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Development of a High Resolution (0.02° x 0.02°) Regional Bathymetry for the Gulf of Mexico

November, 2011

1 Introduction

Recent research goals require the use of a more accurate and of higher resolution bathymetry for the general area of the Gulf of Mexico. This bathymetry will be an integral part of a Gulf of Mexico prediction system (under development). Luis Zamudio-Lopez (*NRL*, Luis.Zamudio@nrlssc.navy.mil) kindly offered an initial $1/100^{o}$ (~ 1000 m) bathymetric grid for the region, as shown in Figure 1. This grid has been computationally modified and substantially hand edided *(a)* to better match the shoreline definition, *(b)* fill the voids in the water depths and *(c)* if possible, to more accurate represent the interpolated water depths. The produced $1/50^{o}$ bathymetry (Figure 2) conforms to the $1/25^{o}$ (~ 4000 m) North Atlantic *HYCOM* computational domain, where they are both matched at 76.40^{o} W longitude. The $1/50^{o}$ bathymetry was further locally smoothed to produce the final version of the $1/50^{o}$ bathymetry (Figure 3). The difference between the un-smoothed and the smoothed $1/50^{o}$ bathymetries is shown in Figure 4.

Three different databases were used for the development of the new grid: *(a)* a high resolution shoreline definition (*GSHHS*: A Global Self-consistent, Hierarchical, High-resolution Shoreline Database, http://www.soest.hawaii.edu/pwessel/gshhs/), *(b)* the *GEBCO* 30 arc-sec global grid (http://www.gebco.net/data_and_products/gridded_bathymetry_data/) and *(c)* the National Geophysical Data Center's (*NGDC*) 6 arc-sec U.S. Coastal Relief Model database, volumes: 2, 3, 4 and 5, http://www.ngdc.noaa.gov/mgg/coastal/crm.html. The incorporation of these three databases in the development of the new Gulf of Mexico grid, as well as the interpolation method for the determination of the water depths in the domain are described in Section 2.

The available data files, plots and documentation are contained in the following directory structure:

gom2kbath –> The root directory under which the various files and directories are stored.

data –> This sub-directory contains the data files for the *GoM* 0.02^{o} bathymetry (total size 64 MB).

gom_bath-header-2kHC.dat : the header definitions for the bathymetry (e.g., idm, jdm, plon(max/min), qlon(max/min), etc. (ascii, *HYCOM* conformant).

gom_bath-latlon-2kHC.dat : the data for the longitude/latitude values (unformatted, big endian, *HYCOM* conformant).

gom_bath-depth-2kHC.dat : the data for the water depths (unformatted, big endian, *HYCOM* conformant).

plots –> This sub-directory contains the map plots for the bathymetry (total size 97 MB).

plots_grid –> This sub-directory contains plots for the grid points of the bathymetry. They are used to determine how well the grid matches the shoreline and to aid a further correction/adjustment of the grid (if needed). The postscript files are named as: gom_area00_MINLON-MAXLON_MINLAT-MAXLAT .eps (i.e., the domain has been divided in 24 areas, total size 93 MB).

bath2k_guide.pdf –> The manual of the developed *GoM* 0.02^{o} bathymetry (this file).

