper right) white areas were surveyed by ships and black areas are unsurveyed. (lower right) Google Earth image showing the same areas of seafloor. Note the 400 km scale. Also note the attribution to 2008 Europa Technologies. The red areas point to a 400 km long and 4000m tall that is predicted using a variety of information and methods developed at SIO and NOAA.



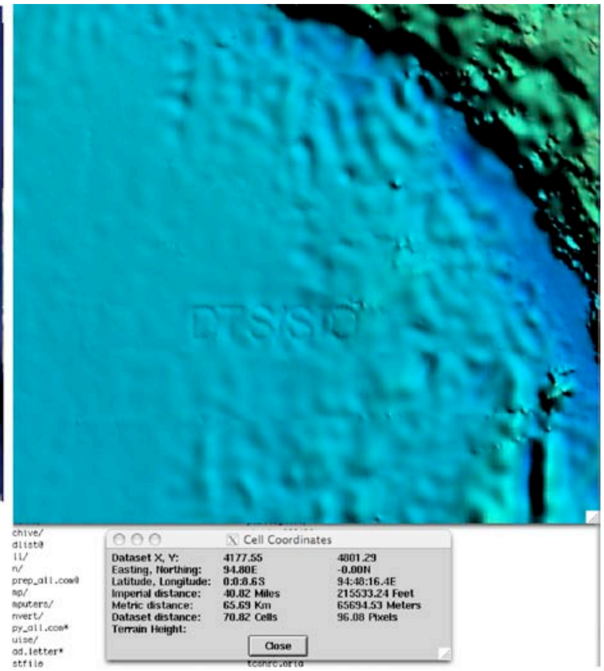


Figure 2. (left) Google Earth image of Kiribati Island in the Pacific Ocean showing a major blunder in the SRTM30_PLUS V1.0 grid produced at SIO. (right) The latest version of SRTM30_PLUS V5.0 has many of the blunders repaired. A small signature (DTS/SIO) was added to an area of predicted depth to provide a positive ID of the global grid.

The latest improvements in these bathymetry and gravity grids focus on the shallow continental margin areas (< 300 m deep). After the 2005 crash of the Nuclear Submarine USS San Francisco into an uncharted seamount, the National Geospatial Agency opened their global proprietary shallow water depth soundings in order to improve the digital maps [*Becker et al.,* 2008]. These new data were used for constructing the V11.1 and SRTM30_PLUS depth grids. However, the exact location of the soundings remains proprietary and cannot be encoded in the depth grids. A low-resolution plot of location all the data shown in Figure 3 reveals the global nature of the shallow water soundings. A better indication of the improved data density (similar but not proprietary data) is shown in Figure 4 (lower). Our previous global bathymetry models had very poor depth control in the 0-300 m depth range whereas now we have excellent control.

Global Bathymetry and Topography - A more complete description of SRTM30_PLUS can be found in a manuscript submitted to the Journal *Marine Geodesy* [*Becker et al.,* 2008].

Abstract - A new 30-arc second resolution global topography (SRTM30_PLUS) is available for download. The data combines dense SRTM30, ICESat, and GEBCO elevation data with 263 million edited soundings interpolated by a 1-minute bathymetry derived from satellite altimetry. The data format is the same as the 33 SRTM30 tiles, and the data's provenance is available.

Global Ocean and Land Gravity Anomaly - A more complete description of the global gravity model used for creating predicted depth can be found in *Sandwell and Smith*, [2008].

Abstract - Three approaches are used to reduce the error in the satellite-derived marine gravity anomalies. First, we have retracked the raw waveforms from the ERS-1 and Geosat/GM missions resulting in improvements in range precision of 40% and 27%, respectively. Second, we have used the recently published EGM2008 global gravity model as a reference field to provide a seamless gravity transition from land to ocean. Third we have used a biharmonic spline interpolation method to construct residual vertical deflection grids. Comparisons between shipboard gravity and the global gravity grid show errors ranging from 2.0 mGal in the Gulf of Mexico to 4.0 mGal in areas with rugged seafloor topography. The largest errors of up to 20 mGal occur on the crests of narrow large seamounts. The global spreading ridges are well resolved and show variations in ridge axis morphology and segmentation with spreading rate. For rates less than about 60 mm/yr the typical ridge segment is 50-80 km long while it increases dramatically at higher rates (100-1000 km). This transition, spreading rate of 60 mm/yr also marks the transition from axial valley to axial high. We speculate that a single mechanism controls both transitions; candidates include both lithospheric and asthenospheric processes.

