Merging Multiple Digital Elevation Models to Create Seamless Terrain Applied to Maine and the Atlantic Maritimes.

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Abstract

USGS Digital Elevation Models (DEMs) are the primary resource for relief cartography in the United States. However, for US states that share an international border this common resource fails to allow cartographers to illustrate the geographic area beyond the US political boundary at a similar resolution. Our specific task was to create an editable terrain model for use in the *Historical Atlas of Maine*, a current research project at the University of Maine. The *Atlas* project demanded a high resolution, editable, scalable raster base image suitable for vector overlays in a Macintosh desktop publishing environment. To satisfy these criteria we merged multiple DEM resources to create a continuous coverage. These resources include GTOPO30 data , USGS1:250,000 DEMs, and digital bathymetry for the Gulf of Maine. Applied to Maine, this allows the state to be illustrated in its true geographic relationship with Quebec, New Brunswick and Nova Scotia. By merging multiple raster models we accentuate the best attributes of each resource while minimizing their deficiencies. This allows the map reader to better visualize the complexities of Maine's coastal geography and its relationship within the Atlantic Maritimes.

KEYWORDS: Digital Elevation Model, bathymetry, cartography, Maine, Gulf of Maine, Canada.

Introduction to Maine's Geography

Maine is truly the last frontier of New England. In many ways Maine is more a part of Canada than the lower 48, yet cartographically Maine is often illustrated with no Canadian context. This is unfortunate, as the geography of the Atlantic Maritimes is just beginning. As place, Maine enjoys a heritage rich with myth and lore, a mysterious geography of sacred mountains, interconnected streams and lakes, and a rugged, granite coastline peppered with islands.

It is the intricate coastline and island relationship that defines Maine in so many ways: historically, culturally and economically. Yet, cartographically, these are the very elements that are often missing. The exact numbers of islands has been speculated and disputed for centuries, and modern literature will often reference Maine as having "more than 2,500 miles of coastline and about 3,000 islands". Which are more islands than the rest of the entire US eastern seaboard (Conklin, 1981).

Modern science, using aerial photographs and GIS technology, has yielded specific numbers that are considerably larger. Maine has a linear coastline of approximately 250 miles, but the actual, continuous coastline of the mainland measures 4,568 miles. Add the coastlines of the 4,617 islands, and the total measures 7,039 miles (Conklin, 1999).

Yet Maine is often portrayed cartographically with as few as a dozen islands, and on occasion with none.

Knowing that cartographic design plays a key role in people's perception of place, we wanted to build a relief model that could illustrate the tremendous fragmentation and perforation of such a coastline. Recalling the advice of my cartographic mentor, David DiBiase, who summarized quality map design in one word: "richness". Realizing that generalization principles would have to be applied, the goal was to minimize data loss and convey the sense that there were indeed more islands, coves, bays, inlets and estuaries than one could count. If the map could provide, at minimum, a sense of the intricate texture of true landscape, perhaps the map reader could absorb that sense of place.

Digital Elevation Resources

The common international public domain DEM is GTOPO30, useful because it illustrates Maine in context with Canada (Figure 1). The problem with using it as a primary model is its resolution is too coarse for Maine's intricate coastline and island topography .
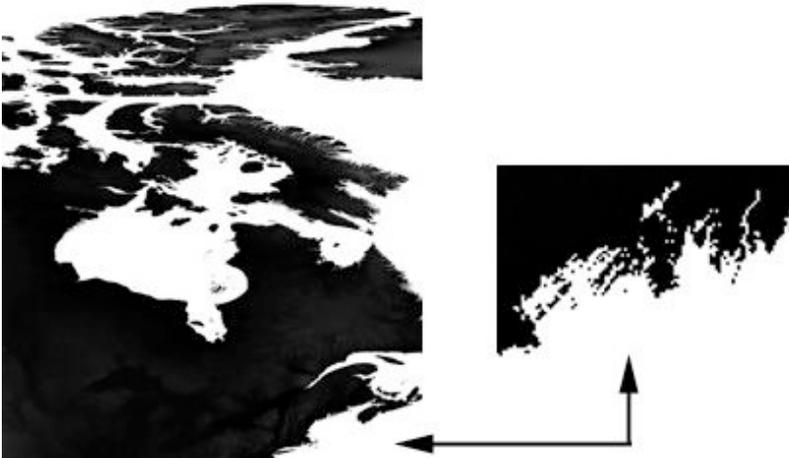

