PROCESSING GLOBAL SELF-CONSISTENT HIERARCHICAL HIGH-RESOLUTION SHORELINE (GSHHS) DATA VERSION 1.2 INTO ESRI ARCGIS VECTOR AND RASTER DATA

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Abstract

This paper details processing of publicly available Global Self-consistent Hierarchical High-resolution Shoreline (GSHHS) Data Version 1.2 into vector and raster GIS data layers which dichotomise Earth's surface into those areas which are primarily land and those which are primarily water. In the most disaggregate form five different classes are distinguished: ocean (water0); land bounded by ocean (land0); water bodies contained and bounded by land0 (water1); land contained and bounded by water1 (land1); water bodies contained and bounded by land1 (water2).

GSHHS data Version 1.2 (GSHHS_1.2) was released on the 18th of May 1999 and made available on-line, in two formats, via the following URL:

> http://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html

Our processing of GSHHS_1.2 was done using the ESRI Shapefile format data. Whilst processing these data we realised that GSHHS data Version 1.3 (GSHHS_1.3) had been released on the 1st of October 2004. GSHHS_1.3 is available in a binary format that can be readily converted to an ASCII format using GSHHS and Generic Mapping Tool (GMT) Version 4.0 software. GSHHS and GMT software that are freely distributed from the following URLs:

> http://www.soest.hawaii.edu/wessel/gshhs/gshhs.html
> http://gmt.soest.hawaii.edu/

In online documentation it is claimed that the changes from GSHHS_1.2 to GSHHS_1.3 are minor: Lingering crossovers, duplicate points and unclosed polygon problems have been resolved for about 50 polygons. Major errors in the Puget Sound coastline have also been corrected. Pre-processing GSHHS_1.3 became a priority during the writing of this paper. This work is being detailed in a subsequent working paper. During the course of this work, various issues to do with coordinate precision were identified.

The pre-processed GSHHS_1.2 detailed in this paper are obsolete given that pre-processing of GSHHS_1.3 is now complete, although there may still be some academic

interest in comparing them. Pre-processed GSHHS_1.3 data that are in a compressed ESRI ArcGIS interchange vector format have been made available at the following URL:

http://www.geog.leeds.ac.uk/people/a.turner/data/gshhs1.3_dd.zip

We encourage users of these to consider their uncertainty and report errors to the developers and maintainers of the GSHHS data. They are also encouraged to think about how the data sets can be enhanced as an online resource. Any feedback is gratefully received.

Contents

Acronyms

ArcGIS	ESRI GIS
CSI	Consortium for Spatial Information
DCW	Digital Chart of the World
DD	Decimal Degrees
DM	Decimal Minutes
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System(s)
GMT	Generic Mapping Tool
GRASS	Geographic Resources Analysis Support System
GSHHS	Global Self-consistent Hierarchical High-resolution Shoreline
GSHHS_1.2	GSHHS Data Release Version 1.2
GSHHS_1.3	GSHHS Data Release Version 1.3
LAW	Land/Air/Water
NASA	National Aeronautics and Space Administration
NGA	National Geospatial-Intelligence Agency
NGDC	National Geophysical Data Center
NOAA	National Oceanic and Atmospheric Administration
SRTM	Shuttle Radar Topography Mission
USGS	Unites States Geological Survey
WDB	World Data Bank
WVS	World Vector Shoreline

1. Introduction

The main reason for this work was a demand for a water/non-water mask that we could readily use to process high resolution digital elevation data from the Shuttle Radar Topography Mission (SRTM). This elevation data has been made available, primarily by National Aeronautics and Space Administration (NASA 2004), the United States Geological Survey (USGS 2003a, 2004), and by secondary distributors in various re-processed formats from (CSI-CGIAR 2004; GLCF 2004; Jarvis *et al.* 2004).

SRTM data are available in a geographical projection at a number of resolutions. The data are estimates of above mean sea level elevations. Global SRTM data sets from latitudes of approximately 60°S to 60°N at a resolution of 3 arc seconds are available. There are two types of these data: the 'research grade'; and, the 'finished' (USGS 2003b). Research grade SRTM data have not been processed with a detailed land/water mask although a coarse mask has been used in pre-processing 'research grade' data to remove most estimates for those cells (small surface regions) that are generally covered by water, i.e. ocean, seas and lakes.

For a number of reasons, a more detailed land/water mask is required for these data. This paper describes our attempts at processing the Global Self-consistent Hierarchical High-resolution Shoreline (GSHHS) Database Version 1.2 (Wessel and Smith 1996; NGDC 1999) to provide such a mask.

