Digital Elevation Models of Wake Island: Procedures, Data Sources and Analysis

Prepared for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research by the NOAA National Geophysical Data Center (NGDC)
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1. Introduction

The National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), has developed two integrated bathymetric–topographic digital elevation models (DEMs) centered on Wake Island for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). The coastal DEMs will be used as input for the Method of Splitting Tsunami (MOST) model development by PMEL to simulate tsunami generation, propagation and inundation. A 3 arc-second DEM[1] (Fig. 1) was generated from diverse digital datasets in the region (grid boundary and sources shown in Fig. 4) and will be used for tsunami modeling, as part of the tsunami forecast system SIFT (Short-term Inundation Forecasting for Tsunamis) developed by PMEL for the NOAA Tsunami Warning Centers. A smaller 1/3 arc-second DEM (Fig. 2) was generated for the immediate area surrounding Wake Island, where high-resolution multibeam data were available, to increase forecasting accuracy. This report provides a summary of the data sources and methodology used in developing the Wake Island DEMs.

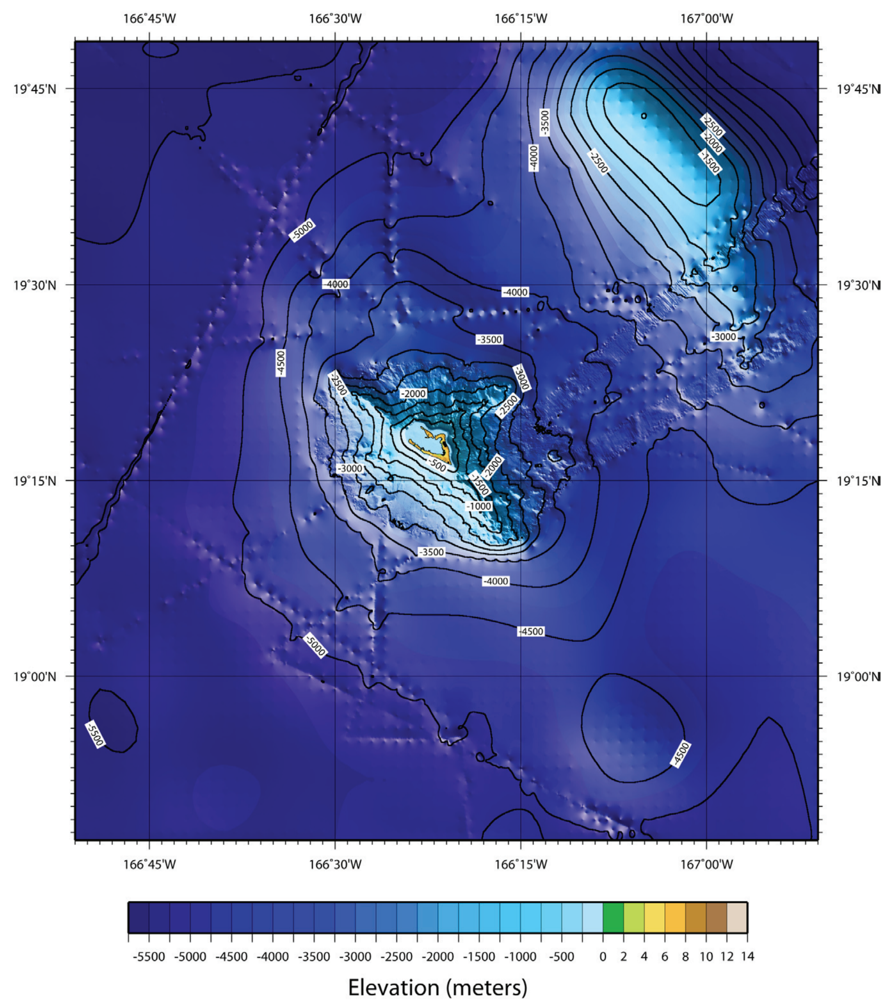

Figure 1. *Shaded-relief image of the 3 arc-second Wake Island DEM. Contour interval is 500 meters.*

1. The Wake Island DEMs are built upon a grid of cells that are square in geographic coordinates (latitude and longitude), however, the cells are not square when converted to projected coordinate systems, such as UTM zones (in meters). At the latitude of Wake Island (19°16’N, 166°35’E) 1/3 arc-second of latitude is equivalent to 10.35 meters; 1/3 arc-second longitude equals 9.87 meters.. Three arc-seconds is equivalent to 91.14 meters; 3 arc-seconds longitude equals 88.35 meters

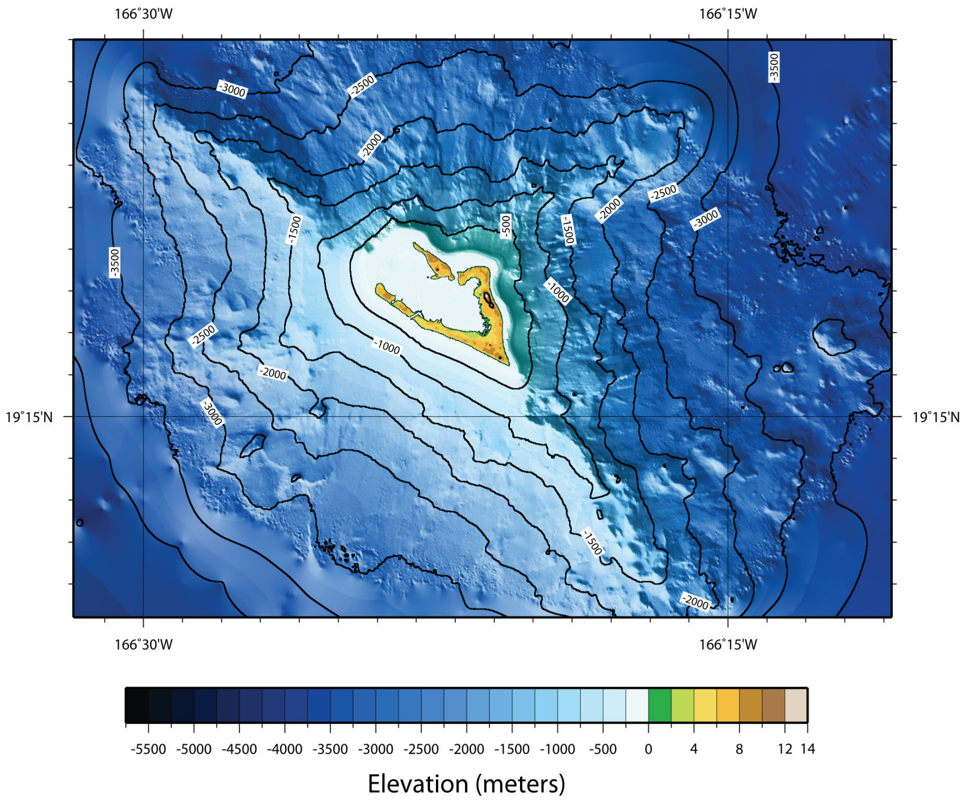

Figure 2. *Shaded-relief image of the 1/3 arc-second DEM. Contour interval is 500 meters.*

2. Study Area

Wake Island is a coral atoll with only twelve miles of coastline, located in the North Pacific Ocean approximately two-thirds of the way from Hawaii to the Northern Mariana Islands. The atoll consists of three low coral islands, Peale, Wake, and Wilkes, built upon an underwater volcano, with a central lagoon that was its former crater.

In 1940 and 1941 an air and naval base was constructed on the island, but the island was captured in December 1941 by the Japanese and held until the end of the war. Later, Wake Island was used as a stopover and refueling site for military and commercial aircraft transiting the Pacific. Since 1974, the island has been used by the US military and as an emergency landing strip (Fig. 3).

Figure 3: *Airstrip on Wake Island, currently only for military use or emergency landings. (http://upload.wikimedia.org/wikipedia/commons/7/75/Ioke-wake-damage002.jpg)*

3. Methodology

The Wake Island DEMs were developed to meet PMEL specifications (Table 1), based on input requirements for the MOST inundation model. The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: World Geodetic System 1984 (WGS84) and Mean High Water (MHW), respectively, for modeling of "worst-case scenario" flooding. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

Table 1a: PMEL specifications for the 3 arc-second Wake Island DEM.

Grid Area	Wake Island
Coverage Area	166.15º to 167.10º E; 18.84º to 19.76º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS84)
Vertical Datum	Mean High Water (MHW)
Vertical Units	Meters
Cell Size	3 arc-second
Grid Format	ESRI Arc ASCII grid

Table 1b: PMEL specifications for the 1/3 arc-second Wake Island DEM.

Grid Area	Wake Island
Coverage Area	166.42º to 166.82º E; 19.17º to 19.40º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS84)
Vertical Datum	Mean High Water (MHW)
Vertical Units	Meters
Cell Size	1/3 arc-second
Grid Format	ESRI Arc ASCII grid

3.1 Data Sources and Processing

Shoreline, bathymetric, and topographic digital datasets (Fig. 4) were obtained from several U.S. federal agencies including: NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS), and the U.S. Geological Survey (USGS). Safe Software's (http://www.safe.com/) *FME* data translation tool package was used to shift datasets to WGS84 horizontal datum and to convert them into ESRI (http://www.esri.com/) *ArcGIS* shape files. The shape files were then displayed with *ArcGIS* to assess data quality and manually edit datasets. Vertical datum transformations to MHW were accomplished using *FME* and *ArcGIS*, based upon data from a NOAA tide station near Wake Island. Applied Imagery's *Quick Terrain Modeler* software (http://www.appliedimagery.com/) was used for evaluating some datasets before the final gridding process.