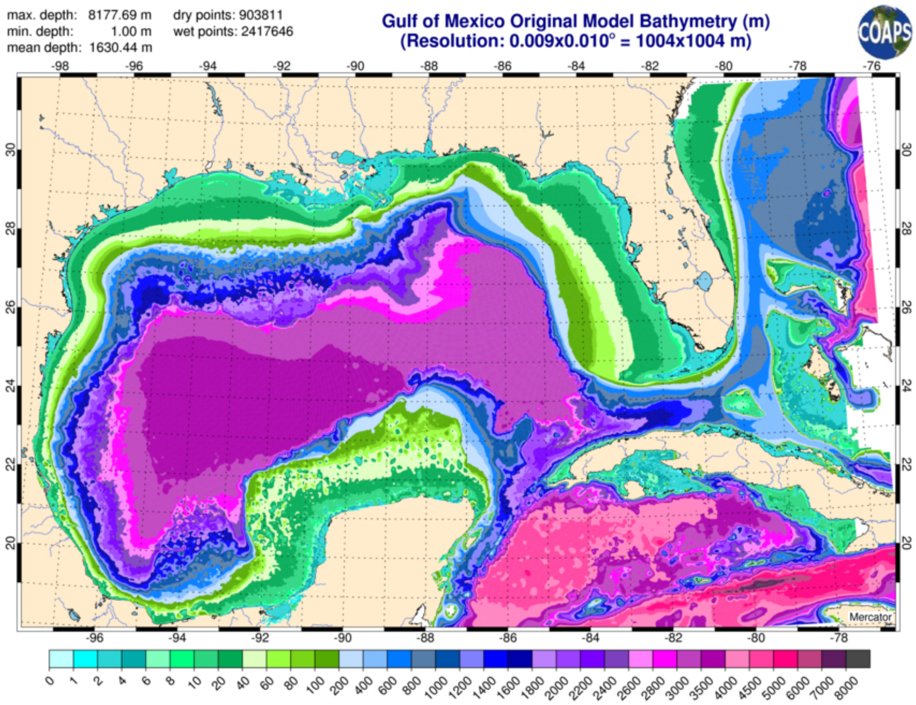

Figure 1 Gulf of Mexico 1/100 $^{\mathrm{O}}$ original bathymetry.

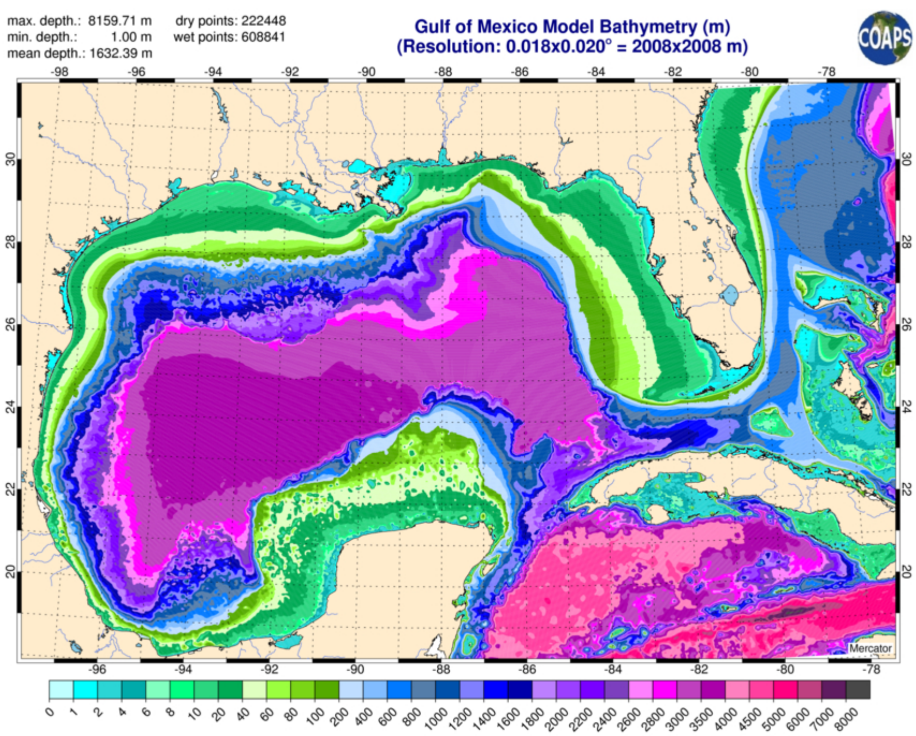

Figure 2 Gulf of Mexico 1/50 $^{\mathrm{O}}$ bathymetry.