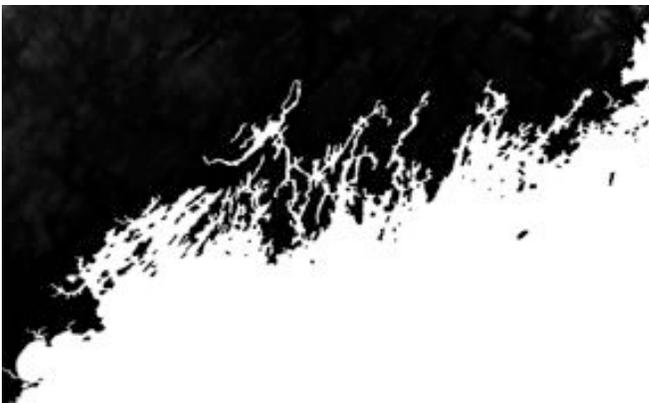Figure 1. Raw GTOPO30 tile with close-up of Casco Bay illustrating low resolution.

Figure 2. USGS 1:250,000 DEMs of Casco Bay illustrating higher resolution.

The USGS 1:250,000 DEMs are a higher resolution resource which overlap onto Canadian land (Figure 2). This data set offers a good political illustration of the differences in availability of US and Canadian digital map data. The USGS1:250,000 paper maps extend deep into Quebec and New Brunswick, yet the DEM tiles are split in half, and the side that does not include US land is not available (Figure 3). Except for one, Eastport, which includes the southwestern tip of Nova Scotia. Peculiar, perhaps, but cartographically this proves very helpful for registering data.
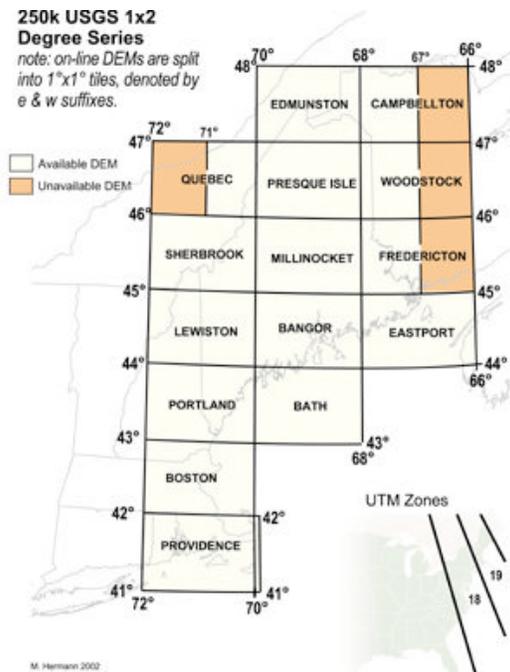

Figure 3. Available coverages of USGS 1:250,000 scale maps of Maine.

It appears USGS has the data, but for political reasons chooses to withhold it. This is due to the very different way our northern neighbors handle distribution of cartographic data. The Canadian Government sells digital data at relatively expensive rates that remain copyright protected with use limitations.

The USGS 1:24,000 DEM's would provide the highest level of detail, but the sheer volume overwhelms their use. 709 tiles comprise Maine, and they will be used extensively throughout the *Atlas* project, but they are not manageable as a statewide model.

