DIGITAL ELEVATION MODEL FOR PORT ENSENADA, BAJA CALIFORNIA, MEXICO

1. INTRODUCTION

The National Geophysical Data Center (NGDC), an office of the National Oceanographic and Atmospheric Administration (NOAA), has developed a bathymetric/topographic digital elevation model (DEM) of Port Ensenada, Baja California, Mexico (Fig. 1). The 3 arc second elevation grid was generated from numerous, diverse digital data sets in the region (grid boundary and sources shown in Fig. 3).

This report provides a summary of the data and methodology used in developing the Port Ensenada DEM.

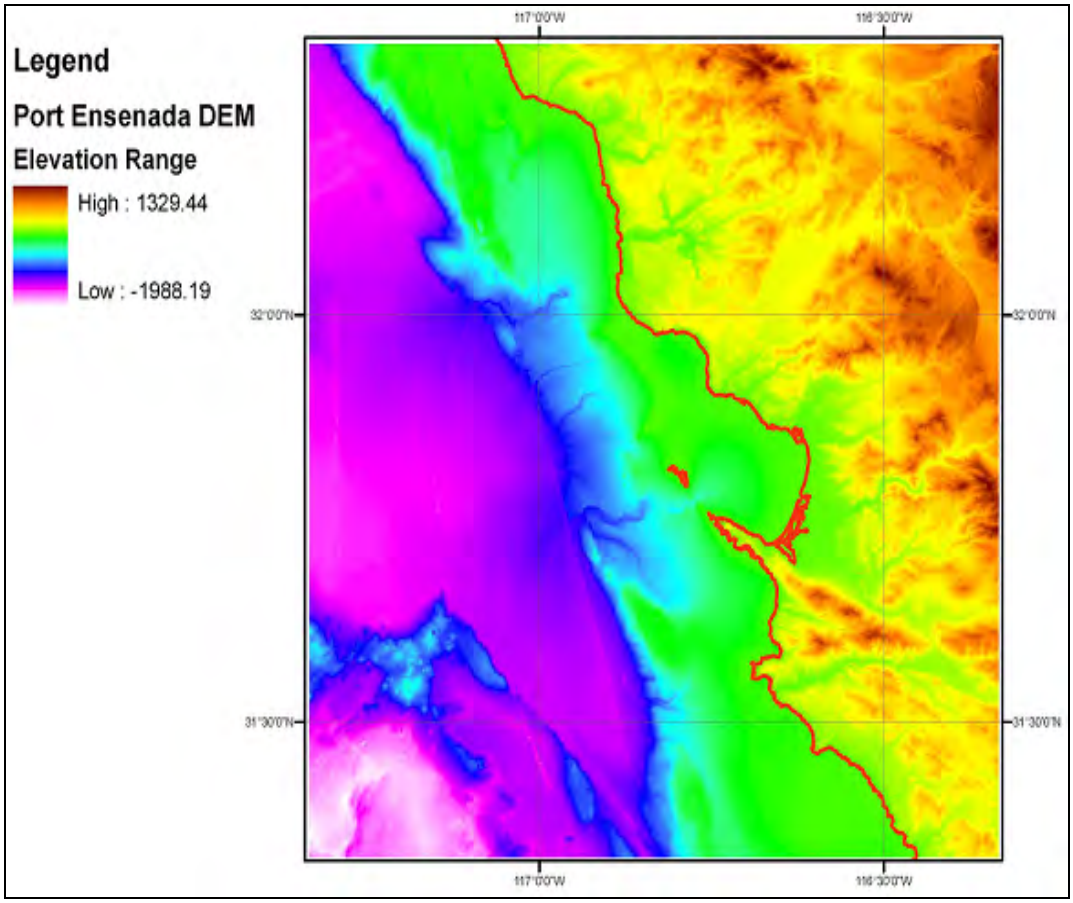

Figure 1 Shaded relief image, derived from the 3 arc-second grid, of the Ensenada region

2. STUDY AREA

The study area covers the coastal region of Port Ensenada, Baja California, Mexico, in a polygon area between latitudes 31° 20' 00" N - 32° 20' 00" N and longitudes 116° 20' 00" W - 117° 20' 00" N. Ensenada is also known as "La Bella Cenicienta del Pacifico" (The Beauty Cinderella of Pacific), and is located in a natural bay, "Bahia de Todos Santos" in Baja California State, Mexico, 110 kilometers (75 miles) south of the United States border. This is a dynamic port of multiple vocations, and is important due to its commerce, industry, fishing and tourist activity, putting it in eighth place in the world economy. According to the 2000 Census (http://www.inegi.gob.mx), the municipality of Ensenada has a population of 370,730.

3. METHODOLOGY

The Port of Ensenada DEM was developed to the specifications in Table 1. The best available data were obtained by NGDC and used to produce the DEM. Data processing, grid assembly, and quality assessment are described in the following subsections.

Table 1 Specification for Port Ensenada, Baja California, Mexico DEM

Grid Area	Port Ensenada, Baja California, Mexico
Coverage Area	116.333° to 117.333° W; 31.333° to 32.333° N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System (WGS84)
Vertical Datum	Mean High Water
Vertical Units	Meters
Grid Spacing	3 arc seconds
Grid Format	ASCII raster grid

3.1. Data Sources and Processing.

Shoreline, bathymetric and topographic data (Fig. 2) were obtained from U. S. and Mexican federal and state government agencies, including the NOAA's National Geophysical Data Center (NGDC), Office of Coast Survey (OCS) [U. S.]; Oceanography, Hydrography and Meteorology Deputy General Directorate (DIGAOHM) and National Institute of Statistics, Geography and Informatics (INEGI) [Mexico].

Safe software's (http://www.safe.com) FME data translation tool package was used to convert datasets into ESRI (http://www.esri.com/) ArcGIS shape files. The shape files were displayed to assess data quality and manually edit datasets.

