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A GIS Based Analysis of the Benthic Community in the Western
Arctic Ocean

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Arctic Ocean**

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Report

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This report is dedicated to my family, for always supporting me
my mom and dad, Björg Bjarnadóttir and Árni Jónsson
my sisters, Anna Margrét, Bjarney, Fríða and Lena
my nieces, Ásdís Björg, Lilja Dögg and Árný Rún
and my late grandfather, Jón Guðmundsson

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Abstract

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Knowledge of the spatial distribution of benthos in the Western Arctic Ocean gives valuable information of the effects of global change on the ecology of the Arctic Ocean. The goal of this research was to construct a geospatial database and analyze the benthic community in the Western Arctic Ocean using Geographical Information Systems (GIS). The study area includes the Beaufort, Chukchi, East Siberian and Northern Bering Seas. Benthic sample data were assembled in a relational database and analyzed in ArcView and Arc/Info. A Geostatistical Analyst extension to ArcMap was used to interpolate benthic biomass with kriging techniques. The kriging model shows regions of high benthic biomass in the Bering and Chukchi Sea, where the warm nutrient rich waters of the Pacific Ocean mix with the Arctic Ocean. The benthic biomass is significantly lower in the Beaufort Sea, while regions of relatively high benthic biomass appear to exist in the vicinity of fresh water inflow from major rivers.

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Chapter 1: Introduction

1.1 BACKGROUND

The goal of the National Science Foundation's (NSF) Arctic Systems Science (ARCSS) program is to establish knowledge of the physical, geological, chemical, biological and sociocultural processes of the Arctic system. The program supports large integrated research projects to establish an understanding of the Arctic Ocean and its response to global warming. Knowledge of the Arctic Ocean can then be used to create policy response options to global climate change (NSF, 1999).

One of four ongoing components of ARCSS is the Ocean/Atmosphere/Ice Interaction of the Arctic System (OAI) program. OAI seeks to enhance the understanding of the continuous link between water, ice, air, biota, dissolved chemicals, and sediments in the Arctic and adjacent oceans, in order to get a clearer picture of the Arctic's role in global climate change (ARCSS, 2000).

The Western Arctic Shelf Basin Interactions (SBI) project is one of the ARCSS/OAI projects. It emphasizes the Chukchi and Beaufort Sea region in the Western Arctic Ocean and focuses on the connection between the Arctic shelves, slopes and deep basins with regard to biological, physical and geochemical processes (WASBI, 2000).

Arctic Benthic Biota - Links to Global Change is a research project within the scope of SBI. It concentrates on the benthic community in the western Arctic and its goal is to link patterns of the benthos to physical and biological processes,

and thereby establish knowledge of the effects of global change on the ecology of the Arctic Ocean. Benthic organisms are often considered integrators of the life in the water column above. Since the water column filters out high frequency seasonal variations to some extent, the abundance of benthic organisms does not change drastically with seasons. Therefore with sufficient measurements they are good indicators of long-term changes.

Mapping of the geographic extent and character of benthic organisms in the context of other features such as ocean depth, freshwater inflow from rivers, etc. is essential to comprehend the information available and to connect different physical and biological factors applicable in the Arctic Ocean. The Geographical Information Systems (GIS) framework can efficiently handle this sort of investigation. The ArcView and Arc/Info GIS platforms, developed by the Environmental Systems Research Institute (ESRI), are capable of visualization and various analyses of point, vector and raster data.

1.2 STUDY OBJECTIVES

The objectives for this first year of the *Arctic Benthic Biota - Links to Global Change* study were devoted to the preparation of data and the development of methods for further analysis. The work was carried out as a joint effort of the Marine Science Institute (MSI) and Center for Research in Water Resources (CRWR). Most of the effort has been dedicated to the GIS component of the project while a search for adequate benthic data has been extensive and is not yet completed. The study objective consists of six tasks:

- **Benthic data compilation.** Sample data of the benthic community structure are available from the National Oceanographic Data Center (NODC) and other sources. The NODC data are reformatted and compiled into a relational database (Microsoft Access). In Access, data selection is made and records are imported to ArcView.
- **Digital bathymetry map.** Several sources of digital bathymetry/elevation are available for the study area. Comparison of the grids in ArcView reveals differences in the resolution and the interpolation techniques of the various grids. Therefore an evaluation of what data sources are best for the project is carried out in this research.
- **Orientation database construction.** Several GIS datalayers are available or were developed in order to place other layers in a better geographical context. These involve nautical charts from the National Oceanic and Atmospheric Administration (NOAA), coastlines and rivers from the Digital Chart of the World (DCW), and others.
- **Importation of oceanographic model results.** An Ice-Ocean Arctic Ocean model has been developed at the Naval Postgraduate School (NPS) in Monterey California (Maslowski, 2000). By changing the file format of the models output, benthic data can be compared to ocean currents, temperature and salinity. Extrapolation of benthic data may be interconnected with those physical features.
- **Geostatistical Analysis.** A *Geostatistical Analyst* extension of Arc/Info 8 can interpolate point data with deterministic and geostatistic techniques. Thereby

it has the potential to create gridded maps of benthic patterns, and patterns associated with physical and biological processes.

1.3 STUDY AREA

The Arctic Ocean, the smallest of the world's four oceans (after the Pacific, Atlantic, and the Indian Ocean), has an area of approximately 14 million sq km. An ice sheet generally covers the area above 75° N, while further south, ice occurrence is seasonal. The major water exchange with other oceans is through circulation into and from the Atlantic Ocean through the Fram Strait between Greenland and Svalbard, where the cold water of the Arctic blends with the warmer water of the Atlantic. The Arctic Ocean connects to the Pacific Ocean through the Bering Strait where the warm, nutrient rich waters of the Pacific come up through the Bering Strait (Smith 1990). North of the Bering Strait, between Siberia and Alaska, lies the Chukchi Sea. To the east of Chukchi Sea, north of Alaska, is the Beaufort Sea (Figure 1.1).

The study area of this research extends from 62° to 75° North and from 160° East to 128° West (Figure 1.1), encompassing the northern part of the Bering Sea, the Bering Strait, the Chukchi Sea and the Beaufort Sea. The area is characterized by high benthic productivity in the shallow Bering and Chukchi Sea shelf, where the ocean depth is generally less than 60 m. Nutrient flux into the Beaufort Sea is very limited and consequently, the productivity in the Beaufort Sea is considerably lower. The Mackenzie River does, however, carry large

amounts of sediment and nutrients to the Beaufort Sea, and higher benthic productivity is identifiable in the vicinity of the river's mouth.