The Maine State Office of GIS (MEGIS) provides 1:100,000 vector coverages in UTM projection. This will be a primary data element for the Atlas, and must be compatable with the raster models. USGS 1:250,000 and GTOPO30 data is in a Plate Carree projection, also called 'geographic'. In laymans terms, the UTM projection is the 'long skinny Maine,' and the geographic projection is the 'short fat Maine' (Figure 4). The DEMs were not compatable with the vector data.
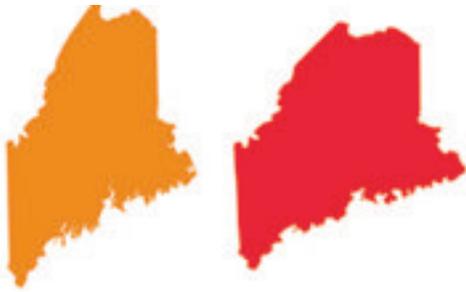
Figure 4. Conflicting data projections.

This disparity causes a workflow problem for cartographers with limited GIS capability. Reprojection of raster data remains a technological hurdle for map publishers designing on desktop computers. It would be beneficial if the USGS made both 1:250,000 and GTOPO30 data available in the same projection (UTM) to match data commonly posted by state level offices. This simple coordination will greatly enhance the usability of the data by non-GIS production cartographers.

Jim Sloan, a cartographer and GIS instructor at the University of Florida, reprojected the DEM data to UTM using Arc Info. Sloan also reprojected digital bathymetry of the Gulf of Maine that oceanographers E. Roworth and R. P. Signell at USGS Woods Hole created and made available on-line. http://pubs.usgs.gov/openfile/of98-801/ Sloan provided ASCII Grid files of the three DEMs (Figure 5).

Figure 5. GTOPO30 data, cropped at 40° to 55° North by 60° to 78° West and reprojected in UTM.

The Design Process

With multiple raster data sets available in the same projection as ASCI Grid files, we could use MacDEM beta 9.5, in which author Jerry Farm added the importation capability of ASCII Grid data, a common export from ESRI software.

In MacDEM we created a seamless color palette for all models and exported as tiff images. Traditional cartographic relief color schemes rely on a series of yellows and browns to imply higher elevations. While perhaps applicable in the southwestern regions of the US, this model is not realistic for New England. These mountains are called the White Mountains, and the Green Mountains, for a reason. We wanted the color schemes to reflect that vernacular geography. For specific use as historical agricultural base maps, we emphasized Maine's primary farmlands at elevations below 600 ft, hence the richer green hues (Figure 6).
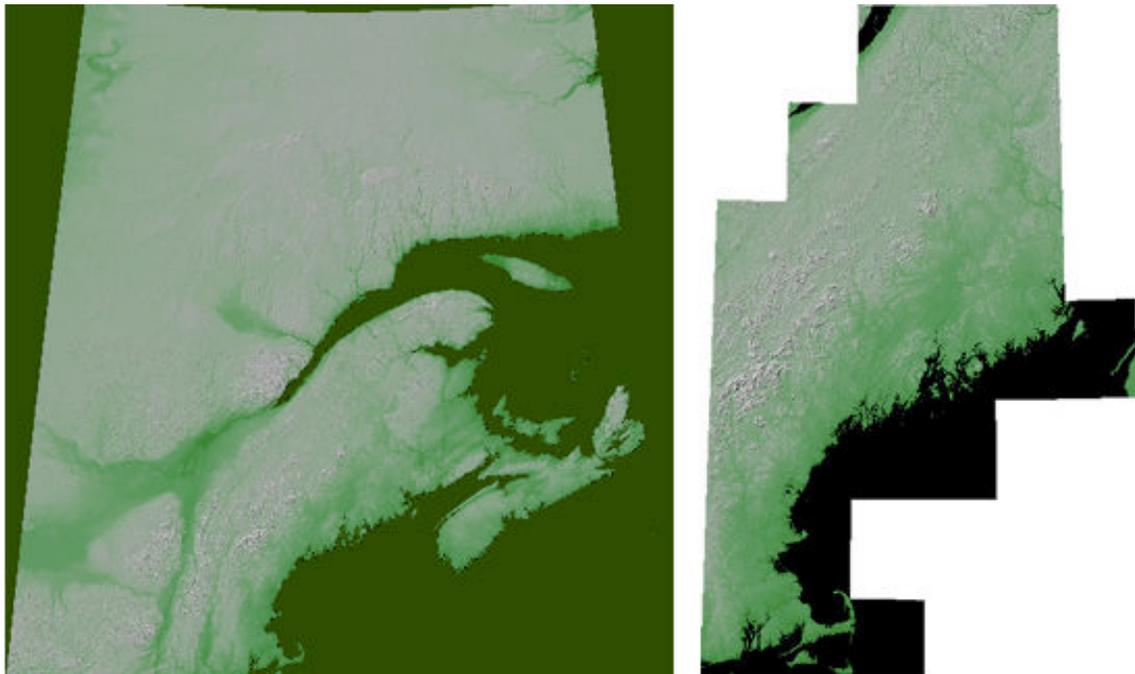