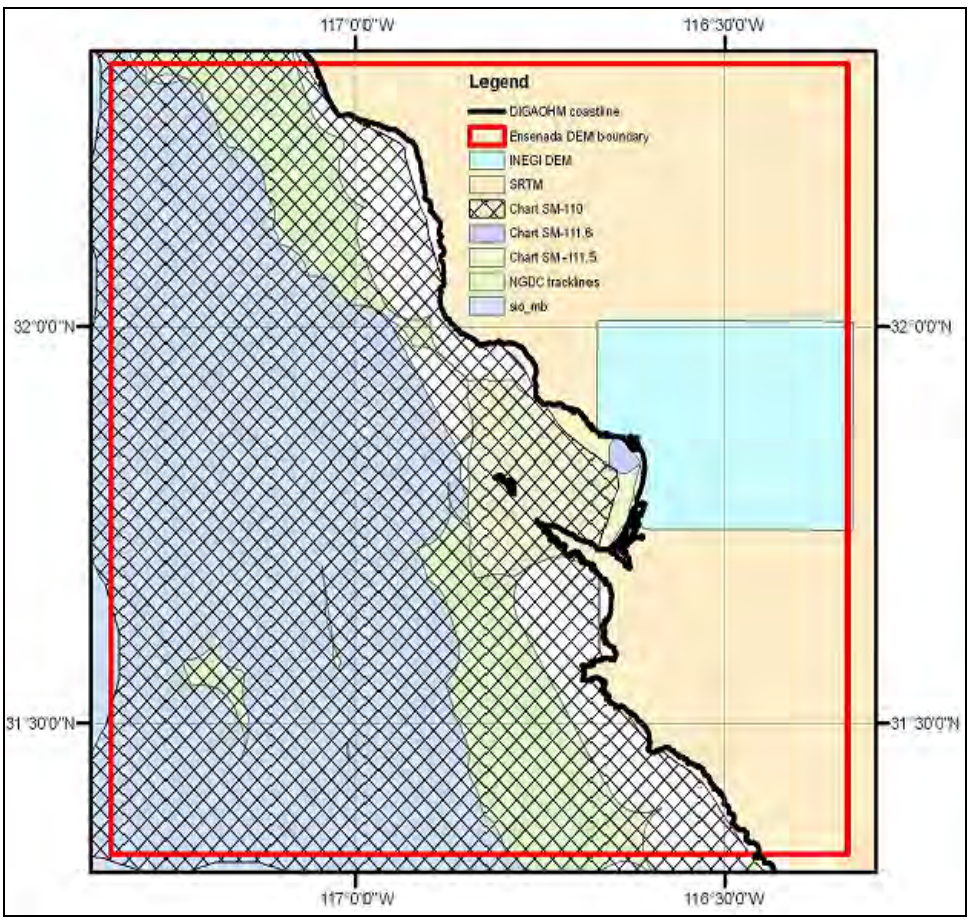

Figure 2 Coverage of data sources used to compile the 2 arc-second and 3 arc-second Ensenada region grids

3.1.1. Shoreline

Digital shorelines (Fig. 3) were obtained from NOAA's Office of Coast Survey (OCS) and Oceanography, Hydrography and Meteorology Deputy General Directorate (DIGAOHM).

OCS electronic navigational chart

One electronic navigational chart (ENC: 18020 "San Diego to Cape Mendocino", scale 1:1,444,000 at Lat. 38° N) was available for the Ensenada region which was downloaded from NOAA's Office of Coast Survey (OCS) website (http://chartmaker.ncd.noaa.gov/). The chart data includes a coastline data file (inferred MHW, though not clearly specified), which was compared with DIGAHOM's Hydrographic Office coastline datasets, and Google Earth satellite imagery.

The ENC coastline does not match with the other coastlines. The coastline dataset does not include one offshore Todos Santos islands and includes two false islands near to Punta Banda Cape (see Fig. 3). This dataset was not used in the gridding process.

DIGAOHM coastline

Three digital navigational charts for Port Ensenada (SM-110: "San Diego a Cabo Colnett", scale 1:350,000 at Lat. 31° 30' N; SM-111.5 "Bahia de Todos Santos", scale 1:35,000 at Lat. 31° 48.5' N and SM-111.6 "Ensenada", scale 1:7,500 at Lat. 31° 51' N), were provided by DIGAOHM. A comparison of these coastline datasets was made. The SM-110 and SM-111.5 coastline does not match between them and this could be because the SM-110 "San Diego a Cabo Colnett" was made with information obtained until 1964. The best coastline was gotten from the navigational chart SM-111.6 "Bahia de Todos Santos" to represent best coastline delineation, with data obtained in 2003 to produce this chart. The three coastlines have significantly higher detail. They were used in the grid compilation, though each required editing to delete data along map edges and to remove piers (e.g. Fig. 3).

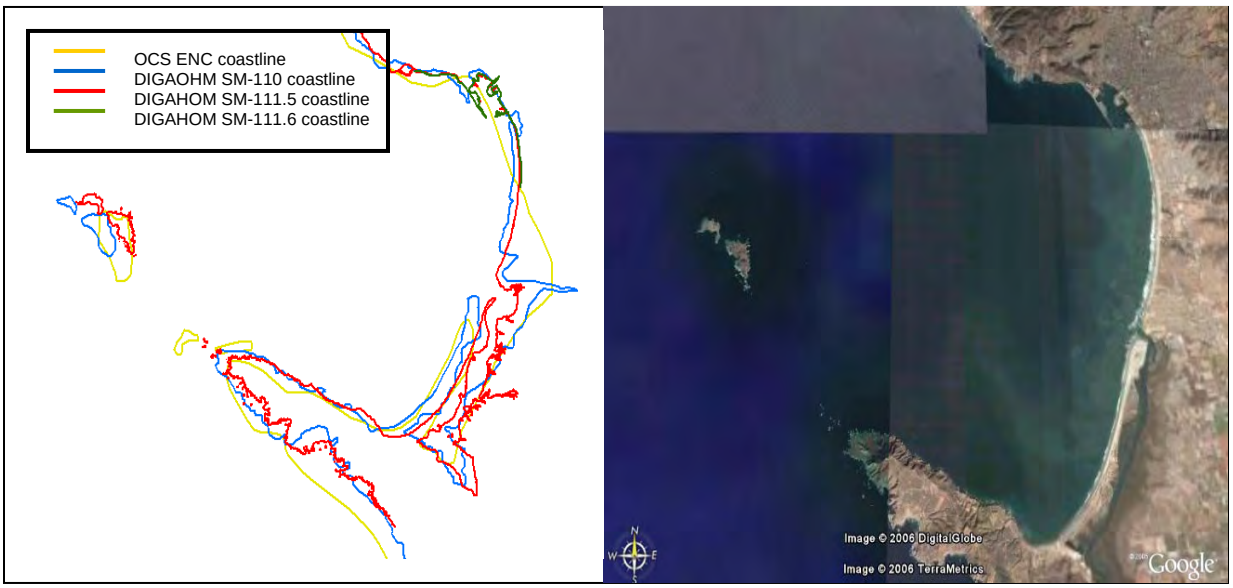

Figure 3 NGDC coastline in the area of Port Ensenada (left) and a Google Earth view of same area (right)

The three DIGAOHM coastlines were used in the gridding process. Each data set was edited and combined to create a combined coastline. The coastline was subsampled to 90 meter spacing and converted to point data (Fig. 4).