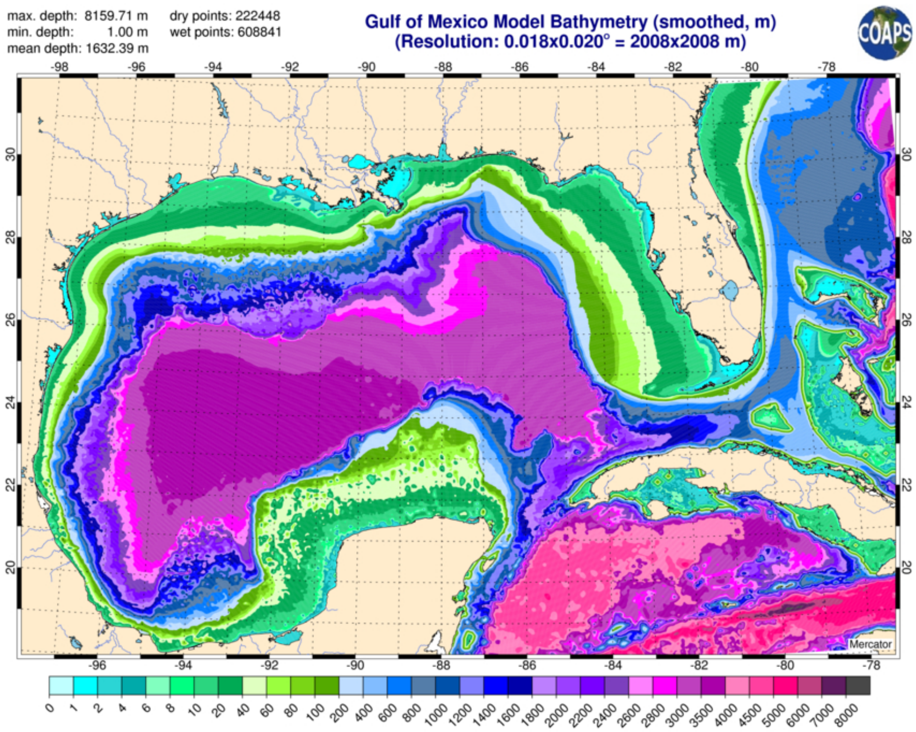

Figure 3 Gulf of Mexico $1/50^{\mathrm{o}}$ final bathymetry.

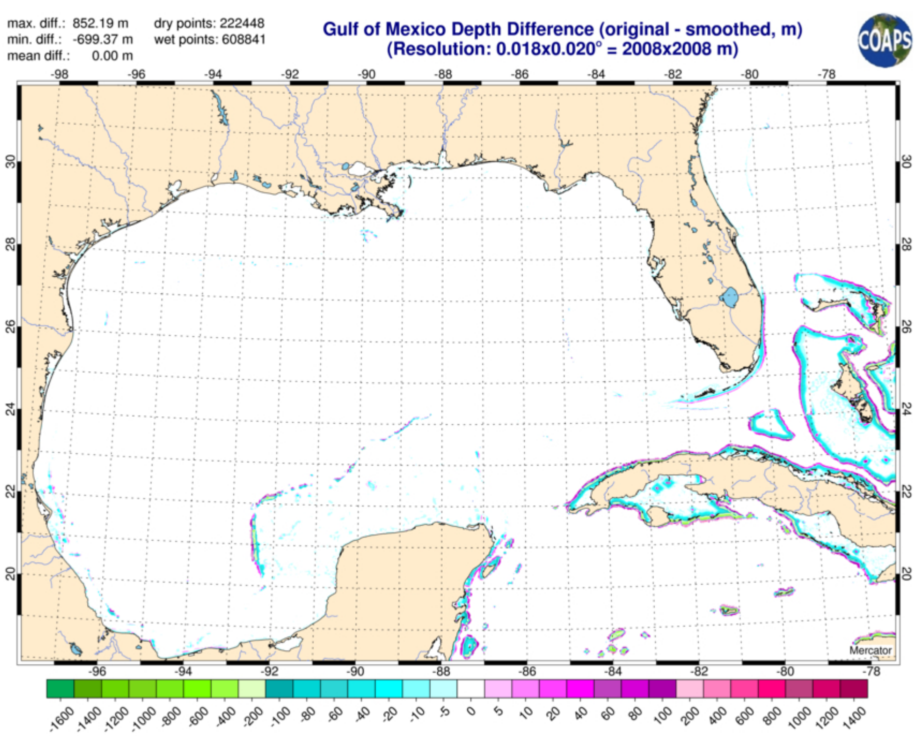

Figure 4 Difference between the un-smoothed (Fig. 2) and the smoothed (Fig. 4) bathymetries.

2 Technical Details

The three databases described in Section 1, to the best of my knowledge, are based on the *MSL* vertical datum and the *WGS-84* ellipsoid. The *GEBCO* 30 arc-sec data for *GoM* were extracted from the *GEBCO* global grid using their online delivery tool: https://www.bodc.ac.uk/data/online_delivery/gebco/select/ (registration and login is required). The *NGDC* 6 arc-sec U.S. Coastal Relief Model data were extracted using their online *GEODAS* Grid Translator - Design-a-Grid tool (http://www.ngdc.noaa.gov/mgg/gdas/gd_designagrid.html). These two databases overlap in the *GoM* area as shown in Table 1.

