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Specifications for Accurate, Consistent, and Seamless Public Topographic-Bathymetric DEMs of U.S. Coasts

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Overview

The National Geophysical Data Center (NGDC), an agency of the National Oceanic and Atmospheric Administration (NOAA), and the Earth Resources Observation & Science (EROS) Center, an agency of the U.S. Geological Survey (USGS), have collaboratively developed a draft sustainable framework for the creation of accurate, consistent and seamless topographic-bathymetric digital elevation models (DEMs) of the U.S. coastal zone that will be freely available for public use. This framework is specific to square-cell “raster” models, which are the most commonly used, not triangular irregular networks (TINs) or other types of DEMs, though some of the requirements and recommendations described herein may also be applicable to those DEM types. This framework will be tested and improved upon by building a suite of square-cell coastal DEMs of the New York-New Jersey shoreline that were impacted by storm-surge from Hurricane Sandy in 2012.

Square-cell, coastal DEMs support a wide variety of uses, including modeling of coastal flooding, coastal change analysis, habitat mapping, spatial planning, and Earth visualization. In order to support the seamless merging of coastal DEMs built by multiple government agencies, academia and the commercial sector, such DEMs need to be developed within a well-defined framework, which includes key DEM requirements and recommendations, as well as consistent documentation to support discovery, access, and use. This framework needs to be robust and capable of being implemented by multiple groups (i.e., be agnostic with respect to software being utilized in DEM development). Discovery and delivery of the coastal DEMs will be addressed separately following the framework review.

The square-cell, coastal DEM framework described herein will be tested, reviewed, and improved as part of the Sandy Supplemental work. The goal is to generate a sustainable framework for the Nation that enables shared development of seamless, mergeable and public topo-bathy elevation models of U.S. coastal areas as called for in the President’s National Ocean Policy [*National Ocean Council*, 2013]. The framework needs to:

- define key coastal DEM specifications necessary to support seamless merging of DEMs
- provide recommendations and best practices for data processing, DEM development, and DEM assessment
- describe techniques for efficiently updating coastal DEMs as new, public elevation data are released
- determine documentation requirements to capture important data processing and DEM development steps (e.g., in standards-compliant metadata records and spatial metadata)
- identify areas for future improvement, such as gaps in data acquisition and processing, improvements in data delivery, and coastal areas where collaborations and synergies can improve DEM accuracy and coverage

Coastal DEM Specifications

There are several key coastal DEM specifications (Table 1) that square-cell, public models of U.S. coasts must adhere to, to ensure that coastal DEMs built by different groups will consistently align on a cell-by-cell basis. DEMs that do not align will not be capable of being merged as part of the national coastal and oceanic database of seamless elevation.

Projection	Local UTM Zone		Geographic				
Cell size	1 meter	3 meter	1/9 arc-sec	1/3 arc-sec	1 arc-sec	3 arc-sec	9 arc-sec
Offshore coverage	1 nm	3 nm	3 nm	24 nm	500-m depth	200 nm	ECS, LMEs
Grid registration	Pixel						
Horizontal datum	NAD 83 (NSRS2007)						
Vertical datum	NAVD 88 (GEOID12A)				MSL		
Edge precision	3 m		0.01 degrees (36 arc-sec)				
Elevation precision	0.01 m	0.1 meters				1 meter	
Multi-temporal	yes		no				
Surface type	Bare earth						
Restrictions	None/Public						

Table 1. Coastal DEM specifications.

Projection: Square-cell coastal DEMs will be in either a local universal transverse Mercator (UTM) zone projection or geographic coordinates (i.e., unprojected; Table 1). Local UTM zone projections are most appropriate for the highest resolution, meter-scale models at the shoreline. Geographic coordinates are most appropriate for lower-resolution DEMs that extend farther offshore. Because transforming square-cell rasters between the two introduces distortion—square cells in one are not square in the other—such transformations should be minimized.

Cell size: UTM Zone DEMs will have cell sizes of either 1 meter or 3 meters (Table 1). Geographic coastal DEMs will range in cell size from 1/9 arc-second to 9 arc-seconds (Table 1). The factor of three steps will help ensure consistent nesting between coastal DEMs of different cell sizes but same coordinate system (i.e., 9 cells at one cell size will have exactly the same geographic footprint as one cell at the next coarser cell size).