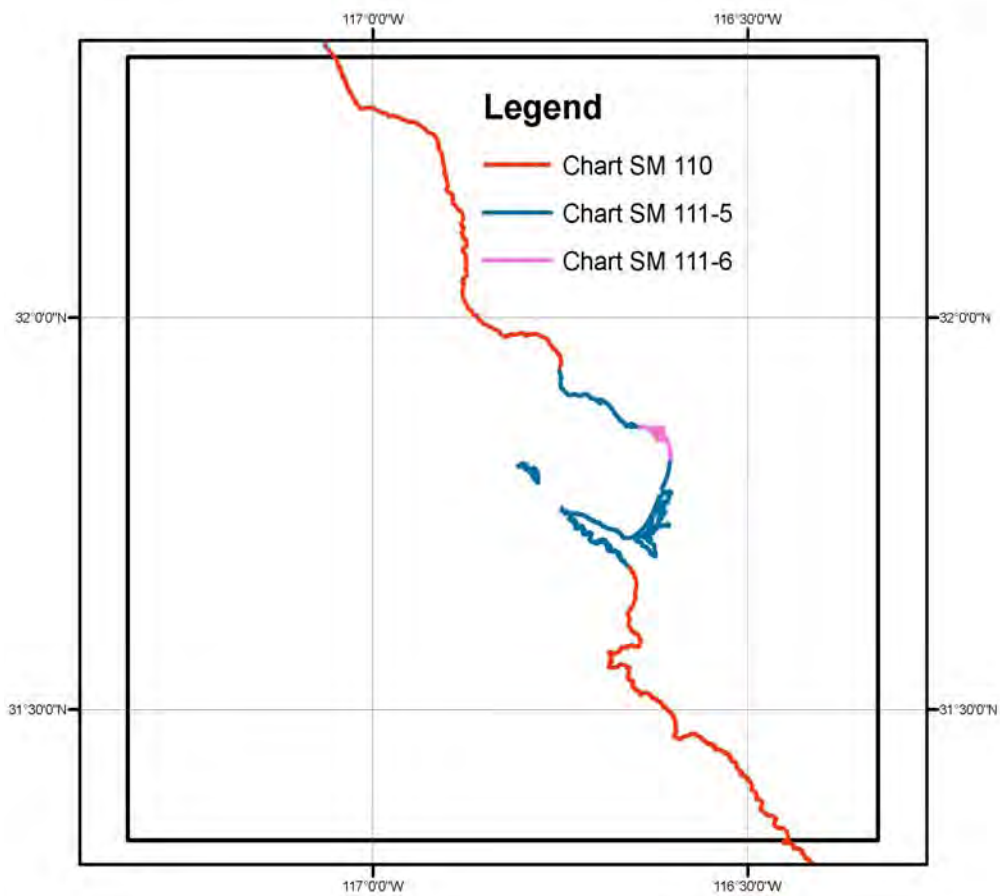

Figure 4 DIGAHOM coastlines in the area of Port Ensenada that were combined for use in the gridding process

Table 2 Shoreline data sources used in gridding.

SOURCE	YEAR	DATA TYPE	HORIZONTAL DATUM	VERTICAL DATUM	URL
OCS Electronic Navigational Chart	1995	coastline	WGS-84	Inferred MHW	http://chartmaker.ncd.noaa.gov/
DIGAOHM Nautical Charts	Until 1964 1973 and 2004 1997 and 2003	coastline	WGS-84	MHW	http://www.semar.gob.mx/

3.1.2. Bathymetry

Bathymetric datasets used in the compilation of the Port Ensenada DEM include hydrographic survey data obtained from NGDC´s online database, multibeam swath sonar surveys obtained from Scripps Institution of Oceanography (SIO) and hydrographic survey data obtained from DIGAHOM (Table 3).

NGDC bathymetric data

A 3 arc-second grid of multibeam swath sonar data, archived at Scripps Institution of Oceanography, was used in deep water area (http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.htlm/).

A total of 55 singlebeam bathymetric data (Fig. 5), conducted between 1961 and 2001, were obtained from NGDC's online database (http://www.ngdc.noaa.gov/mgg/geodas/trackline.htlm/). The datums are assumed MSL and WGS84 (Table 4).

Singlebeam (tracklines) bathymetric data was obtained from NGDC's online database (http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.htlm/), which is a compilation of SIO hydrographic surveys.