Figure 1.1 The Study Area, the Western Arctic

1.4 REPORT OUTLINE

This report is divided into six chapters. The first chapter introduces the study while the second presents an existing literature review on related subjects. The third chapter is dedicated to the description of the data used in the project while chapter four describes the methods and procedures used. The results of the study are presented in the fifth chapter and conclusions are drawn in Chapter six. Appendix A presents details of procedures and ArcView Avenue scripts.

Chapter 2: Literature Review

2.1 BENTHIC COMMUNITY STUDIES

Several research groups have studied the benthic community of the western Arctic Ocean. Broad (1981), Carey (1984) and Wacasey (1974) conducted extensive work in the southern Beaufort Sea, while Feder (1982) and Grebmeier (1987) focused on the Chukchi and Northern Bering Sea.

2.1.1 Southwestern Beaufort Sea, Broad

Broad et al. (1978-1981), explored the nearshore benthos of the Beaufort and Chukchi Sea, during the summers of 1975-1980. He found that the species biomass was very low from 2 m depth to the shoreline, due to annual shore-fast ice. The biomass increased at water depths between 2 m to 20 m, yet were not as high as those measured in offshore regions by Carey (1984). The principal nearshore faunal species were polychaete worms, bivalve mollusks, and crustaceans. An area of higher biomass was recorded just north of Barter Island. The “Boulder Patch”, an approximately 40 km² area of cobbles and boulders with attached kelp and invertebrate life, was discovered in Stefansson Sound, near Prudhoe Bay, Alaska. The Boulder Patch is a rare feature of the Alaskan Beaufort Sea shelf, which is blanketed predominantly by silty sands and mud. This area supports a high biomass kelp community dominated by three species of red and brown algae and by a diverse assortment of invertebrates representing every major taxonomic phylum.

2.1.2 Southwestern Beaufort Sea, Carey

Carey's (1984) final report, "Selected Ecological Studies on Continental Shelf Benthos and Sea Ice Fauna in the Southwestern Beaufort Sea", describes his exploration of the southwestern Beaufort Sea. Five quantitative benthic samples were taken at each location with a 0.1 m² Smith-McIntyre bottom grab. Carey also draws conclusions from the studies of the past years that started in 1971. The conclusions imply that benthic macrofauna biomass is in general at a maximum at the edge of the continental shelf and at the upper continental slope. The temporal variability in the benthic community is greatest at the shelf's edge and is correlated with depth across the shelf. The extent of ice cover in the summer months affects the penetration of light through the water column, thereby affecting primary production of phytoplankton. Where the shelf is at a depth of 20–25m, the benthic macrofauna seems lower than in the surrounding areas, probably caused by ice gouging the bottom of the ocean during the winter.

2.2 GEOSTATISTICAL ANALYST

Benthic data cannot be sampled on a spatially continuous scale but rather at point locations. A continuous surface would however be the optimal result of an exploration. Therefore, ESRI's beta product, the *Geostatistical Analyst* Arc/Info 8 extension was used to interpolate the benthic data. The extension was studied and the *Geostatistical Analyst Tutorial* (2000) reviewed. The tutorial included nine chapters describing geostatistical interpolation techniques and application of them in Arc/Info 8. The tutorial is written in an "easy to

understand” manner while an appendix contains the complete mathematical formulas, which the geostatistical analysis is based upon.

Several methods of gaining familiarity with the data are available before interpolation takes place. Histograms let the user examine the frequency distribution of the data while Normal Quantile-Quantile plots (QQ-plots) look at whether the data can be assumed to have a normal distribution. The Trend Analysis option in the extension allows the user to identify nonrandom trends in the data. This data exploration can assist the user in an identification of outliers and a selection of interpolation technique.

Two groups of interpolation techniques are available in the Geostatistical Analyst extension, deterministic interpolation and geostatistics.

2.2.1 Deterministic Interpolation

Deterministic interpolation techniques are built on the basic law of geography that things close together are more similar than things that are far apart. The Geostatistical Analyst provides four deterministic interpolation techniques, Inverse Distance Weighted, Global Polynomial, Local Polynomial, and Radial Basis Functions.

The Inverse Distance Weighted Function calculates the value at every point by taking a weighted average of the point data in the neighborhood. The weight of a measured data point is inversely proportional to the distance from the measured point to the prediction point. Therefore measurements close by have a greater weight than those further away.

The Global Polynomial Function fits a mathematical function (polynomial) to all the measured points. The process selects the function that minimizes the squared differences between measured and predicted values. The result is a smooth mathematical surface that shows gradual trends in the study area.

The Local Polynomial Function also fits a polynomial to the data but allows for more local variation. While the global interpolation tries to fit all the measured values with one function, the local function uses many polynomial functions to fit the area. Each function applies to a specified neighborhood, but areas overlap to avoid sharp breaks.

The Radial Basis Function fits a smooth surface through every measured point and minimizes the surface curvature. It differs from the polynomial functions since the surface goes through every measured point, while giving a more gently varying surface than the inverse distance weighting method.

2.2.2 Geostatistical Techniques

The geostatistical methods are based on statistics. They have two major tasks, calculating the appropriate statistics and creating a prediction surface. A great advantage of these methods is that they can give an estimate of how well they are predicting the surface, i.e. error of prediction, whereas the deterministic methods cannot. They are all in the kriging family and are generally referred to as kriging methods or cokriging methods for a multivariate case.

Many of the kriging methods assume a normal distribution of the point data. Therefore, it is important to identify whether the data must be transformed

or whether a trend must be removed in the interpolation process. The QQ plots are graphs on which quantiles from two distributions are plotted relative to each other. The normal QQ plots and histograms can show whether the data are normally distributed. The Geostatistical Analyst extension can transform data and remove trends before interpolation and then add these effects back to the interpolated surface.

The kriging technique consists of evaluating the spatial autocorrelation of the data and assigning weights based on the distance from a measured location to the prediction location. Pairs of measurements are grouped together in bins, defined by a distance range and an angle tolerance if anisotropy is considered. An average of squared difference in values for each bin is plotted against the distance that separates the points (an empirical semivariogram). Data pairs located close together should have a smaller difference in observed values than data pairs that are far away from each other. A line is then fit through the points on the semivariogram. That line is then assumed to represent the spatial autocorrelation of the data, and it defines the weight of measured values in a predicted surface.

Anisotropic models create separate models for each direction interval defined by the angle tolerance. An anisotropic model can be good to account for directional characteristics of the data. However if data are sparse, empty bins can exist and bins with few points for averaging may create undesirable variations.