Figure 6. GTOPO30 (left) and USGS 1:250,000 (right) DEMs hillshaded and colorized in MacDEM.

Bathymetry   Models

The bathymetry models presented a different design challenge. We wanted to see bathymetry, but had to exaggerate the model to provide adequate visualization. We merged two models created individually in MacDEM: one with no vertical exaggeration and one exaggerated by a factor of eight. In Photoshop they are layered with the 8x model as the base layer, and using the opacity slider a transparency is achieved using the zero-exaggeration model as a lens (Figure 7).

Figure 7. MacDEM model of the Gulf of Maine, with 8x vertical exaggeration on left, no exaggeration in middle, and merged model on right.

Registering Raster Models in Photoshop

The registration process within Photoshop is a bit abstract. One must open the individual models in Photoshop and scale them to similar sizes. To do this, consider both physical size and resolution because Photoshop will make all composite layers the same resolution. It is necessary to get these files close in size before importing, or pixelation and data loss will occur. This is done through trial and error. We rapidly found ourselves working with a 1 gigabyte model (Figures 8, 9, 10).

For cartographers who work exclusively with GIS, this workflow appears crude and unscientific. They may be accustomed to having the software perform the registration. Scaling by eye has been a basic registration workflow from the beginning of digital cartography by using tiff images as basemaps for applied vector coverages. This can result in a well registered and extremely versatile image. However, applied to raster terrain models the registration becomes a bit more complicated. Recall the 1:250,000 data included the tip of Nova Scotia (Figure 11). This combined with Cape Cod, and the St. Lawrence Seaway, become the key triangulation registration points for this model. Using Photoshop to Transform/Numeric one can scale by tenths of a degree to pursue perfect registration.
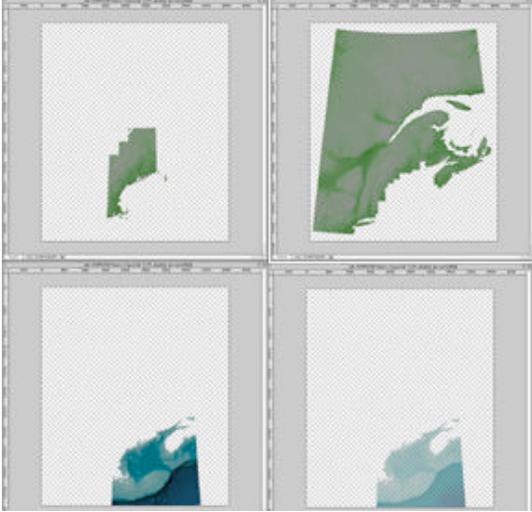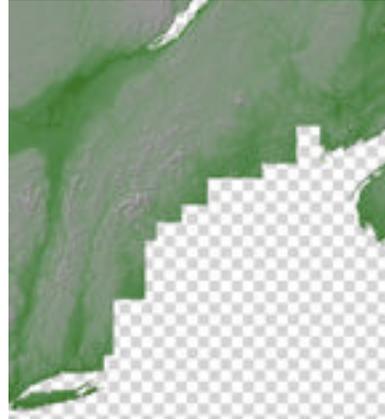
Figure 8

Figure 9

Figure 8. The four DEMs as they appear in Photoshop, each DEM on an individual layer prior to flattening.
Figure 9. A close-up of the GTOPO30 model with the coastline cropped. The coarse resolution of the GTOPO30 coastline becomes irrelevant after registration when sections are deleted to avoid misrepresentation when merged with the detailed USGS 1:250,000 DEMs.