This paper details the creation of two ArcGIS data layers, one vector and one raster. Each data layer has 5 distinct classes. Each polygon or raster cell is assigned one (and only one) of these classes to form a continuous global surface. These classes are:
- ocean (water0);
- land bounded by ocean (land0);
- water bodies contained and bounded by land0 (water1);
- land contained and bounded by water1 (land1);
- water bodies contained and bounded by land1 (water2).

The resulting GIS data layers are thus crisp and continuous. However, natural Earth surface boundaries between land and water are not crisp, they are inherently fuzzy, and

they change over time. Water levels rise and fall, the depth of water bodies varies, land is eroded and created, solid surfaces can be smooth or highly variable, vegetation can grow and float and die and ice can do similar things. The solid surface of Earth is also three dimensional and is in places multilayered, for example; where there are bridges, or overhanging cliffs. Indeed when considered in detail there is a third body that interface, that of the air, really this paper examines data on the boundaries between land, water and air.

Natural variation in land/air/water (LAW) boundaries make it impossible to accurately or precisely define it with a single discrete raster or vector data layer in two spatial dimensions. Furthermore, there is geographical variation in the uncertainty (fuzziness) of LAW boundaries: in some areas water levels rise and fall more; water is shallower; solid land surfaces are more bumpy or variable; or, vegetation/ice is more of an issue.

Uncertainty in the spatial definition of land and water bodies complicates efforts to produce a crisp and continuous two dimensional area classification. On the boundaries this complication becomes more difficult to handle (which is a major problem), yet small areas in general are more readily classed as the resolution and precision of data increases. Although the general issues of data uncertainty and their relationship with data classification, resolution and scale data are important, they are not examined in this paper. The source data are already classified and their uncertainty is not considered in any quantified way. The pre-processing steps outlined here were compiled with the aim of producing data with only a minimum of added uncertainty.

Although the issue of uncertainty is not explicitly addressed in detail in this paper, there are implications with respect to the precision and resolution of the data and these are important and relevant to the pre-processing detailed herein and so should be kept in mind. Much that can be done to enhance the data described in this paper, both the source data and the pre-processed data derived from it. A useful layer that could accompany the pre-processed or derived raster data is a surface at the same resolution that estimates the uncertainties in its classification. Additionally, the data could be made available in the form of two coincident raster layers: one an estimate of the likelihood that more than a fixed proportion of a cell had a water/air boundary, and the other an

estimate of the likelihood that more than a fixed proportion of a cell had a land/air boundary.

Originally we planned to make the pre-processed GSHHS_1.2 GIS data layers described in this paper available on-line, however the release of GSHHS Version 1.3 (GSHHS_1.3) and our pre-processing of these have made these data somewhat obsolete. This paper really only serves as documentation for our referral to help us detail further work.

Section 2 details the GSHHS source data. Section 3 details the processing and the resulting GIS data layers produced.

2. GSHHS source data details
Version 1.2 of the GSHHS database (GSHHS_1.2) was released on the 18th of May 1999 and made available on-line (NGDC 1999). These data were originally amalgamated from two data bases in the public domain:

1. The World Data Bank II (WDBII) containing coastlines, lakes, political boundaries, and rivers. These data have an approximate working scale of 1:4 million (or an accuracy of 400m), meaning these features are considered to be accurately located on maps using this scale or smaller (Gorny and Carter 1987).
2. The World Vector Shoreline (WVS) data containing shorelines along the ocean/land interface. These data have an approximate working scale of 1:1 million and an accuracy of 100m (Soluri and Woodson 1990; Feistel 1999).

Both the precision and quality of the WVS data are estimated as being an order of magnitude better than the WDBII data, Wessel and Smith (1996). It is reasonable therefore that the WDBII data were mainly used for lakes since these do not appear in the WVS data, and the WVS data was used in the main. Consequently users of these data working on areas that have lakes should take note and treat the data with greater caution.

The WVS and WDBII source data have undergone extensive processing and although GSHHS Version 1.3 (GSHHS_1.3) corrects a few internal inconsistencies such as erratic points and crossing segments, Version 1.2 is largely free of such things. Wessel and Smith (1996) detail the processing and assembly of the GSHHS data.

The main source material for the WVS was the Digital Landmass Blanking (DLMB) data which was derived primarily from the Joint Operations Graphics and coastal nautical charts produced by the Defence Mapping Agency of the United States of America, (Soluri and Woodson 1990). The DLMB data consists of a land/water flag file on a 3 by 3 arc-second interval grid. Perversely, this is something very similar to what the pre-processing described in this paper attempts to reproduce. Unfortunately, the DLMB data was not found to be available on-line.