Database	Min λ ($^{\text{o}}$)	Max λ ($^{\text{o}}$)	Min ϕ ($^{\text{o}}$)	Max ϕ ($^{\text{o}}$)	Mean $\Delta\lambda$ ($^{\text{o}}$)	Mean Δx (m)	Mean $\Delta\phi$ ($^{\text{o}}$)	Mean Δy (m)
GEBCO, *GoM*	−99.0000	−74.0083	16.0083	33.0000	0.0083	840.0751	0.0083	926.6245
NGDC, vol. 2	−82.0000	−75.0000	31.0000	33.0000	0.0017	157.1564	0.0017	185.3249
NGDC, vol. 3	−87.0000	−78.0000	24.0000	31.0000	0.0017	164.2829	0.0017	185.3249
NGDC, vol. 4	−94.0000	−87.0000	24.0000	31.0000	0.0017	164.2829	0.0017	185.3249
NGDC, vol. 5	−98.0000	−94.0000	25.0000	31.0000	0.0017	163.5572	0.0017	185.3249

Table 1 Area coverage of the bathymetric databases

The Cartesian Coordinate System used, is the usual *ENU* system that is, the x coordinate incearses from West to East and the y coordinate increases from South to North. z is the "up" direction in the *ENU* system.

2.1 Development of the Numerical Grid

The shoreline used in the present work (Figures 1-4) was extracted from the full *GSHHS* database (Wessel and Smith [1996]) such that the lowest area limit of the shoreline features (e.g., islands) was set to 4 km^2 thus, ensuring that the numerical grid can resolve these features by applying the 2-grid point rule in each direction.

In the first stage of the development, the shoreline segments (polygons) for the *GoM* area were extracted from the *GSHHS* database and then were fed into an *IDL* program to determine the majority of the land points in the field. In the second stage, significant "hand editing" was applied to fine-tune the final grid and to make sure that the resulting grid exhibits the best possible match to the shoreline (e.g., see Figure 5).