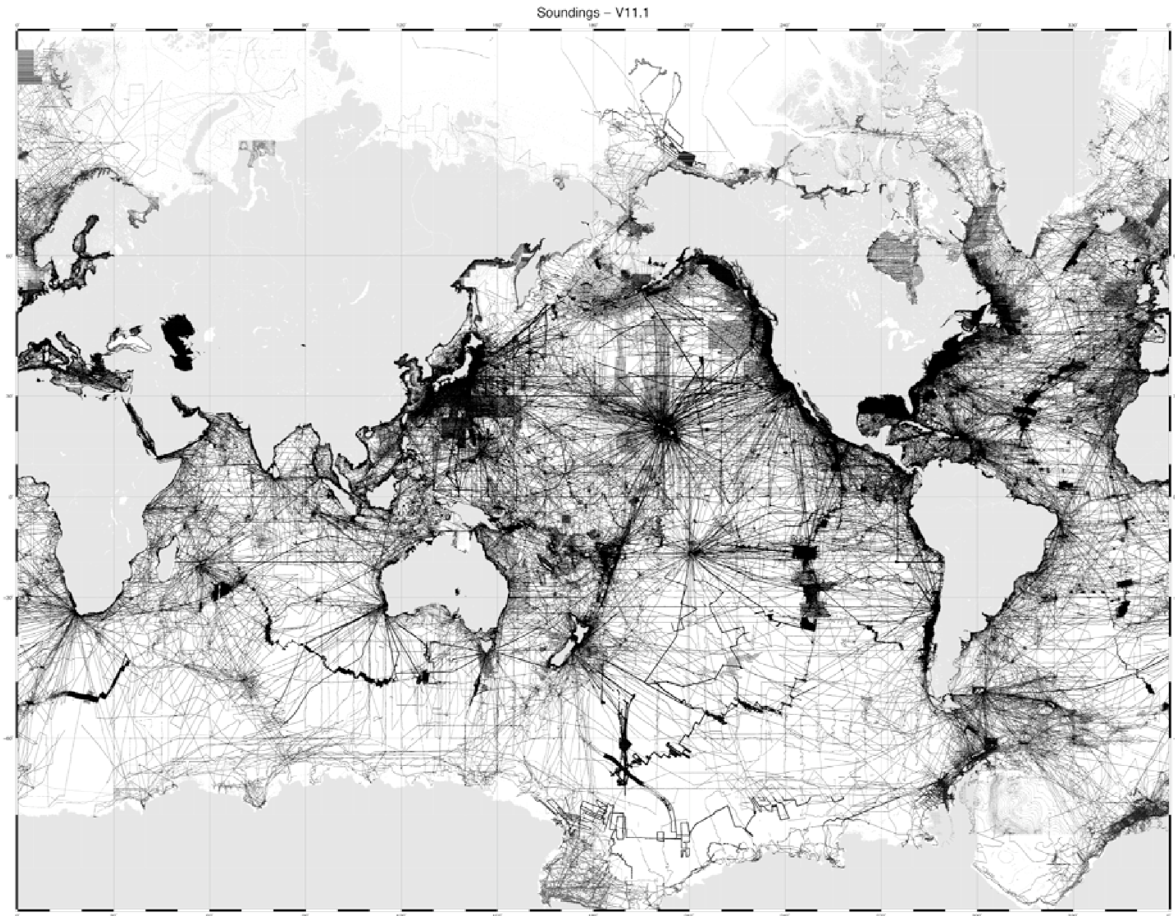


Figure 3. Ship track plots of all the soundings used in the SRTM30_PLUS global bathymetry grid [*Becker et al*., 2008]. Note the high density of soundings in shallow water areas.