While the kriging technique uses information on one variable, the cokriging process uses information on several variables. It estimates the autocorrelation of the main variable of interest and the crosscorrelation between

the main variable and all other variables. This is done in order to use more widely sampled variables and their correlation to the variable of interest. However, if there is however no correlation between a pair of variables, this method can introduce more errors, since more statistical constants are estimated.

Several different kriging and cokriging methods are available in the Geostatistical Analyst extension, including ordinary, simple, universal, probability and disjunctive kriging and cokriging.

- Ordinary kriging assumes an unknown constant mean μ , but adds an error factor, $\varepsilon(\mathbf{s})$ evaluated based on autocorrelation. $Z(\mathbf{s}) = \mu + \varepsilon(\mathbf{s})$, where \mathbf{s} is a spatial location
- Simple kriging assumes a known constant mean, μ , but adds an error factor, $\varepsilon(\mathbf{s})$ evaluated based on autocorrelation. If the mean is exactly known this model gives more exact results than the ordinary kriging where μ and therefore $\varepsilon(\mathbf{s})$ had to be estimated. $Z(\mathbf{s}) = \mu + \varepsilon(\mathbf{s})$
- Universal kriging assumes a mean, $\mu(\mathbf{s})$, where $\mu(\mathbf{s})$ is a deterministic polynomial function. $Z(\mathbf{s}) = \mu(\mathbf{s}) + \varepsilon(\mathbf{s})$
- Indicator kriging is used for binary data that are created either from a threshold in continuous data or if the data are all 0 or 1. Apart from that, the model is the same as the ordinary kriging model. $Z(\mathbf{s}) = \mu + \varepsilon(\mathbf{s})$
- Probability and disjunctive kriging are intended to do the same thing as indicator kriging. Disjunctive kriging is a generalization of the indicator kriging, but requires a bivariate normality assumption of errors.

Chapter 3: Data

A major objective of this research project is to obtain quantitative benthic data for the Beaufort Sea, Chukchi Sea, and northern Bering Sea and to create representative surfaces from the point data. Investigators at the Marine Science Institute (MSI) and the author at the Center for Research in Water Resources (CRWR) have invested great effort to finding benthic data from various sources to import into a relational database. However, benthic data cannot tell the whole story alone. Therefore digital data sources have been explored in order to find helpful data layers, such as bathymetry grids, nautical charts, coastlines, and major rivers. Also the output of the NPS Ice-Ocean Arctic model has been adapted to the ArcView framework.

The data were derived from various sources, and were in various file formats and projections. This chapter describes the data and their sources.

3.1 BENTHIC DATA

Several groups have researched the benthic community structure and biomass in the study area. Many of the data used in this study were compiled at the National Oceanographic Data Center (NODC), while other data came from literature or were obtained as spreadsheets from researchers. Figure 3.1 shows the locations of the benthic sampling. The point locations are divided up colors according to the tables their source.

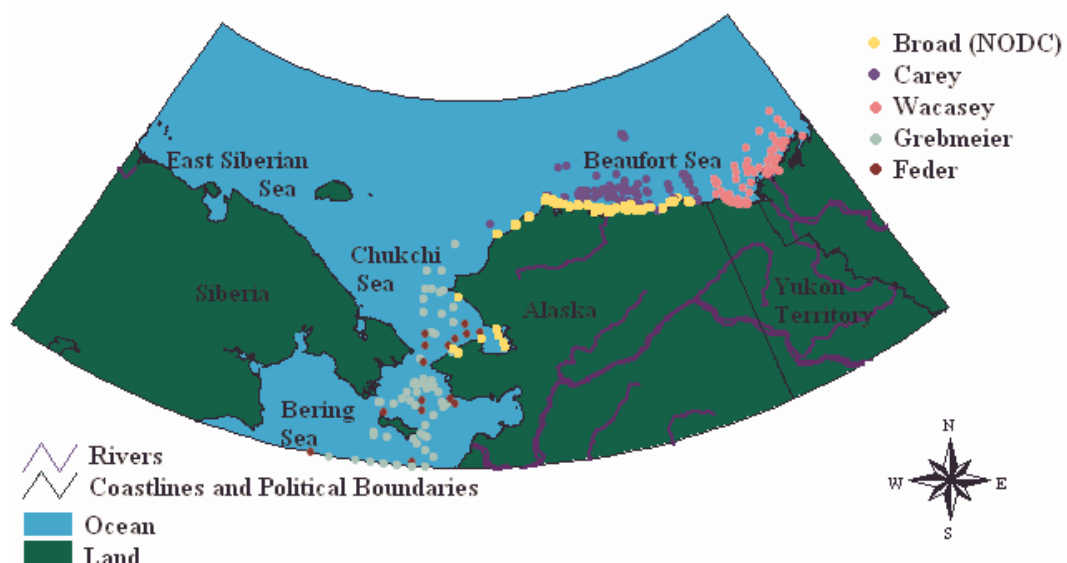


Figure 3.1 Benthic Data Sampling Location along with DCW Coverages

3.1.1 Benthic data from NODC

Broad (1981) researched the Western Beaufort Sea and submitted results to the National Oceanographic Data Center (NODC). Most of the NODC data for the study area are from his research. Benthic data were requested from the NODC for the study area and the data were supplied in a heavily coded text file. The translation of the coded file to a spreadsheet text file required extensive computer script writing effort, which was carried out at the MSI. The resulting tables are four; *Station*, *Site*, *Sample* and *Taxon*.

A station is the specific location where the sampling boat stops at on a specific date. The *Station* table (Figure 3.2) includes the number of the station, the date on which the samples were taken, the station's exact location and habitat composition. The location is given as latitude and longitude in decimal degrees.

	Station	Date	Latitude	Longitude	Habitat composition
+	13702	6/8/70	70.15667	-143.14	OPEN WATER (NO BEACH)
+	13703	6/6/70	70.13767	-143.6833	OPEN WATER (NO BEACH)
+	13704	6/7/70	70.15	-143.6833	OPEN WATER (NO BEACH)
+	13705	6/6/70	70.095	-144.0833	OPEN WATER (NO BEACH)
+	13706	6/6/70	70.125	-144.0833	OPEN WATER (NO BEACH)
+	13707	6/8/70	70.00667	-144.9067	OPEN WATER (NO BEACH)

Figure 3.2 The *Station* table

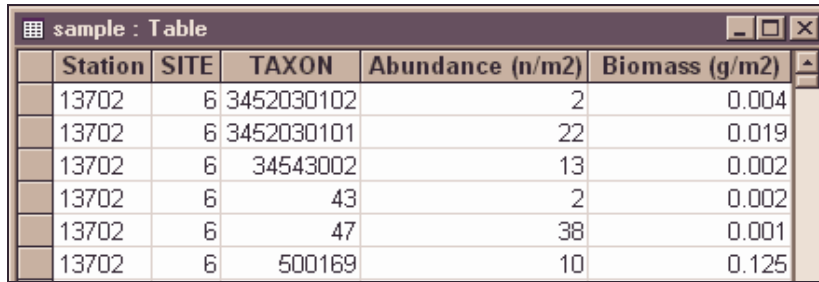
At each station there are many sites where samples of the seafloor are collected. The *Site* table (Figure 3.3) lists every record of a site, the site's station number, its temperature (°C), salinity (ppt) and depth (m). It also lists the type of grab that was used for sampling.