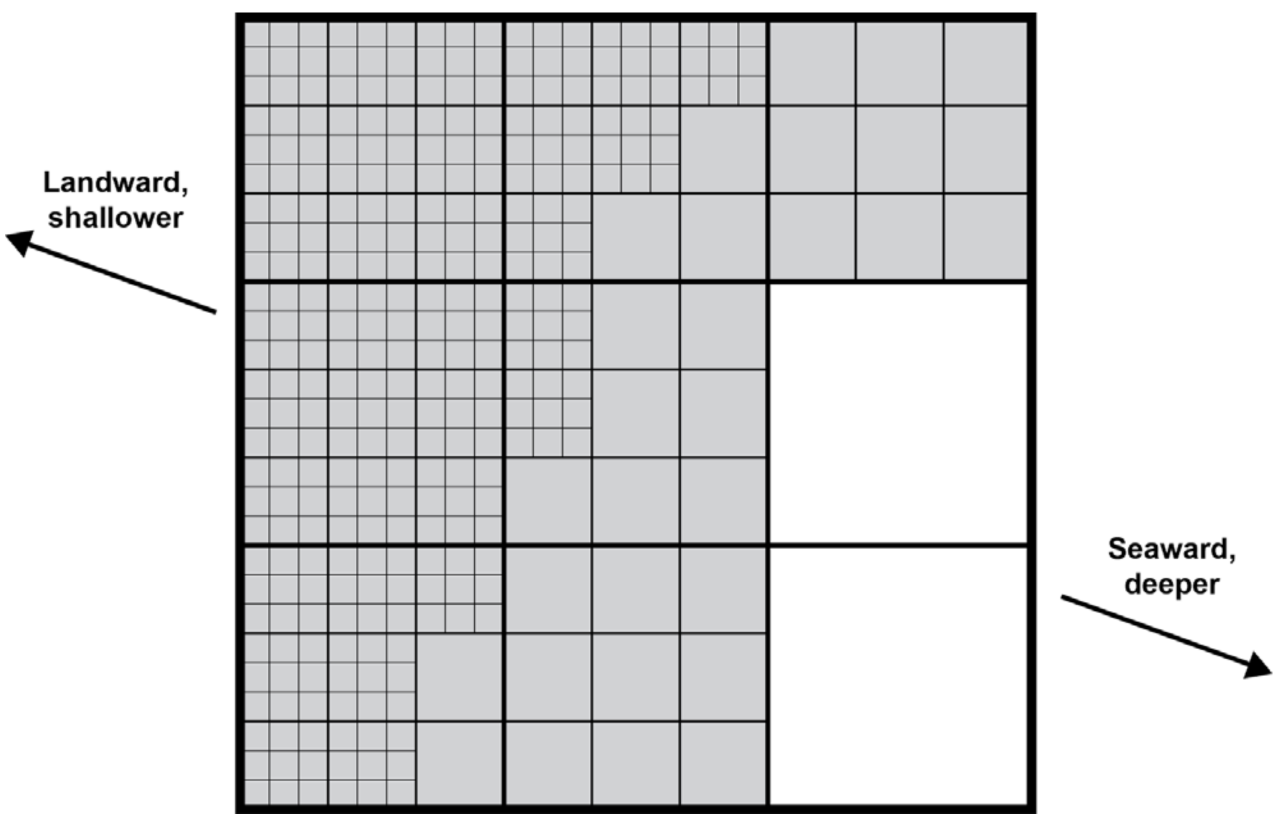

Figure 1. Example of DEM cell nesting. One, bold-outlined cell at the coarsest resolution, is comprised of 9 cells at the next higher resolution, which in turn has some cells comprised of 9 gray cells at the next higher resolution, and so on. In this schematic for coastal DEMs, the coastline would be towards the top left.

Offshore coverage: Each successively coarser coastal DEM will extend farther offshore (Table 1; Figure 1) so that there is a rough correspondence between bathymetric data density and cell size (e.g., in deeper waters, soundings are farther apart). Table 2 lists the minimum offshore extents of these "telescoping" geographic DEMs, shown in the Figure 2 schematic. The 1 arc-second geographic DEMs will extend out to approximately the 500-m depth contour, roughly corresponding to the edge of the continental shelf. The 3 arc-second DEMs will extend out to the 200 nm limit of the U.S. Exclusive Economic Zone (EEZ), while the 9 arc-second DEMs will encompass deeper water in farther offshore areas, such as large marine ecosystems (LMEs), small ocean basins (e.g., Gulf of Mexico), and the U.S. Extended Continental Shelf (ECS).