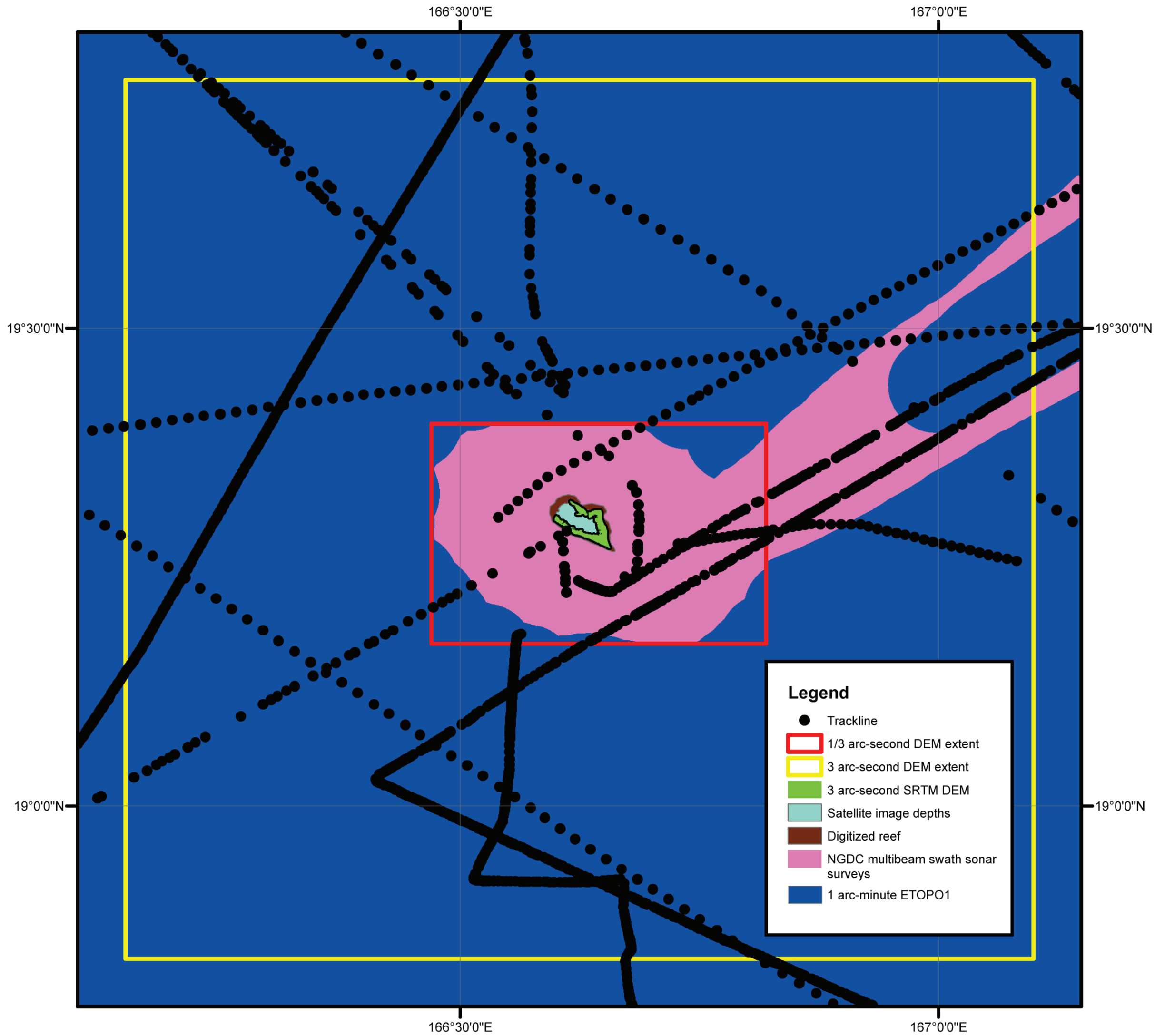

Figure 4. *Source and coverage of datasets used to compile the Wake Island DEMs.*

3.1.1 Shoreline

The World Vector coastline dataset for the Wake Island region is of low resolution and was not used in the DEMs. There is no electronic navigational chart (ENC) available for Wake Island, therefore NGDC digitized the coastline based on the NOAA raster nautical chart (RNC) #81664, digital images from *Google Earth*, and the 3 arc-second SRTM topographic DEM. (Table 2; Fig. 5).

Table 2: Shoreline datasets available for the Wake Island DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Coordinate System*	*URL*
NOAA RNC	2009	vector	1:15,000	WGS84 geographic	Mean High Water	http://www.nauticalcharts.noaa.gov/mcd/Raster/index.htm
NGDC World Vector Shoreline	2004	vector	1:250,000	WGS84 geographic	Mean High Water	http://www.ngdc.noaa.gov/mgg/shorelines/shorelines.html

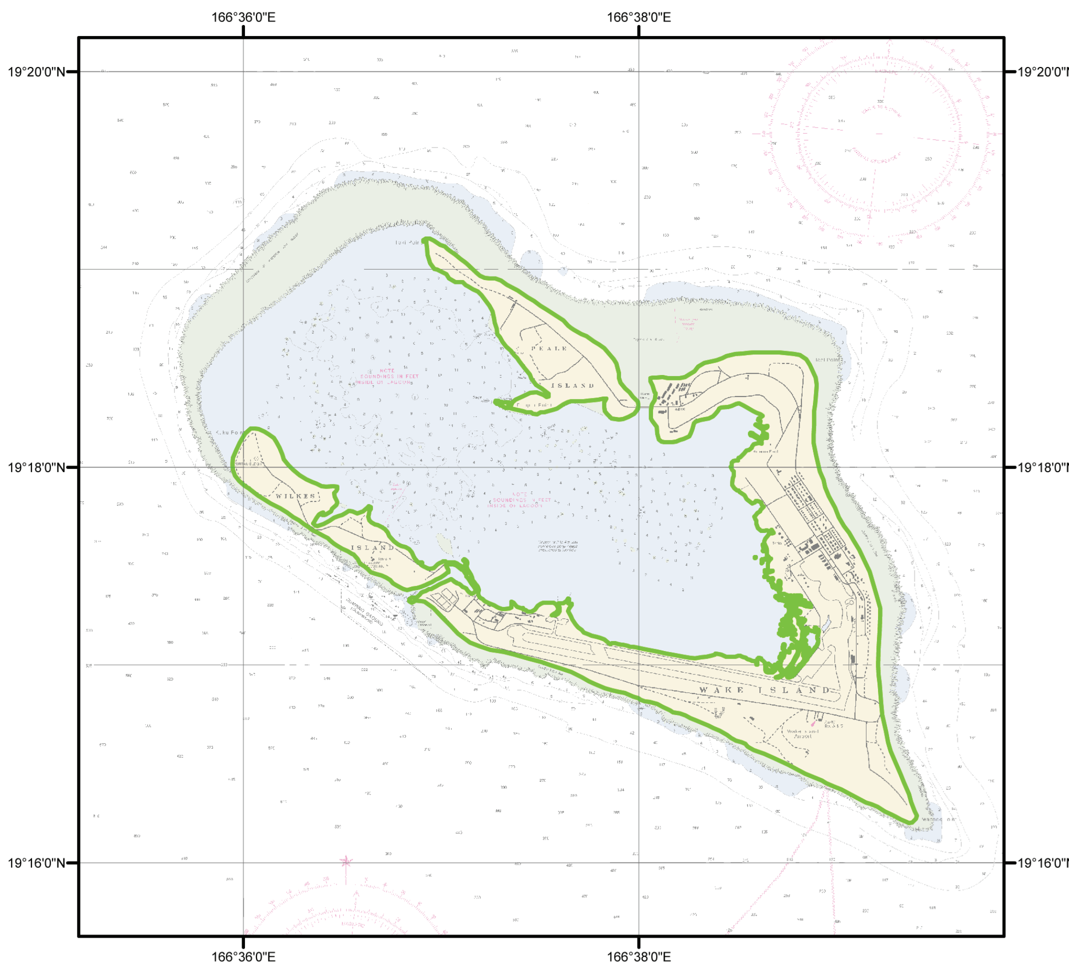

Figure 5. *Wake Island coastline (in green), based on NOAA RNC #81664.*

1) NGDC Digitized Coastline

NGDC digitized the Wake Island coastline from the RNC #81664 (Table 3), which has a resolution of 1:15,000 and 1:3,500. The 3 arc-second SRTM DEM, and *Google Earth* satellite imagery were used to assess the final coastline.

Table 3: NOAA nautical charts available for Wake Island.

Chart	*Title*	*Edition*	*Edition Date*	*Format*	*Scale*
81664	Wake Island with inset of Wake Island Boat Basin	6th	1998	RNC	1:15,000 and 1:3,500

2) NGDC World Vector Shoreline

NGDC did not use the Wold Vector Shoreline (http://www.ngdc.noaa.gov/mgg/shorelines/shorelines.html) in the DEM. The low-resolution dataset (1:250,000) did not align with the 3 arc-second SRTM DEM or the NOAA RNC (Figure 6).

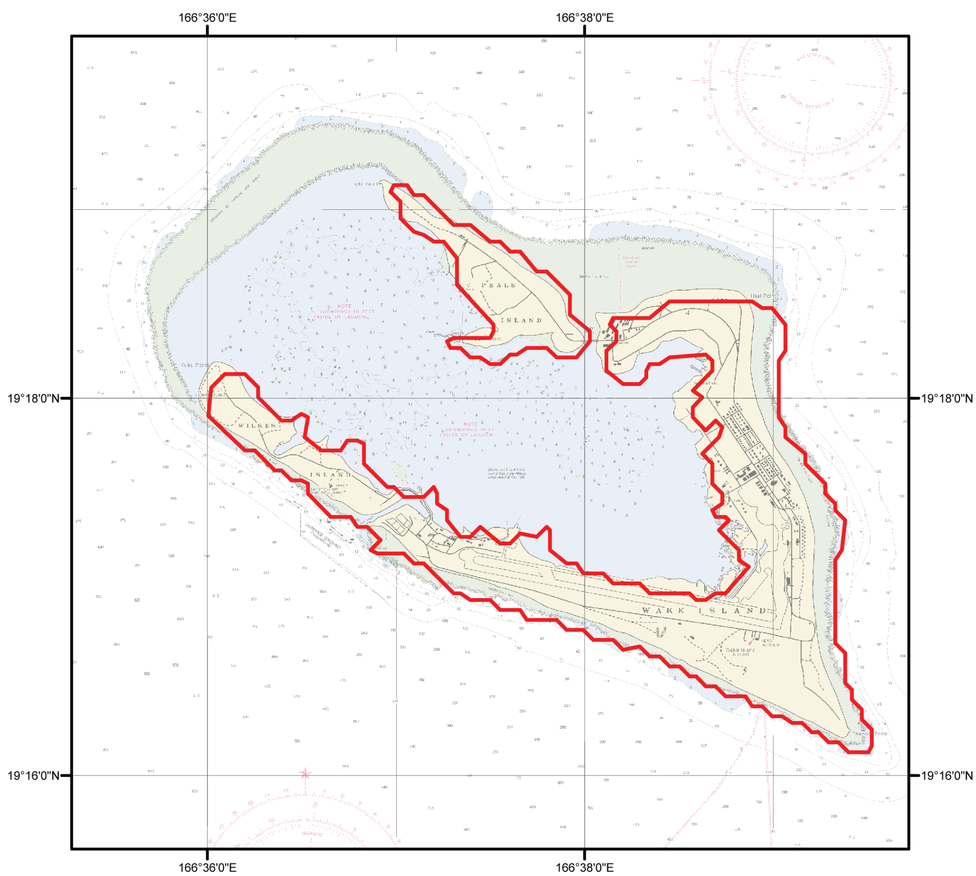

Figure 6. *World Vector Coastline at a scale of 1:250,000 is not consistent with NOAA RNC #81664, and was not used in the final coastline.*

