APPLICATIONS OF CHESMAP - AN ENVIRONMENTAL DATA MAPPING PROGRAM

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ABSTRACT

A computerized approach to displaying environmental data in maps is an important tool to those interested in analyzing the data. With the development of CHESMAP, customized maps are now available to anyone with access to SAS®. CHESMAP was written using the macro facility features of SAS and the graphics procedures of SAS/GRAPH®. The program creates data point, contour, overlay, time-plot or response surface multicolor maps in two- or three-dimensions. The map may be of the entire Chesapeake Bay region or a subregion based on longitude and latitude or by common areas (e.g. rivers, upper, lower, or mainstream Chesapeake Bay). This paper demonstrates the various options available with CHESMAP using some historical dissolved oxygen data from the Maryland portion of the Chesapeake Bay. While the environmental mapping program was developed using the Chesapeake Bay map coordinates, it can also produce maps of other geographic locations by using new map coordinates.

INTRODUCTION

The Chesapeake Bay, one of the largest and most productive estuarine systems in the Western Hemisphere, is the focus of the University of Maryland Sea Grant College statewide research and outreach program. An important tool in the analysis of environmental data on important processes and characteristics of the Chesapeake Bay is to map the data in a variety of ways (e.g., response surfaces, contours). Temporal and spatial trends and relationships between environmental factors may be uncovered which can lead to a better understanding of such a complex estuarine system (Swartz et. al, 1986).

CHESMAP can create a map of the entire Chesapeake Bay or the user can zoom in on a subregion based on latitude and longitude. The user supplies the environmental data in a SAS data set and selects the appropriate options. Each observation in the data set includes the response variable (e.g., salinity, dissolved oxygen, station identification code) along with the latitude and longitude where it was recorded. CHESMAP will generate the SAS code necessary to create the map based on a grid of locations (i.e. water, shoreline, or land) used to determine where data points, station locations, contours, or response surfaces can be displayed. Please see Jacobs and Swartz (1987) for details of CHESMAP's development and process used to create a map.

This paper shows how to use CHESMAP to create the many different maps it can produce. Maps are created by selecting and setting values to the appropriate macro variables in the macro call statement. All of the macro variables in a CHESMAP call are keyword parameters. Some of the macro variables have default values to make the programming easier. The entire Chesapeake Bay estuarine system is available for mapping by CHESMAP. However, we focused on the middle region of the Chesapeake Bay enclosed in the box in Figure 1. This area, bounded by the Choptank and Patuxent Rivers, has been extensively sampled to monitor dissolved oxygen and other water column characteristics (Figure 2). A portion of this historical dissolved oxygen data set was used to
demonstrate how to use CHESMAP. A caveat, CHESMAP was developed, tested, and used in the CMS operating environment but the SAS code is operating system independent. Files mentioned in this paper follow CMS file naming conventions.

GETTING STARTED

Before CHESMAP can produce a map of an area for the first time, you must create two SAS data sets, a map grid data set and a boundary point data set, for the area. The map grid data set is a reduced set of 10,000 coordinates from the master grid which is composed of approximately 1.5 million coordinates that indicate allowable locations for data representation (e.g., water). The boundary point data set is a subset of shoreline coordinates from the approximately 240,000 coordinates in the master shoreline file. All latitude and longitude coordinates are given in decimal notation. To create the appropriate SAS data sets, CHESMAP is run with the following macro variables:

- **MAKEMAP** - must be set to MAKEGRID
- **REGION** - 1-8 character name of the area used as the filename for the two SAS data sets. Add REPLACE if region exists.
- **XLOW** - furthest east longitude
- **XHIGH** - furthest west longitude
- **YLOW** - furthest south latitude
- **YHIGH** - furthest north latitude

These are optional macro variables that can be used to change some of the default settings:

- **MASTERG** - use different master grid file
- **MASTERB** - use different master shoreline file
- **DISK** - use different disk to store data sets
- **PREFIXG** - 1-8 character name for the map data filetype (default = MAPGRID)
- **PREFIXB** - 1-8 character name for the boundary data filetype (default = SHOREPT)
- **MAXSIZE** - grid density (default = 10,000)
- **DES** - brief description of area, up to 25 characters (default = .)
- **TABLE** - region table (default = REGIONS.CHESMAP)