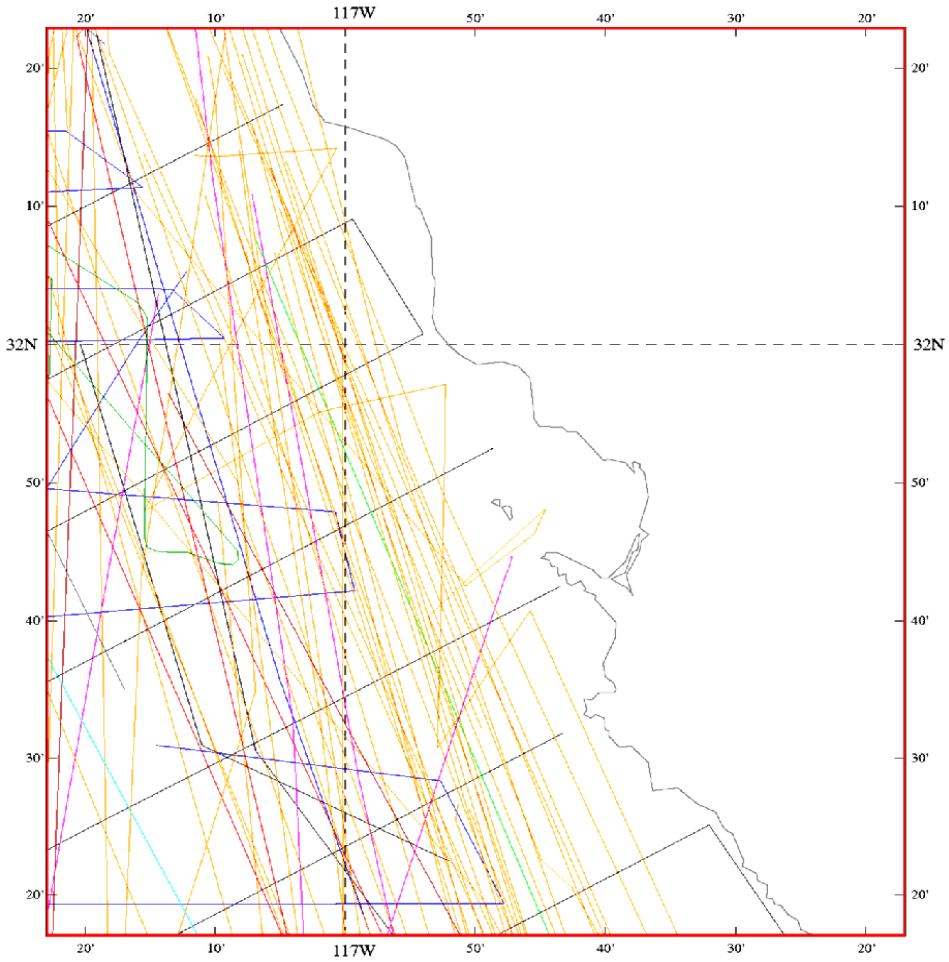

Figure 5 Singlebeam bathymetric data coverage

Table 3 Bathymetric data sources used in gridding

SOURCE	YEAR	DATA TYPE	HORIZONTAL DATUM	VERTICAL DATUM	URL
SIO	1985 to 2005	Multibeam	WGS-84	MSL	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.htlm/
NGDC	1961 to 2001	Tracklines	WGS-84	Inferred MSL	http://www.ngdc.noaa.gov/mgg/geodas/trackline.htlm/
DIGAOHM	Until 1964 1973, 1997, 2003 and 2004	Hydrographic survey soundings	WGS-84	MLLW	http://www.semar.gob.mx/

Table 4 Digital NGDC hydrographic surveys included in the Port Ensenada, Baja California Mexico DEM

SURVEY ID	YEAR	REGION	VERTICAL DATUM	HORIZONTAL DATUM
12574	1974	Open Ocean	MSL	WGS84
07184	1984	Open Ocean	MSL	WGS84
15174	1974	Open Ocean	MSL	WGS84

74010906	1974	Open Ocean	MSL	WGS84
78123003	1979	Open Ocean	MSL	WGS84
UM6503-A	1965	Open Ocean	MSL	WGS84
CONMCALF	1970	Open Ocean	MSL	WGS84
AMLR94	1994	Open Ocean	MSL	WGS84
BAJA75	1975	Open Ocean	MSL	WGS84
WEL7503	1975	Open Ocean	MSL	WGS84
Y7302MG	1973	Open Ocean	MSL	WGS84
YAQ7309	1974	Open Ocean	MSL	WGS84
SWAN-1AR	1961	Open Ocean	MSL	WGS84
CARR01BD	1964	Open Ocean	MSL	WGS84
APRO-1EB	1968	Open Ocean	MSL	WGS84
GAM-1EB	1967	Open Ocean	MSL	WGS84
GAM2-1EB	1968	Open Ocean	MSL	WGS84
GMBL01EB	1968	Open Ocean	MSL	WGS84
GMBL02EB	1968	Open Ocean	MSL	WGS84
IGUA05EB	1972	Open Ocean	MSL	WGS84
DSDP54GC	1977	Open Ocean	MSL	WGS84
DSDP65GC	1979	Open Ocean	MSL	WGS84
BNFC01MV	1973	Open Ocean	MSL	WGS84
CCTW01MV	1974	Open Ocean	MSL	WGS84
CCTW04MV	1974	Open Ocean	MSL	WGS84
HYPO-1MV	1972	Open Ocean	MSL	WGS84
INMD01MV	1977	Open Ocean	MSL	WGS84
FD7707MV	1977	Open Ocean	MSL	WGS84
BMRG01MV	1995	Open Ocean	MSL	WGS84
WEST14MV	1995	Open Ocean	MSL	WGS84
MOCE05MV	1999	Open Ocean	MSL	WGS84
OXMZ01MV	1999	Open Ocean	MSL	WGS84
DRFT02RR	2001	Open Ocean	MSL	WGS84
ERDC11WT	1975	Open Ocean	MSL	WGS84
SIQR-1WT	1974	Open Ocean	MSL	WGS84
DPSN02WT	1976	Open Ocean	MSL	WGS84
GUAY01WT	1978	Open Ocean	MSL	WGS84
PASC01WT	1983	Open Ocean	MSL	WGS84
CERE02WT	1982	Open Ocean	MSL	WGS84
ARIA03WT	1982	Open Ocean	MSL	WGS84
CENT01WT	1978	Open Ocean	MSL	WGS84
CERE04WT	1982	Open Ocean	MSL	WGS84
TUGA01WT	1987	Open Ocean	MSL	WGS84
PLUM01WT	1990	Open Ocean	MSL	WGS84
TERA01WT	1991	Open Ocean	MSL	WGS84
SERA02WT	1991	Open Ocean	MSL	WGS84
VNTR01WT	1989	Open Ocean	MSL	WGS84
ENCR01WT	1992	Open Ocean	MSL	WGS84
RAPA01WT	1990	Open Ocean	MSL	WGS84
ENCR02WT	1992	Open Ocean	MSL	WGS84
19920015	1988	Open Ocean	MSL	WGS84
L176MX	1976	Open Ocean	MSL	WGS84
S179MX	1979	Open Ocean	MSL	WGS84
BA341418	1974	Open Ocean	MSL	WGS84
AT03L49	2000	Open Ocean	MSL	WGS84

A comparison between these two kinds of bathymetric data was made. The multibeam data covers almost all the deep water in the area and the tracklines overlap with it. Accordingly soundings from the singlebeam surveys were edited and used only in areas where multibeam data does not exist (Fig. 6). One near shore survey conducted in 1968 (GMBL01EB) was not included as it is inconsistent with other bathymetric data and the combined DIGAHOM coastline.