3.1.2 *Bathymetry*

Bathymetric datasets used in the compilation of the Wake Island DEMs include three multibeam swath sonar surveys downloaded from the NGDC multibeam sonar database, seven trackline surveys, depths extracted from satellite imagery, NGDC digitized depths, and extracted data from ETOPO1 Global Relief Model (Table 4; see Fig. 4). Figure 7 shows the spatial coverage of data used in the 1/3 arc-second DEM.

Table 4: Bathymetric datasets used in compiling the Wake Island DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*	*URL*
NGDC	1992 to 2007	Multibeam sonar swath files	raw MB files gridded to 1/3 arc-second	WGS84 geographic	assumed Mean Sea Level	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html
NGDC	1968 to 1982	Trackline	100's of meters along profile	WGS84 geographic	assumed Mean Sea Level	http://www.ngdc.noaa.gov/mgg/geodas/trackline.html
Digital Globe	2008	Satellite Imagery	1 to 2 meters	undefined	undefined	
NGDC	2009	Digitized Depths	several meters	WGS84 geographic	MHW (meters)	
ETOPO1	2008	Global Relief Grid	1 arc-minute	WGS84 geographic	MSL	http://www.ngdc.noaa.gov/mgg/global/global.html

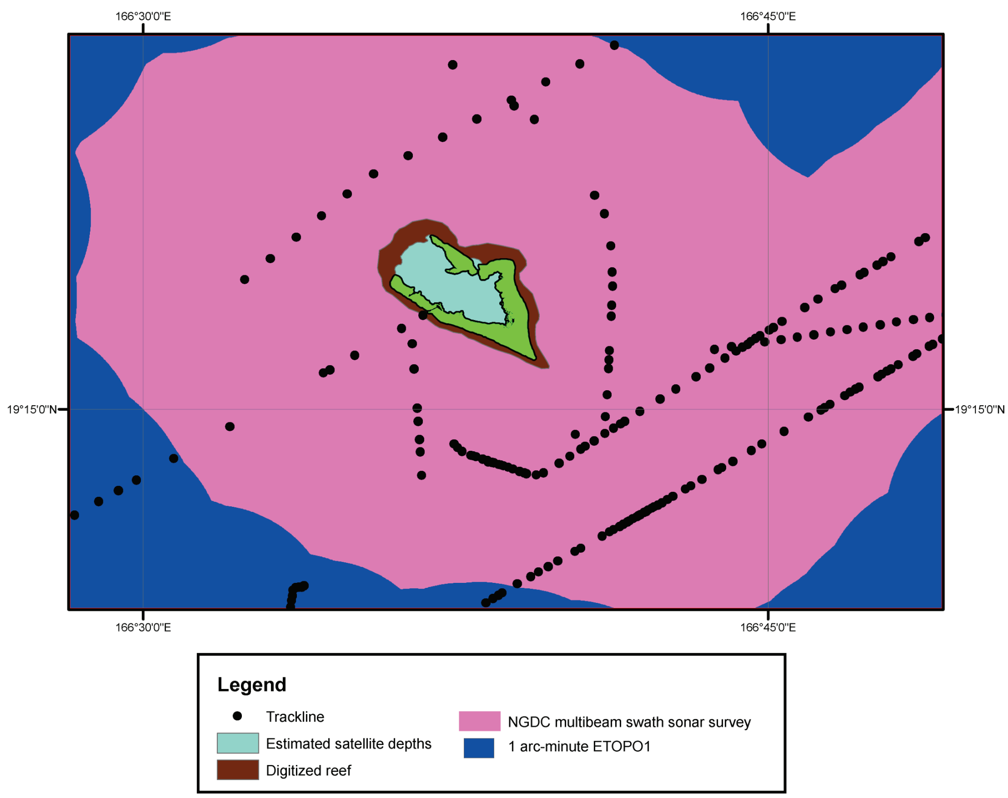

Figure 7. *Spatial coverage of bathymetric datasets used to compile the 1/3 arc-second Wake Island DEM. Final coastline is shown in black.*

1) Multibeam swath sonar surveys

Three multibeam swath sonar surveys were available from the NGDC multibeam bathymetry database (http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html) for use in the Wake Island DEMs (Table 5, Fig. 8). This database is comprised of the original swath sonar surveys conducted mostly by the U.S. academic fleet. The downloaded data were gridded to 1/3 arc-second resolution using *MB-System*. *MB-System* is an NSF-funded free software application specifically designed to manipulate submarine multibeam sonar data (http://www.ldeo.columbia.edu/res/pi/MB-System/).

Surveys by the Ahi and Hi'ialakai ships provide excellent shallow-water bathymetry, surrounding the island to approximately 10-15 km offshore (Fig. 9). The flanks of the atoll dip steeply to abyssal depths. After assessing individual survey quality, the gridded data were transformed to MHW (see section 3.2.1) and xyz format using *FME*, and edited using *ArcMap*.

Table 5: Multibeam swath sonar surveys used in compiling the Wake Island DEMs.

Cruise ID	*Ship*	*Year*	*Original Vertical Datum*	*Original Horizontal Datum*	*Institution*
AHI-07-01	Ahi	2007	assumed mean sea level	WGS84 geographic	National Oceanic and Atmospheric Administration (NOAA/NMES)
HI-07-01	Hi'ialakai	2007	assumed mean sea level	WGS84 geographic	National Oceanic and Atmospheric Administration (NOAA/NMES)
TUNE09WT	Thomas Washington	1992	assumed mean sea level	WGS84 geographic	University of California, Scripps Institute of Oceanography (UC/SIO)

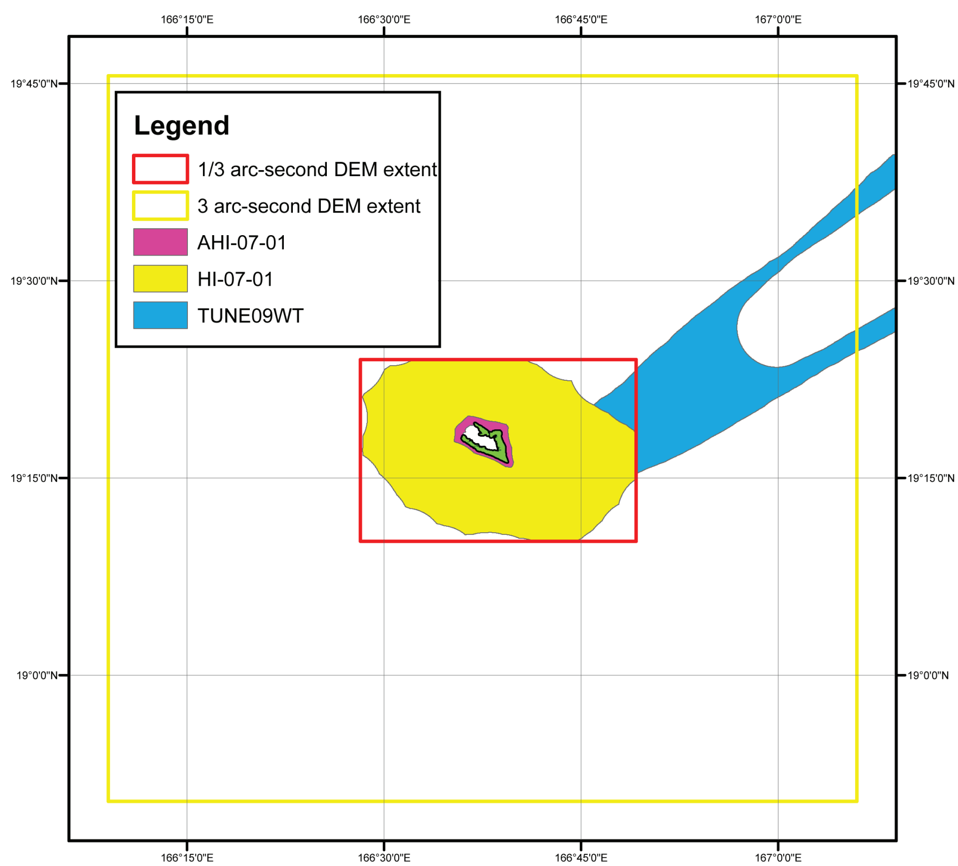

Figure 8. *Spatial coverage of multibeam swath sonar files used in compiling the Wake Island DEMs. Coastline is shown in black.*