Figure 10. The composite of all four layers.

Figure 11. Best fit example – now the aesthetic design work begins using Photoshop's full suite of image editing tools. The seam is visible on land but can be quickly dissolved. The helpfulness of the Eastport DEM for registration can be seen in the seam on Nova Scotia.

Registering the land to bathymetry is not as seamless. White areas just a few pixels across represent areas of no data – meaning they may be land or water. This can be addressed two ways: one works well and the other works extremely well. To choose the former, simply select the inverse of the bathymetry data (in the layered Photoshop file) and make that the same color as the lightest color of the bathymetry. This is fast and works reasonably well for small scale use, but the islands and coastlines are compromised. To make the model work exceptionally well, we overlay a detailed vector coastline layer as a reference and use a variety of Photoshop tools to individually address discrepancies at the pixel level. The smudge and airbrush tools are valuable, especially when the pressure settings are set at very low thresholds. Use the rubber stamp tool carefully as it can leave visible artifacts. When working with water, think like water: avoid the tendency to parallel the coastline. Instead, move back and forth the way the tide flows, and be sure to zoom in to the pixel level. Tedious work, certainly, but the realistic results are worth it. For this project, that process took several days, and continues to be refined as we work with the model (Figure 12).
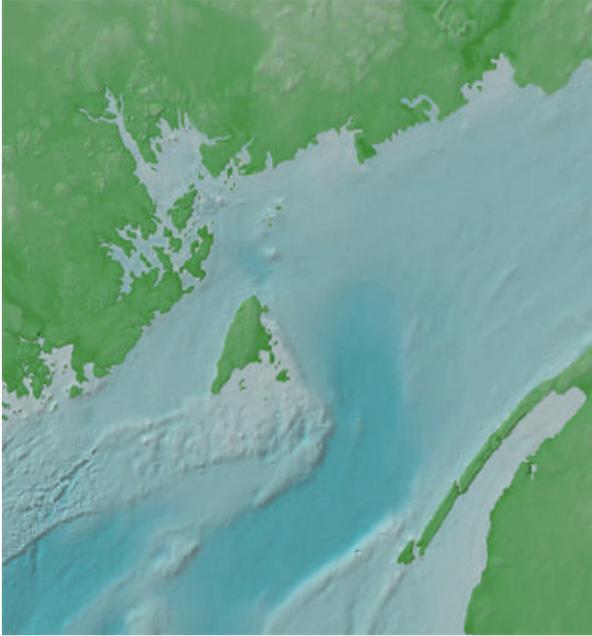
Figure 12. Detail work completed, the coarseness of the GTOPO30 data is minimized, and the base model is ready for vector overlays.

Conclusion

By combining multiple models we have developed a high quality and versatile terrain image to represent Maine (Figure 12). The raster models are now ready for vector overlays such as political boundaries, hydrography and cultural data. The acquisition and clean-up of the vector data is a separate process and presents a different set of design challenges. The *Historical Atlas of Maine* continues to develop as a work in progress on many fronts. These terrain models will serve as the foundation of the cartographic design throughout that effort. It is our hope that we have illustrated Maine's geography in a way that fosters visual exploration without misrepresenting the complexities of this unique area.

Figure 12. Southern section of Hermann's model combining GTOPO30, USGS 1:250,000 DEM, Roworth and Signell's bathymetry data in a Macintosh desktop publishing environment.

Bibliography

Islands in Time, P. Conklin 1999

Resources:

GIS data for Maine:
	http://apollo.ogis.state.me.us/
GTOPO30 data:
	http://edcdaac.usgs.gov/gtopo30/gtopo30.html
Woods Hole digital bathymetry of the Gulf of Maine
	http://pubs.usgs.gov/openfile/of98-801/