	Station	SITE	Sal (ppt)	Temp (C)	Depth (m)	GRAB TYPE
	13702	1	26	0	10	Smith-McIntyre
	13702	2	27	0	10	Smith-McIntyre
	13702	3	27	0	10	Smith-McIntyre
	13702	4	28	0	10	Smith-McIntyre
	13702	5	28	0	10	Smith-McIntyre
	13702	6	28	0	10	Smith-McIntyre

Figure 3.3 The *Site* table

At each site many different types of animals are collected in the grabs and they are listed in the *Sample* table (Figure 3.4). Therefore, there are many samples for each site. In the *Sample* table, there is a record for every animal found at each site. It lists the taxonomic number of each animal, the site and station of where it was found, and its abundance and biomass. The abundance is

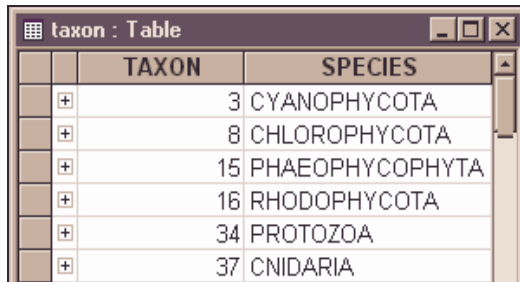
the number of individuals found while the biomass is the wet weight of all the individuals (g/m²).



Station	SITE	TAXON	Abundance (n/m2)	Biomass (g/m2)
13702	6	3452030102	2	0.004
13702	6	3452030101	22	0.019
13702	6	34543002	13	0.002
13702	6	43	2	0.002
13702	6	47	38	0.001
13702	6	500169	10	0.125

Figure 3.4 The *Sample* table

Finally, the *Taxon* table (Figure 3.5) pairs the taxonomic numbers in the *Sample* table with the name of each animal.



TAXON	SPECIES
3	CYANOPHYCOTA
8	CHLOROPHYCOTA
15	PHAEOPHYCOPHYTA
16	RHODOPHYCOTA
34	PROTOZOA
37	CNIDARIA

Figure 3.5 The *Taxon* table

3.1.2 Benthic Data from other Sources

The search for quantitative benthic data is still going on. As of now the database includes Broad's (1981) NODC data, two collections submitted by Grebmeier (1987, 1985) and data from investigations carried out by Carey (1984), Wacasey (1974) and Feder (1982). All data used in this study required location data (lat, long) and wet weight biomass (g/m²) while other fields give various

additional information. All the tables are consistent in measurement units and can therefore be merged.

Grebmeier’s data from the Chukchi and Northern Bering Sea were submitted in four spreadsheets. Data from the hx59 and hx85 cruises are in two tables (Figure 3.6). *Thesisjmg* gives the general information for each station, location, date, depth, temperature, salinity etc. while the *hx59-hx85-benthic* table lists each animal type, its biomass and abundance. Data from the hx139 cruise are set up in a similar way (Figure 3.7). The table *hx1391* gives general information for the station and each grab, including latitude, longitude and date, while the table *hx139benthic* gives abundance and biomass of the animal species found in the grab.

Station	Date	Latitude	Longitude	Depth (m)	Temp (C)	Bot Sal (psu)	Abundance (n/m2)	Biomass (g/m2)
59070	6/28/80	63.209	-168.466	26	-0.98	33.429	313	549.6
59071	6/29/80	63.151	-168.231	20	-0.24	33.229	463	2143.8
59074	6/29/80	63.092	-168	19	0	33.237	140	42
59081		63.492	-168.166	25	-0.68	33.412	900	388.8

Station	Taxon_no	Count	Biomass wetw	Species
59070	3.303E+11	2.5	2.792	ANTHOZOA
59070	4.801E+11	2.5	0.192	POLYCHAETA
59070	4.80101E+11	12.5	1.13	POLYNOIDAE
59070	4.80124E+11	17.5	36.707	NEPHTYIDAE
			7770	35.3

Figure 3.6 The Tables from the hx59 and hx85 Cruises

Station	Grab No	Sta Name	Latitude	Longitude	Date	V
4	1	NUN1	60.014	-168.0171	6/1/90	VV
4	2	NUN1	60.014	-168.0171	6/1/90	VAN
4	3	NUN1	60.014	-168.0171	6/1/90	VV
4	4	NUN1	60.014	-168.0171	6/1/90	VV

Station	CODE	BENTHIC FAUNAL	Abundance (n/m2)	Biomass (g/m2)
4	5.33122E+11	HAUSTORIIDAE	2	0
4	5.33126E+11	ISAEIDAE	398	1
4	5.33134E+11	LYSIANASSIDAE	42	0
4	5.33137E+11	OEDICEROTIDAE	12	0

Figure 3.7 The Tables from the hx139 Cruise

Data from the Western Beaufort Sea were extracted from reports by Carey (1984). Four tables with Carey's data are in the database (Figure 3.8). Data from a research done in 1971 are in two tables, *Websec-71-600* and *Carey1971*. They give the location, date and biomass. The Outer Continental Shelf (OCS) project was carried out in the years 1975-1978 by Carey (1984); the data from those cruises are in the tables *CareyOCS* and *CareyOCS_bio*. *CareyOCS* gives the location, date, grab number and depth while the *CareyOCS_bio* table lists the species, and the biomass, found in every grab listed in the *CareyOCS* table.

The image shows four overlapping spreadsheet windows. The top window, 'Websec-71 600 : Table', contains three rows of data for stations WBS-13, WBS-14, and WBS-15. The second window, 'Carey1971 : Table', shows three rows for stations 1, 5, and 6. The third window, 'CareyOCS : Table', shows three rows for stations PPB-25, PPB-55, and PPB-55. The bottom window, 'CareyOCSbio : Table', shows four rows of biomass data for station 1087 across different biological groups.