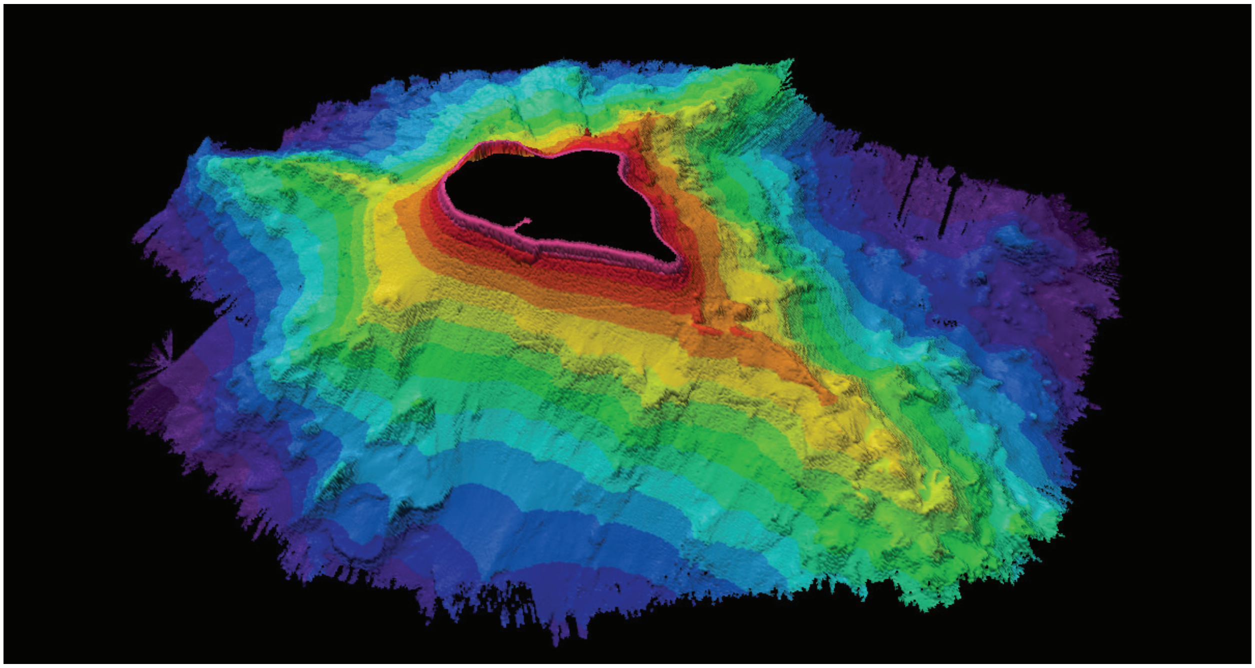

Figure 9. *Perspective image of the atoll's flanks as revealed in the AHI-07-01 and HI-07-01 surveys. Image from http://www.soest.hawaii.edu/pibhmc/PRIAs_images/Jarvis_60m3D_.jpg.*

2) Trackline surveys

Seven single-beam trackline surveys were available from the NGDC marine geophysical trackline database (http://www.ngdc.noaa.gov/mgg/geodas/trackline.html) for use in the Wake Island DEMs (Table 6, Fig. 10). This database is comprised of bathymetry, magnetics, gravity, and seismic navigation data collected during marine cruises from 1953 to present. The data was downloaded as xyz files in WGS84 and converted to mean high water.

The trackline surveys are at a scale of 100's of meters and therefore were only used where no high resolution multibeam surveys existed.

Table 6: Trackline surveys in the Wake Island region.

Cruise ID	*Ship*	*Year*	*Original Vertical Datum*	*Original Horizontal Datum*	*Institution*
STYX07AZ	Agassiz	1968	assumed MSL	WGS84	Scripps Institution of Oceanography
76010301	Kana Keoki	1976	assumed MSL	WGS84	University of Hawaii, HIG
MARA11WT	Thomas Washington	1979	assumed MSL	WGS84	Scripps Institution of Oceanography
81062604	Kana Keoki	1981	assumed MSL	WGS84	University of Hawaii, HIG
GH814-A	Hakurei Maru	1981	assumed MSL	WGS84	Geological Survey of Japan
GH814-B	Hakurei Maru	1981	assumed MSL	WGS84	Geological Survey of Japan
L882NP	Samuel P. Lee	1982	assumed MSL	WGS84	USGS Branch of Pacific Marine Geology

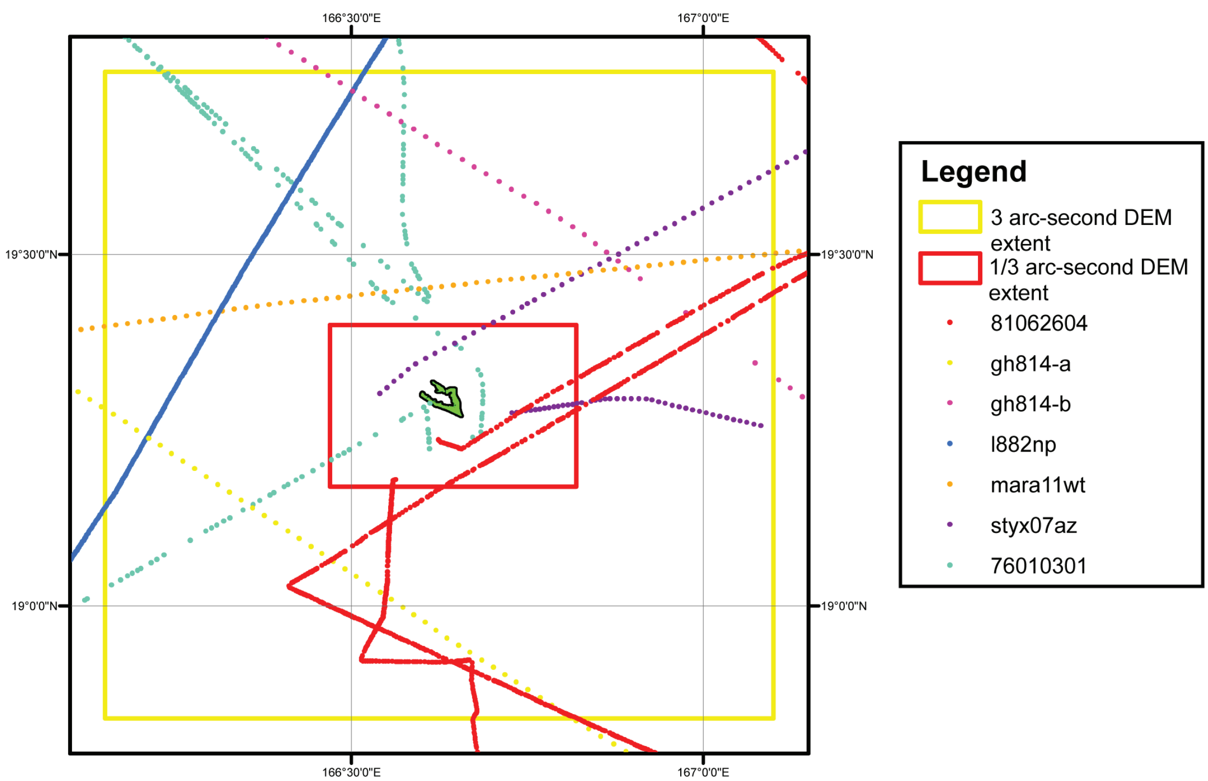

***Figure 10.** Spatial coverage of trackline surveys in the Wake Island region.*

3) Estimated bathymetry from satellite imagery

The lagoon on Wake Island does not contain bathymetric surveys. The only available data are sparse soundings from NOAA RNC #81664. To create high-resolution data for the lagoon, NGDC developed a methodology to convert satellite image ocean color into estimated bathymetric depths. A Digital Globe Satellite image from *Google Earth* was downloaded and georeferenced in *Arcmap* and converted to gray scale (Fig. 11). The depths from the RNC were used as control points to establish the relationship between depths and pixel values from the gray scale image (Fig. 12)(see section 3.3.1).

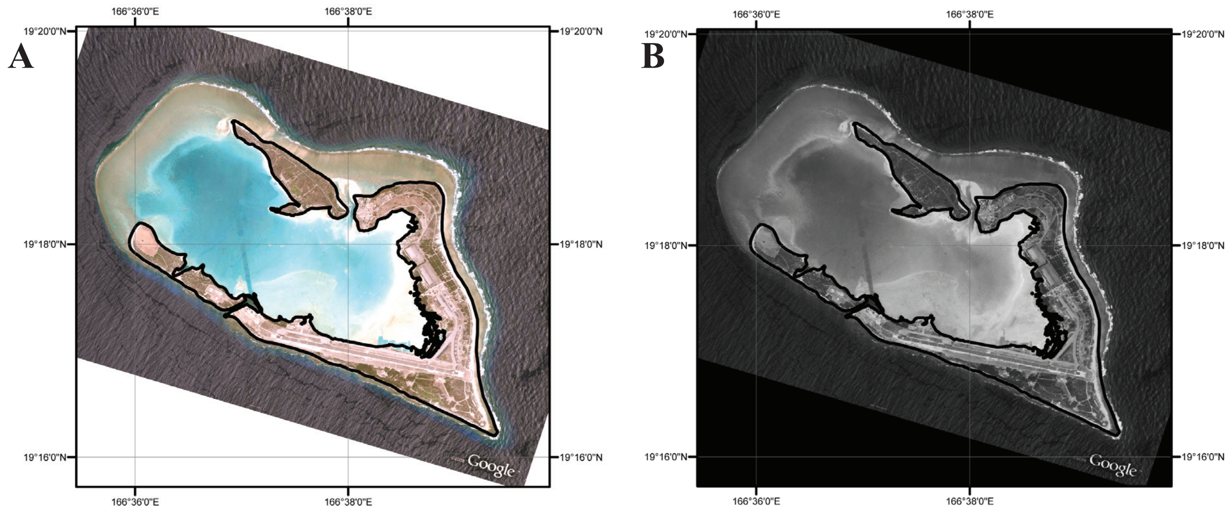

Figure 11. *Digital Globe satellite image used to estimate depths for the Wake Island lagoon. A) Color satellite image georeferenced in ArcMap B) a gray scale geotiff used for pixel vs. depth analysis.*