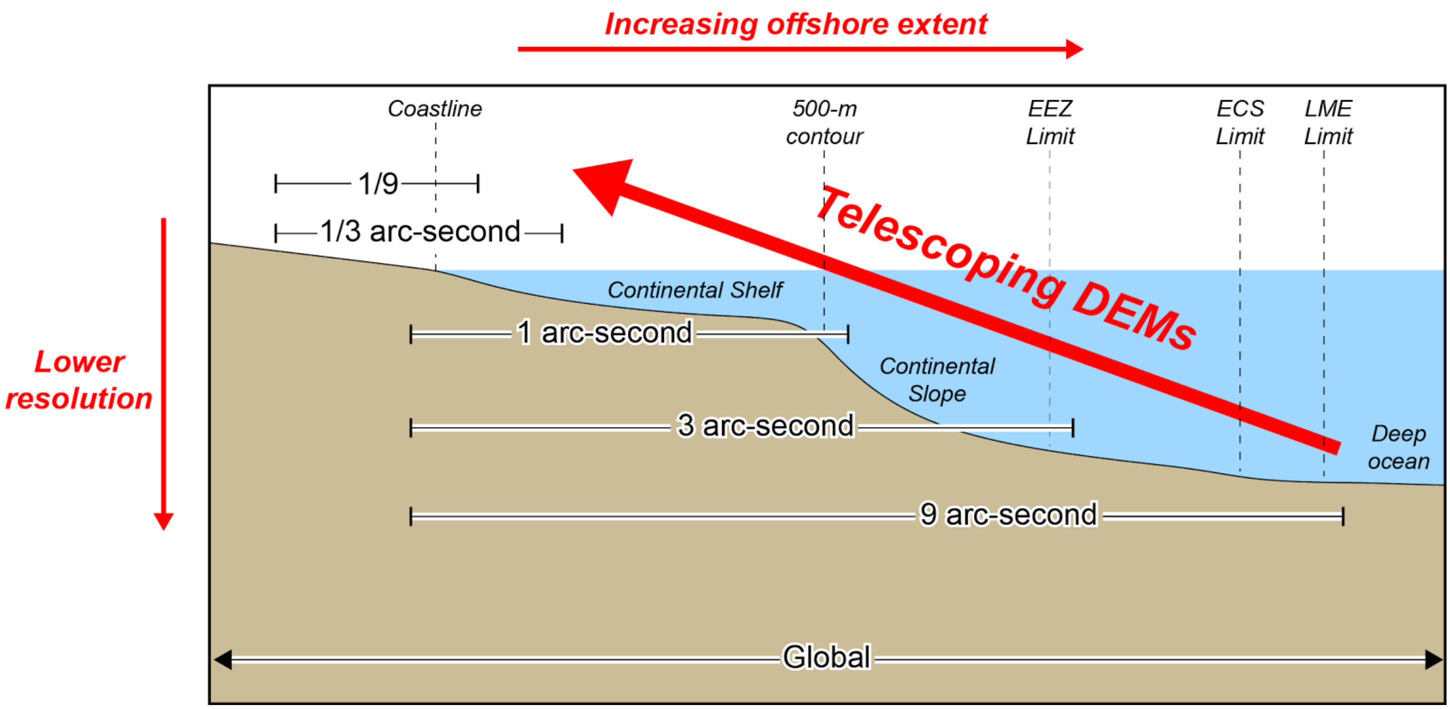

Figure 2. Example of DEMs extending farther offshore as cell size increases and resolution decreases.

Table 2. Minimum offshore extents of geographic DEMs.

1/9 arc-sec	3 nm limit of State waters
1/3 arc-sec	24 nm limit of U.S. contiguous zone
1 arc-sec	500-m depth contour
3 arc-sec	200 nm limit of U.S. EEZ
9 arc-sec	Encompass ECS, LMEs and small ocean basins

Grid registration: UTM Zone and geographic coastal DEMs will be defined by the corners of the cells, also known as pixel- or cell-based registration (Table 1). This will help ensure that the coastal DEMs can be seamlessly merged with the USGS National Elevation Dataset (NED). NED topography is available in 1/9, 1/3 and 1 arc-second cell sizes, and NAD 83 and NAVD 88 horizontal and vertical datums, respectively. Pixel registration will also better enable web-delivery of the coastal DEMs and corresponding color-relief images.

Horizontal datum: The horizontal datum of U.S. coastal DEMs will be the North American Datum of 1983 (NAD 83, NSRS2007 readjustment; Table 1). This datum is nearly identical with the global World Geodetic System of 1984 (WGS84) horizontal datum, and for the geographic DEMS, the two can be considered identical.

Vertical datum: The vertical datum of higher-resolution DEMs will be the North American Vertical Datum of 1988 (NAVD 88, GEOID12A realization; Table 1). Lower-resolution models will be in mean sea level (MSL).