To create the two SAS data sets for the middle region of the Chesapeake Bay, the following code was used:

```sas
%CHESMAP(MAKEGRID=MAKEGRID, REGION=MIDBAY, DES=DO STUDY AREA, XLOW=%STR(-76.1), XHIGH=%STR(-76.67), YLOW=38.25, YHIGH=39.00);
```

The two data sets created (MIDBAY.MAPGRID and MIDBAY.SHOREPT) are permanent SAS data sets and were used in all of the following CHESMAP examples. CHESMAP can list the regions already created and available for use. The list of regions, associated map grid and boundary data sets, minimum and maximum x and y coordinates, grid density, and comments as stored in the region table will be printed by using:

```sas
%CHESMAP(MAKEMAP=REGIONS);
```

If the region table is different from the default, use:

```sas
%CHESMAP(MAKEMAP=REGIONS, TABLE=ft.fn);
```

where ft.fn is the filetype and filename of the region table.

CREATING THE MAPS

Now that the map grid and shoreline data sets have been created, maps depicting environmental data for this area can be produced. CHESMAP can depict the data or station locations in 2- and 3-dimensional multicolor maps. These macro variables are used in any map request:

- **MAKEMAP** - type of map: DATA, FILL, OUTLINE, SURFACE
- **RAWDATA** - filename of raw data (if needed)
- **REGION** - name of the region to map
- **TABLE** - region table (default = REGIONS.CHESMAP)
- **XVAR** - x axis variable
- **YVAR** - y axis variable
- **ZVAR** - response variable

The XVAR, YVAR and ZVAR are the variable names as stored in the raw data or SAS data set. Use the following macro variables to change default settings on how the axes are to be drawn:

```sas
CAXIS - color for all axes (default - WHITE)
CTEXT - color for all text (default - WHITE)
```
GAXES - extra GPLOT or G3D options.  
NOAXES prevents axes from being drawn (default = none).

XTICKS - X axis intervals  (default = 4)

YTICKS - Y axis intervals  (default = 4)

Data and Area of Study Maps

You can have CHESMAP produce two- and three-dimensional maps depicting the raw data values, the station locations, or the area of study by setting MAKEMAP = DATA. You then need to select the type of data map by setting the MAPTYPE macro variable to the appropriate value:

NODATA - 2D map of the area of study
ID - 2D station map using ZVAR values
SYMBOL - 2D station map using a symbol (S1)
TWOD - 2D response variable (ZVAR) map
THREED - 3D response variable (ZVAR) map

The dissolved oxygen study area, shown in Figure 2, was created using MAPTYPE=NODATA. The map also shows how CHESMAP adjusts the axes to avoid distortion of the map.

There are two ways to depict station locations. When MAPTYPE = 1D, the ZVAR variable contains alphanumeric station codes or names instead of response variable values. The second way is to have a symbol represent the station locations using MAPTYPE = SYMBOL and by setting the macro variable S1 equal to the symbol to be used. An example of the second way of showing station locations is shown in Figure 3 and was created using the following code:

```sas
%CHESMAP(MAKEMAP=DATA,MAPTYPE=SYMBOL,REGION=MIDBAY,XVAR=LONG,YVAR=LAT,ZVAR=DO,GAXES=NOAXES,RAWDATA=DO);
```

When the map is in two dimensions (MAPTYPE is NODATA, ID, SYMBOL or TWOD), you can change how CHESMAP does the axes (unless GAXIS = NOAXES). To modify axes use:

XAXIS - extra AXIS statements for X axis
YAXIS - extra AXIS statements for Y axis
FONT - text font (default = SIMPLEX)
XLABEL - label for the X axis (default = none)
YLABEL - label for the Y axis (default = none)

You can also set the color and size of the symbol used to represent the station location or the color and size of the data values using:

CTOP - symbol or raw data color  (default = RED)
SIZE - symbol or raw data value size (default = 1)