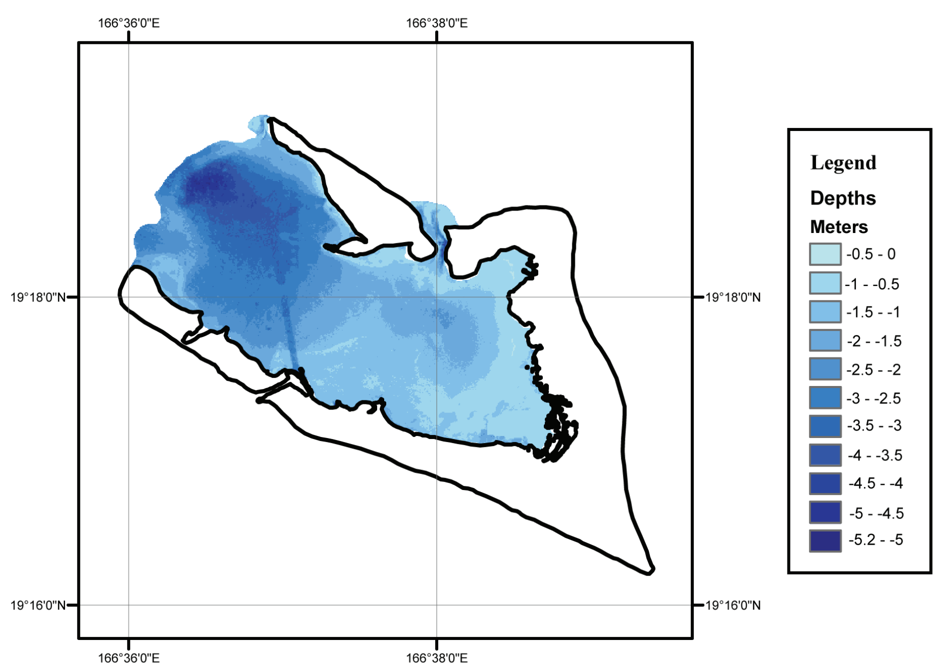

Figure 12. *Estimated Depths of the Wake Island lagoon calculated from satellite imagery.*

4) NGDC digitized depths

NGDC digitized depths from RNC #81664 where no data were available (Fig. 13). The depths inside the lagoon were not used in the final gridding but were used for the control in the satellite depth analysis. The reef that surrounds the perimeter of Wake Island was not included in the satellite imagery depth analysis as the bottom substrate of coral reflected light differently than the lagoon. NGDC digitized the reef that surrounds the perimeter of the lagoon, as identified in the RNCs, to approximately 120 meters offshore where the high-resolution multibeam bathymetry data exists. Values between 0.5 to 2.5 meters were used as depths.

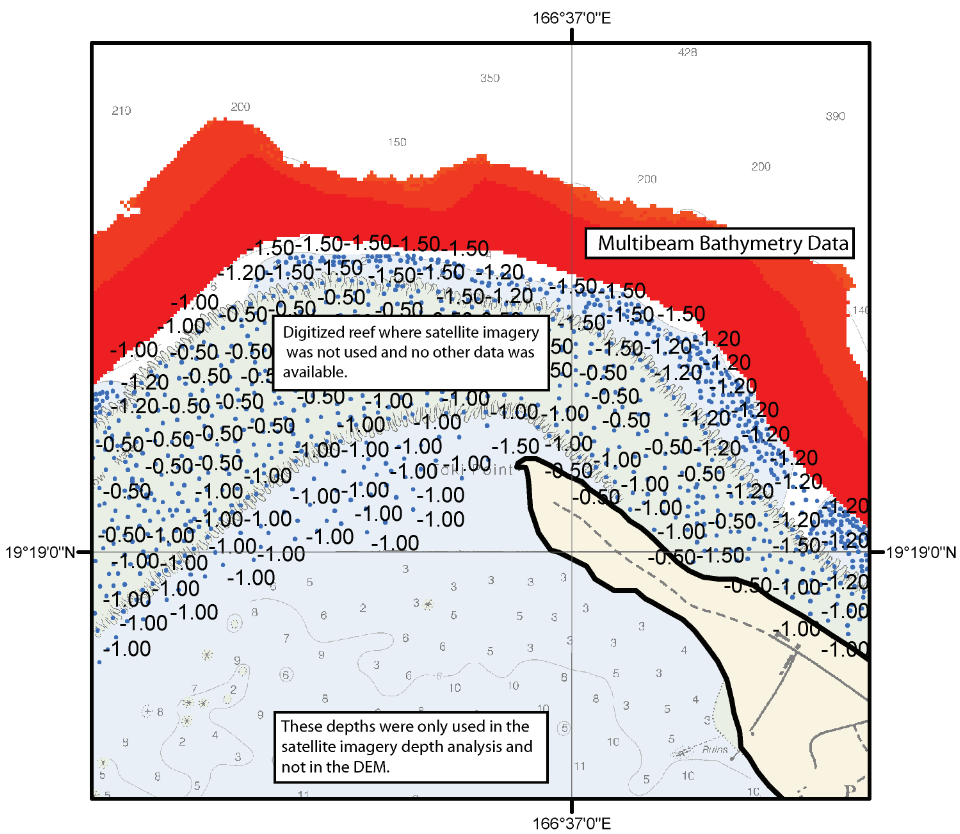

Figure 13. *Digitized reef. The reef surrounds the perimeter of Wake Island approximately 120 meters offsore with depths of 0.5 to 2.5 meters.*

5) ETOPO1

The majority of the Wake Island region contains no bathymetric measurements. NGDC's ETOPO1 Global Relief Model, which is derived from satellite altimetry, was used to fill this region.

The ETOPO1 grid has 1 minute cell size with data in WGS84 geographic coordinates and MSL. These data are exceptionally coarse at the resolution of the 1/3 arc-second and 3 arc-second Wake Island DEMs, however, they provide the only digital constraint on the bathymetry in deep water of the Wake Island DEMs. Extracted bathymetric data are generally shallower than overlapping measured bathymetric values and are considered to be of low accuracy.

3.1.3 Topography

The NASA Space Shuttle Radar Topography (SRTM) 3 arc-second DEM provided full coverage of the Island and was obtained and used to build the Wake Island DEMs (Table 7; Fig. 14).

Table 7: Topographic dataset used in compiling the Wake Island DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*	*URL*
NASA	2000	Topographic DEM	3 arc-second	WGS84 Geographic	WGS84 Geoid	http://srtm.usgs.gov/

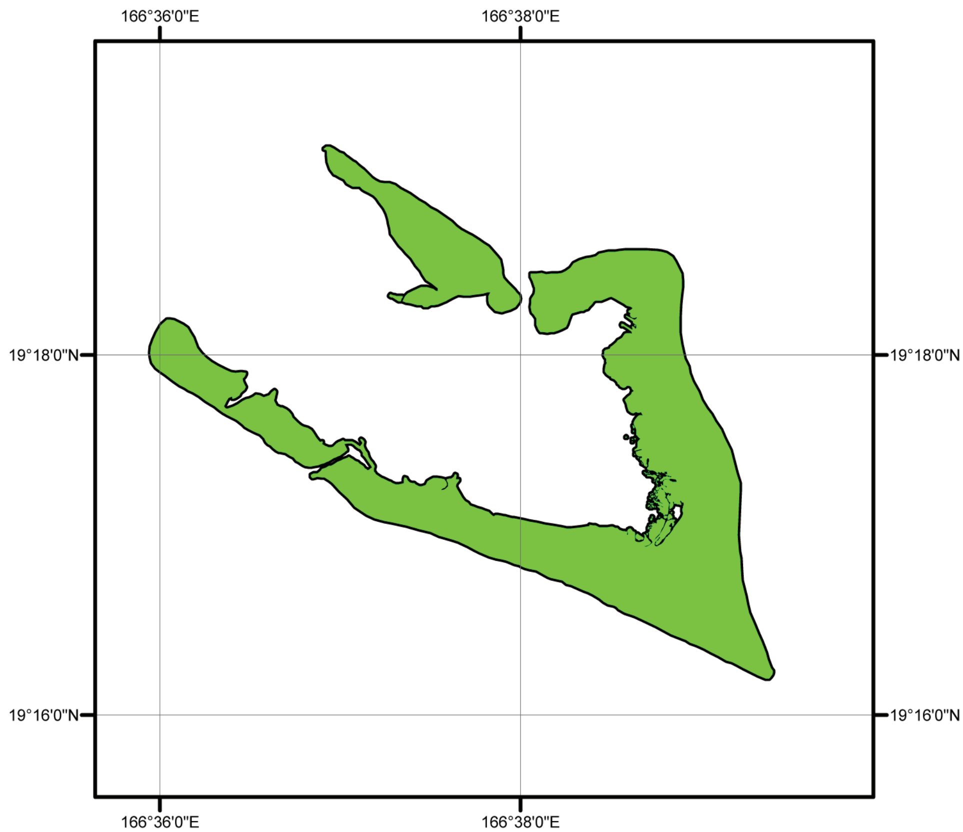

Figure 14. *SRTM data coverage for Wake Island (green). Coastline in black.*

1) NASA space shuttle radar topography

The NASA Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth[2]. The SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. Data from this mission have been processed into 1 degree x 1 degree tiles that have been edited to define the coastline, and are available from the USGS Seamless web site (http://seamless.usgs.gov/) as raster DEMs. The data have not been processed to bare earth, but meet the absolute horizontal and vertical accuracies of 20 and 16 meters, respectively.

The SRTM DEM is at 3 arc-seconds and referenced to the WGS84 Geoid. To create a 1/3 arc-second grid, NGDC sampled the data to 1/3 arc-seconds to create a smooth interpolation of the land (Fig. 15). The SRTM data were converted into a shapefile using *FME.* Using *ArcMap*, the kriging tool was used to smooth the 3 arc-second surface, which was converted to an xyz file, and gridded into a 1/3 arc-second grid using GMT (see section 3.3.3).