Edge precision: The precision of the edges/bounding extents of each UTM zone model, in meters, must be wholly divisible by three (i.e., result must be an integer, without remainder; Table 1). To help ensure alignment between coastal DEMs built by different developers, the edge precision of each geographic model must be limited to two decimals of latitude and longitude (i.e., 0.01 degrees/36 arc-seconds; Table 1).

Elevation precision: The precision of elevation values within coastal DEMs needs to be appropriately limited to the resolution of the coastal DEM, to avoid implying greater accuracy in the DEM than is warranted (Table 1). For 1-meter cell-size UTM zone DEMs the elevation precision will be limited to 0.01 m. For the 3-m cell-size UTM Zone DEMs, and 1/9, 1/3 and 1 arc-second geographic DEMs, the elevation precision will be 0.1 m. For the 3 and 9 arc-second geographic DEMs, the elevation precision will be 1 m.

Multi-temporal aspect: The UTM Zone coastal DEMs need to include a multi-temporal aspect that will enable high-resolution coastal change analysis (Table 1). To support this, the survey dates and spatial footprints of the source data used to build each model need to be clearly documented so that spatial-temporal differences between models can be quantified. The geographic coastal DEMs will not be expressly temporal, though older versions of coastal DEMs should be archived and publicly accessible.

Surface type: The coastal DEMs will represent the bare ground surface, or “bare earth.” Buildings, trees, and other above- or below-ground surfaces will not be represented in the models, and must be removed from source elevation data sets. Exceptions are large, solid structures, such as jetties and dams, that are impervious barriers to water flow. The documentation should identify any structures that are represented in the DEM.

Restrictions on public access and use: No restrictions, other than “not to be used for navigation” are to be placed on public access to and/or use of the square-cell coastal DEMs that are part of this framework (Table 1). Proprietary data that imposes restrictions on use and public dissemination of derived products (i.e., DEMs) are not to be used in coastal DEM development, unless the data owner provides written consent that the DEM can be fully released to the public without restrictions. Such consent must be documented.

Documentation Requirements

The goal of DEM documentation is to provide all necessary information to users as to its limitations and appropriate use. This could include such things as coastal DEM specifications (see Table 1) and source data sets used in coastal DEM development, as well as processing, gridding and assessment techniques used. Other important factors, such as identifying manmade structures represented in the coastal DEM or consent to public release of a DEM built using restricted data, also need to be clearly documented. This DEM documentation will also enable online discovery in text and GIS search tools. This Sandy Supplemental project will investigate efficient ways to development and disseminate DEM documentation to the public.

XML metadata: High-level descriptions of source elevation data, DEM development methods, and assessment results for each coastal DEM need to be documented in standards-compliant XML metadata that is compatible with the ISO 19115 standard, and translatable to the FGDC standard. Published, maintained XML metadata records can be provided to search portals, such as Data.gov and the Global Change Master Directory, for broader coastal DEM discovery. A draft XML template for coastal DEMs will be created during this Sandy Supplemental project, which will be shared for review within the broader DEM development community before being made publicly available.

Spatial metadata: Spatial metadata that contain the footprints and descriptions of source data sets will enable online visual display of the spatial relationships between source data and coastal DEM morphology. Such metadata will support the UTM zone coastal DEMs as the multi-temporal aspect of these DEMs is dependent upon the overlapping footprints and dates of the source data, not the coverage of the DEMs, which are an amalgamation of a wide variety of surveys over years to decades. Web-based tools may also enable linking from a coastal DEM to source data ("provenance") to better support data discovery. What form this spatial metadata will take, and what information is required in it, will also be investigated during this Sandy Supplemental project.

Metadata grids: Each coastal DEM needs to include cell-level distinction between measured elevations, gridding interpolation, and cells without an elevation value, which could be expanded to include source data set identifiers. The bathymetric attributed grid (BAG) file format might accommodate this, though this format is not yet in wide-spread use. Alternatively, this information could be included in a separate, companion grid that would accompany the coastal DEM. How to properly document this cell-level data/interpolation distinction will be investigated more thoroughly during the development of the coastal DEMs of the NY-NJ shoreline.

Cell-level uncertainty: Quantifying DEM accuracy at the cell level will be of great benefit to many DEM users, especially those modeling coastal processes, such as tsunamis, storm surge, or morphologic change. The BAG file format supports cell-level uncertainty, though quantifying the various sources of uncertainty (e.g., source data, interpolation, morphologic change) at the cell level is still a challenge. How to estimate the sources of coastal DEM cell-level uncertainty, and then properly document this uncertainty will also be investigated more thoroughly during the development of the coastal DEMs of the NY-NJ shoreline.