At the time of writing GSHHS_1.2 was available online in two formats. The processing described in Section 3 involved the processing of the ESRI Shapefile data where the coordinates are believed to have been originally stored with so called *single precision* accuracy. This precision guarantees that the first seven significant digits of any coordinate are correct, and is referred to hereafter as ESRI single precision. (ESRI double precision guarantees that the first fifteen significant digits are correct.) The ESRI Shapefile data had a total size of 197,924,878 bytes

The alternative binary format of the GSHHS_1.2 available on line is in ways more sophisticated (more compact and less uncertain) and in retrospect this should have been used instead of the ESRI Shapefile data version. It is likely that the Shapefile version GSHHS_1.2 was pre-processed from the binary data, but no documentation has been found. Freely available software can be used to convert the binary data into formats that can be directly imported into ESRI ArcGIS and other proprietary Geographical Information System (GIS) formats. The Generic Mapping Tools (GMT) package and the open source GIS known as GRASS offer some functionality in this respect. GMT is an open source collection of tools for manipulating geographic and Cartesian data sets in Version 4.X and 3.4.5 these are distributed in a bundle with GSHHS_1.3 (Wessel and Smith 1991; Wessel and Smith 2004a). Some versions of GRASS have a utility for importing GSHHS ASCII files and exporting the data as ESRI Shapefiles. Neither the binary data nor the software referred to above were used in the pre-processing detailed here, instead we used the Shapefile version of GSHHS_1.2 and Version 8.3 of the ARC / INFO GIS developed by the Environmental Systems Research Institute (ESRI) referred to here as ArcGIS.

3. Vector data processing

The downloaded source GSHHS_1.2 data Shapefiles were viewed in ArcGIS. The data were lines in a standard geographic projection with units of Decimal Degrees (DD) with the Western most shorelines crossing at 0° West (0° W) and Eastern most values crossing 360° East (360° E). The most southerly line represented the coastline of Antarctica. The most northerly lines did not go as far North (N) as 90°. It was important to view the data and examine how coastlines were treated at the extremes due to wrap-a-round effects since 0°W is also 360°E and because the entire Northern and Southern edges of the data are respectively in reality points.

Derived data with the Greenwich meridian and equator (0°E, 0°N) at the centre is wanted for masking the SRTM data. The task of producing a mask from GSHHS_1.2 to use in this process could have been approached in a number of ways. We decided to use ArcGIS and develop Arc Macro Language (AML) programs in an ad-hoc way and to carry out the work on a PC running Windows XP with 1GB of RAM in two stages. The first stage described in this section involved generating an ArcGIS polygon coverage spatially coincident with the SRTM data. Algorithm 3.1 details the processing steps that are presented as an AML in Appendix A. ESRI double precision was specified for use. The second stage involved rasterising this polygon coverage, the details of which are presented in Section 4.

Algorithm 3.1

A method for generating and outputting a global geographic projection ArcGIS polygon coverage in decimal degrees with the Greenwich meridian and equator at centre.

1. The source Shapefile was converted into a line coverage (cov0) using the SHAPEARC command.

2. The coverage cov0 was then projected using the PROJECT command and the XSHIFT subcommand to form a new line coverage (cov1) that was a duplicate of cov0 that's east side would join to west side of cov0. A line coverage (box0) was created using the GENERATE command. This was a rectangular shaped box for the desired study area.

3. The MAPJOIN command was used to join the line coverages together into a single layer (cov2). The BUILD command was used to create line topology. The coverage box0 was rebuilt with polygon topology.

4. The CLIP command was used to clip cov2 using box0 into a new coverage (cov3) specifying a very small fuzzy tolerance. The resulting coverage was further processed with the CLEAN and BUILD commands to create polygon topology.

5. Using ARCPLOT, RESELCT, NSELECT and WRITESELECT commands the external polygon of cov3 (the external polygon being that with cov3# equal to 1) was selected and converted into a new coverage (l1). Additionally, polygons not adjacent to the external polygon of cov3 were selected and converted into a new coverage (cov4). The coverage cov4 contained all polygons that were not water0 or land0, i.e. water1, land1 and water2.

6. Step 5 was repeated but with cov4 input and new coverages l2 and cov5 output. Step 5 was repeated again but with cov5 input and new coverages l3 and cov6 output. Step 5 was part repeated again but with cov6 input and a new coverage l4 output.