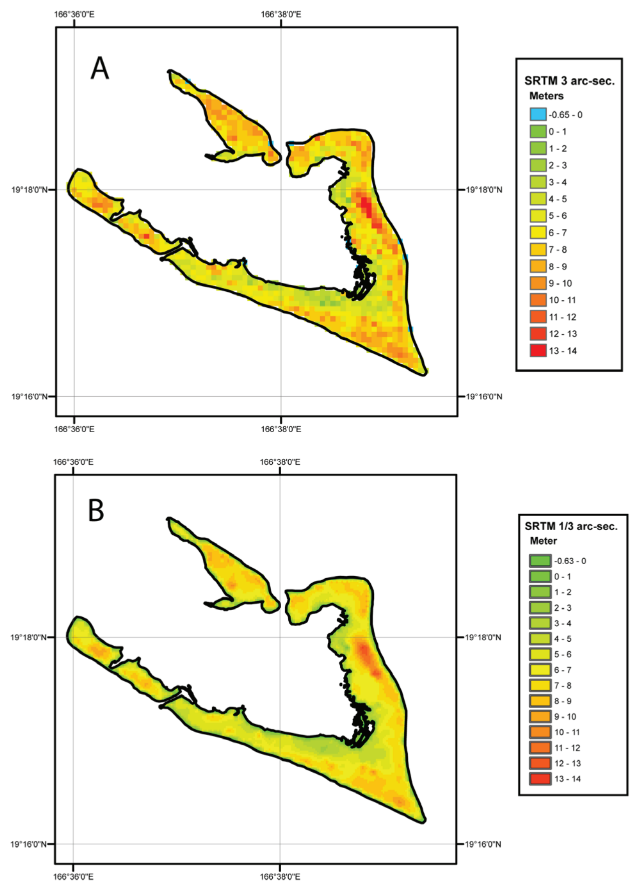

Figure 15. *SRTM clipped to the coastline, A) original 3 arc-second B) smoothed 1/3 arc-second*

2. The SRTM data sets result from a collaborative effort by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA – previously known as the National Imagery and Mapping Agency, or NIMA), as well as the participation of the German and Italian space agencies, to generate a near-global digital elevation model (DEM) of the Earth using radar interferometry. The SRTM instrument consisted of the Spaceborne Imaging Radar-C (SIR-C) hardware set modified with a Space Station-derived mast and additional antennae to form an interferometer with a 60 meter long baseline. A description of the SRTM mission can be found in Farr and Kobrick (2000). Synthetic aperture radars are side-looking instruments and acquire data along continuous swaths. The SRTM swaths extended from about 30 degrees off-nadir to about 58 degrees off-nadir from an altitude of 233 km, and thus were about 225 km wide. During the data flight the instrument was operated at all times the orbiter was over land and about 1000 individual swaths were acquired over the ten days of mapping operations. Length of the acquired swaths range from a few hundred to several thousand km. Each individual data acquisition is referred to as a "data take." SRTM was the primary (and pretty much only) payload on the STS-99 mission of the Space Shuttle Endeavour, which launched February 11, 2000 and flew for 11 days. Following several hours for instrument deployment, activation and checkout, systematic interferometric data were collected for 222.4 consecutive hours. The instrument operated almost flawlessly and imaged 99.96% of the targeted landmass at least one time, 94.59% at least twice and about 50% at least three or more times. The goal was to image each terrain segment at least twice from different angles (on ascending, or north-going, and descending orbit passes) to fill in areas shadowed from the radar beam by terrain. This 'targeted landmass' consisted of all land between 56 degrees south and 60 degrees north latitude, which comprises almost exactly 80% of Earth's total landmass. [Extracted from SRTM online documentation]

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Wake Island DEMs were originally referenced to vertical datums of Mean Lower Low Water (MLLW), Mean Sea Level (MSL), and WGS84 Geoid. All datasets were transformed to MHW to provide the worst-case scenario for inundation modeling. Depth values in the lagoon on the RNC were converted from feet to meters as appropriate.

1) **Bathymetric data**

The shallow-water multibeam, trackline surveys, and ETOPO1 were transformed from MSL to MHW, using *FME* software, by adding a constant offset of -0.307 meters measured at the Wake Island NOAA tidal station (see table 9) (http://tidesandcurrents.noaa.gov/). NGDC digitized points from RNC #81664 were converted from feet to meters, and then from MLLW to MHW by adding a constant offset of -0.653 meters.

2) **Topographic data**

The SRTM topographic DEM was originally in WGS84 Geoid vertical datum. There are no survey markers near Wake Island that relate this datum to the local tidal datum. Thus, we assumed the datum to be essentially equivalent to MSL in this area (Table 9). Conversion to MHW was accomplished by adding a constant value of -0.307 meters.

Table 8: Relationship between Mean High Water and other vertical datums in the Wake Island region.*

Vertical Datums	*Difference to MHW*
MSL	0.307
MLLW	0.653

*Datum relationships determined by tidal station 1890000 at Wake Island

3.2.2 Horizontal datum transformations

Datasets used to compile the Wake Island DEM were originally referenced to WGS84 geographic and needed no conversion.

3.3 Digital Elevation Model Development

3.3.1 Estimating bathymetry from satellite imagery

There are no digital soundings for the lagoon at Wake Island. The only available data were sparse RNC soundings. Depths for the lagoon were estimated by calculating shallow-water depths from a satellite image. The image was extracted from *Google Earth Pro*, converted to tif format and orthorectified in *ArcMap* using stable, identifiable features, such as the airstrip. The image was then converted to a 16-bit greyscale image (single value per pixel) and compared to the sparse RNC soundings. An approximate logarithmic relationship between pixel value and sounding (Fig. 16) was calculated using *MatLab*, a numerical computing environment and programming language maintained by MathWorks (http://www.mathworks.com/), and this equation was applied to the grayscale image to obtain estimated depths. The resulting Arc raster was resampled to 1/3 arc-second, clipped to the combined coastline, then converted to a ESRI point shapefile, which was edited to remove depths from the land, coral reefs, waves, and clouds identifiable in the satellite image.

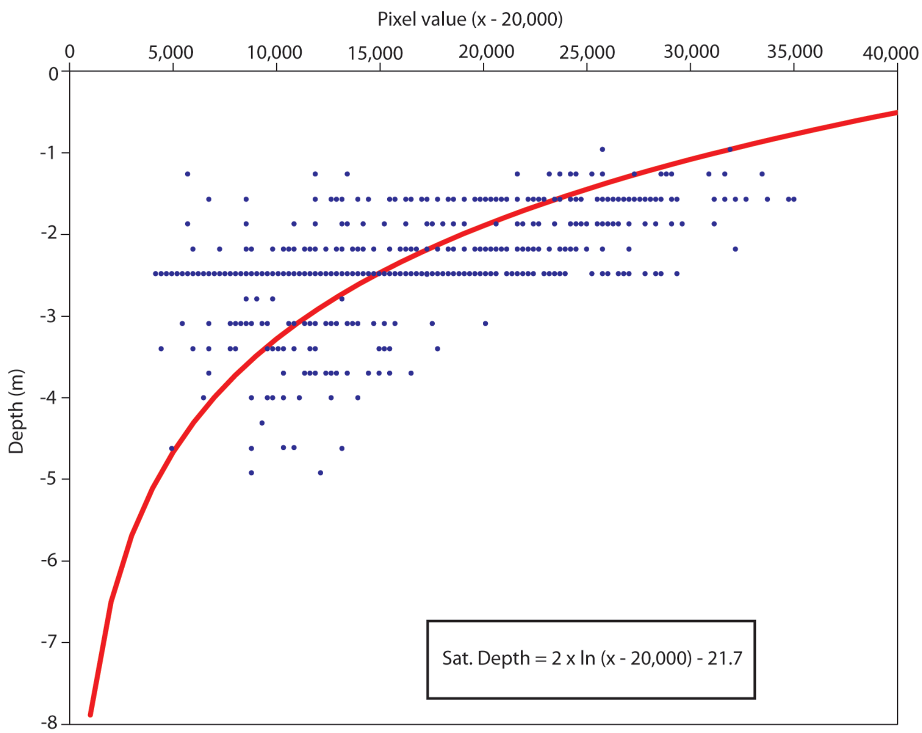

Figure 16. *Satellite greyscale pixel value plotted against depth. A logarithmic equation relating the two parameters was derived and used to estimate depths in the lagoon.*

3.3.2 Verifying consistency between datasets

After vertical transformations were applied, the resulting ESRI shape files were checked in *ArcMap* for consistency between datasets. Problems and errors were identified and resolved before proceeding with subsequent gridding steps. The evaluated and edited ESRI shape files were then converted to xyz files in preparation for gridding. Problems included:

- No digital survey soundings of the lagoon or of the surrounding coral reef
- No bathymetric measurements in the deep ocean
- Different bottom substrate reflections for satellite depth analysis
- Only 3 arc-scond SRTM topographic data were available

3.3.3 Smoothing of bathymetric data

Two 'pre-surface' bathymetric grids were generated for the Wake Island DEMs due to the varying resolution of data coverage. A 1 arc-second-spacing bathymetric grid was created for the 1/3 arc-second DEM extent, and a 3 arc-second-spacing bathymetric grid was created for the 3 arc-second DEM extent because of the low-resolution datasets in the deep ocean.