Station	Date	Latitude	Longitude	Depth (m)	Wet Wt Tot (g)
WBS-13 CG-20	8/25/71	71.31667	-147.7667	2295	0.05
WBS-14 CG-22	8/26/71	71.15667	-148	2560	4.2
WBS-15 CG-23	8/27/71	70.64	-148.0667	27	0.9

Station	Latitude	Longitude	Depth (m)	Density (No/m2)	Biomass (g/m2)
1	70.2583	-143.66	33	2060	120
5	70.5767	-143.6333	106	1280	59
6	70.76	-143.59	495	1490	14

Station	Date	Grab	Lat	Long	Depth
PPB-25	10/26/75	1087	71.145	-153	25
PPB-55	10/29/75	1088	71.318	-153	59
PPB-55	10/29/75	1089	71.318	-153	59

Grab	Group	Biomass (g/m2)
1087	Annelida	6.8
1087	Arthropoda	0.2
1087	Mollusca	5
1087	Misc.	0.1

Figure 3.8 The Tables with Carey's Data

Wacasey's (1974) report provides general information on stations in the southern Beaufort Sea, along with the benthic biomass and abundance. Those data are gathered in the table titled *Wacasey* (Figure 3.9).

Station	Date	Latitude	Longitude	No of Species	Abundance (n/m2)	Biomass (g/m2)	Depth (m)	Temp (C)	Sal (ppt)
1	7/24/75	69.24167	-138.4833	8	3367	0.36	1.4	9.1	7.5
100	7/17/75	69.10833	-137.95	9	176	0.29	13	1	28.3
104	7/15/75	68.98333	-137.35	8	576	1.13	3	0.3	26.2
107	7/16/75	68.96667	-137.2167	4	86	0.05	2.8	1.6	27.5

Figure 3.9 The Table *Wacasey*

Information from Feder's (1982) report on the Chukchi and the northern Bering Sea are gathered in the table titled *Feder*, which gives general information on stations, biomass and abundance (Figure 3.10).

Station No	Date	Latitude	Logitude	Depth (m)	Density (n/m2)	Biomass (g/m2)
25	5/17/80	62.00333	-176.3717	102.4	870	77.5
26	5/22/80	62.17333	-168.985	34.6	1352	32.5
38	6/5/80	64.02667	-168.5233	34	15664	649.4
40	6/6/80	64.395	-168.52	39.8	9542	485.2

Figure 3.10 The Table *Feder*

3.2 DIGITAL BATHYMETRY

Several sources of gridded bathymetry/elevation are available for the study area. The grids differ in their data sources, resolution and accuracy. Therefore the available literature associated with the grids was reviewed. A description of these grids and their sources are given below. The sources considered for this project are the following:

- *ETOPO5*, a global 5-minute bathymetry grid (NGDC, 2000)
- A global bathymetry map built on marine gravity along with ship sounding (Sandwell, 2000)
- *IBCAO*, a bathymetry grid of the Arctic Ocean (Jacobson, 2000b)
- *GTOPO30*, a global 30 arc second elevation grid (EROS, 2000)

3.2.1 ETOPO5 5-minute Gridded Elevation Data

The information site for the ETOPO5 (NGDC, 2000) gives some details about the global digital bathymetry/elevation dataset. The grid was assembled from various data sources available in 1988, resulting in a 5-minute degree cell grid. It is not clear whether the data sources are raw ship soundings, contours, or

grids. Since little detail were available for oceanic data shallower than 200m, the interpolation algorithm used to interpolate contour charts was set to an arbitrary cut of -10m to prevent overshooting, i.e. creation of imaginary islands.

ETOPO5 can be downloaded from a NGDC Internet website, <http://www.ngdc.noaa.gov/mgg/global/seltopo.html>. The corner points of a region of interest are given in geographic coordinates. Then a server extracts the correct area and creates an ASCII delimited text file, either as an XYZ list (long, lat, depth/elevation) or as a matrix of depth/elevation. A negative value indicates a depth while a non-negative value is elevation above mean sea level. Data for the study area were extracted and the resulting grid can be seen in Figure 3.11.

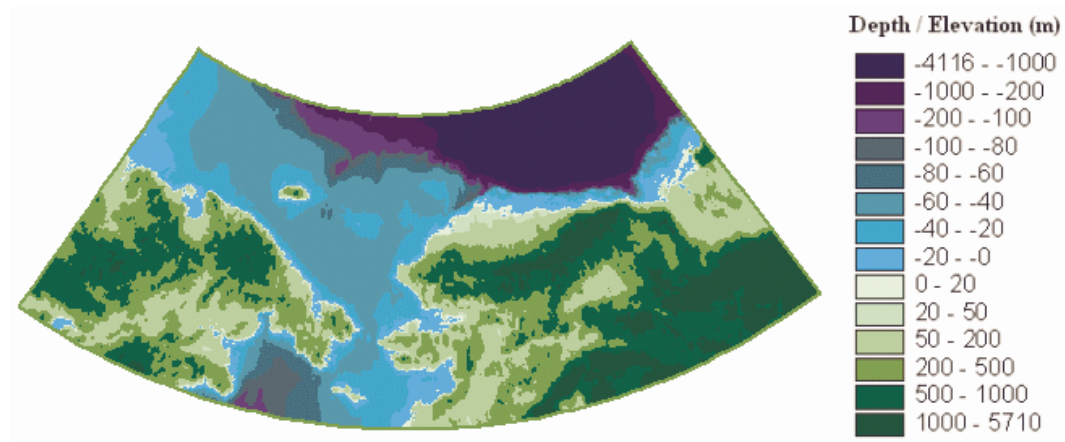


Figure 3.11 The ETOPO5 Bathymetry / Elevation Grid

3.2.2 Global Bathymetric Prediction for Ocean Modelling and Marine Geophysics

In an article by Sandwell and Smith (1996) a global digital bathymetric map is described. This map has a resolution of 3-10 km and is created by combining ship soundings from the past 30 years with high-resolution marine

gravity information provided by the Geosat, ERS-1/2, and Topex/Poseidon satellite altimeters. Previous global bathymetry maps have relied on only the ship soundings. Ship soundings are used with precaution in this map; older soundings are not as reliable as the most recent Global Positioning System (GPS) navigated multibeam data. Gravity anomalies are highly correlated with seafloor topography, therefore the ship soundings are used to calibrate the gravity information, i.e. to find the topography/gravity ratio. While this bathymetry map does not agree with earlier maps such as ETOPO-5 bathymetry model, the high accuracy and spatial resolution of gravity information reveal many bathymetric features previously unrecognized.