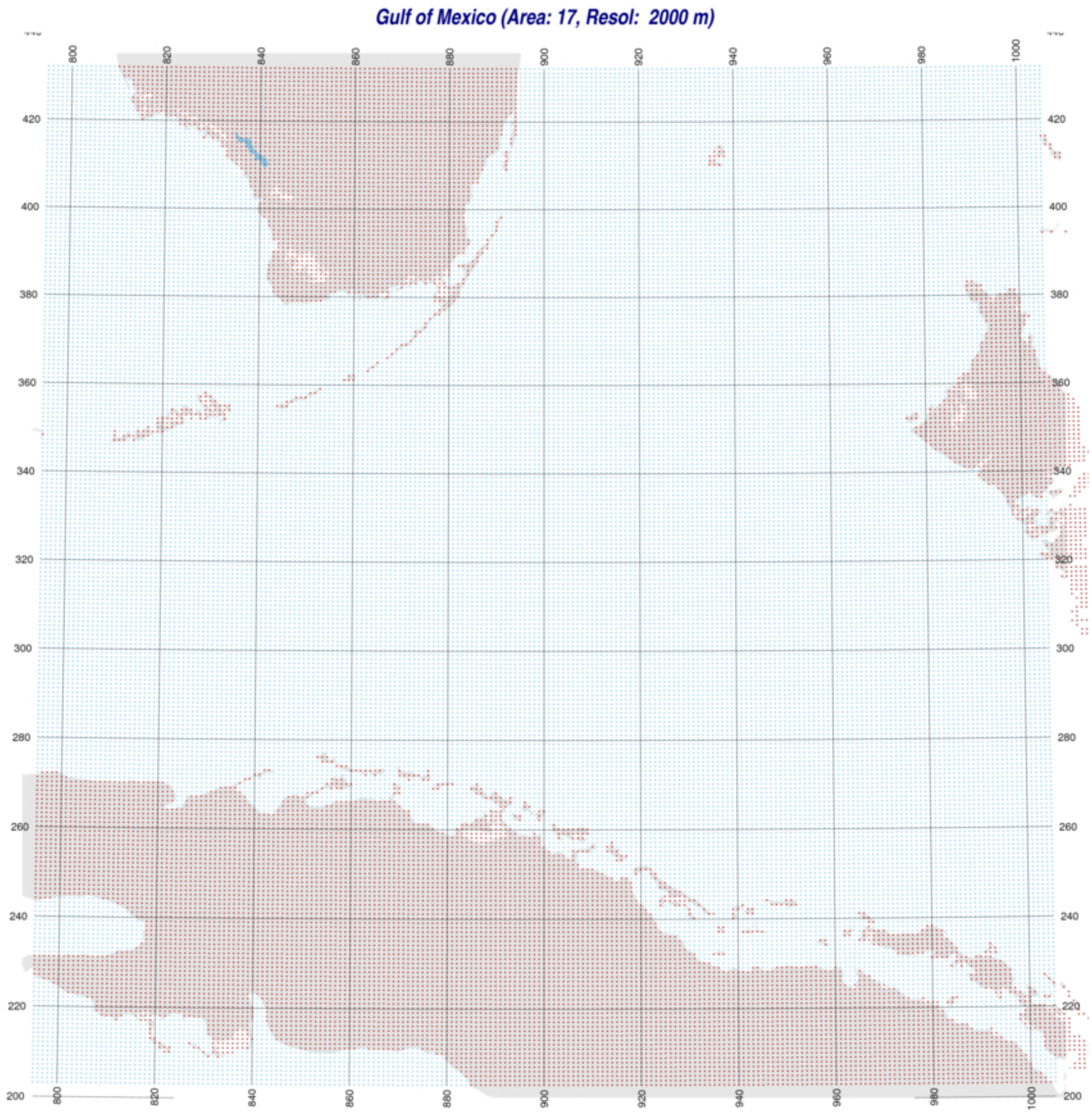

Figure 5 Gulf of Mexico Grid: Florida Keys.

2.2 Determination of the Water Depths

Upon completion of the numerical grid, the water depths were determined by applying a Natural-Neighbors (*NN*) Interpolation algorithm (Sibson [1981], Sambridge et al. [1995]). The original *Fortran/C* code was obtained from Dr. M. Sambridge (personal communication) and his contribution is gratefully acknowledged (http://rses.anu.edu.au/geodynamics/nn/nn.html). The code has been modified such that can be called from within *Fortran*, *C* and *IDL* programs.

For a "wet" grid point, an effective area of radius of 1 km^2 was searched to determine, at most, the 9 nearest points with water depth values from the two bathymetric databases. Depending upon the proximity of the grid point to the area covered by the databases (see Table 1), one or both of theses databases were used during the interpolation, ensuring a smooth transition between databases. The discovered points were then perturbed slightly to avoid co-linearity. After the last step, the *NN* was applied to determine the water depth at the grid point. The process was continued until all "wet" grid points were exhausted.

In general, the above process due to the high resolution of the bathymetric databases, was producing 6-9 available points to be used in the *NN* interpolation. In case, that the search was producing 3 or less available points, the fall-back interpolation method was the Inverse Distance or the Nearest Neighbor interpolation (never occured though).

3 Natural-Neighbors Interpolation

The *NN* is essentially a weighted area interpolation that has been successfully applied for the interpolation of scattered or arbitrarily distributed meteorological, oceanographic and geophysical data for many years, generally producing smooth and accurate interpolations of the field. Some properties of the *NN* interpolation are that: *(a)* the original observed or measured variable values (F_i) are recovered exactly at the sampling points; and *(b)* the interpolated function has continuous derivatives, except at the sampling points (Sambridge et al. [1995]).

The method is applied here by constructing Delaunay triangles and their dual Voronoi cells (known in 2D spaces as Thiesen polygons) for the given data set using the Watson triangulation algorithm. Natural neighbors of any sampling point are considered: *(a)* the sampling points in the neighboring Voronoi cells, and *(b)* the sampling points to which it is connected by the sides of the Delaunay triangles. Each sampling point has only one Voronoi cell (known as first order Voronoi cell) associated with it.