The NGDC multibeam surveys are high resolution with beam spacing 10 meters apart, a marked contrast with the 1 arc-minute (2 km) ETOPO1 data. A buffer was created between the multibeam and the ETOPO1 data (Fig. 17). The grids were generated using *GMT*, an NSF-funded share-ware software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

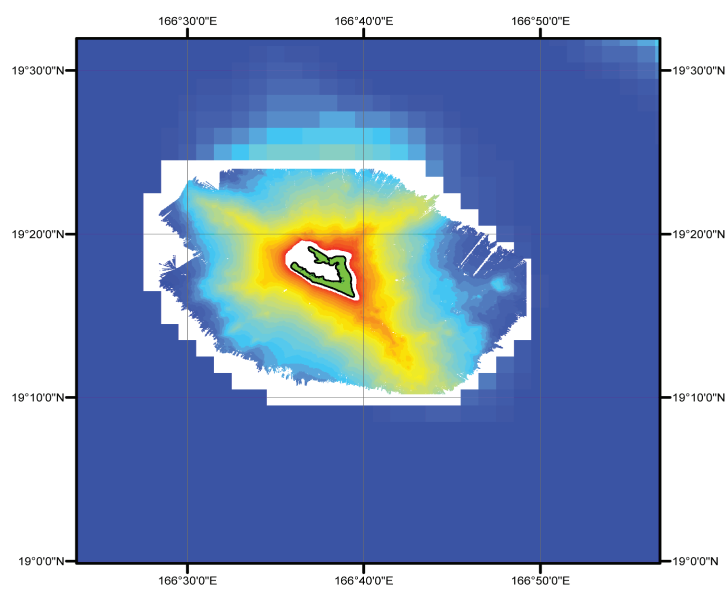

***Figure 17.** Buffer established between the high-resolution NGDC multibeam sonar surveys and the low-resolution ETOPO1.*

The point data were median-averaged using the *GMT* tool 'blockmedian' to create 1 and 3 arc-second grids 0.05 degrees (~5%) larger than the Wake Island DEM gridding region. The *GMT* tool 'surface' was then used to apply a tight spline tension to interpolate elevations for cells without data values. The *GMT* grid created by 'surface' was converted into an ESRI Arc ASCII grid file, and clipped to the combined coastline (to eliminate data interpolation into land areas). The resulting surface was compared with original soundings to ensure grid accuracy (Fig. 18) and exported as an xyz file for use in the final gridding process (see Table 10).

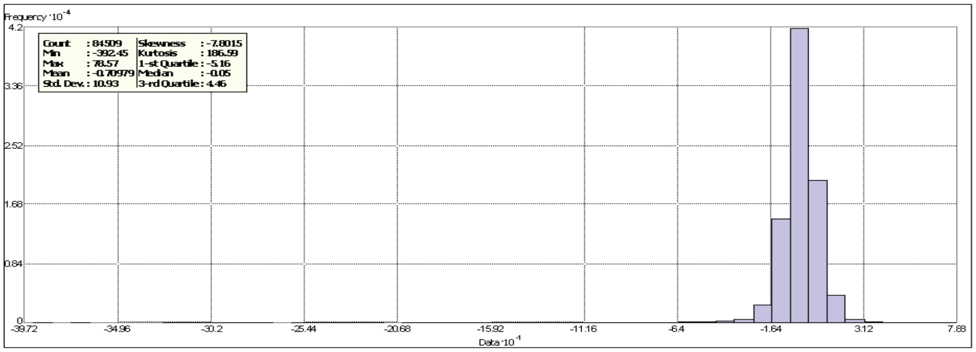

Figure 18. *Histogram of the differences between NGDC multbeam sonar survey, AHI-07-01 and the 1 arc-second bathymetric grid.*

3.3.4 Gridding the data with MB-System

MB-System (http://www.ldeo.columbia.edu/res/pi/MB-System/) was used to create the Wake Island DEMs. The *MB-System* tool 'mbgrid' was used to apply a tight spline tension to the xyz data, and interpolate values for cells without data. The data hierarchy used in the 'mbgrid' gridding algorithm, as relative gridding weights, is listed in Table 10. Greatest weight was given to the digitized features. Least weight was given to the coastline SRTM topographic DEM, and ETOPO1.

Table 9. Data hierarchy used to assign gridding weight in MB-System.

Dataset	*Relative Gridding Weight*
NGDC digitized features	1,000
NGDC Multibeam surveys	100
Satellite Imagery Depths	100
Trackline	10
Pre-surfaced bathymetric grid	10
1/3 arc-second DEM (for the 3 arc-second DEM only)	10
SRTM Topographic DEM	1
Wake Island coastline	1
ETOPO1	1

3.4 Quality Assessment of the DEMs

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Wake Island DEMs are dependent upon cell location and the datasets used to determine corresponding DEM cell values. The SRTM topographic DEM has an estimated accuracy of 90 to 100 meters. Bathymetric features are resolved only to within a few thousand meters in deep-water areas. Shallow, near-coastal regions, and harbor surveys have an accuracy of 10 meters. Positional accuracy is limited by: the lack of deep-water soundings, simplified methodology for extracting depths from satellite images, and by man made morphologic change (i.e., channel dredging).

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the Wake Island DEMs are also highly dependent upon the source datasets contributing to DEM cell values. The SRTM topographic DEM has an estimated vertical accuracy between 10 and 16 meters. Bathymetric areas have an estimated accuracy of between 0.1 meters and 1% of water depth for the 1/3 arc-second DEM. The deep water values in the 3 arc-second DEM have an estimated accuracy of hundreds of meters due to gridding interpolation between sparse soundings and course estimated depths from ETOPO1.

3.4.3 Slope maps and 3-D perspectives

ESRI *ArcCatalog* was used to generate slope grids from the Wake Island DEMs to allow for visual inspection and identification of artificial slopes along boundaries between datasets (e.g., Fig. 19). The DEMs were transformed to UTM Zone 58 coordinates (horizontal units in meters) in *ArcCatalog* for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis. Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEMs. Three-dimensional viewing of the UTM-transformed DEMs was accomplished using ESRI *ArcScene*. Figure 20 shows a perspective view of the 1/3 arc-second Wake Island DEM in its final version.

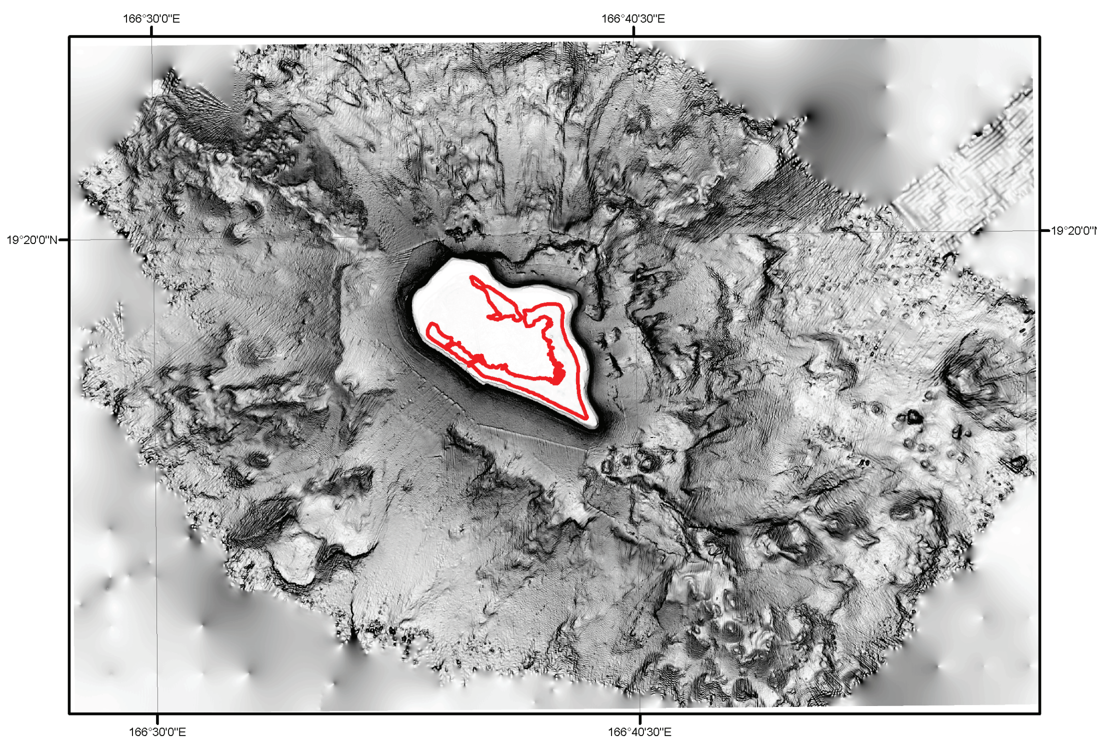

Figure 19. *Slope map of the 1/3 arc-second Wake Island DEM. Flat-lying slopes are white; dark shading denotes steep slopes; Wake Island coastline in red.*

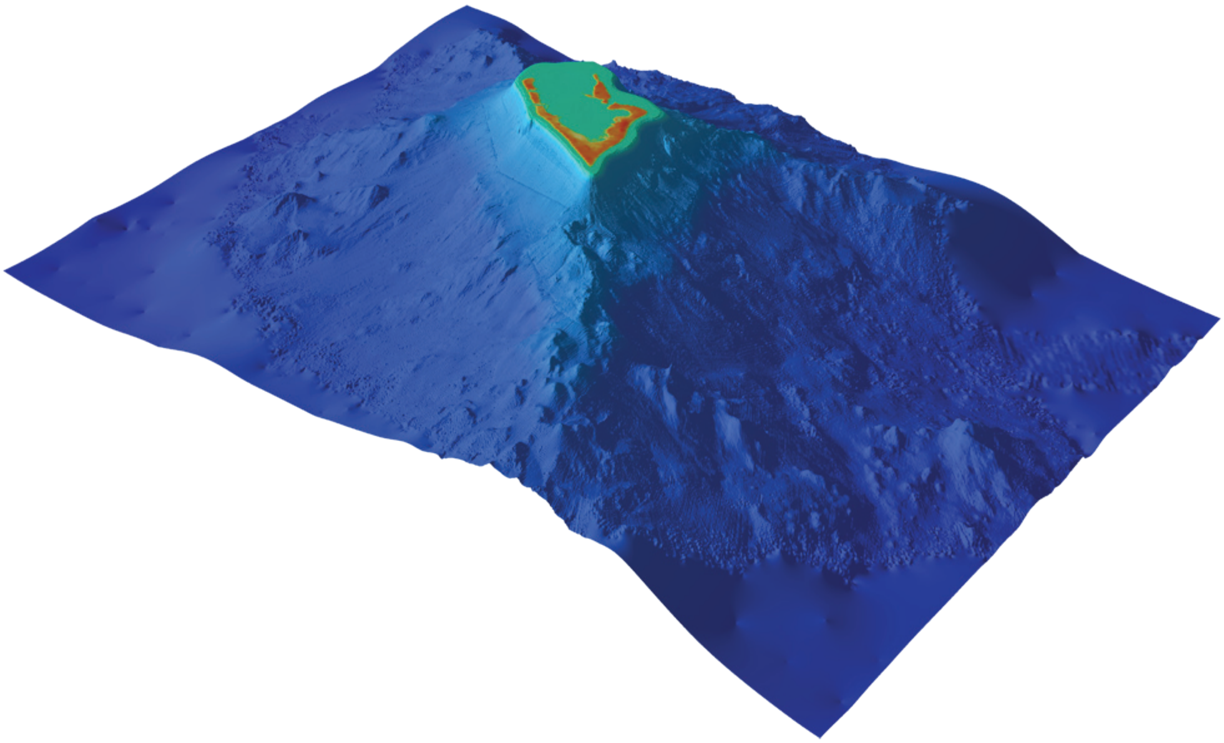

Figure 20. *Perspective view from the east of the 1/3 arc-second Wake Island DEM. 5x vertical exaggeration.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the Wake Island DEMs were compared to select source data files. Files were chosen on the basis of their contribution to the grid-cell values in their coverage areas (i.e., had the greatest weight and did not significantly overlap other data files with comparable weight). A histogram of the differences between the NGDC multibeam survey AHI-07-01 and the 1/3 arc-second Wake Island DEM is shown in Figure 21. Differences range from -200 to 20 meters, where negative values indicate that elevations of the multibeam data are higher than the DEM elevations. The area where the greatest difference occurred is where the two multibeam surveys, AHI-07-01 and Hi-07-01, overlap and have variations in depth.