7. Four new and identically defined value fields v1, v2, v3, and v4 were added to each of the coverages l1, l2, l3 and l4 using the ADDITEM command. For each coverage l1, l2, l3 and l4 all polygons except for their respective external polygons were selected and the value of v1, v2, v3, and v4 respectively were set to 1.

8. The coverages l1, l2, l3 and l4 were joined step by step into a new coverage (gshhsp12_dd) using the UNION command (again a very low fuzzy tolerance was specified).

9. A new value field (class) was added to gshhsp12_dd and calculated as the sum of all the value fields v1, v2, v3, and v4 set in Step 7. The class value field contained values from 0, 1, 2, 3, and 4, where: values of 0, 2 and 4 represented water polygons; and, values of 1 and 3 represented land polygons.

10. The DROPITEM command was used to remove all but the area, perimeter, gshhsp12#, gshhsp12-id and class items; and finally, the coverage gshhsp12_dd was exported into an ArcGIS interchange file gshhsp12_dd.e00 using the EXPORT command.

The processing of GSHHS_1.2 Shapefile data as detailed in Algorithm 3.1 introduced error (additional spatial uncertainty) by way of generalisation of the spatial data. This is difficult to avoid during such processing although there is a small chance that it did not occur. Where the errors were most likely to occur (at the boundaries), the data was

examined visually and it was reckoned that the added errors were insignificant given the inherent uncertainties in the source data.

Spatial operations in ArcGIS require a fuzzy tolerance. This is a value which represents the minimum distance separating coordinates and regulates how far coordinates can move during specific operations. Where possible, a very small fuzzy tolerance was always specified for use, see Appendix A for details. However, this desired tolerance was usually declared as 'below the minimum resolution for this data' and a higher fuzzy tolerance was used by ArcGIS instead. This fuzzy tolerance is believed to be the minimum that ArcGIS would use given the data and the operations performed and the precision with which coordinates were being stored. The inability to use smaller fuzzy tolerance values is a limitation of the ArcGIS software, but nevertheless, some fuzzy tolerance is necessary when intersecting data during the clipping operation of Step 4. Not all lines that cross the boundary are guaranteed to do so at points that can be specified exactly as coordinates, some shift up or down, some rounding, is necessary to constrain to the specified coordinate precision.

After each processing step a visual on-screen inspection and comparison of the data was undertaken. As mentioned above, minute changes were detected, but these were reckoned to be insignificant given the inherent spatial uncertainties in the data as described in Section 1. Unfortunately there are no guarantees that coordinates were not moved as part of the joining operation in Step 8 of Algorithm 3.1. There is no reason for them to have been, but no systematically analysis or check was done. It is possible to do the processing without having to use the ArcGIS UNION command, but a more satisfactory means has not yet been identified. It remains a challenge for other ArcGIS experts to detail what would be better to use, especially since this step is also used in the pre-processing of GSHHS_1.3 that is being detailed in a subsequent paper.

4. Rasterisation

There are a number of considerations to make in rasterising vector data. What is best to do, depends on what the raster data is for. This section describes the production of a mask layer from the gshhsp12_dd coverage (generated via Algorithm 3.1) to be considered for using with the SRTM data. What is wanted is a mask that is coincident with the SRTM data which identifies all surface cells that are usually underwater. An estimate of

which cells are usually underwater can be generated by setting a unique and fixed arbitrary value for cells that contain a part of a polygon of gshhsp12_dd with a value of 1 or 3. The ArcGIS command POLYGRID offers a direct means to derive this data.

Version 8.3 of ArcGIS is limited by file size and cannot handle grids where any file associated with it is over 2^{32} bytes in size. Consequently, the processing was done in parts and a set of 45 grids arranged in 5 rows and 9 columns were created with a tiling (tessellating arrangement) that coincided with tiling of the SRTM data that was pre-processed concurrently. Algorithm 4.1 details the production of the 45 mask grids.

Algorithm 4.1
A method for rasterising the global geographic projection ArcGIS polygon coverage generating by Algorithm 3.2 into a global grid with a resolution of 3 arc seconds.

1. The coverage gshhsp12_dd was projected to create a new coverage (m) with units of Decimal Minutes (DM) using the ArcGIS PROJECT command. This was done as in DM units the required cell size for an equivalent 3 arc second resolution can be expressed exactly (0.05). The projected coverage m was then built with polygon topology using the ArcGIS BUILD command.

2. Two INFO files LT and WT were defined so as to be used as look_up_table and weight_table respectively in the ArcGIS POLYGRID command. These tables were populated with values. For the look_up_table: (class) values of 1 and 3 were mapped to a (code) value 1; and, (class) values of 0, 2, and 4 were mapped to a (code) value of 0. For the weight_table (code) values of 0 were mapped to a (weight) value of 0 and (code) values of 1 were mapped to a (weight) value of 1.

3. The entire coverage m was then converted bit by bit to form 45 mask grids using the ArcGIS POLYGRID command. Each of these 45 mask grids was processed in parts due to ArcGIS software limitations. The ArcGIS SETNULL command was used to set values of 0 to null_values.

It should be noted that ArcGIS Version 9.x has no limitation with respect to file sizes for grids.

5. Further work

There is an ongoing challenge to define and map geographical features and the boundaries between them. Always improvements can be made and more detailed information about uncertainty and variability can be compiled. Comparisons between GSHHS coastline data and other coastline data should be encouraged and a full evaluation of the pre-processed (reformatted) data should be done. Details of the processing of GSHHS_1.3 will be provided in a subsequent paper.

Appendix A: Detail of ArcGIS commands for Algorithm 3.1

Step 1
Arc: shapearc gshhs.shp cov0

Step 2
Arc: project cover cov0 cov1
      input
      projection geographic
      units dd
      xshift -360
      parameters
      output
      projection geographic
      units dd
      parameters
      end
Arc: generate box
      line
      1
      -180,-90
      -180,90
      180,90
      180,-90
      -180,-90
      end
      end
Arc: build box0 line

Step 3
Arc: mapjoin cov2
      cov0
      cov1
      box0
      end
Arc: build box0 poly

Step 4
Arc: clip cov2 box0 cov3 line 0.000000001
Arc: clean cov3 # # 0.000000001 poly

Step 5
Arc: arcplot
Arcplot: reselect cov3 poly cov3# = 1
Arcplot: writeselect l0.sel
Arcplot: aselect cov3 poly adjacent 0
Arcplot: nselect cov3 poly
Arcplot: writeselect cov4.sel
Arcplot: q
Arc: reselect cov3 cov4 poly cov4.sel poly
Arc: reselect cov3 l0 poly cov4.sel poly

Step 6
Arc: arcplot
Arcplot: reselect cov4 poly cov4# = 1
Arcplot: writeselect l1.sel
Arcplot: aselect cov4 poly adjacent 0
Arcplot: nselect cov4 poly
Arcplot: writeselect cov5.sel
Arcplot: q
Arc: reselect cov4 cov5 poly cov5.sel poly
Arc: reselect cov4 l1 poly cov4.sel poly

Step 6 continued…
Arc: arcplot
Arcplot: reselect cov5 poly cov5# = 1
Arcplot: writeselect l2.sel
Arcplot: aselect cov5 poly adjacent 0
Arcplot: nselect cov5 poly
Arcplot: writeselect cov6.sel
Arcplot: q
Arc: reselect cov5 l3 poly cov6.sel poly
Arc: reselect cov5 l2 poly cov5.sel poly

Step 7
Arc: additem l0.pat l0.pat v0 4 5 b
Arc: additem l1.pat l1.pat v1 4 5 b
Arc: additem l2.pat l2.pat v2 4 5 b
Arc: additem l3.pat l3.pat v3 4 5 b
Arc: arcplot
Arcplot: calculate l0 poly v0 = 1
Arcplot: reselect l0 poly l0# = 1
Arcplot: calculate l0 poly v0 = 0
Arcplot: calculate l1 poly l1 = 1
Arcplot: reselect l1 poly v1# = 1
Arcplot: calculate l1 poly l1 = 0
Arcplot: calculate l2 poly v2 = 1
Arcplot: reselect l2 poly l2# = 1
Arcplot: calculate l2 poly v2 = 0
Arcplot: calculate l3 poly v3 = 1
Arcplot: reselect l3 poly l3# = 1
Arcplot: calculate l3 poly v3 = 0
Arcplot: q

Step 8
Arc: union l0 l1 u0 0.000000001
Arc: union u0 l2 u1 0.000000001
Arc: union u1 l3 cov7 0.000000001

Step 9
Arc: additem cov7.pat cov7.pat class 4 5 b
Arc: arcplot
Arcplot: calculate cov7 poly class = v0 + v1 + v2 + v3
Arcplot: q

Step 10
Arc: copy cov7 gshhsp12_dd
Arc: dropitem gshhsp12_dd.pat gshhsp12_dd.pat
      l0
      l0#
      l0-id
      l1
      l1#
      l1-id
      l2
      l2#
      l2-id
      l3
      l3#
      l3-id
      end
 export cover gshhsp12_dd gshhsp12_dd.e00

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