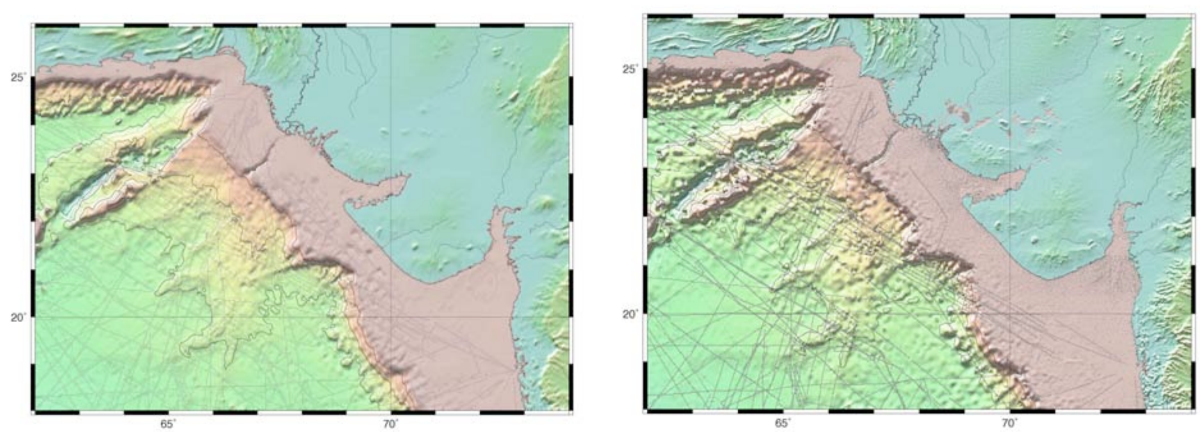


Figure 4. Bathymetry and topography of the Arabian Sea near Karachi Pakistan and western India. Grey dots show locations of soundings. (left) 2 minute resolution [V8.2, *Smith and Sandwell, 1997)*] and the new SRTM30_PLUS grid at 30 second resolution (right). Note the dramatic increase in soundings on the Indian continental margin.

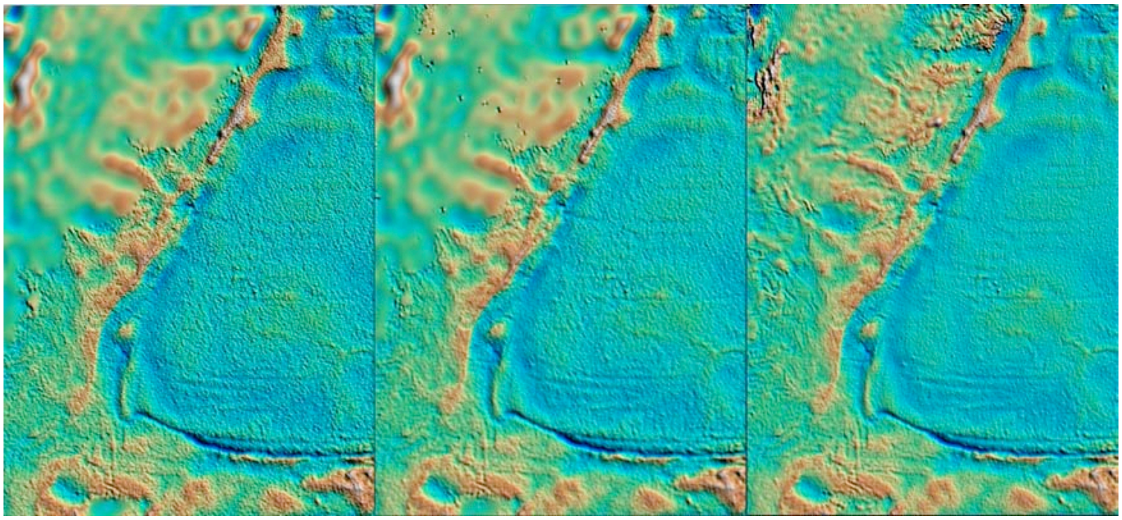


Figure 5 shaded gravity anomaly for a large region in the South Atlantic centered at the Falkland Basin (latitude –57˚ to –27˚, longitude 294˚ to 318˚). Colors saturate at +/- 80 mGal. The visual noise level decreases as one moves from V9.1 (left) to V11.1 (center) to V18.1 (right). Small-scale gravity structure is visually apparent in V18.1 but hidden in the higher noise of V9.1. Improved gravity resolution translates directly into improved topography resolution.