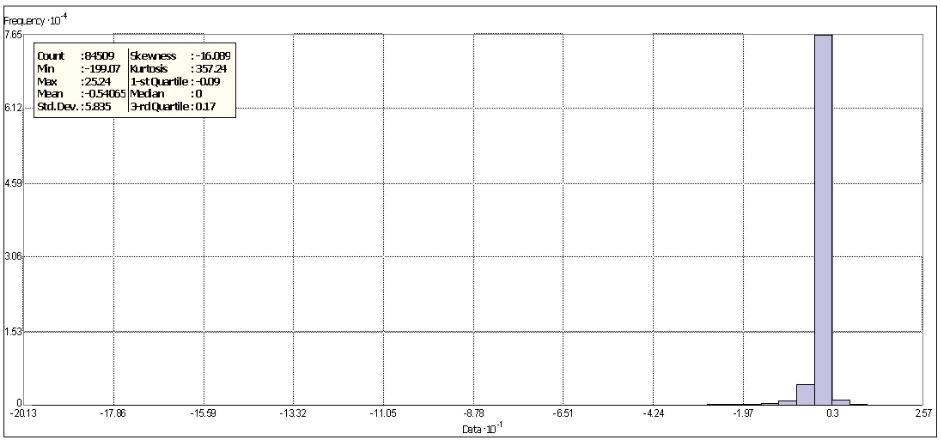

Figure 21. *Histogram of the differences between the NGDC multibeam survey AHI-07-01 and the 1/3 arc-second Wake Island DEM.*

A histogram of the differences between ETOPO1 and the 3 arc-second DEM is shown in Figure 22. Differences range from -687 meters to 638 meters, where negative values indicate that elevations of the ETOPO1 data are higher than the DEM elevations. The area where the greatest difference occurred is along the buffer zone between the high resolution multibeam data and the ETOPO1 DEM. Values along the edge of the buffer zone are affected by gridding interpolation to create a smooth surface between the datasets. There is also a difference between the ETOPO1 and the 3 arc-second DEM where trackline data exists. Trackline data was given a heavier weight than the ETOPO1 data in the gridding process, so have a stronger influence over the cell value.

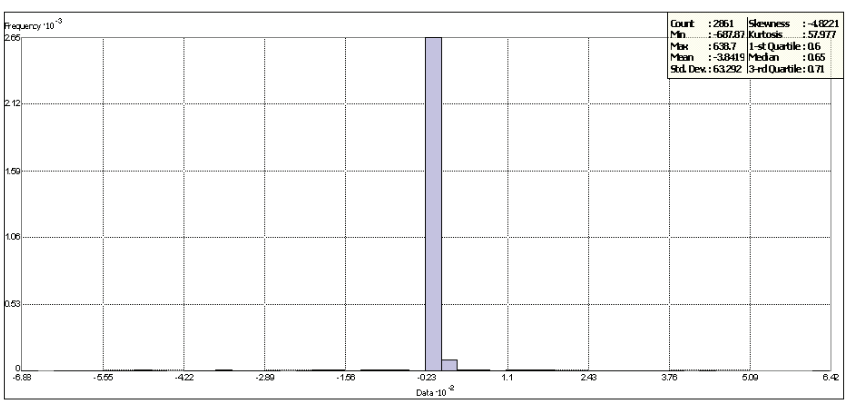

Figure 22. *Histogram of the differences between ETOPO1 and the 3 arc-second Wake Island DEM.*

A histogram of the differences between the SRTM topographic DEM and the 1/3 arc-second DEM is shown in Figure 23. Differences range from -3.5 meters to 0.98 meters, where negative values indicate that elevations of the SRTM data are higher than the DEM elevations. These minor differences are most likely due to resampling of the 3 arc-second SRTM to 1/3 arc-second.

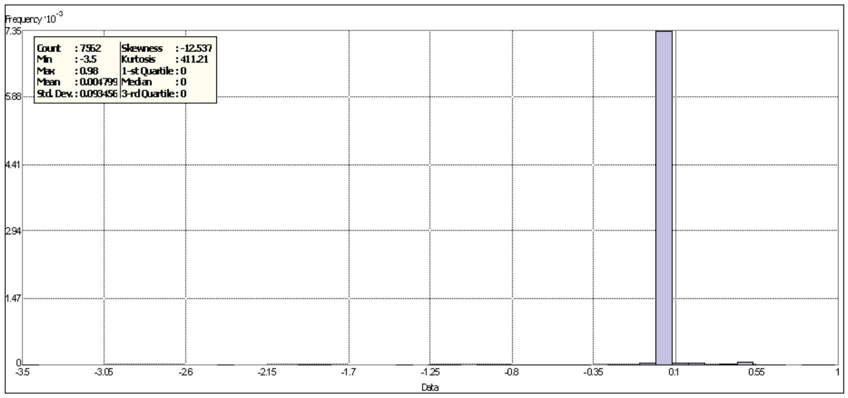

Figure 23. *Histogram of the differences between SRTM data and the 1/3 arc-second Wake Island DEM.*

A histogram of the differences between the estimated depths from Digital Globe Satellite and the 1/3 arc-second DEM is shown in Figure 24. Differences range from -0.74 meters to 2.05 meters, where negative values indicate that elevations of the estimated depths are higher than the DEM elevations. These minor differences are most likely do to the averaging of cell values when the coastline falls in the same cell as an estimated depth.

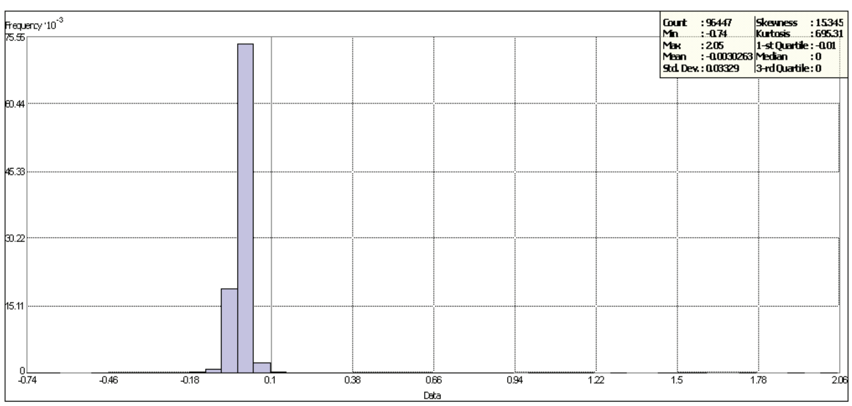

Figure 23. *Histogram of the differences between the Digital Globe Satellite estimated depths and the 1/3 arc-second Wake Island DEM.*

4. Summary and Conclusions

Two integrated bathymetric–topographic digital elevation models of the Wake Island region, with cell spacing of 3 arc-second and 1/3 arc-second, were developed for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research. The best available digital data from U.S. federal agencies were obtained by NGDC, shifted to common horizontal and vertical datums, and evaluated and edited before DEM generation. The data were quality checked, processed and gridded using ESRI *ArcGIS, FME, GMT, MB-System*, and *Quick Terrain Modeler* software.

Recommendations to improve the Wake Island DEM, based on NGDC's research and analysis, are listed below:

- Conduct hydrographic surveys for near-shore areas, especially in the lagoon and of the reefs.
- Complete bathymetric–topographic LiDAR surveying of the island and near shore region.
- Conduct hydrographic surveys for the deep ocean.
- Digitize the Raster Nautical Chart as an Electronic Nautical Chart (ENC).

5. Acknowledgments

The creation of the Wake Island DEM was funded by the NOAA Pacific Marine Environmental Laboratory. The authors thank Nazila Merati and Vasily Titov (PMEL); and Ann Gibbs (USGS Pacific Science Center).

6. References

Nautical Chart #81664 (RNC), 6th Edition, 1998. Wake Island. Scale 1: 15,000 and 1:3,500. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

7. Data Processing Software

ArcGIS v. 9.2, developed and licensed by ESRI, Redlands, Oregon, http://www.esri.com/

FME 2008 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

GEODAS v. 5 – Geophysical Data System, free software developed and maintained by Dan Metzger, NOAA National Geophysical Data Center, http://www.ngdc.noaa.gov/mgg/geodas/

GMT v. 4.1.4 – Generic Mapping Tools, free software developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu/

MATLAB v. 7.2.1,developed and licensed by hWorks Inc., 2005, http://www.mathworks.com/

MB-System v. 5.1.0, free software developed and maintained by David W. Caress and Dale N. Chayes, funded by the National Science Foundation, http://www.ldeo.columbia.edu/res/pi/MB-System/

Quick Terrain Modeler v. 6.0.1, LiDAR processing software developed by John Hopkins University's Applied Physics Laboratory (APL) and maintained and licensed by Applied Imagery, http://www.appliedimagery.com/