If the map is in three dimensions (MAPTYPE = THREED), you can modify how CHESMAP creates the data map using:

CBORDER - boundary color (default = BLUE)
CTOP - raw data color (default = RED)
ROTATE - degree of rotation (default = 70)
S3D - raw data shape  (default = BALLOON, see SAS/GRAPH Ver. 5, pg. 406 for other shapes)
SIZE3D - size of raw data shape (default = 1)
TILT - degree of tilt (default = 10)
XAXIS - extra AXIS statements for X axis
YAXIS - extra AXIS statements for Y axis
XLABEL - label for the X axis (default = none)
YLABEL - label for the Y axis (default = none)
ZLABEL - label for the Z axis (default = none)
ZMIN - minimum response variable value (default = none)
ZMAX - maximum response variable value (default = none)
ZTICKS - number of intervals for Z axis (default = 4)

Figure 4 is a 3-D map of the bottom dissolved oxygen values recorded in August, 1985. The CHESMAP requested used was:

```sas
%CHESMAP(MAKEMAP=DATA,MAPTYPE=THREED,REGION=MIDBAY,RAWDATA=DO,XVAR=LONG,YVAR=LAT,ZVAR=DO,DIRECT=LESS,XLABEL=LONGITUDE,YLABEL=LATITUDE,ZLABEL=DO);
```

Contour Maps

With CHESMAP, you can create contour maps with the contour levels filled in using different symbols and/or colors (MAKEMAP = FILL) or outlining the contour levels using different line types in black and white or color (MAKEMAP = OUTLINE). Contour information is controlled by:
L1-L10 - specify up to 10 contour values
(defaults - none)

DIRECT - specify if only have one contour level (L1)
MORE - values increase towards center of contour
LESS - values decrease towards center of contour

CTYPE - how contour levels are displayed:
BW - black & white using symbols (S1-S10)
COLOR - colors (CCOLORS) & symbols (S1-S10)

CTOP - color of map if CTYPE = BW
(default = RED)

CCOLORS - if CTYPE = COLOR, specify colors
to depict contours with defaults:
NONE RED GREEN BLUE
MAGENTA CYAN BLACK
YELLOW GREY TAN PINK

When MAKEMAP = FILL there are 10 symbol macro variables available to assign the symbols used to fill in the contour areas. The variables and their default settings are:

S1 - NONE S6 - O
S2 - F=SIMPLEX S7 - SQUARE
S3 - PAW S8 - Z
S4 - Y S9 - HASH
S5 - X S10 -
(See SAS/GRAPH manual for other symbols and fonts)

If MAKEMAP = OUTLINE, you assign the types of lines used to outline contours with the macro variable LINETYPE. The default line types are 1 24
23 22 4 3 21 2 20 25 (See the SAS/GRAPH manual for other line types).

You can also modify how the axes and legend information are displayed by CHESMAP using:

BOUNDARY - edge data name for the legend
(default = SHORE)
CBORDER - color for the edge data
(default = BLUE)
FONT - text font (default = SIMPLEX)
LEGEND - set to NOLEGEND if don't want a legend to be included in map
LEGOPT - add extra LEGEND statements
XAXIS - extra AXIS statements for X axis
YAXIS - extra AXIS statements for Y axis

XLABEL - label for X axis (default = none)
YLABEL - label for Y axis (default = none)
ZLABEL - label for legend (default = none)

Areas of anoxia (dissolved oxygen <= 4 ppm) are shown in contour maps in Figures 5 and 6 of the mid-Bay region. Figure 5, showing filled in contour areas, was created using:

%CHESMAP(MAKEMAP=FILL,
REGION=MIDBAY,RAWDATA=DO,
XVAR=LONG,YVAR=LAT,ZVAR=DO,
ZLOW=0,ZHIGH=4,L1=4,L2=2,L3=0,
XLABEL=LONGITUDE,
YLABEL=LATITUDE,ZLABEL=DO);

and Figure 6, showing isopeths, was created by changing MAKEMAP from FILL to OUTLINE.