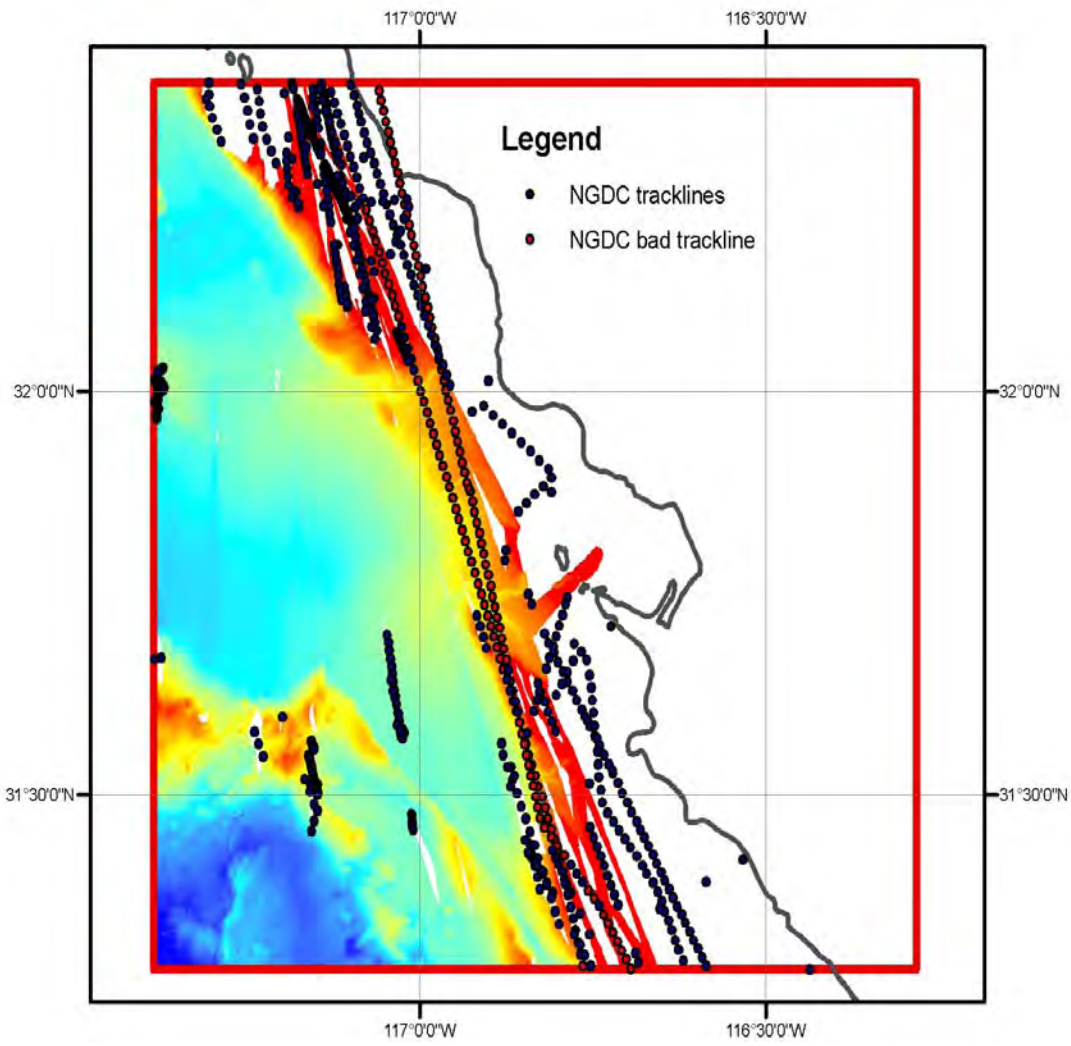

Figure 6 SIO multibeam survey and NGDC hydrographic survey coverage in the Port of Ensenada region used in the DEM. OCS ENC coastline in black.

DIGAOHM survey data

The Oceanography, Hydrography and Meteorology Deputy General Directorate (DIGAHOM), has conducted hydrographic surveys of Port Ensenada region (Fig. 7).

These surveys, in the form of xyz data files, were provided by its Hydrographic Office, and represent a compilation of surveys made by several institutions until 1964 (SM-110 “San Diego a Cabo Colnett”), surveys conducted in 1973 and 2004 (SM-111.5 “Bahia de Todos Santos”) and, 1997 and 2003 (SM-111.6 “Ensenada”).

The recently survey operations, 2003 and 2004, were made in coordination with the U. S. Naval Oceanographic Office (NAVOCEANO). The survey data are in WGS-84 and MLLW (meters).