Areas of interests from the global topography dataset are available up to latitude of 72°N as seen on Figure 3.12. They can be downloaded as an ASCII XYZ text file at the Internet website in geographic coordinates, http://topex.ucsd.edu/cgi-bin/get_data.cgi.

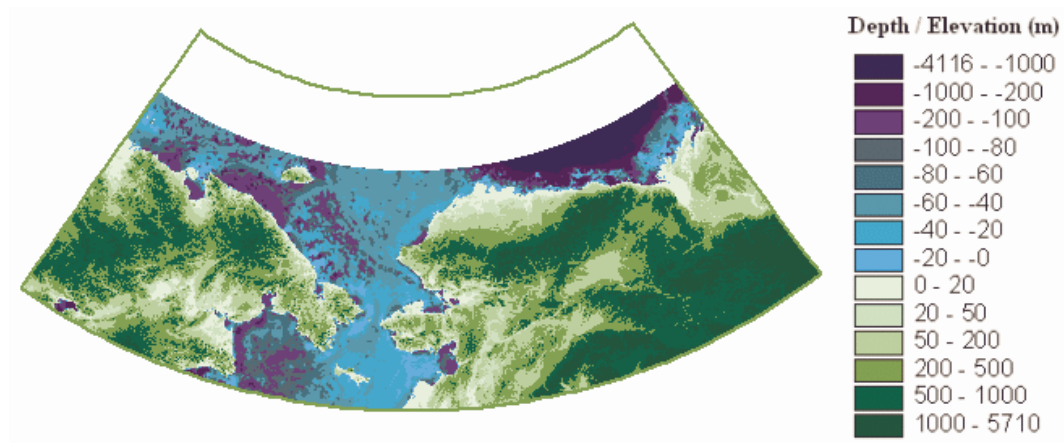


Figure 3.12 Global Bathymetric Prediction Built on Gravity Information

3.2.3 International Bathymetric Chart of the Arctic Ocean (IBCAO)

A technical reference and user's guide along with the Beta Version of the IBCAO digital grid became downloadable from the Internet site in the spring of 2000. According to the guide (Jakobsson, 2000a), the grid was built from all available contour, grid, point, and track data north of 64°N, and will be further improved once additional data are collected. Gridding of the source data to a cell size of 2.5 km was done using curvature splines in a tension algorithm using the Generic Mapping Tools (GMT) program *Surface* with a tension parameter set to 0.35. Subsequently the effects of randomly spaced ship tracks were smoothed out using a weighted average convolution.

The guide contains several application suggestions and information on how the grid can be viewed and used; it does however not mention ArcView or Arc/Info applications.

The IBCAO grid can be downloaded from the Internet site: <http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/ibcaobetagrid.html>. It is only available in its complete version, i.e. regions of interest cannot be selected. The data are available as an ASCII or a netCDF file and Table 3.1 describes the original grid while Figure 3.13 shows the extent of the grid in the study area.

Grid type:	Cartesian (XYZ)
Projection:	Polarstereographic, true scale at 75 °N.
Horizontal datum:	WGS 84
Grid spacing:	2.5 x 2.5 km
Origin:	The Cartesian origin (0,0) is located at the center of the grid, this corresponds to the North Pole
Data organization:	Grid registration, row major with first coordinate at Upper left
Coordinates of upper left corner:	-2902500m,2902500m
Coordinates of upper right corner:	2902500m, 2902500m
Coordinates of lower left corner:	-2902500m,-2902500m
Coordinates of lower right corner:	2902500m, -2902500m

Table 3.1 Description of the Original IBCAO Grid

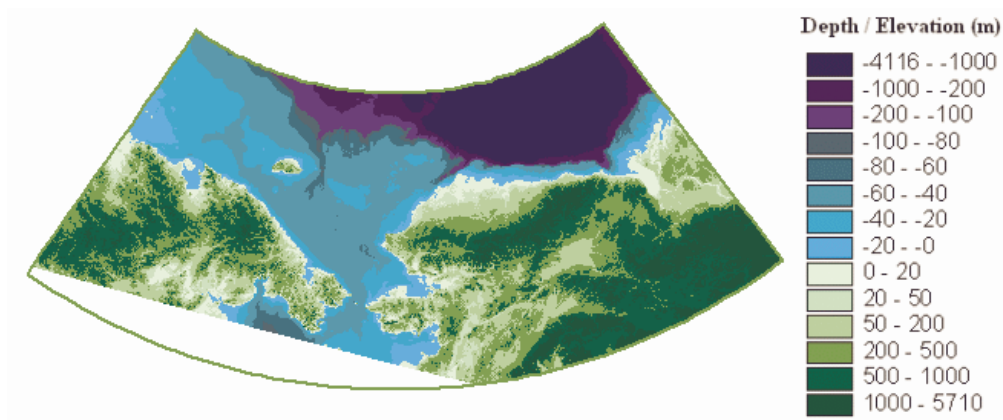


Figure 3.13 The IBCAO Bathymetry Grid

3.2.4 Global Digital Elevation Model, GTOPO30

The GTOPO30 is a global data set of elevation developed by U.S Geological Survey's Earth Resources Observation Systems (EROS) Data Center (EDC). A *Readme* text file gives information about the dataset (EROS, 2000). Elevations in GTOPO30 are given at 30-arc second regularly spaced intervals over the whole land surface of the globe. The data set is available at the Internet site <http://edc.usgs.gov/landdaac/gtopo30/gtopo30.html> where the zipfiles,

E140N90, W180N90 and W140N90, encompass the study area (Figure 3.14). The Digital Elevation Model is provided as 16-bit signed integer data in a simple binary raster; a Readme file provides instruction on how to translate the file into an ArcInfo grid. The horizontal reference system is referenced to the WGS84 spheroid; latitude and longitude are given in decimal degrees. Ocean areas have been given the nodata value -9999.