Coastal DEM Recommendations

Publicly available data: Publicly available elevation data should be gathered from as many sources as possible, including NOAA, USGS, State and local government offices, academia, and the commercial sector. Academic journals, technical reports, development projects, and local associations may provide contacts for accessing offline elevation data [Eakins and Grothe, 2014].

Transformations: Source elevation data need to be transformed from their original horizontal and vertical datums into the datums of the final coastal DEM. This may also include conversions to common file formats to support data visualization, editing, and DEM development. Where available, the NOAA *Vertical Datum* (*VDatum*) tool [*Parker et al*., 2003] is to be used to convert bathymetric data in tidal datums to either NAVD 88 (GEOID12A) or MSL, depending upon DEM cell size (see Table 1). In its absence, vertical datum conversions should be done following one of the methods outlined in *Eakins and Grothe* [2014] and needs to be clearly documented.

Data processing: Available elevation data need to be processed to bare earth (to remove docks, piers, trees, buildings, etc.). Lidar data may need to be classified to support this requirement. The spatial footprints of all source data sets need to be generated to support accurate coastal DEM documentation. Where data sets overlap, less accurate data (typically older and sparser) should be removed prior to DEM development. Visual inspection of source data in a GIS environment is necessary to ensure that data artifacts, anomalies or non-Earth surface detections are removed. A detailed, bare-earth NAVD 88 zero line may also need to be developed to support seamless integration of bathymetric and topographic data at the coast. This "coastline" should be made available to other coastal DEM developers to help ensure consistency between overlapping DEMs. How this coastline sharing occurs will be investigated during the

Sandy Supplemental project.

Gridding: Geographic coastal DEMs require every cell to have an elevation value. If most DEM cells are constrained by measured data, and data gaps are therefore at most a few cells across, the choice of gridding technique (e.g., spline, inverse distance weighting, triangulation, kriging) can be left to the DEM developer. In regions where data are sparse at the resolution of the geographic DEM, requiring interpolation over a large number of cells, use of spline or kriging is recommended. In UTM Zone DEMs, cells without a number ("not a number"; NaN) are acceptable—to indicate data gaps—and choice of gridding technique, for infilling of small gaps, can be left to the DEM developer. The gridding technique used in coastal DEM development must be clearly documented. A spatial buffer of elevation data surrounding each coastal DEM should be used, in order to minimize gridding artifacts along DEM edges. The buffer's width should be approximately 10% that of the DEM. Existing higher-resolution geographic DEMs need to be resampled to the next coarser resolution prior to use in building or updating those coarser DEMs. This will help ensure elevation consistency between overlapping models of differing cell sizes.

Tiling scheme: In order to support efficient coastal DEM development, updating, and delivery, the DEMs should be built in tiles. Geographic 1/9 and 1/3 arc-second tiles should have extents bounded by $1/4^{th}$ of a degree, or 15 arc-minutes. Geographic 1, 3, and 9 arc-second tiles should cover 1 degree squares. Tiles should overlap neighboring tiles by at least 6 cells to minimize seams along tile edges.

Hydro-enforcement of topography: The topography of the UTM zone coastal DEMs need to be hydro-enforced to ensure proper modeling of surface water flow.

DEM assessment: The coastal DEM should be statistically compared to select source and independent data sets, with the root mean square error (RMSE) documented in the accompanying XML metadata. Investigation of histogram outliers may reveal problems that can be corrected. The DEM should also be visually inspected in a GIS environment for significant anomalies and artifacts. This may include inspection of derived slope and curvature grids. Coastal DEMs should also be peer-reviewed by other parties, initially NOAA NGDC and USGS EROS, to ensure that accuracy is properly documented and that the DEMs are consistent with other, published DEMs.

DEM updating: Coastal DEMs should be routinely updated as new elevation data are acquired and made publicly available. This could be accomplished by retaining all processed source data and integrating with the new, processed data. It could also be accomplished by gridding the new, processed data to the specifications of the coastal DEM to be updated, and then assessing the accuracy of the new grid compared to the existing coastal DEM. Differencing of the new grid with the coastal DEM will highlight significant changes that need to be evaluated. If warranted, the grid of new data can then be merged or blended with the existing DEM. This second technique shall be investigated more thoroughly during the development of the coastal DEMs of the NY-NJ shoreline.

Future Considerations

VDatum expansion: VDatum currently has limited extent up rivers and offshore. Expanding the spatial coverage of VDatum to go farther inland/up river and to go farther offshore, as well as to other U.S. coastal areas (such as Alaska and Hawaii) will increase the accuracy of vertical datum transformations of elevation data in tidal datums in these regions, as well as resultant coastal DEMs.

References

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