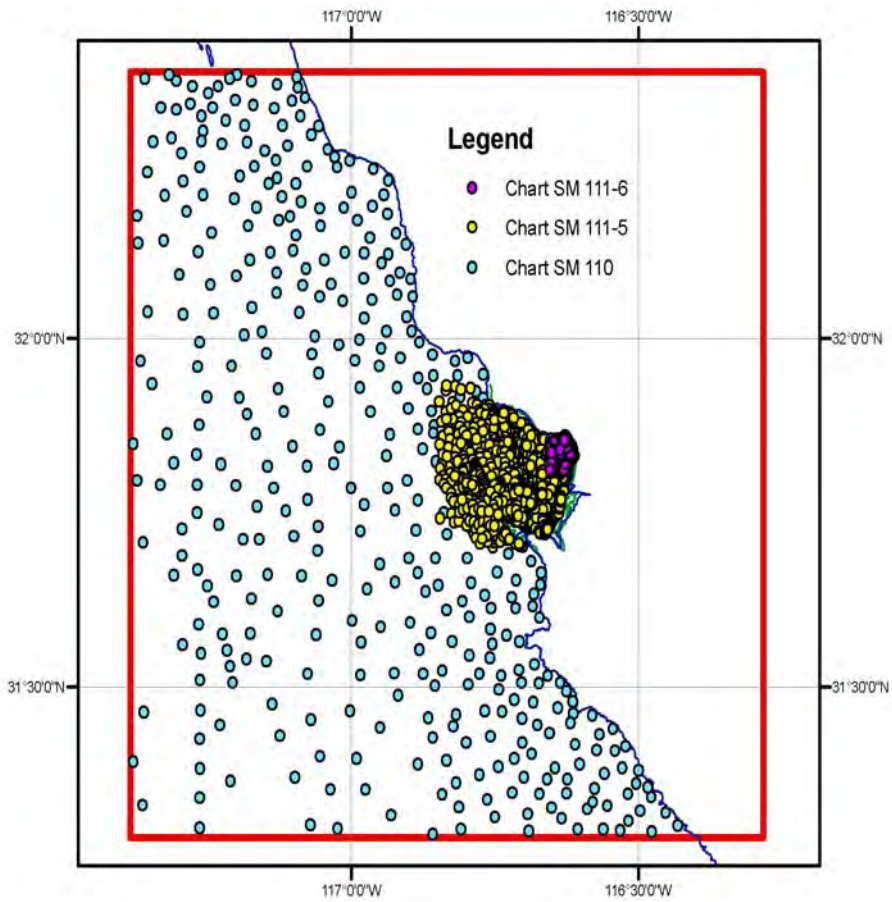

Figure 7 Digital DIGAOHM hydrographic survey coverage of Port Ensenada region

All the collected data were then converted to WGS-84 using FME software, an integrated collection of spatial extract, transform, and load tools for data transformation (http://www.safe.com). The surveys were subsequently clipped to polygon 0.05 degrees (~5%) larger than the final gridding area to support data interpolation along grid edges. After converting all NGDC, SIO and DIGAOHM survey data to MHW (see Section 3.2.1), the data were displayed in ESRI ArcMap ver. 9.1, and reviewed for digitizing errors against original and pdf format nautical charts, and compared to current SRTM topographic data, the combined DIGAOHM coastline, and Google Earth satellite imagery.

3.1.3. Topography

Topographic data was obtained from the following sources: Shuttle Radar Topography Mission (SRTM[1]) "Finished" 3 arc second (~90 meter) gridded topography, and National Institute of Statistics, Geography and Informatics (INEGI). See Table 5.

SRTM topography

Shuttle Radar Topography Mission (SRTM) was downloaded from the United States Geological Survey's (USGS) Seamless website (http://seamless.usgs.gov/) and used to generate a digital topographic map of Port Ensenada with data points spaced every 3 arc second for Global coverage of latitude and longitude (approximately 90 meters). The extracted bare-earth elevations have a vertical accuracy of +/- 10 meters (Fig. 8)

[1]The Shuttle Radar Topography Mission (SRTM) is a joint project between NASA and NGA (National Geospatial-Intelligence Agency) to map the world in three dimensions. SRTM utilized dual Spaceborne Imaging Radar (SIR-C) and dual X-band Synthetic Aperture Radar (X-SAR) configured as a baseline interferometer, acquiring two images at the same time. These images, when combined, can produce a single 3-D image. Flown aboard the NASA Space Shuttle Endeavour February 11-22, 2000, SRTM successfully collected data over 80% of the Earth's land surface, for all area between 60 degrees N and 56 degrees S latitude.
SRTM data is being used to generate a digital topographic map of the Earth's land surface with data points spaced every 3 arc second for Global coverage of latitude and longitude (approximately 90 meters). The SRTM "finished" data meet the absolute horizontal and vertical accuracies of 20 meters (circular error at 90% confidence) and 16 meters (linear error at 90% confidence), respectively, as specified for the mission. The vertical accuracy is actually significantly better than the 16 meters. It is closer to +/- 10 meters. [Extracted from USGS seamless website]

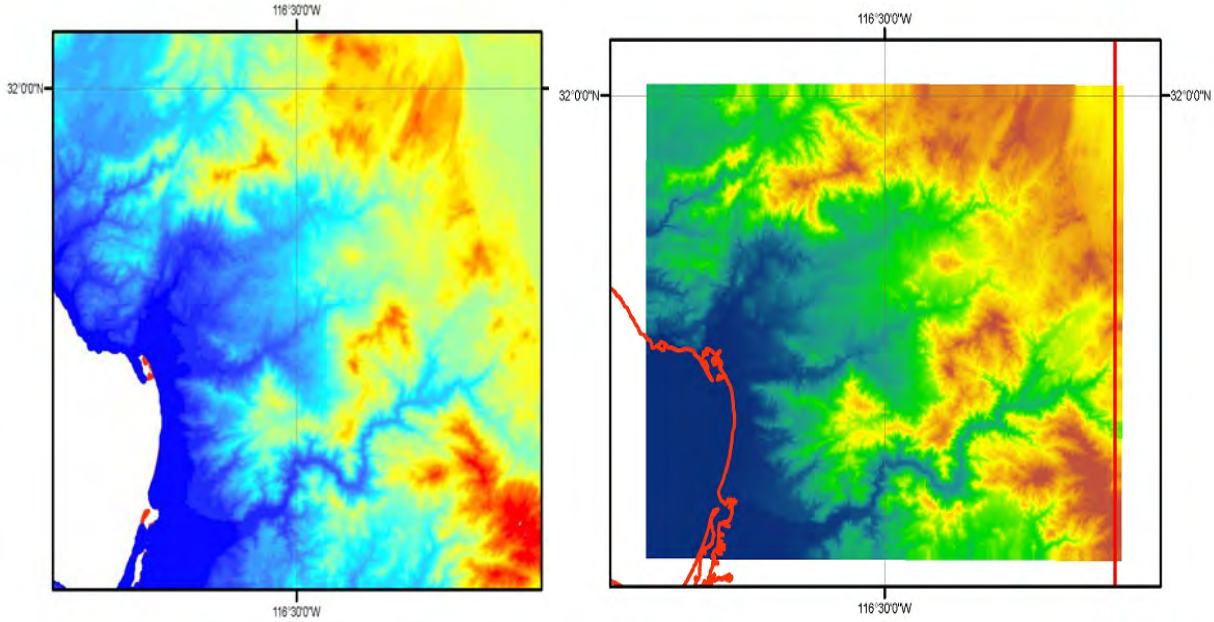

Figure 8 Color image comparison of Port Ensenada derived from SRTM 3 arc second DEM (left) and from chart H11B12 "Ensenada" 2 arc second DEM (right) illustrating "zero" values (blue) over the ocean.