The 2D horizontal domain is partitioned by assigning each grid point (x, y) to the nearest sampling point or observation station (S) such that:

$$\text{Voronoi Cell} = \{(x, y) : |S_i - (x, y)| \leq |S_j - (x, y)| \quad \text{for all } j \neq i\} \tag{1}$$

Each grid point also has only one Voronoi cell (known as second order Voronoi cell) associated with it. The Natural Neighbor interpolation on the given grid is local and influenced only by its natural neighbor Voronoi cells. The interpolated values $F(x, y)$ are calculated from the observed values F_i using the following equation:

$$F(x, y) = \sum_{i=1}^{N} w_i(x, y) F_i \tag{2}$$

where $i = (1, N)$ represents the index of the neighboring sampling points or observation stations, $w_i(x, y)$ represents the weight functions and F_i is the observed value at the neighboring Voronoi cell "i". Full details of the method can be found in Sibson [1981], Watson [1992] and Sambridge et al. [1995].

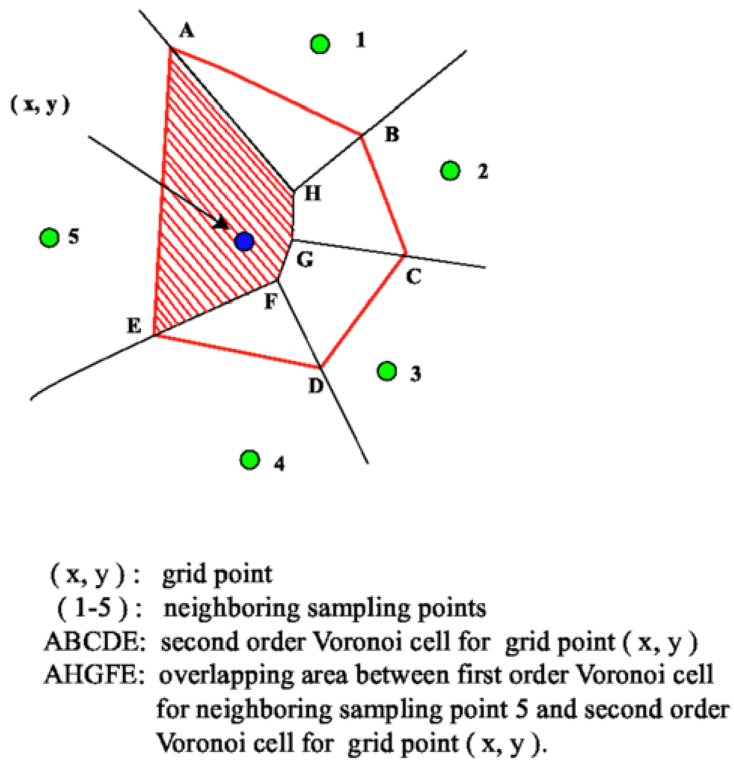

Figure 6 Definition of the Natural Neighbor interpolation weight functions.

The weight functions are defined as the area of overlap between the second and the first order Voronoi cells (see Figure 6). Mathematically, the weight functions are defined as:

$$w_i(x, y) = \frac{A_i(x, y)}{A(x, y)} \tag{3}$$

Using the above definition of the weight functions equation 2 is written as:

$$F(x, y) = \sum_{i=1}^{N} \frac{A_i(x, y)}{A(x, y)} F_i \tag{4}$$

where $A_i(x, y)$ is the overlapped area of the first order Voronoi cell "i" and the second order Voronoi cell for the grid point (x, y) and $A(x, y)$ is the total area of the second order Voronoi cell for the grid point (x, y). The definition of the weights implies that $\sum_{i=1}^{N} w_i(x, y) = 1$.

The Natural Neighbor interpolation method produces smooth interpolated fields. Physically, the smoothness of the interpolated data set is necessary to avoid sharp gradients, however, the accuracy of the final gridded surfaces is not related to the degree of smoothness of the interpolated field, but rather to the correct determination of the weight functions.

References

1. M. Sambridge, J. Braun, and H. McQueen. Geophysical Parameterization and Interpolation of Irregular Data Using Natural Neighbors. *Geophysical Journal International*, 122:837–857, 1995.
2. R. A. Sibson. *A brief Description of Natural Neighbor Interpolation, in Interpreting Multivariate Data*. John Wiley, New York, 1981.
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4. P. Wessel and W. H. F. Smith. A Global Self-consistent, Hierarchical, High-resolution Shoreline Database. *Journal of Geophysical Research*, 101:8741–8743, 1996.