CHESMAP will also create overlay maps for your use. Pluses are drawn at the four corners of each map to make alignment easier. Maps used as overlays are requested including the macro variable OVERLAY in the request (default = NO). Set OVERLAY = YES and only the contour areas are drawn. Set OVERLAY = FIRST to have the shoreline drawn along with the axes, if requested. In Figure 7, the outline map was overlayed onto a map of station locations. A second example, shown in Figure 8, are the May and August bottom dissolved oxygen levels shown side-by-side. The shoreline was left in for better reference since transparencies cannot be included in this paper.

Response Surface Maps

Setting MAKEMAP = SURFACE, you can produce two types of response surface maps. The values for the response surface are derived from the raw data and spline interpolation using PROC G3GRID. The further you go from the cluster of data points, the more uncertain are the values. With spline fitting it is not possible to provide confidence intervals. Also, this method of interpolation does not adjust for the physical dynamics or constraints of the estuary. If a user has a model that provides more accurate values, it may be substituted for PROC G3GRID values.

The type of response surface map is chosen by setting the macro variable MAPTYPE to:
GRID - response surface as a grid with the land areas depressed
POINT - response surface composed of just water with the land trimmed off

You must also specify the direction of the response variable for the z axis by setting DIRECT equal to:
LESS - response variable decreases in value as one goes up the z axis (above the xy plane) or
MORE - response variable increases in value as one goes up the z axis (above the xy plane)

When you ask CHESMAP to create a response surface that depressed the land areas (MAPTYPE = GRID), you can control the surface colors using:
CTOP - color of grid top (default = RED)
CBOTTOM - color of grid bottom (default = BLUE)

If just the water portion of the response surface is to be displayed (MAPTYPE = POINT) then you use these three macro variables to control the color, shape and size of the grid points:
CTOP - color of the points (default = RED)
S3D - point shape (default = BALLOON) (see SAS/GRAPH Ver. 5, pg. 406 for other shapes)
SIZE3D - raw data shape size (default = 1)

You can control how CHESMAP draws the axes, axis values, and axis labels using these optional macro variables:
GRID - extra G3D options (default = GRID). NOAXES prevents axes to be drawn.
ROTA TE - degree of rotation (default = 70)
TILT - degree of tilt (default = 10)
XLABEL - label for the X axis (default = none)
YLABEL - label for the Y axis (default = none)
ZLABEL - label for the Z axis (default = none)
ZTICKS - number of intervals for Z axis (default = 4)
ZMIN - minimum response variable value (default = none)
ZMAX - maximum response variable value (default = none)

The two types of response surfaces are shown in Figures 9 and 10. The code used to create a response surface with the land area depressed was:

%CHESMAP(MAKEMAP=GRID,
REGION=MIDBAY,RAWDATA=DO,
XVAR=LONG,YVAR=LAT,ZVAR=DO,
ZLOW=0,ZHIGH=4,DIRECT=LESS,
XLABEL=LONGITUDE,
YLABEL=LATITUDE,ZLABEL=DO);

OTHER CHARACTERISTICS OF CHESMAP

CHESMAP can save any map it creates for later display. All you have to add to any macro call are the following three macro variables:
GOUT - two-level graphics catalog name
NAME - up to eight character map name
DES - description of up to 25 characters

You must specify all three for the map to be created and saved. It will be displayed unless you include the OPTIONS NODISPLAY; statement prior to the %CHESMAP call. For more information about saving and redisplaying SAS graphs, please see the SAS/GRAPH manual.

CHESMAP also has limited memory of the values assigned to some of the macro variables. This means you can call CHESMAP several times in a program to create several maps and do not have to repeat specifying certain macro variables. CHESMAP will use the value given to one of the memory macro variables in subsequent macro calls unless the macro variable is respecified. This is different from those macro variables with set default values since the value retained was originally supplied by the user and not CHESMAP. These are the memory macro variables:
REGION YHIGH ZLOW
XVAR XLABEL ZHIGH
XLOW YLABEL ZLABEL
XHIGH RAWDATA L1-L10
YLOW ZVAR