INEGI high resolution topography

A DEM derived from the INEGI's topographic digital chart H11B12 "Ensenada" (2 arc-second), scale 1:50,000 was used. It includes "zero" values over the open ocean, therefore data were clipped to the combined coastline (see Fig. 8).

Table 5 Topographic data sources used in gridding

SOURCE	YEAR	DATA TYPE	HORIZONTAL DATUM	VERTICAL DATUM	URL
USGS Seamless website	2000	Shuttle Radar Topography Mission (SRTM)	WGS-84	Assumed MSL	http://seamless.usgs.gov/
INEGI	1999	Digital	ITRF-92	MSL	http://www.semar.gob.mx/

3.2. Establishing Common Datums

3.2.1. Vertical datum transformations

Datasets used in the compilation of the grids were originally referenced to a number of vertical datums including Mean Sea Level (MSL), Mean High Water (MHW) and Mean Lower Low Water (MLLW). All datasets were transformed to a Mean High Water datum to provide the worst case scenario for inundation modeling (Table 6).

Bathymetric data

As no VDatum (http://nauticalcharts.noaa.gov/csdl/vdatum.htm) model was available for the gridding area, transformation of bathymetric data to MHW was made using FME software to convert data points to MHW; FME is an integrated collection of spatial extract, transform, and load tools for data transformation and data traslation (http://www.safe.com). Soundings referenced to MHW were adjusted to MLLW using a constant value of -1.407 meters (see Table 6) – derived by computing the average difference between MHW and MLLW over the gridding area – prior to transformation to MHW.

Topographic data
SRTM and INEGI high resolution data were converted to MHW using FME software by adding a constant value of -0.565 meters (see Table 6), as INEGI DEM is in MSL and the SRTM is in WGS-84/EGM96 (assumed MSL)

Table 6 Relationship between Mean High Water and other vertical datums in the Port Ensenada region*

VERTICAL DATUM	DIFFERENCE TO MHW
MSL	-0.565
MHW	-0.407

* Datum relationships determined by tidal station at Port Ensenada, Baja California and recorded on nautical charts

3.2.2. Horizontal datum transformations
Datasets used to compile the grids were originally horizontally referenced to UTM Zone 11 N and WGS-84. The relationship and transformational equations between these horizontal datums are well stablished. All data were converted to a horizontal datum of WGS-84 using FME software.

3.3. Digital Elevation Model Development

3.3.1. Verifying consistency between datasets
After horizontal and vertical transformations were applied, ESRI shape files were generated for each data file, and value consistency between datasets was checked in ESRI ArcMap.

3.3.2. Gridding the data with GMT system
All processed xyz files were gridded using GMT system.

3.4. Quality Assessment of the DEM

3.4.1. Horizontal accuracy
The digital elevation model has an estimated horizontal accuracy of 1 to 2 meters for topographic features.

3.4.2. Vertical accuracy
The digital elevation model has an estimated vertical accuracy of 0.1 and +/- 10 meters for topographic areas and 0.1 meters to 5% of water depth for bathymetric areas. Topographic values are derived from SRTM DEM, which has an estimated vertical accuracy of +/- 10 meters and INEGI DEM which has an estimated vertical accuracy of 0.1 to 2 meters. Bathymetric values are derived from the range input data single and multibeam sounding measurements from the early 20th centuries to recent.

3.4.3. Slope maps and 3-D perspectives
ESRI ArcCatalog was used to generate a slope map from the 3 arc second grid to allow for visual inspection of the grid, and identification of artificial slopes alog the boundaries between datasets (Fig. 9); the grid was transformed to UTM Zone 11 North coordinates (horizontal unit in meters) in ArcCatalog for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis. Three dimensional viewing of the UTM-transformed DEM (Fig. 10) was accomplished using ESRI ArcScene. Analysis of preliminary grids revealed suspect data points, which were corrected before regridding the data.

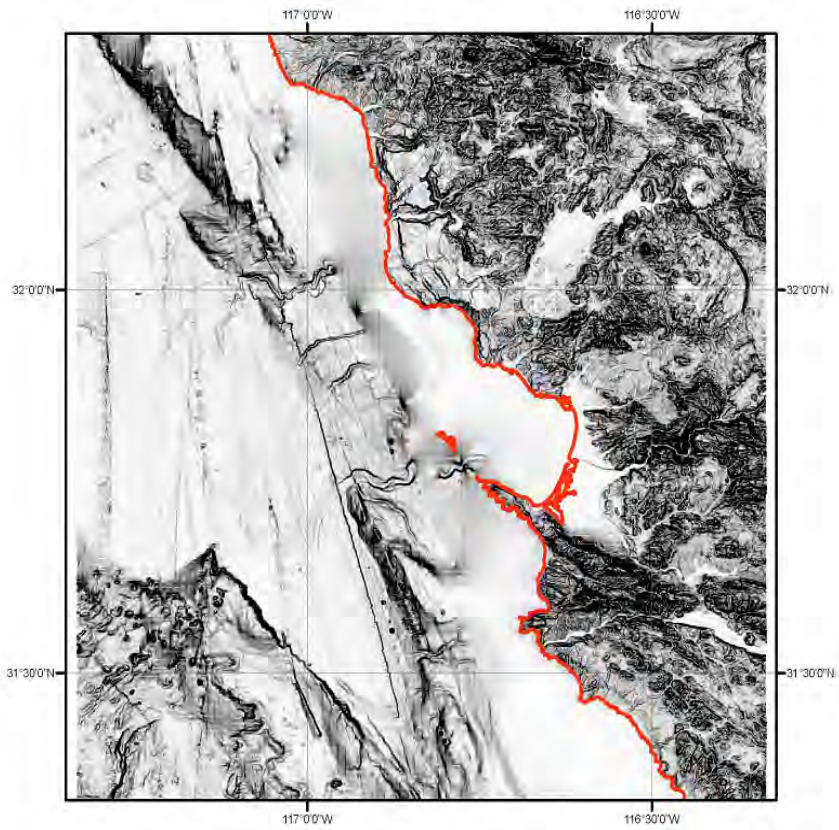

Figure 9 Slope map of the 3 arc sedond Port Ensenada DEM. Flat lying slopes are white, dark shading denotes steep slopes; DIGAHOM coastline in red.