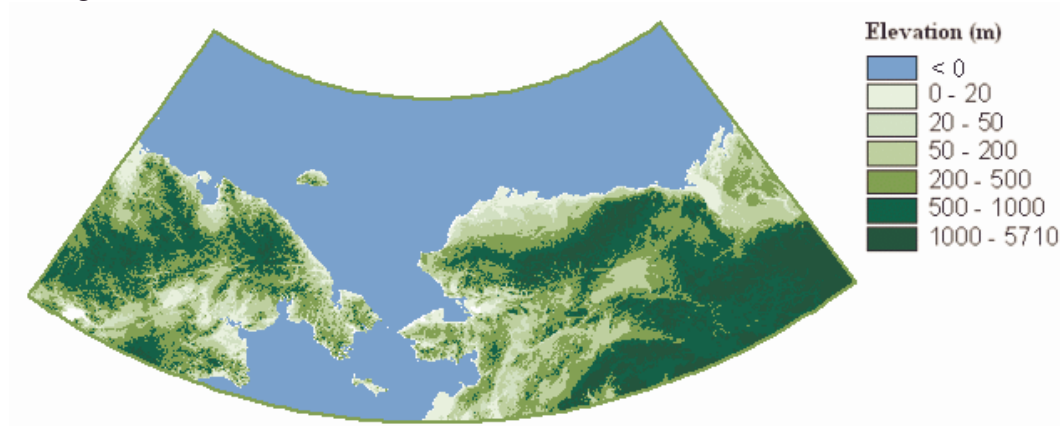


Figure 3.14 The GTOPO30 Digital Elevation Grid

3.3 GIS FILES FOR ORIENTATION

Several GIS data layers were collected to give the benthic information a better geographical background. These involve nautical charts from the National Oceanic and Atmospheric Administration (NOAA), as well as coastlines and rivers from the Digital Chart of the World (DCW). A description of these data is in the following two sections.

3.3.1 The NOAA Nautical Charts

Digital raster charts of the entire NOAA chart collection are now available through *Maptech's* mapserver (Maptech, 2000). The charts are scanned version of the NOAA nautical charts and include every detail found in the paper version. The digital charts can be imported into ArcView using a *Chartviewer* extension downloadable from a NOAA (2000) Internet site along with a *Chart Reprojector* extension. The charts are in various projections but the *Chartviewer* extension reads the projection of each file and sets the view projection while the *Reprojector* projects the charts permanently.

Charts of the study area, (R 36 CD) Alaska Norton Sound to Beaufort Sea CD-ROM, were purchased from Maptech. A sample of the maps is shown in Figure 3.15.

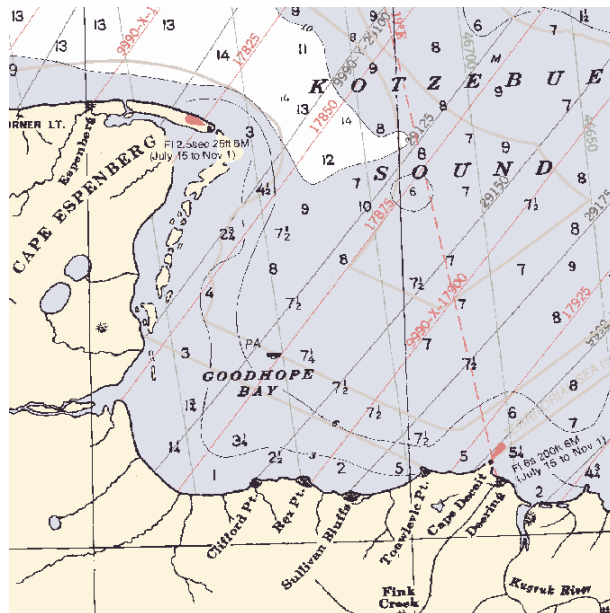


Figure 3.15 A Sample of the NOAA Nautical Charts

3.3.2 Digital Chart of The World

The Digital Chart of the World (DCW) was originally developed for the US Defense Mapping Agency (DMA) by ESRI. The source is DMA 1:1,000,000 scale aeronautical charts. A detailed description of the dataset can be found at the Pennsylvania State University Libraries Internet site (2000). Several datasets are available from the DCW. However, for this research, only the coastlines and river coverages were downloaded from the Internet site (PSU, 2000). The Arc/Info coverages downloaded were for the areas: East Russia, Alaska, the Yukon Territory and the Northwest Territories. All the coverages, (Figure 3.1) are in geographic projection.

3.4 ICE-OCEAN MODEL FOR THE ARCTIC OCEAN

An ice-ocean model with a cell size of 18 km has been developed for the Arctic Ocean in an attempt to explain the Arctic Ocean response to global variations (Maslowski, 2000). The model consists of an ocean general circulation model coupled to a sea ice model calibrated with 20 years of atmospheric data from the European Center for Medium-range Weather Forecasts (ECMWF). The grid cell size of the model is 1/6-degree, a little more than 18 km, and the grid consists of 368x304 cells. The output is produced in four ways, as follows:

- 30-day averages of sea surface height and 3-D fields of temperature, salinity, and velocity vectors (called ocean t-files)
- 30-day snapshots of similar fields plus fresh water and Atlantic water tracers (h-files)

- 3-day snapshots of selected 2-D fields (T,S,u,v and tracers) (movie-files)
- 3-day averages of most sea ice predicted fields (thickness, concentration, growth/melt, etc.) (ice t-files)

Ocean t-files for the year of 1993 were made available for this study, they included 12 monthly mean files (t.c6.93-*.cdf.gz) a land mask file (kmp.levels), bathymetry file (bath.levels) and a model grid file (latlonh.dat). Each of the 12 monthly mean files is in a netCDF format and includes matrices (368 columns x 304 rows) for several variables. The variables include sea surface height - AH1 (cm), velocity – AU, AV (cm/sec), temperature –ATEMP (°C) and salinity - ASALT (ppt). An example of the surface temperature and salinity grids is shown in Figure 3.16 and Figure 3.17.