Proposed Research, Milestones: As described above, global bathymetry models are based on two sources of information satellite-derived gravity and ship soundings. We propose to enhance these models and deliver a copy of the data to Google. Our proposal has three main components:

1. **Global Bathymetry and Topography (years 1 and 2)** – Over the next two years we will continue to refine our global bathymetry and topography grids. This will involve the assembly and editing public domain depth soundings and adding depth uncertainties on the raw soundings for refinement of the models. Of particular interest will be to add new data for inland bodies of water such as the Caspian Sea and to extend the use of the proprietary NGA data to a depth of 500 m from the current depth limit of 300 m. The 300 - 500 m depth data are available but need a careful screening for outliers. We will also focus on particular areas such as the Chukchi Sea where sounding coverage is very sparse.
2. **Global Ocean and Land Gravity Anomaly (year 2)** – The recent merging of our 1-minute marine gravity with the 5-minute land gravity from EGM2008 has provided seamless gravity at the shoreline at 1-minute resolution (Figure 5). Using shipboard gravity we propose to evaluate the accuracy of the gravity field along this land/ocean boundary. In addition, the European Space Agency will launch CRYOSAT-2, the next generation of non-repeat orbit satellite altimeter in November 2009 (**http://www.esa.int/esaLP/ESA0DL1VMOC_LPcryosat_0.html**). While CRYOSAT-2 is focused on polar science, it will also be operated continuously over the oceans for gravity field recovery. We are investigators on the project will include these new data in future versions of the gravity and bathymetry models.
3. **Develop a tool *grd2geotiff* (year 1) –** The ocean science community uses a software package called Generic Mapping Tools (GMT **http://gmt.soest.hawaii.edu/**) for analysis and preparation of all types of data. For example, about 1/2 of all the posters shown at the Fall 2008 American Geophysical Union Meeting have a figure made using GMT. GMT uses a machine-independent netcdf grid format. The GMT package is an excellent tool for making publication-quality shaded relief maps (e.g., Figures 3 and 4). However, it is difficult to bring the postscript imagery into Google Earth. We have developed a very preliminary tool called grd2geotiff that enables one to rapidly translate a netcdf grid file into a shaded image and output it as a geotiff for easy import to Google Earth. For example, the SIO Visualization center was the first group to display the topography from the B4 laser

altimeter project in Google Earth (http://siovizcenter.ucsd.edu/topo/b4.php) by converting thousands tiles of topography into the kmz format. We propose to refine the *grd2geotiff* code and make it available as a GMT supplement. We believe this will greatly accelerate the use of Google Earth within the ocean science community.

People: The proposed research will be performed by a post doctorate researcher (50% funded under this proposal). David Sandwell will supervise the research in collaboration with Walter Smith at NOAA. The postdoc and Sandwell will collaborate with researchers at Google Earth to refine the global grids. The postdoc will also be involved in the processing and scientific analysis of the CRYOSAT-2 altimeter data. Topography grids will be available for use as the base layer in Google Earth. Data products such as gravity anomaly and ship track distribution will be converted to kmz format and made available on our web site http://topex.ucsd.edu.

Budget:

Year 1 (3/1/09 – 2/28/10)	
Post Doctorate Researcher Salary 6 mo.	26796.
Travel to Google, Mountain View, CA - 6 days	2400.
Travel to fall AGU meeting	2000.
Total direct	31196.
Overhead (54.5%)	17001.
Total – year 1	48197.
Year 2 (3/1/10 – 2/28/11)	
Post Doctorate Researcher Salary 6 mo.	28940.
Travel to Google, Mountain View, CA - 6 days	2400.
Travel to fall AGU meeting	2000.
Total direct	33340.
Overhead (54.5%)	18170.
Total – year 2	51510.
Total	**99707.**

References:

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, submitted to *Marine Geodesy*, October 8, 2008.

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, Edward Caro, Robert Crippen, Riley Duren, Scott Hensley, M. P. Michael Kobrick, Ernesto Rodriguez, Ladislav Roth, David Seal, J. S. Scott Shaffer, Jeffrey Umland, Marian Werner, Michael Oskin, and a. D. A. Douglas Burbank, The Shuttle radar topography mission, *Reviews of Geophysics*, 45(RG2004), 2007.

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.,* in press, October, 2008.

Sandwell, D. T., W.H.F. Smith, Bathymetric Estimation, *in Satellite Altimetry and Earth Sciences,* ed., L.L. Fu and A. Cazenave, Academic Press, 441-457, 2001.

Smith, W. H. F., and D. T. Sandwell, Bathymetric prediction from dense satellite altimetry and sparse shipboard bathymetry, *J. Geophys. Res., 99*, 21803-21824, 1994.

Smith, W. H. F., and D. T. Sandwell, Global sea floor topography from satellite altimetry and ship depth soundings, *Science,* 277(5334), 1956-1962, 1997.