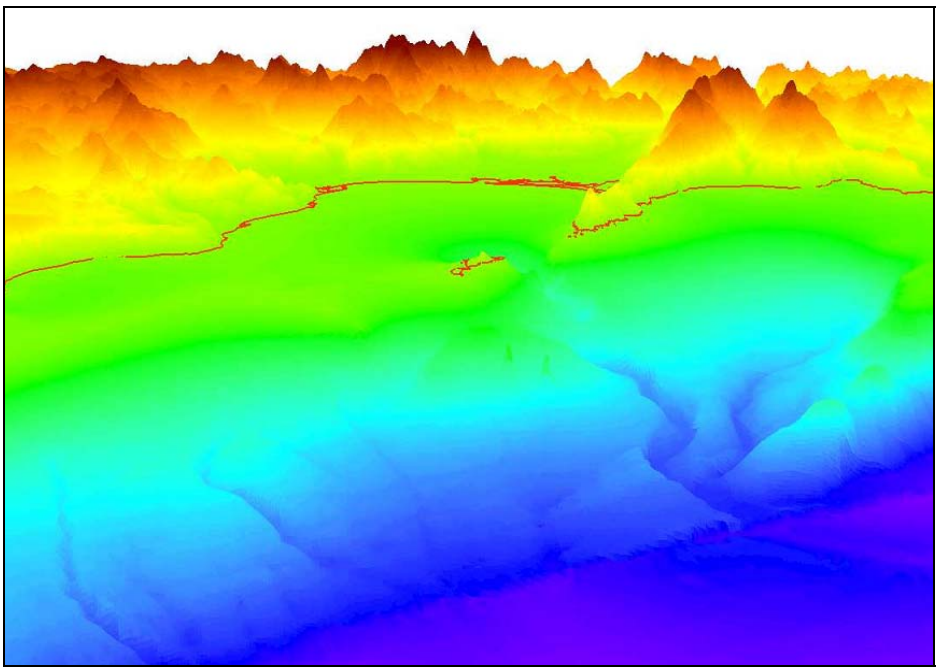

Figure 10 Perspective view from the west of Todos Santos islands, region of Ensenada DEM. DIGAHOM coastline in red; vertical exaggeration-times 5.

4. SUMMARY

A bathymetric/topographic digital elevation model with cell spacing of 3 arc-second (~ 90 meters) of Port Ensenada, Baja California, Mexico area, was developed. The best available data from U. S. and Mexican federal and state government agencies were obtained from grid compilation. The data were quality checked, processed and gridded using ESRI Arc GIS, FME and GMT software.

5. RECOMMENDATIONS

The recommendation to improve the DEM's based on research and analysis is to survey Todos Santos Canyon in complete detail (Fig. 11).

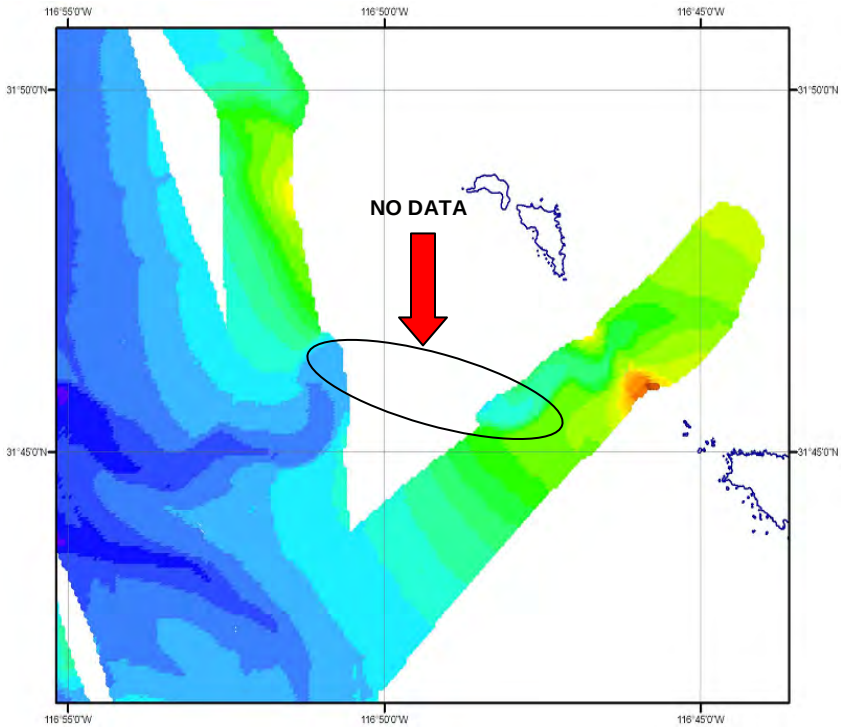

Figure 11 Figure showing a gap in the multibeam coverage area

6. AKNOWELEDGMENTS

The author thanks Christopher Fox, George Sherman, Lisa Taylor, Robin Warnken, Kelly Carignan and Barry Eakins (NGDC), Lt. Jorge Falcon and Lt. Raul Mendez (DIGAOHM) and Jose Frias (INEGI).

7. REFERENCES

Nautical Chart # 18020, 35th Edition, 1995, "San Diego to Cape Mendocino", scale 1:1,444,000, U. S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart SM-110 "San Diego a Cabo Colnett", 1st Edition/Rev. 2003, scale 1:350,000 at Lat. 31° 30' N, Secretariat of Navy; Research and Development General Directorate; Oceanography, Hydrography and Meteorology Deputy General Directorate.

Nautical Chart SM-111.5 "Bahia de Todos Santos", 3rd Edition, 2004, scale 1:35,000 at Lat. 31° 48.5' N, Secretariat of Navy; Research and Development General Directorate; Oceanography, Hydrography and Meteorology Deputy General Directorate.

Nautical Chart SM-111.6 "Ensenada", 3rd Edition, 2004, scale 1:7,500 at Lat. 31° 51' N, Secretariat of Navy; Research and Development General Directorate; Oceanography, Hydrography and Meteorology Deputy General Directorate.

Topographic Chart H11B12 "Ensenada", 1st Edition, 1999, scale 1:50,000, National Institute of Statistics, Geography and Informatics (INEGI)

8. REFERENCES

ArcGIS v. 9, developed and licensed by ESRI, Redlands, California, http://www.esri.com/

FME 2006 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

GMT v 4.1.1 – Generic Mapping Tools, shareware developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu/