EXTRACTING DATA FROM HYCOM FOR NESTED BAROCLINIC MODELS

HYCOMEXTRACT THEORY REPORT AND USERS MANUAL

HYCOM Surface Temperature, Sept. 24, 2004
Gulf of Mexico Region from 1/12˚ North Atlantic Domain
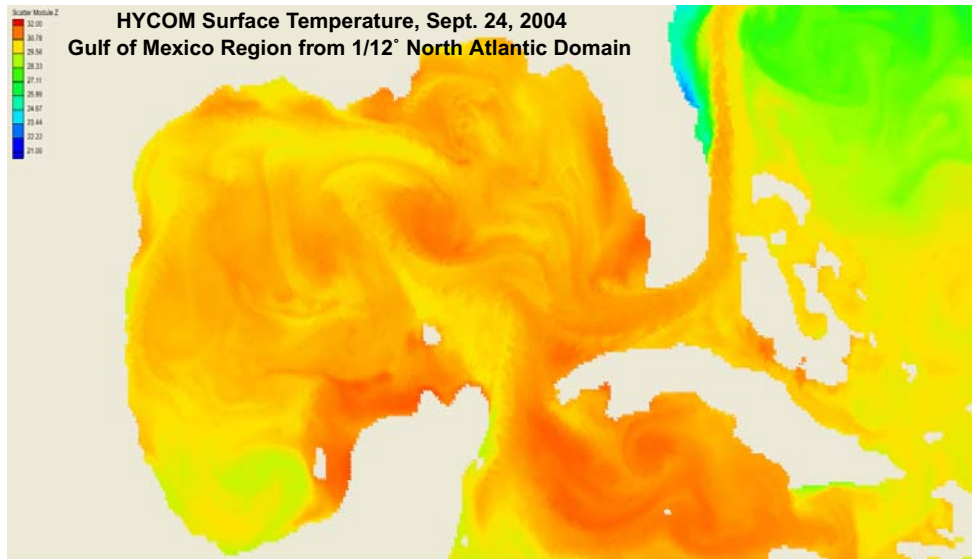
Prepared for the Texas Water Development Board (TWDB)
Austin, Texas

Kendra M. Dresback, Christine M. Szpilka, Anthony M. Szpilka, and Randall L. Kolar
School of Civil Engineering and Environmental Science
Natural Hazards and Disaster Research - National Weather Center
University of Oklahoma, Norman, OK 73019

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ABSTRACT

Accurate simulations of 3D, baroclinic, coastal processes require that the dominant physical features, such as intricate coastlines, shallow straits, salinity/temperature gradients, and underwater canyons, be mapped to a high resolution computational grid, often on the order of tens of meters. However, even with the monumental advances in computing power over the last several decades, the computational demands for this type of modeling limits the domain size. Moreover, baroclinic simulations are prone to instabilities and inaccuracies if the initial and boundary conditions are not realistic, yet salinity and temperature data are frequently not available at the desired scales. One solution to both of these problems is to "nest," or couple, a coarser grid model to the fine-scale, coastal model and downscale initial and boundary condition information from the coarser to the finer grid. Given its prominence in global baroclinic modeling, we chose to use the structured grid HYbrid Coordinate Ocean Model (HYCOM) as the source for baroclinic information. In particular, a software tool, "HYCOMextract," has been developed that downscales HYCOM information to a coastal model. In this report, we present the theory and algorithm behind the software, and demonstrate its use with the 3D, baroclinic ADCIRC code as the coastal model. However, the procedures are general enough that they can be adopted by any coastal model using either structured or unstructured grids.

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Section 1. Conventions and Disclaimers.

In order to be consistent and make this report as easy to use as possible, the following notation and font conventions will be followed throughout the document:

[Underlined blue text](#) for internet addresses

Italics for directories or program/variable names

`Courier font` for computer commands

It is assumed that the user of this software is familiar with the Unix/Linux operating systems and command line processing.

It is also assumed that the user of this software is processing the best estimate product from the HYCOM results.

Section 2. Project Background and Description.

2.1. Problem Statement.

Accurate simulations of coastal processes require that the dominant physical features, such as intricate coastlines, shallow straits, mixing zones, and underwater canyons, be mapped to a high resolution computational grid, often on the order of tens of meters. However, even with the monumental advances in computing power over the last several decades, the computational demands required by three-dimensional, high resolution modeling limits the domain size, particularly if being run in scalar (single-workstation) mode. Thus, the open boundary ends up being placed in a region dominated by complex, nonlinear processes, so an accurate specification of the boundary condition is difficult. Furthermore, the difficulty in obtaining 3D field data precludes direct measurement as a source for all initial and boundary conditions. Yet, if boundary or initial conditions are unrealistic, model results will be inaccurate and, perhaps, even unstable.

2.2. Proposed Solution.

A proposed solution to this problem is to couple the fine, often unstructured, grid coastal model (the "inner" model), which is being used for high resolution studies of Texas coastal processes, with a structured grid model, which is more suited for deeper oceanic regions. In particular, the proposed scope of work involves one-way coupling of the inner model to the structured grid HYbrid Coordinate Ocean Model (HYCOM), which is run daily by the Center For Ocean Atmospheric Prediction Studies (COAPS) at Florida State University, and made publically available through their OPeNDAP (Open-source Project for a Network Data Access Protocol) server (http://dev.hycom.org/dataserver).

HYCOM was developed from the Miami Isopycnal Coordinate Ocean Model (MICOM), but whereas MICOM uses only an isopycnal vertical coordinate, HYCOM uses one of three coordinate methods, depending on location: isopycnal (deep, stratified waters), sigma (shallower, un-stratified waters), or *z* (surface mixed layer or other un-stratified layers) [4]. HYCOM solves the shallow water equations on the Arakawa "C" grid with curvilinear coordinates. For the temporal discretization, it uses a leap-frog scheme with a time filter for the baroclinic portion of the solution, and for the barotropic portion, it employs a split explicit free surface scheme that is shifted in time [2,3]. For the boundary conditions, HYCOM utilizes a either a Newtonian relaxation through sponge layers or full open ocean boundaries. The rivers are implemented as precipitation, which is a separate monthly climatological field from the standard precipitation field, and is treated as a mass flux into the system.

HYCOM is run weekly on Wednesdays in near real time mode and produces a ten-day hindcast and a fourteen-day forecast. Results from the 1/12-degree equatorial resolution model (4500 x 3300 x 32 layers resulting in an approximately 7 km average horizontal resolution) are publically available from the

HYCOM data server (http://dev.hycom.org/dataserver). The 1/12-degree Atlantic model, also publically available, uses 26 vertical layers (vs. 32 for the global model) and information from a ETOPO 2.5 data set provides the bathymetry used in these simulations. For the simulations, two timesteps are utilized: a 240 second timestep for the baroclinic fields and a 7.5 second timestep for the barotropic fields. This simulation obtains information from the Navy Operational Global Atmospheric Prediction System (NOGAPS) for the surface stresses, which includes the wind stress, wind speed, heat flux and precipitation. In the case of the boundaries, the model uses the Newtonian relaxation technique mentioned earlier by relaxing the temperature and salinity values on the north and south boundaries to the values given by the monthly climatological temperature and salinity from Modular Ocean Data Assimilation System (MODAS). One data product that will be of primary interest to the TWDB will be the archived simulations for the five-year period from 2003-2008, for which data has been assimilated via NCODA (Navy Coupled Ocean Data Assimilation) [1] using the mean sea surface elevation data from a 5 year run of MICOM forced by ECMWF daily winds along with satellite altimeter observations. The duration of this archive will be expanded as more data sets become available. Further HYCOM simulation information can be found at the HYCOM dataserver website, http://dev.hycom.org/dataserver.

Note that computational advances are allowing even structured grid models like HYCOM to use much higher resolution throughout the domain, so that 1/25-degree results (and finer), which previously were in the development stage, are now publically available. However, the results have not be data assimilated and therefore are still in the experimental stages. Consequently, the software created as part of this project is flexible enough to accommodate any HYCOM resolution as long as the file format follows that of the best-estimate product.

2.3. Research Assistance to the TWDB.

Coupling inherently nonlinear processes between models that have different numerical and grid strategies raises many research and implementation issues that must be addressed. For the TWDB contract, we addressed the following five research tasks.

1. Develop guidance to the TWDB on modification needed to their coastal models in order to be compatible with HYCOM initial/boundary forcing. We anticipate this will primarily involve extending the domain to the appropriate depth on the continental shelf/rise region.
2. Establish the protocol for downloading the information from the HYCOM server (data is stored in NetCDF format - http://www.unidata.ucar.edu/software/netcdf/) and translating it into a data format consistent with the inner model; software requirements are given.
3. Develop a data extraction algorithm for mapping boundary conditions at the interface from the structured grid HYCOM model to the unstructured grid inner model. At present, we provide the following boundary conditions: temperature, salinity, sea surface elevation, and velocity field.
4. Develop a data extraction algorithm for mapping initial conditions throughout the domain from the structured grid HYCOM model to the unstructured grid inner model. At present, we provide the following initial conditions: temperature, salinity, sea surface elevation, and velocity field.
5. Prepare a users manual and conduct a training workshop for TWDB personnel on coupling considerations and procedures.

Section 3. Information on the Boundary Location for Coastal Models.

In determining the placement of the open ocean boundary for the coastal models when coupling to a regional/global model such as HYCOM, the boundary must lie well within the domain of the regional/global model. If the boundary lies outside of the regional/global model domain, then all of the information used in the coastal model would have to be extrapolated from the HYCOM information, which could lead to either instabilities or inaccurate results because some of the physics (e.g., eddies and density changes) occurring on the shelf and in deeper ocean regions is not being included in the coastal model. Even if the

inner model is extended so that the boundary coincides with the HYCOM extent, this is not enough because it does not allow a "transition" zone for the baroclinic processes to spin up in the inner model. Moreover, it precludes the use of interpolated values for initial conditions. Thus, we recommend a significant amount of overlap between HYCOM and the inner model, which places the inner model's open boundary far enough away from the region of modeling interest that non-physical transients introduced at the boundary have time to die off.

As an example, consider Figure 1 that shows the 1/12° Atlantic HYCOM domain with colored contours representing regions of active HYCOM nodes, while a current configuration of some of the Texas bays and estuaries are shown by the unstructured, triangular grid. Note that almost the entire unstructured
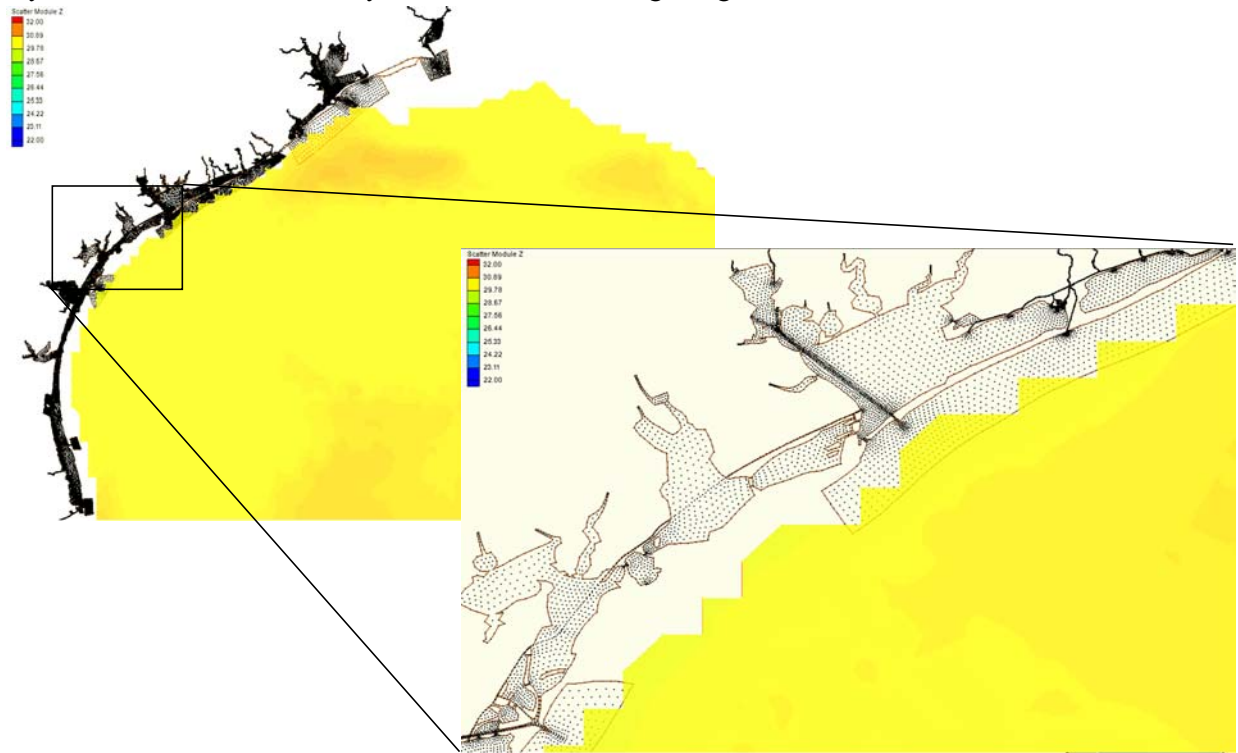

Figure 1   The inland extent of the active nodes from the 1/12° Atlantic HYCOM domain is shown by the colored contours, while the black triangles show the current configuration of the Texas coastal models in use by the TWDB.

grid lies outside of the HYCOM domain, which is problematic. Based on our experiences with this coupling to date, it is recommended that the unstructured grid boundary should extend to include areas where some of the physics of the shelf and deeper ocean regions could be brought into the model. In our application with the Northern Gulf of Mexico region (shown later as Figure 9), the boundary for the coastal model has been placed at the 1000 m bathymetry contour, which allows for an overlap on the order of 100 to 200 km. This has produced stable results thus far; however, we anticipate the amount of overlap is highly dependent on the region.

Section 4. Information on Software Needs and Data Format.

4.1. Unidata NetCDF software.

The HYCOM model output is provided in netCDF (network Common Data Form) format (.nc file extension) and an extra utility is required to access the data. NetCDF is a set of software libraries and machine-independent data formats that allow universal access and sharing of large scientific data sets. Also,

netCDF falls under the umbrella of metadata, meaning that the data files contain header information that describes the data contained therein, including the type of data and variable naming conventions. An example of a NetCDF file is given in the Appendix in Section 8.1.

The easiest way to get netCDF running on a workstation is to download a pre-compiled binary distribution from http://www.unidata.ucar.edu/downloads/netcdf/netcdf-4_0/index.jsp. Common platforms that are covered include the following: linux-x86, irix, solaris-sparc, solaris-x86, aix-powerpc, and darwin (Mac). Instructions for downloading and unpacking the tar file are given on the website. However, if the TWDB compiler/machine operating system combination is not listed at that site, then you will need to download the source distribution and compile it on a machine with the native compiler using the `make` utility. Support and FAQs links can also be found at http://www.unidata.ucar.edu/software/netcdf/.

When you have either unpacked the pre-compiled version or successfully compiled the source version, you will have four subdirectories: *lib*, *include*, *man* and *bin*. The *lib* subdirectory contains the netCDF libraries for these programming languages: C, Fortran and C++. The *include* subdirectory contains the files necessary for linking with other programs: netcdf.h (C), netcdf.inc (Fortran), ntcdfcpp.h (C++) and various .mod files (Fortran90). The *bin* subdirectory contains the `ncgen` and `ncdump` binary utilities, which can be used to generate and read netCDF files. Finally, the *man* subdirectory contains the netCDF documentation ("man" pages).

You may also visit the documentation page at http://www.unidata.ucar.edu/software/netcdf/docs/ to get more information about the netCDF utilities and how to use them. How to link these NetCDF files to the HYCOM interpolation program created at the University of Oklahoma will be covered in Section 5.11; more about linking with other user created programs can be found at the <Language> Interface Guide links from the above documentation page.

4.2. HYCOM Data Server.

The HYCOM data server is online at http://dev.hycom.org/dataserver. It provides access to data sets from several different HYCOM products, as well as multiple types of access, including ftp (file transfer protocol), openDAP (Open-source Project for a Network Data Access Protocol), and LAS (Live Access Server). The data server homepage given above has links with more information about each of these access types. For the model coupling protocol outlined herein, we will restrict ourselves to ftp file transfer. However, the software structure developed on this project would be compatible with other means of access.

Documentation for some of the products is given in the *Quick Links to HYCOM Data* table under the Documentation column on the data server homepage. At present, we will be using data from the North Atlantic Ocean Prediction System, which is described in more detail at http://dev.hycom.org/dataserver/98-atlantic-info and the various sublinks. In summary, this system is configured for the North and Equatorial Atlantic region and uses HYCOM as the dynamic model. The computational domain covers the area from 98˚ W to 36˚ E and 28˚ S to 70˚ N and the computations are performed on a 1/12˚ Mercator grid (1678 x 1609 grid points with an average resolution of 6.5 km). The North Atlantic Ocean Prediction System is a nowcast/forecast system and the "best-estimate" product is what will be used herein. Data is available for every day, that is, daily output at 00 hours GMT, from 06/01/2003 through 07/09/2008.

4.3. HYCOM Data Structure and Naming Convention.

Unfortunately, there is not a consistent naming convention between all of the HYCOM products; however, the best-estimate product from the North Atlantic Ocean Prediction System does have an intuitive convention. Output posted on the data server is named such that the model version, grid region, data type and date are self evident. For example, the file *hycom_2.1_nat_1o12ml_salt_20030606.nc* contains salinity data from a HYCOM run on the native coordinate 1/12˚ mercator grid for June 6, 2003 (in netCDF format - .nc). For each data type, the file naming convention is identical, with the data type replaced accordingly; e.g., for sea surface height data for the same day, _salt_ is replaced by _ssh_, etc. There are 25 data types

available for this best-estimate product. The ones that we will be most interested in are as follows:

- *lthk* – layer thickness file [m or Pascal] (contains information about the hybrid vertical coordinate structure under each horizontal grid point)

- *salt* – salinity [psu] (contains the 3D salinity data for all horizontal and vertical grid points)

- *ssh* – sea surface height [m] (contains 2D data for ssh at all horizontal grid points)

- *temp* – potential temperature [˚C] (contains 3D temperature data for all horizontal and vertical grid points)

- *ubaro* – eastward barotropic water velocity [m/s] (contains 2D eastward barotropic effects of the baroclinic water velocity data for all the horizontal grid points)

- *uvel* – eastward baroclinic water velocity [m/s] (contains 3D eastward water velocity data for all horizontal and vertical grid points)

- *vbaro* – northward barotropic water velocity [m/s] (contains 2D northward barotropic effects of the baroclinic water velocity data for all the horizontal grid points)

- *vvel* – northward water velocity [m/s] (contains 3D water velocity data for all horizontal and vertical grid points)

Data for each of these types are in separate directories on the data server (the subdirectory name is the data type – e.g., *ssh*, *salt*) and the naming convention for these particular products is as follows: *hycom_2.1_nat_1o12ml_datatype_date.nc,* where the *datatype* and *date* will vary.

Note that the two velocity files, *ubaro* and *uvel* or *vbaro* and *vvel*, are evaluated and then must be added together in order to obtain the total velocity due to the combined effects of baroclinic and barotropic forcing (however, the latter does not include tides), which is needed for the horizontal velocity values utilized as either initial or boundary conditions. The *ubaro* and *vbaro* are 2D values, so they are evaluated as surface data and the *uvel* and *vvel* are 3D values and are evaluated on each of the vertical layers. Therefore, for each layer the *ubaro* or *vbaro* values must be added to *uvel* or *vvel* results, respectively.

4.4. Downloading HYCOM Data.

From the HYCOM data server homepage click on the FTP Server link, this will take you to ftp://hycom.coaps.fsu.edu/datasets/. Follow the atlantic directory to get to the best-estimate data for the time period you are interested in: atlantic - ATLd0.08_native_coordinate_data - best estimate (ftp://hycom.coaps.fsu.edu/datasets/atlantic/ATLd0.08_native_coordinate_data/best-estimate/). From here, there is a list of directories for each of the data types available, currently 25. Within each of these data type subdirectories, data is available for every day from 06/01/2003 through 07/09/2008. You will need to download the file for the appropriate date from each of the data types listed above in Section 4.3.

You can do this from the ftp website in a browser window by right-clicking on the filename and then specifying the desired location on your local machine. You may also use an ftp client and command line processing to navigate through the subdirectories to the desired location. For the latter, the first thing to do is ftp to *hycom.coaps.fsu.edu* and login as "anonymous" (you can leave the password blank or include your email address). Be sure to type *bin* at the ftp prompt to change to binary file transfer mode, otherwise the transferred files may be incomplete or corrupted. Change the remote directory by typing *cd datasets/atlantic/ATLd0.08_native_coordinate_data/best-estimate* and then list the files and subdirectories by typing *ls*. You will have to cd to each subdirectory for the data types that you want (e.g., *cd ssh*, *cd salt* …), list the

files (*ls*), get the file you want by typing *get file_name*, and then *cd* back to the best-estimate directory (to go up one directory, type *cd ..*). Since you know the file naming convention, you do not necessarily have to list all of the available files (5 years worth!). For example, to get the ssh for June 30, 2004 you would type the following series of commands:

- `cd ssh`

- `get hycom_2.1_nat_1o12ml_ssh_20040630.nc`

- `cd ..` (after successful transfer)

where the first command changes you to the appropriate directory, the second downloads the file, and the third changes you back to the parent directory.

Section 5. The *HYCOMextract* Program.

As currently written, the data extraction program, *HYCOMextract*, is interactive, so it prompts the user for various inputs and writes the final output to a file. If necessary, we can modify the *HYCOMextract* program to operate more in "batch" mode so that less interaction is required. However, regardless of the user interaction required, it is important to understand what *HYCOMextract* is doing, so that the end product can be properly interpreted and data can be used with confidence.

5.1. General Description.

The *HYCOMextract* program takes regularly spaced data from the HYCOM model and interpolates it onto any user supplied grid, with two main assumptions. One, the HYCOM data is assumed to be on a square Mercator projection grid, which is currently the default standard; and two, the user supplied grid should be contained in a single ASCII (text) data file.

For developing initial conditions through the inner model domain, the information for the coastal grid, assumed to be a triangular unstructured mesh, should be formatted as follows:

Line 1: Description of the grid

Line 2: Number of elements (*NE*), number of nodes (*NN*)

Lines 3 thru *NN*: *number longitude latitude bathymetry*

where the first line gives a description of the grid, the second line contains only the number of elements and number of nodes, and the subsequent lines, lines 3 through *NN*, contain the node number and its longitudinal and latitudinal position, along with its bathymetry. The convention for the longitudinal and latitudinal position in HYCOM is -180˚ to 180˚ from the International Date Line and 0˚ to 90˚ from the equator, respectively. The bathymetry values are assumed to be in meters, which will be used in developing the 3D vertical information. Further lines in the file traditionally contain the element-node connectivity table, but this information is not used by the *HYCOMextract* program.

It is important to note that because *HYCOMextract* does not use any nodal connectivity information, the type of mesh is really irrelevant. As long as the nodal information where data is desired is provided as indicated above, the software will return the requested data values at the nodal locations. At that point, it is up to the user to determine how to feed that information to the inner baroclinic model. For ADCIRC, we have developed another piece of software that takes the *HYCOMextract* output and puts it into the format needed by the 3D, baroclinic ADCIRC model.

The format of the grid file used for developing the boundary condition information with the *HYCOMextract* program differs from that used above in the number of nodes. In this case, the grid file

should be formatted as follows:

> Line 1: Description of the grid

> Line 2: Number of elements (*NE*), number of open ocean boundary nodes (*NOBN*)

> Lines 3 thru *NOBN*: *number longitude latitude bathymetry*

where again the first line gives a description of the grid, the second line contains only the number of elements and number of open ocean boundary nodes, and the subsequent lines, lines 3 through *NOBN*, contain the node number and its longitudinal and latitudinal position, along with the bathymetry of the open ocean boundary node. It is not necessary for this file to contain any element information as it is not utilized by the *HYCOMextract* program, but you will have to include a number for *NE* on line 2. (Note: The program reads in the *NE* number, but does not use it for anything.)

The HYCOM data can be either of two main types; namely, 2D surface data (e.g. sea surface height and barotropic velocities) and full 3D data (e.g. salinity, temperature and 3D velocities). Furthermore, the 3D data is subdivided into two additional categories; those typically requiring depth-averaging (e.g. horizontal velocities) and those used in a full 3D capacity (e.g. salinity, temperature and 3D velocities). The *HYCOMextract* program developed herein extracts both 2D surface data and 3D data for the horizontal and vertical nodes, along with depth-averaged results when indicated. *HYCOMextract* has built-in subroutines to handle these two data types, as well as any interpolation and/or extrapolation needed to put the HYCOM data onto the user supplied grid. It dynamically allocates any arrays, depending on the HYCOM data type, and searches through the user supplied grid one node at a time until all nodes (and any vertical layers under that node, if appropriate) have been assigned data from the HYCOM files.

5.2. HYCOM Grid Structure.

For each node in the user supplied grid, *HYCOMextract* first determines the vertices (*i, j* indices) of the HYCOM "cell" that contains the grid point. HYCOM utilizes a constant longitudinal grid spacing (in degrees) while the latitudinal spacing varies with cos(*lat*) to give a square grid cell in meters; the spacing near the poles is smaller. The standard HYCOM model runs on a 2.0° Atlantic Ocean domain (ATLb2.00), but several regional grids are also available that have a higher resolution. The data that will be used herein are from the ATLd0.08 domain, which utilizes 1/12° (or 0.08°) equatorial longitudinal spacing. A schematic of the Mercator projection, centered at λ_0, for this grid (1678 x 1609 resolution) is shown in Figure 2.
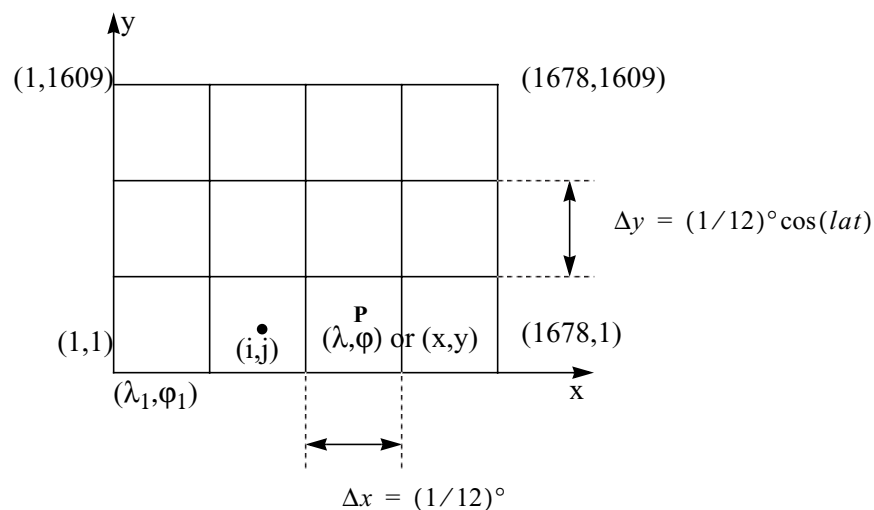

Figure 2   Coordinate relationships on a Mercator projection.

Due to the regular structure of the HYCOM grid and knowing the relationship between the (x, y) coordinates and the (λ, φ) position for the Mercator projection, we can derive an expression for in which (i, j) HYCOM cell a random (λ, φ) point P lies. This ability allows us to know exactly which cell a point from the user supplied grid lies in without having to search through all of the HYCOM grid points. Within each HYCOM data type .nc file, the starting longitude and latitude are provided (λ_1, φ_1). With this information, we can derive the x-index as

$$i = INT\left(\frac{x - \lambda_1}{\Delta x}\right) + 1 \tag{1}$$

where the additional one is due to the indexing starting at one instead of zero. The y indexing is a bit more complicated due to the variable spacing in the latitudinal direction. Note that the y-coordinate for the jth cell (in radians) is given by

$$y_j = j\Delta x \frac{\pi}{180} \tag{2}$$

If we substitute this for y in the relationship given in Figure 2 and solve for the index j, we get

$$j_y = \frac{180}{\pi\Delta x} \ln\left[\tan\left(\frac{\pi\varphi_y}{360} + \frac{\pi}{4}\right)\right] \tag{3}$$

However, due to the variable spacing in the latitudinal direction, we must compute an index j_1 for the origin and the point P, j_p, and then take the difference to get the actual index j. If we do this we have

$$j_1 = \frac{180}{\pi\Delta x} \ln\left[\tan\left(\frac{\pi\varphi_1}{360} + \frac{\pi}{4}\right)\right] \tag{4}$$

$$j_p = \frac{180}{\pi\Delta x} \ln\left[\tan\left(\frac{\pi\varphi_p}{360} + \frac{\pi}{4}\right)\right] \tag{5}$$

then we compute the y-index for point P as

$$j = INT(j_p - j_1) + 1 \tag{6}$$

where again the additional one is due to the indexing starting at a value of one. Thus for any point P, we can determine the indices of the HYCOM grid point in which point P lies.

5.3. Horizontal Interpolation - Standard Cells.

Once the HYCOM cell location of point P has been determined using the steps in Section 5.2 and illustrated below in Figure 3, we can use bilinear interpolation to assign a data value to point P. A graphical interpretation of bilinear interpolation is to weight each grid point with the area of the opposite quadrilateral divided by the area of the entire cell. For example, grid point (i,j) would be weighted by the red-hashed area in Figure 3. If we do this for each of the 4 vertices, then we can assign a value $f(x,y)$ to point P as follows:
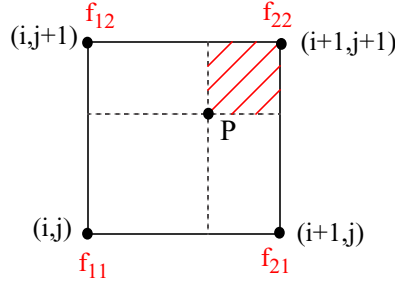
Figure 3   Sample grid cell for bilinear interpolation.

$$f(x, y) \; = \; \frac{(x - x_i)(y - y_j)}{\Delta x \Delta y} f_{i+1, \, j+1} + \frac{(x_{i+1} - x)(y - y_j)}{\Delta x \Delta y} f_{i, \, j+1} +$$

$$\frac{(x - x_i)(y_{j+1} - y)}{\Delta x \Delta y} f_{i+1, \, j} + \frac{(x_{i+1} - x)(y_{j+1} - y)}{\Delta x \Delta y} f_{i, \, j} \qquad \textbf{(7)}$$

This equation can be simplified to the following:

$$f(x, y) \; = \; pq f_{i+1, \, j+1} + (1 - p)q f_{i, \, j+1} + p(1 - q) f_{i+1, \, j} + (1 - p)(1 - q) f_{i, \, j} \qquad \textbf{(8)}$$

with p and q defined as $\; p \; = \; \dfrac{x - x_i}{\Delta x} \;$ and $\; q \; = \; \dfrac{y - y_j}{\Delta y} \;$, or using a "base cell" notation, it can be written as

$$f(x, y) \; = \; pq f_{22} + (1 - p)q f_{12} + p(1 - q) f_{21} + (1 - p)(1 - q) f_{11} \, . \qquad \textbf{(9)}$$

5.4. Horizontal Interpolation - Special Cases.

       Due to the global nature of the HYCOM model, and the necessarily coarse resolution, the coastlines cannot be as finely defined, as is common with unstructured triangular meshes. Consequently, often the smaller interior water bodies, such as back bays, inlets and marshes are not defined in the HYCOM grid. In fact, often they are designated as dry or unsubmerged areas in the HYCOM model and do not have valid data. An example is shown in Figure 4, where the colored squares indicate available HYCOM data (wetted areas) and the black dots indicate the unstructured mesh. Notice that much of the unstructured grid may lie outside the available HYCOM data.

       Two general dry-node cases are defined in the HYCOMextract program: 1) full extrapolation – all four cell vertices are dry and 2) substitution – at least one of the HYCOM cell vertices is wet. Full extrapolation will be covered in Section 5.5; fourteen special cases where substitution is utilized will be covered in the remainder of this section. In order to have at least one wet HYCOM grid point, it is possible to have one, two or three of the grid points defined as dry nodes. These three classifications can be further subdivided, depending on which of the grid points are wet. Four basic cases are shown in Figure 5; the other ten cases are variations on these four with different dry grid point positions in the base cell shown in Figure 3. Note that wet grid points are indicated with open circles and dry points by filled squares. The arrows in the figure indicate that information is passed (or substituted) from wet grid points to the dry grid points.

       For all variations of case a in Figure 5 (one dry point), the dry grid point is replaced with the average of the two adjacent wet grid points. For the base cell (refer to Figure 3) configuration shown in Figure 5(a),
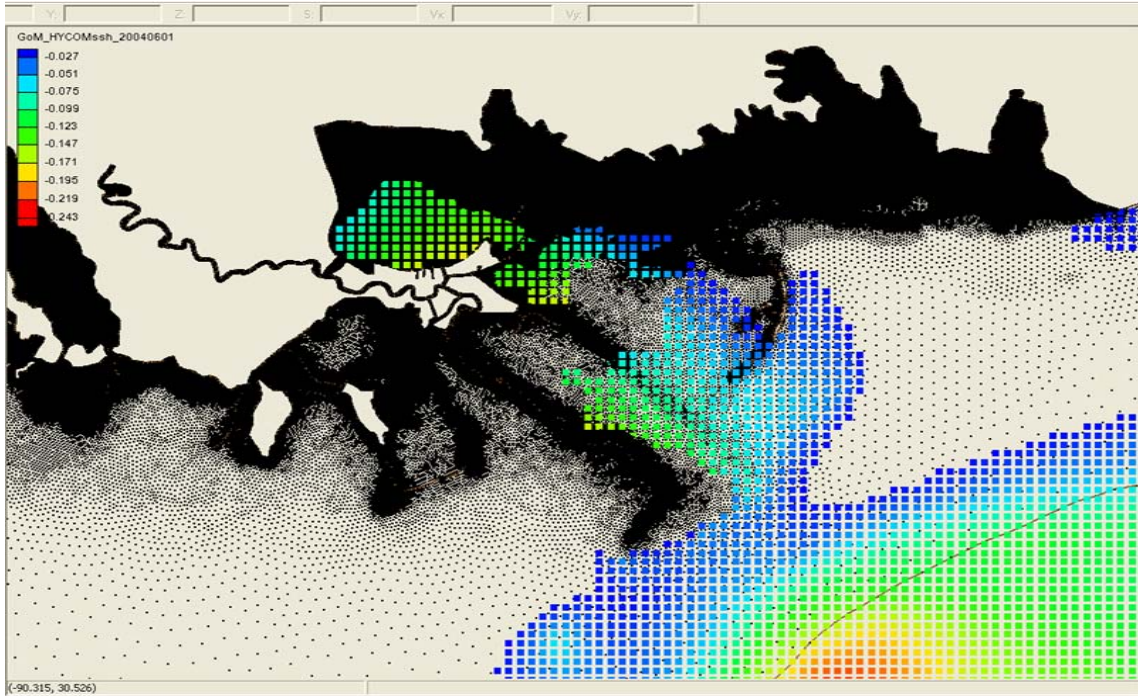
Figure 4   Example of the contrasting resolutions between HYCOM and a coastal model. The black dots shown are node points from the unstructured inner model, while the colored squares indicate where HYCOM has values that are not designated as dry or unsubmerged areas. In order to obtain information in the finer resolution of the unstructured grid, we must extrapolate from the values shown in the color squares. Note that the color scale shown is for the sea surface height.
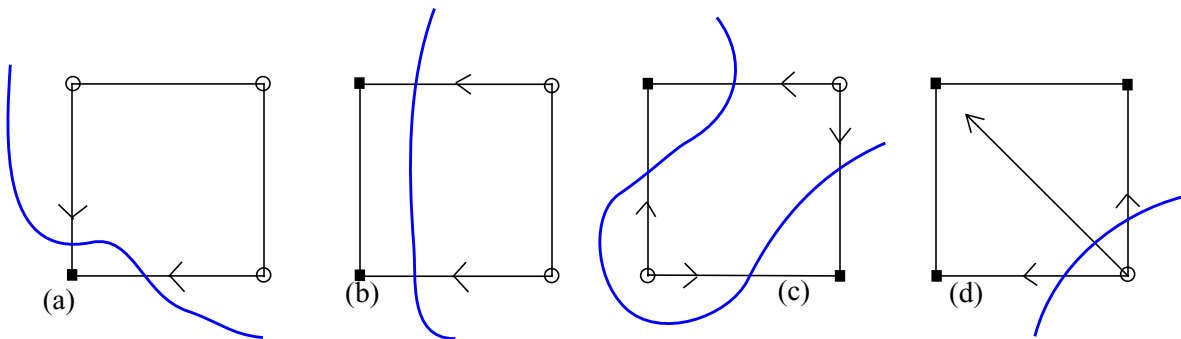

Figure 5   Four basic HYCOM grid configurations with at least one dry grid point (represented by black squares): (a) one vertex on land, (b) two adjacent vertices on land, (c) two opposite vertices on land, (d) three vertices on land.

the appropriate substitution would be

$$f_{11} = 0.5(f_{12} + f_{21}) \tag{10}$$

For all variations of case b in Figure 5 (two adjacent dry points), the dry points are replaced with the value at their adjacent wet grid point. For the base cell configuration shown in Figure 5(b), the appropriate substitutions would be

$$f_{11} = f_{22} \quad \text{and} \quad f_{12} = f_{21} \tag{11}$$

For all variations of case c in Figure 5 (two opposite dry points), the dry points are replaced with the average value of the two opposite wet points. For the base cell configuration shown in Figure 5(c), the appropriate substitution would be

$$f_{12} = f_{21} = 0.5(f_{11} + f_{22}) \tag{12}$$

Finally, for all variations of case d in Figure 5 (three dry points), all of the dry points are set to the value of the single wet point; i.e. all four vertices are given the value of the wet point. Once the appropriate substitutions have been made, the value at point P is calculated using the bilinear interpolation formula given in Section 5.3.

5.5. Horizontal Extrapolation.

As discussed in the previous section, occasionally the unstructured point lies in a HYCOM cell with four dry vertices, a "landlocked" point. In this case, *HYCOMextract* contains a subroutine, *extrap,* that takes care of the full extrapolation by searching for nearby HYCOM grid points with valid (wet) values. At present, this subroutine starts by checking the HYCOM grid point that lies in the NE corner of the HYCOM grid cell that point P lies in. The subroutine checks the four nodes of the HYCOM grid cell and then spirals out from this grid cell searching for wet grid points; this search pattern is shown in Figure 6.
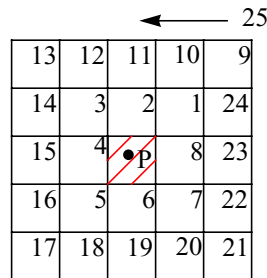

Figure 6   Spiral search pattern to find nearest wet node.

Figure 6 shows two "rings" of the spiral search pattern; the outer nodes of cells 1 thru 8 represent ring 2 and outer nodes of cells 9 thru 24 represent ring 3. The routine continues searching outward until it finds at least one wet node is found in a ring. If only one wet node is found in a given search ring, then its value is assigned to point P. If more than one wet grid point is found in a given ring, then the value of the closest grid point is assigned to point P, where the distance between any wet grid point and point P is calculated as

$$d = \sqrt{(\lambda - \lambda_p)^2 + (\varphi - \varphi_p)^2} \tag{13}$$

5.6. Vertical Interpolation.

In order to obtain the vertical variation of the salinity, temperature or velocity fields, we follow a three part process that maps the HYCOM information onto an intermediate nodal-based grid and then to the

vertical layers of the unstructured grid. Figure 7 shows the three grids employed in this process. Initially utilizing both the layer thickness values and the component field being analyzed from the HYCOM information, we develop the HYCOM grid information shown in Figure 7. The component values are given on
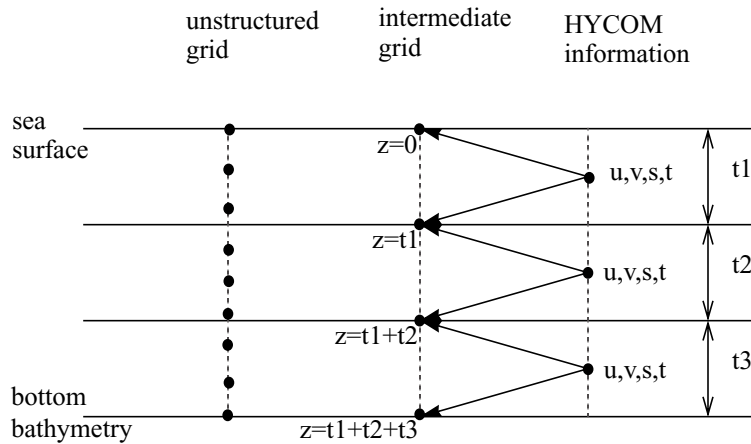

Figure 7   Schematic of the vertical interpolation and the three grids utilized in the process.

an elemental basis, while the layer thickness values are given on layers. An intermediate grid is used to map the elemental-based information to nodal-based information. Non-zero thickness values are used in determining the depth for which the HYCOM information is valid. If the thickness values are greater than zero meters, the component values are used; however, if the thickness values are equal to zero meters, then the values are not used in the nodal-based intermediate grid. Note that HYCOM provides values in some variables for these layers even though they are not part of the vertical grid. In the intermediate grid, we utilize the first and last elemental values as the surface and bottom nodal values, respectively. For all other nodal values, we average the two elemental values from the HYCOM information. The next step is to linearly interpolate the information from the intermediate grid onto the vertical layers of the unstructured grid. In obtaining the vertical node placement for the unstructured grid, we utilize a generalized sigma coordinate system. The generalized sigma coordinate system utilized by the HYCOMextract program varies from a value of -1 at the bottom layer and 1 at the top layer. Placement of the nodes between the top and bottom layers of the generalized sigma coordinate system is determined from the user's choice of the nodal spacing options, called IGC. The nodal spacing options allow for the vertical nodes to be placed either a constant distance apart or more nodes placed in the upper portion or lower portion of the water column. Further information on the generalized sigma coordinates and the various spacing options with ADCIRC can be found at the ADCIRC website, www.adcirc.org. Based on the developed sigma system, we convert the sigma values into the actual depth values using the bathymetry given in the grid file. The depth values are then compared with the depth information in the intermediate grid and the value of salinity, temperature or velocities is obtained by linear interpolation. When a vertical node of the unstructured grid falls below the HYCOM vertical grid, we assign values from the vertical node above on the unstructured grid. Thus, we are not linearly extrapolating any values in the vertical grid.

5.7. Vertical Depth-Averaging.

The vertical-averaging of 3D HYCOM information can occur within the HYCOMextract program and is initiated based on the user response. In order to average the 3D information over the depth, the HYCOMextract program must first interpolate the information onto the vertical grid (i.e. it must go through the process discussed in Section 5.6). After this process is completed, the values are vertically-averaged using the bathymetric information.

5.8. Initial Conditions.

At present, *HYCOMextract* can be used to develop both the initial and boundary condition files for the coastal model. In developing an initial condition file, the first step is to obtain the HYCOM data files (e.g., ssh, salt, etc. as mentioned in Section 4.3) for the date of interest. For example, if the user is interested in a simulation that runs from September 18 to September 20, 2005 then all the files mentioned in Section 4.3 would have to be downloaded for September 18, 2005 from the HYCOM data server. Next, the *HYCOMextract* program should be called multiple times; once for each of the HYCOM data files needed for the initial condition file on the user supplied grid for the date of interest. Thus, for the scenario described in Section 4.3, *HYCOMextract* program will have to be executed 7 times, once for each the data types needed for the initial conditions. After obtaining all the extracted files for the different data types; they can be employed in developing an initial condition file to be used by the near-shore model. The exact format of this files is model dependent, but for the ADCIRC examples illustrated herein, this file is similar to the "hotstart" or "restart" files of the coastal model.

A step-by-step example of the process for extracting HYCOM information for the initial condition file is given in the Appendix in Section 8.2.

5.9. Boundary Conditions.

In developing the boundary condition file, the first step is to obtain all the HYCOM data files for each day of the simulation and for the data types to be utilized on the boundary. Again, as an example, if the user is interested in a simulation that runs from September 18 to September 20, 2005 and they are interested in using the temperature information at the boundary, then it would be necessary to download the following files from the HYCOM data server: *hycom_2.1_nat_1o12ml_temp_20050919.nc* and *hycom_2.1_nat_1o12ml_temp_20050920.nc.* (Note: September 18 data is used for the initial conditions, which includes the boundary information.) If the user wanted to use other data types at the boundary, then the files for that information for these two days would have to be downloaded from the HYCOM data server. Next, the *HYCOMextract* program would be called multiple times for each variable to be employed on the boundary, and it needs to be called for each simulation day. Therefore, if the user wants to develop the boundary condition files for both temperature and salinity for the simulation period given above, then the *HYCOMextract* program would have to be executed 4 times (2 variables x 2 days) utilizing the user-specified boundary grid. After developing the extracted files from the HYCOM information for the boundary, then they can be put into the proper format for use as a boundary condition file for the coastal model.

A step-by-step example of the process for extracting HYCOM information for the boundary condition files is given in the Appendix in Section 8.3.

5.10. Output Format for the *HYCOMextract* Program.

The output format of the *HYCOMextract* file for the 2D surface information is as follows:

Line 1: Indicates from which HYCOM file data is being extracted

Line 2: blank (for readability)

Line 3: Description of the information contained in the file (*n,lon,lat,itrue,jtrue,idata,jdata*)

Line 4: Description of the information contained in the file (*depth, extracted values*)

Line 5: blank (for readability)

Lines 6 thru *NL:number,longitude,latitude,xcoordinate1,ycoordinate1,xcoordinate2,ycoordinate2*

Lines 7 thru *NL:depth, extracted value*

where *NL* can be either the number of nodes in the domain or the number of open ocean boundary nodes, depending on whether the file being developed is for the initial or boundary conditions, respectively. Line 6

includes the node number, its longitude and latitude values, the first set of *x* and *y* coordinates is the HYCOM node that is associated with the longitude and latitude values (called *itrue* and *jtrue*) while the second set of *x* and *y* coordinates is the HYCOM node where the data is extracted from (called *idata* and *jdata*). Line 7 gives the depth at the node and the extracted value. The format of these two lines are then repeated for all the nodes of interest. For the 2D information, the depth values are not recorded, so the information in this placeholder will be junk.

The output format of the *HYCOMextract* file for the 3D information is as follows:

Line 1: Indicates which HYCOM files data is being extracted from

Line 2: Indicates which HYCOM thickness file information is being extracted from

Line 3: blank (for readability)

Line 4: Description of the information contained in the file (*n,lon,lat,itrue,jtrue,idata,jdata*)

Line 5: Description of the information contained in the file (*depth, extracted values*)

Line 6: blank (for readability)

Lines 7 thru *NL:number,longitude,latitude,xcoordinate1,ycoordinate1,xcoordinate2,ycoordinate2*

Lines 8 thru *NL:depth, extract value*

where *NL* can be either the number of nodes in the domain or the number of open ocean boundary nodes, depending on whether the file being developed is for the initial or boundary conditions, respectively. Line 7 includes the node number, its longitude and latitude values, the first set of *x* and *y* coordinates is the HYCOM node that is associated with the longitude and latitude values while the second set of *x* and *y* coordinates is the HYCOM node where the data is extracted from. Line 8 gives the depth at the node and the extracted value and this line will be included for all the vertical nodes requested by the user. Thus, line 8 will be repeated for all the vertical nodes requested by the user. The format of these two lines are then repeated for all the nodes of interest. Examples of both 2D and 3D output files can be found in the Appendix in Section 8.4

5.11. Program Compilation and Usage.

In order to read the netCDF data format, as supplied from the HYCOM data server, *HYCOMextract* must be linked to the netCDF utilities during compilation. The syntax may vary somewhat for different compilers/machine architectures, but the basic structure is given by the following command:

```
f90 –m/netCDF home directory/include HYCOMextract.f90 -e -o HYCOMextract
-L/netCDF home directory/lib –lnetcdf
```

where the compiler (f90) can be any fortran compiler and the options must all be typed on a single command line. The options are as follows:

–m/netCDF home directory/include specify location of netCDF modules (some compilers use –I instead of –m)

–e allow long lines in Fortran source code, can go over the 70 character limit

–o outfilename specify the name of the resulting executable (default is often a.out)

–L/netCDF home directory/lib –lnetcdf specify location and library name for netCDF. Unless the netCDF library is installed in a standard directory where the fortran linker always looks, you must use the –L and –l options to tell the linker where to find the file (–L option) and which library

you want to link to (–l option).

For more details about linking to the netCDF libraries, go to http://www.unidata.ucar.edu/software/netcdf/docs/netcdf-f90/ and click on the *Compiling and Linking with the NetCDF Library* link. You may also look at the associated link on the .../docs/netcdf-f77/ page.

To invoke the resulting executable program, simply type HYCOMextract (or whatever name is given to the executable using the -o option described above) at the command prompt. The *HYCOMextract* program will then prompt the user 5 to 11 times, depending on the data type specified, to gather the following information:

1. Name of HYCOM file containing source data, *sourcefile*
2. Type of data to be processed, *depthflag*
   - depthflag = 2, 2D surface data (e.g. sea surface height)
   - depthflag = 3, 3D data needing vertical interpolation (e.g. salinity, temperature, vertical velocities)
3. If 3D data, then determine if depth-averaging of results will occur, based on the depthavgflag
   - depthavgflag=1, no depth-averaging needed
   - depthavgflag=2, depth-averaging needed
4. If depthavgflag=2, then enter desired name for output file for depth-averaged values, dpavgout-file
5. If 3D data, then get name of HYCOM layer thickness file, *lthkfile*
6. If 3D data, indicate whether the HYCOM layer thickness source file needs to be converted from Pascal to meters, thknssflag
   - thknssflag=1, no conversion needed
   - thknssflag=2, convert from Pascal to meters (1 m = 9806.0 Pascal)
7. If vertical interpolation needed, get number of vertical layers in target grid, *Nlevels*
8. If vertical interpolation needed, indicate method used to define the vertical layers in the generalized sigma coordinate system, *igc*. Information about the different spacing options and the generalized sigma coordinate system can be found at the ADCIRC website, www.adcirc.org.
   - *igc* = 0, vertical grid read in (sigma grid), user will be asked for a file name
   - *igc* = 1, uniform vertical grid generated
   - *igc* = 2, log vertical grid generated
   - *igc* = 3, log linear vertical grid generated
   - *igc* = 4, double log vertical grid generated
   - *igc* = 5, P-grid generated
   - *igc* = 6, sine grid generated
9. Name of target gridfile for interpolation, *gridfile*
10. Minimum water depth for the grid, *H0*
11. Desired name for output file, *outfile*

Once all of the information is collected, *HYCOMextract* will interpolate/extrapolate the HYCOM data from *sourcefile* (one of the files downloaded according to Section 4.4) onto the user supplied *gridfile* and output it to a file. This data can then be used as initial conditions and boundary conditions in the users program. *HYCOMextract* will have to be called for each data type and each day that the user needs information; e.g if you want temperature, salinity, sea surface height and horizontal velocities, then you'll have to execute *HYCOMextract* 7 times, and if the users wants multiple days worth of boundary condition information *HYCOMextract* must be executed for the multiple days for the data type of interest (e.g., salinity, temperature, etc.).

5.12. Sample Results.

Figure 8 shows initial values for the surface temperature values for the South Atlantic Bight area
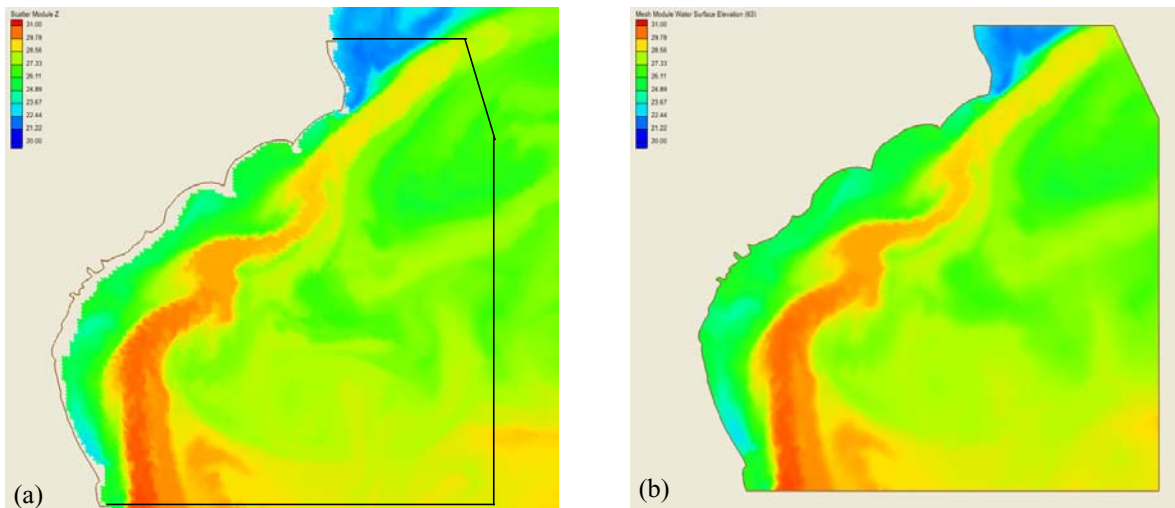

Figure 8   Surface temperature values [˚C] in the South Atlantic Bight region. (a) HYCOM values with the unstructured grid boundaries shown with brown and black lines, (b) values interpolated or extrapolated onto the unstructured grid. Note the scales on these figures are identical.

for September 14, 2006. Figure 8(a) shows the surface temperature directly from HYCOM with the unstructured grid boundaries defined in the brown and black lines. As can be seen, the unstructured grid extends further into the coastal regions than the active cells of the HYCOM grid. Figure 8(b) shows the surface temperature developed from the HYCOMextract program for the unstructured grid. As can be seen, the interpolation/extrapolation program captures the Gulf Stream and extrapolates the near shore results smoothly (no "hot spots") from the given HYCOM information.

As another example, Figure 9 shows the initial conditions for the surface salinity values for the Northern Gulf of Mexico for April 13, 2004. Figure 9(a) gives the HYCOM surface salinity values with the unstructured grid boundaries defined by the brown line with the outer ocean boundary being seen through the red salinity values. The HYCOM information does not extend into the delta region of the Mississippi River or some of the near shore areas. Figure 9(b) shows surface salinity values developed from the HYCOMextract program for the unstructrured grid. In the unstructured grid, we see that the *HYCOMextract* program smoothly extrapolates the delta region of the Mississippi River and the near shore areas. It also shows that the *HYCOMextract* program interpolates near the boundaries accurately.
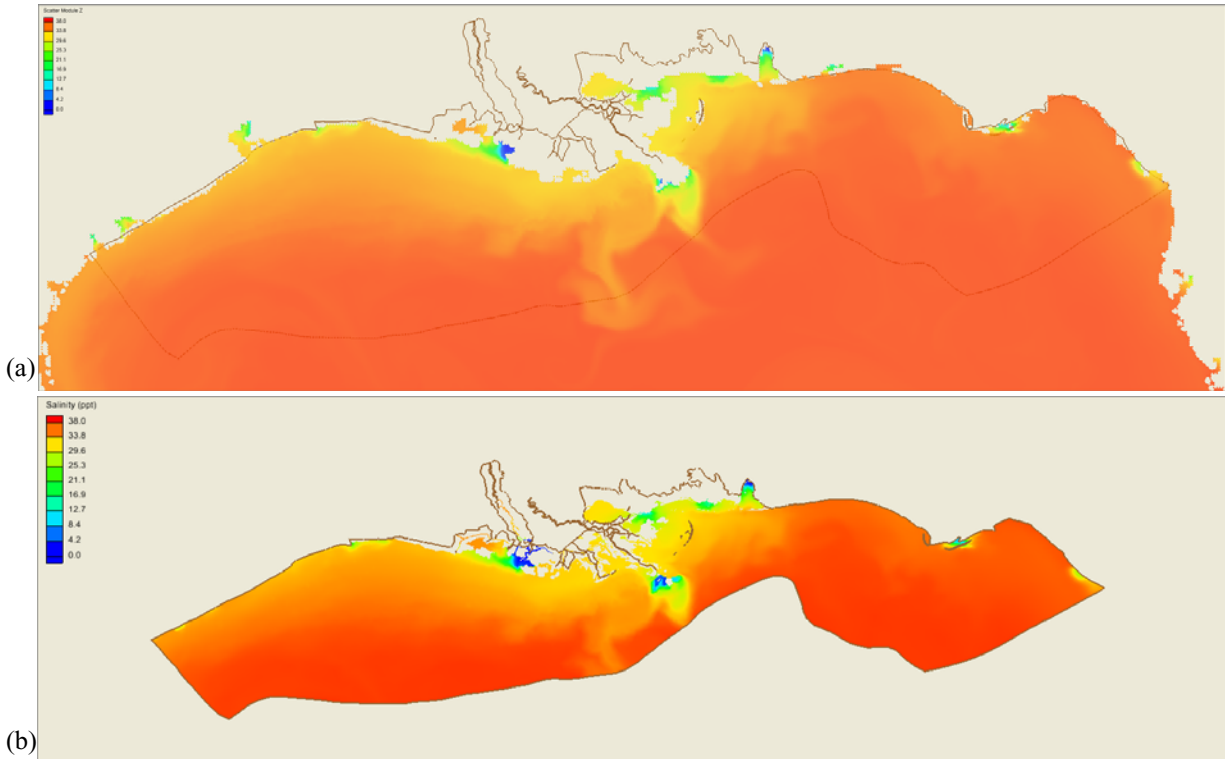
Section 6. Acknowledgements

Figure 9   Surface salinity values [ppt] in the Northern Gulf of Mexico region. (a) HYCOM values with the unstructured grid boundaries shown with brown lines, (b) values interpolated or extrapolated onto the unstructured grid and the gray areas indicate areas where wetting and drying would be required. Note the scales on these figures are identical.

Section 7. Bibliography

[1]   Cummings, J.A., "Operational Multivariate Ocean Data Assimilation," *Quarterly Journal of the Royal Meteorological Society*, 131(613), 3583-604, Oct. 2005.

[2]   Griffes, S. M., C. Boning, F. O. Bryan, E. P. Chassignet, R. Gerdes, H. Hasumi, A. Hirst, A. Treguier, D. Webb, "Developments in Ocean Climate Modeling," *Ocean Modelling*, 2, 123-192, 2000.

[3]   Haidvogel, D., and A. Beckman, *Numerical Ocean Circulation Modeling*, Imperial College Press, 320 pp., 1999.

[4]   http://oceanmodeling.rsmas.miami.edu/hycom/overview.html

Section 8. Appendix

8.1. Example of NetCDF File.

Figure 10 shows the text file of the salinity information from June 23, 2003 produced using the `ncdump` command from the NetCDF software. The .nc file is split into two sections with the first section giving the header information that describes the data contained in the file. This includes the number of grid points in both the longitudinal and latitudinal directions along with the number of layers used in the 3D information, if necessary, along with type of data and variable naming conventions. The second section gives the data in the following order: longitudinal values, latitudinal values, layers (if 3D information), and the data for the file (i.e., salinity, sea surface heights, temperature, etc.).

```
netcdf hycom_2.1_nat_1o12ml_salt_20030623 {
dimensions:
        Longitude = 1678 ;
        Latitude = 1609 ;
        layer = 26 ;
variables:
        float Longitude(Longitude) ;
                Longitude:units = "degrees_east" ;
                Longitude:valid_range = -98.f, 36.16f ;
                Longitude:step = 0.8f ;
                Longitude:standard_name = "longitude" ;
                Longitude:axis = "x" ;
        float Latitude(Latitude) ;
                Latitude:units = "degrees_north" ;
                Latitude:valid_range = -27.94168f, 70.03009f ;
                Latitude:step = 0.8f ;
                Latitude:standard_name = "latitude" ;
                Latitude:axis = "y" ;
        int layer(layer) ;
                layer:units = "layer" ;
        float salt(layer, Latitude, Longitude) ;
                salt:_FillValue = 1.e+34f ;
                salt:units = "pss" ;
                salt:standard_name = "sea_water_salinity" ;
                salt:long_name = "sea_water_salinity" ;
                salt:unit_long = "practical_salinity_scale" ;
                salt:missing_value = 1.e+34f ;
                salt:valid_range = 11.66348f, 40.01402f ;

// global attributes:
                :conventions = "CF-1.0" ;
                :title = "hycom ocean prediction system" ;
                :institution = "Naval Research Lab" ;
                :source = "HYCOM archive file" ;
                :experiment = "expt09.1" ;
                :history = "converted from mean archive file on: 20050125" ;
                :easting = "longitude" ;
                :northing = "latitude" ;
                :reference = "http://hycom.rsmas.miami.edu" ;
                :domain_name = "North Atlantic Ocean" ;
                :field_type = "instantaneous" ;
                :field_date = "20030623-00:00:00" ;
                :field_julian_date = 37429 ;
                :julian_date_unit = "days since 1900-12-31 00:00:00" ;
                :forecast_range = "15" ;
                :forecast_type = "forecast" ;
                :bulletin_date = "20030430-00:00:00" ;
                :bulletin_type = "operational" ;
data:

 Longitude = -98, -97.92, -97.84, -97.76, -97.68, -97.6, -97.52, -97.44,
    -97.36, -97.28, -97.2, -97.12, -97.04, -96.96, -96.88, -96.8, -96.72,
    -96.64, -96.56, -96.48, -96.4, -96.32, -96.24, -96.16, -96.08, -96,
    -95.92, -95.84, -95.76, -95.68, -95.6, -95.52, -95.44, -95.36, -95.28,
    -95.2, -95.12, -95.04, -94.96, -94.88, -94.8, -94.72, -94.64, -94.56,
    -94.48, -94.4, -94.32, -94.24, -94.16, -94.08, -94, -93.92, -93.84,
    -93.76, -93.68, -93.6, -93.52, -93.44, -93.36, -93.28, -93.2, -93.12,
    -93.04, -92.96, -92.88, -92.8, -92.72, -92.64, -92.56, -92.48, -92.4,
    -92.32, -92.24, -92.16, -92.08, -92, -91.92, -91.84, -91.76, -91.68,
    -91.6, -91.52, -91.44, -91.36, -91.28, -91.2, -91.12, -91.04, -90.96,
    -90.88, -90.8, -90.72, -90.64, -90.56, -90.48, -90.4, -90.32, -90.24,
    -90.16, -90.08, -90, -89.92, -89.84, -89.76, -89.68, -89.6, -89.52,
```

Figure 10 Example of text file of the salinity information from June 23, 2003 produced using the `ncdump` command from the NetCDF software.

8.2. Initial Condition Example

        In developing an initial condition file for a simulation spanning September 18 to September 20, 2005, with no conversion necessary for the thickness values, the number of vertical levels set to 21 (evenly spaced) and the minimum water depth of the grid given as 5 m, the step are as follows:

1. Download the following files from the HYCOM data server (ftp://hycom.coaps.fsu.edu/ datasets/atlantic/ATLd0.08_native_coordinate_data/best-estimate/) using the process discussed in Section 4.4:
   - hycom_2.1_nat_1o12ml_lthk_20050918.nc
   - hycom_2.1_nat_1o12ml_salt_20050918.nc
   - hycom_2.1_nat_1o12ml_ssh_20050918.nc
   - hycom_2.1_nat_1o12ml_temp_20050918.nc
   - hycom_2.1_nat_1o12ml_ubaro_20050918.nc
   - hycom_2.1_nat_1o12ml_uvel_20050918.nc
   - hycom_2.1_nat_1o12ml_vbaro_20050918.nc
   - hycom_2.1_nat_1o12ml_vvel_20050918.nc

2. Place a copy of the executable for the *HYCOMextract* program along with a copy of the user specified grid file (can also link the grid file), in the format discussed in Section 5.1, in the same directory as the files from step 1.

3. Run the *HYCOMextract* program for each of these files. An example run of the HYCOMextract program for both a 2D and 3D data run is given below in Figures 11 and 12 with the plain text indicating the program prompts and the bold italic words and numbers indicate what the user would supply to the program:

3a. For the 2D data, *HYCOMextract* would be run on the following files:
   - hycom_2.1_nat_1o12ml_ssh_20050918.nc,
     hycom_2.1_nat_1o12ml_ubaro_20050918.nc,
     hycom_2.1_nat_1o12ml_vbaro_20050918.nc.

```
Enter full name of the HYCOM netCDF file
 (70 chars. max.):
hycom_2.1_nat_1o12ml_ssh_20050918.nc
 Enter 2 if these are 2D (surface) data,
      3 if these are 3D data (needing vertical interpolation)
2
Enter full name of your grid file
 (70 chars. max.):
Texas.grd
 Enter the H0 value or the minimum water depth for the grid:
5
 Enter full name of your output file
 (70 chars. max.):
ssh_20050918
```

Figure 11   Example run of the *HYCOMextract* program for 2D information for the initial conditions.

3b. For the 3D data, *HYCOMextract* would be run on the following files:

- hycom_2.1_nat_1o12ml_salt_20050918.nc,
  hycom_2.1_nat_1o12ml_temp_20050918.nc,
  hycom_2.1_nat_1o12ml_uvel_20050918.nc,
  hycom_2.1_nat_1o12ml_vvel_20050918.nc.

```
Enter full name of the HYCOM netCDF file
 (70 chars. max.):
hycom_2.1_nat_1o12ml_salt_20050918.nc
 Enter 2 if these are 2D (surface) data,
      3 if these are 3D data (needing vertical interpolation)
3
 Enter flag for averaging of 3D data over water column
 1 - no depth-averaged results, 2 - depth-average result
1
 Enter full name of the file containing layer thicknesses
 (70 chars. max.):
hycom_2.1_nat_1o12ml_lthk_20040413.nc
 Enter the flag for conversion of the thickness calculation:
 1 - no conversion needed, 2 - convert from Pascal to m
1
 Enter number of vertical levels desired in your grid
21
 Enter the type of vertical grid (same as IGC in ADCIRC code):
1
 Enter full name of your grid file
 (70 chars. max.):
Texas.grd
 Enter the H0 value or the minimum water depth for the grid:
5
 Enter full name of your output file
 (70 chars. max.):
salt_20050918
```

Figure 12   Example run of the *HYCOMextract* program for 3D information for the initial conditions.

4. After all of the information is extracted from HYCOM onto the user specified grid, an initial condition file can be developed for the coastal model. This file can follow the format of the "hotstart" or "restart" files that some of the coastal models utilize to start their models; the exact format is model dependent. The authors have a fortran code suitable for use by ADCIRC.

8.3. Boundary Condition Example

Next, the steps for developing the boundary condition file for the temperature field are as follows:

1. Download the following files from the HYCOM data server (ftp://hycom.coaps.fsu.edu/datasets/atlantic/ATLd0.08_native_coordinate_data/best-estimate/) using the process discussed in Section 4.4:
   - hycom_2.1_nat_1o12ml_temp_20050919.nc
   - hycom_2.1_nat_1o12ml_temp_20050920.nc
2. Place a copy of the executable for the *HYCOMextract* program along with a copy of the user specified boundary grid file, in the format discussed in Section 5.1, in the same directory as the files from step 1.

3. Run the *HYCOMextract* program for each of these files. An example run of the *HYCOMextract* program for one of these files (3D data) is given in Figure 13 with the plain text indicating the program prompts and the bold italic words and numbers indicate what the user would supply to the program:

```
Enter full name of the HYCOM netCDF file
(70 chars. max.):
hycom_2.1_nat_1o12ml_temp_20050919.nc
Enter 2 if these are 2D (surface) data,
     3 if these are 3D data (needing vertical interpolation)
3
Enter flag for averaging of 3D data over water column
1 - no depth-averaged results, 2 - depth-average result
1
Enter full name of the file containing layer thicknesses
(70 chars. max.):
hycom_2.1_nat_1o12ml_lthk_20040413.nc
Enter the flag for conversion of the thickness calculation:
1 - no conversion needed, 2 - convert from Pascal to m
1
Enter number of vertical levels desired in your grid
21
Enter the type of vertical grid (same as IGC in ADCIRC code):
1
Enter full name of your grid file
(70 chars. max.):
Texas_boundary.grd
Enter the H0 value or the minimum water depth for the grid:
5
Enter full name of your output file
(70 chars. max.):
temp_20050919
```

Figure 13   Example run of the *HYCOMextract* program for 3D information for the boundary conditions. Note change in the full name of the grid file.

4. This is then repeated for all the other boundary information such as salinity and sea surface heights. After all the information is extracted from HYCOM and interpolated or extrapolated onto the user specified open ocean boundary grid, a boundary condition file can be developed for the coastal model. The exact format of these boundary condition files is model dependent, but the following format is used by ADCIRC:

> Timestamp
> for j=1, number of open ocean boundary nodes
> salt(j,k), for k=1, number of vertical levels
> end j loop

where this information would be repeated for every day of boundary information. So in this case, we would have one set of information for September 19 and then right after it in the same file the information for September 20.

8.4. Output File Examples

Figures 14 and 15 show example output file from the *HYCOMextract* program for both the 2D or depth-averaged and 3D information, respectively.

```
      Run on HYCOM file      hycom_2.1_ATL_1o12ml_srfhgt_2006091400.nc

    n      lonP      latP itrue jtrue idata jdata
fP value(s)

    1  -76.358   34.817   271   829   271   829
0.1130-306 -0.2132E+00
    2  -76.345   34.830   271   829   271   829
0.1130-306 -0.2154E+00
    3  -76.370   34.803   271   829   271   829
0.1130-306 -0.2111E+00
    4  -76.350   34.796   271   829   271   829
0.1130-306 -0.2100E+00
    5  -76.337   34.810   271   829   271   829
0.1130-306 -0.2121E+00
    6  -76.318   34.824   272   829   272   829
0.1130-306 -0.2140E+00
    7  -76.327   34.844   271   830   271   830
0.1130-306 -0.2158E+00
    8  -76.368   34.780   271   829   271   829
0.1130-306 -0.2075E+00
    9  -76.382   34.789   271   829   271   829
0.1130-306 -0.2089E+00
   10  -76.330   34.789   271   829   271   829
0.1130-306 -0.2088E+00
   11  -76.348   34.773   271   829   271   829
0.1130-306 -0.2064E+00
   12  -76.311   34.803   272   829   272   829
0.1130-306 -0.2089E+00
   13  -76.291   34.818   272   829   272   829
0.1130-306 -0.2061E+00
   14  -76.300   34.838   272   830   272   830
0.1130-306 -0.2096E+00
   15  -76.309   34.858   272   830   272   830
0.1130-306 -0.2080E+00
   16  -76.367   34.758   271   828   271   828
0.1130-306 -0.1970E+00
   17  -76.380   34.767   271   828   271   828
0.1130-306 -0.1968E+00
   18  -76.394   34.776   271   829   271   829
0.1130-306 -0.2068E+00
   19  -76.323   34.769   271   829   271   829
0.1130-306 -0.2057E+00
   20  -76.309   34.783   272   829   272   829
0.1130-306 -0.2056E+00
```

Figure 14 Example of output format for the 2D information or the depth-averaged information from *HYCOMextract*.

```
     Run on HYCOM file      hycom_2.1_ATL_1o12ml_temp_2006091400.nc
vertically interpolated with hycom_2.1_ATL_1o12ml_thknss_2006091400.nc


    n      lonP     latP itrue jtrue idata jdata
fP value(s)


   1  -76.358   34.817   271   829   271   829
 0.0000E+00  0.2448E+02
-0.6400E+00  0.2448E+02
-0.1280E+01  0.2448E+02
-0.1920E+01  0.2448E+02
-0.2560E+01  0.2448E+02
-0.3200E+01  0.2448E+02
-0.3840E+01  0.2448E+02
-0.4480E+01  0.2448E+02
-0.5120E+01  0.2449E+02
-0.5760E+01  0.2449E+02
-0.6400E+01  0.2449E+02
-0.7040E+01  0.2449E+02
-0.7680E+01  0.2449E+02
-0.8320E+01  0.2449E+02
-0.8960E+01  0.2449E+02
-0.9600E+01  0.2449E+02
-0.1024E+02  0.2449E+02
-0.1088E+02  0.2450E+02
-0.1152E+02  0.2450E+02
-0.1216E+02  0.2450E+02
-0.1280E+02  0.2450E+02
   2  -76.345   34.830   271   829   271   829
 0.0000E+00  0.2447E+02
-0.6535E+00  0.2447E+02
-0.1307E+01  0.2447E+02
-0.1960E+01  0.2447E+02
-0.2614E+01  0.2447E+02
-0.3267E+01  0.2447E+02
-0.3921E+01  0.2448E+02
-0.4574E+01  0.2448E+02
-0.5228E+01  0.2448E+02
-0.5881E+01  0.2448E+02
-0.6535E+01  0.2448E+02
-0.7188E+01  0.2448E+02
-0.7842E+01  0.2449E+02
-0.8495E+01  0.2449E+02
-0.9149E+01  0.2449E+02
-0.9802E+01  0.2449E+02
-0.1046E+02  0.2449E+02
-0.1111E+02  0.2449E+02
-0.1176E+02  0.2449E+02
-0.1242E+02  0.2449E+02
-0.1307E+02  0.2449E+02
```

Figure 15   Example of output format for 3D information from *HYCOMextract*.