For example, the maps shown in Figures 5 and 6 could have been created in one run to take advantage of CHESMAP's limited memory. The code used would look like this:
*CREATE THE REGION DATA SETS;
%CHESMAP(MAKEMAP=MAKEGRID,
REGION=MIDBAY,DES=DO STUDY AREA,
XLOW=%STR(-76.1),XHIGH=%STR(-76.67),
YLOW=38.25,YHIGH=39.00);
*CREATE FILLED CONTOUR MAP;
%CHESMAP(MAKEMAP=FILL,
ZLOW=0,ZHIGH=4,L1=4,L2=2,L3=0,
RAWDATA=DO,XLABEL=LONGITUDE,
YLABEL=LATITUDE,ZLABEL=DO);
*CREATE ISOPLETH MAP;
%CHESMAP(MAKEMAP=OUTLINE);

CHESMAP can also be used to create maps of other regions. The master grid and shoreline files need to be created in the same manner used for the Chesapeake Bay (see Jacobs and Swartz, 1987, and Swartz et. al, 1986). You must also change the equations used to convert the integer stored map grid and shore point data to decimal latitude and longitude and visa versa. These are stored in the default setting for the special macro variables XINTREAL, XREALINT, YINTREAL and YREALINT. The y/x aspect ratios for 2- and 3-d maps are set using the ASPECT macro variable and the default settings are for the Chesapeake Bay. Also, you should change the name of the region table.

A package enabling CHESMAP to be generalized to MAPIT - a package supporting the easy development of a specialized mapping system is under development and will be available in the near future. CHESMAP is currently available under terms set by the authors.

CHESMAP must be installed on your computer prior to using it to create a map as demonstrated in this paper. To do this, you run CHESMAP once to set up the regions table on your account (or on the account where the map grid and boundary data sets will stored) using the code:

%CHESMAP(MAKEMAP=INSTALL);

where the default SAS data set that will contain region information will be called REGIONS.CHESMAP and stored on your A-disk. To change the name of the regions table, you use:

%CHESMAP(MAKEMAP=INSTALL,
TABLE=ft.fn);

where ft.fn is the new filetype and filename. You must set TABLE to this name whenever using regions created and referenced in ft.fn.

The regions file will contain 16 variables and one observation after you install CHESMAP. These variables provide CHESMAP with names of SAS data sets it will need (i.e. map grid data and boundary data) along with the name, comments, grid density, and coordinates of the region.

CONCLUSIONS

We have demonstrated in this paper the utility of CHESMAP. The maps that CHESMAP can generate make it a valuable tool in the pursuit of a better understanding of the Chesapeake Bay, a complex estuarine system. The user is only required to create data files of the environmental data and select the appropriate CHESMAP options to create inexpensive and accurate maps. As added features, the package also contains on-line help and error checking to make it easier to use.

While CHESMAP was developed for the Chesapeake Bay, the programming is not tied to this region. It can quite easily be adapted to other estuarine and non-estuarine areas. In addition, CHESMAP is fully integrated into SAS which insures compatibility with a user’s need for data handling and manipulation and statistical analysis of the data. CHESMAP’s functionality and flexibility, along with the wide availability and acceptance of SAS, makes it a contender for an overall basic system for the analysis and display of environmental data.

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REFERENCES


Figure 1. The Chesapeake Bay. Area enclosed in the box focus of maps (see text).

Figure 2. Middle portion of the Chesapeake Bay.
Figure 3. Station locations used in the dissolved oxygen study.

Figure 4. Three-dimensional map of bottom dissolved oxygen values, August, 1985.

Figure 5. Filled in contour map of bottom dissolved oxygen concentrations, August, 1985.

Figure 6. Contour line map of bottom dissolved oxygen concentrations, August, 1985.
Figure 7. Example of overlay maps: August, 1985, bottom dissolved oxygen levels overlayed on a map of station locations.

Figure 8. Example of overlay maps: May and August, 1985, bottom dissolved oxygen levels shown side-by-side.

Figure 9. Response surface as a grid map of bottom dissolved oxygen concentrations, August, 1985.

Figure 10. Response surface as a point map of bottom dissolved oxygen levels, August, 1985.