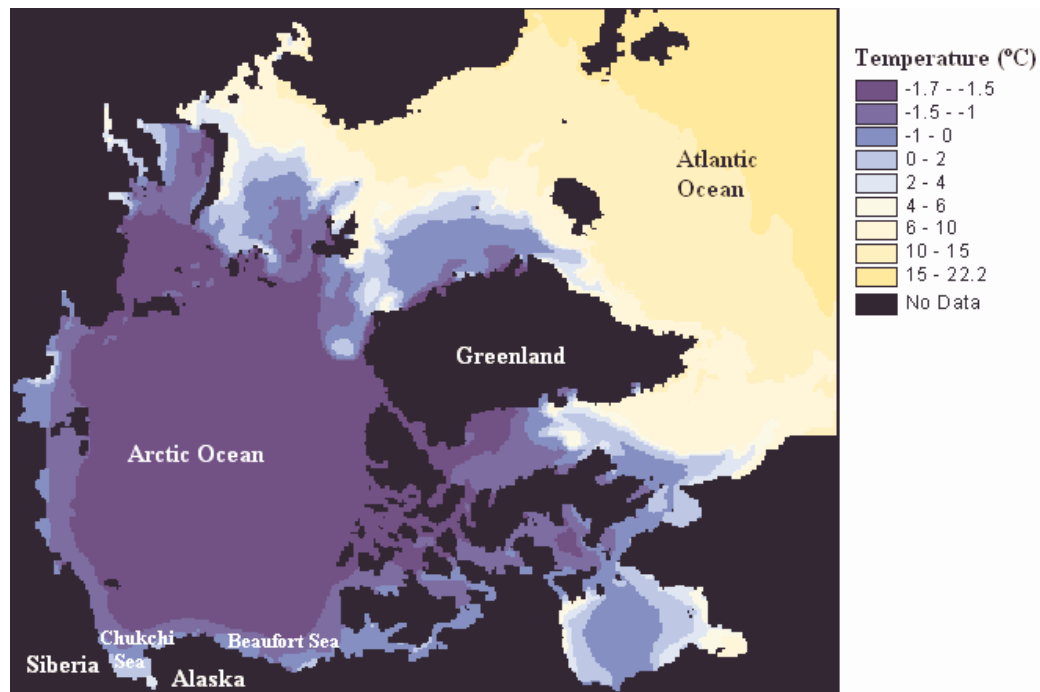


Figure 3.16 The Mean Surface Temperature for July '93 (Ice-Ocean Model)

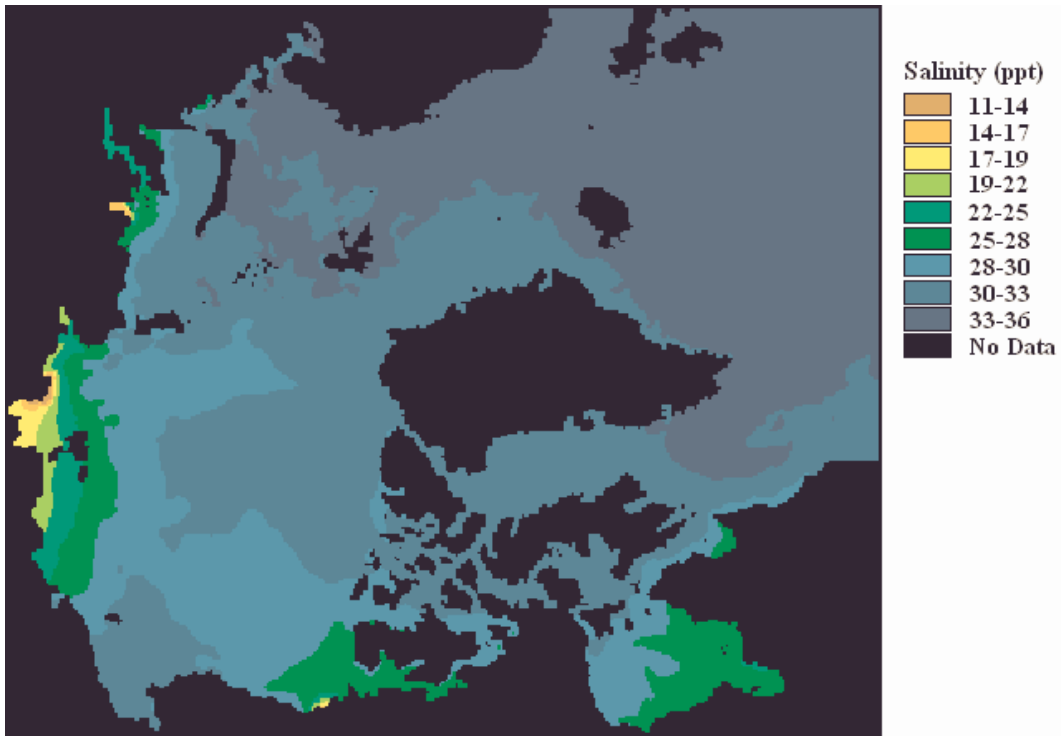


Figure 3.17 Mean Surface Salinity for July '93 (Ice-Ocean Model)

Chapter 4: Methodology

The approach of this study is directed towards the application of ESRI's Arc View and Arc/Info platforms. This study's main focus is to illustrate current state of knowledge of the Western Arctic benthos and to provide a basis for further analysis. This is done by plotting quantitative benthic data from earlier studies, and tying them to other available information, such as bathymetry, temperature, salinity and freshwater inflow. The GIS framework can incorporate data from various sources for nice visualization, and also allow the user to do queries and calculations. Therefore, the ArcView and Arc/Info platforms are optimal for this research.

Numerous organizations have digital data available. The data, however, come in different formats and map projections; much work is involved in reformatting and converting the data. Procedures have to be developed and computer scripts written in order to make further analysis possible.

This chapter describes the general methods and procedures used in the project. Procedure details, Arc Macro Language (AML) and Avenue scripts, can be found in Appendix A. All data layers are distinguished by a **bold font**.

4.1 MAP PROJECTION

Geographic information systems use spatially referenced data, i.e. data are viewed according to their (x,y) coordinates. In order to create a flat map sheet from the curved Earth, its three dimensional surface has to be transformed. The

most commonly known way of displaying geographic data is to assign the longitude to the x-axis and the latitude to the y-axis. This geographic coordinate system distorts shapes and other properties of the data and is therefore not useful for an analysis of the data. However, various mathematical transformations, called map projections, can convert geographic locations to reference systems that preserve some of the data's practical information. Every projection distorts either one or more of the four general properties, shape, area, distance or direction. A choice of projection must be made with regards to the type of analysis intended and the location of study area (Snyder, 1987).

The Polar Stereographic projection is a widely used projection in the polar regions; it is practical for navigational purposes since it preserves direction, i.e. local angles are accurate everywhere. This project, however, deals with an interpolation of benthic biomass; therefore preservation of area is more important than direction. The Lambert Azimuthal Equal-Area projection retains the true Earth surface area at the same scale, while other properties are somewhat distorted.

The specific parameters of the Lamberts Azimuthal Equal-Area were chosen with regards to the study area. The chosen radius of sphere of reference is the default radius in Arc/Info. The longitude of center of projection was chosen so that the extent of the study area is vertically symmetrical, while the North Pole was selected as the longitude of center of projection. False easting and northing were chosen so that all points in the study area have positive locations.

All data used in this research have been projected to the Lambert projection; the specific parameters can be found in Table 4.1

Projection:	Lambert Azimuthal Equal-Area
Units:	Meters
Radius of sphere of reference:	6370997 m
Longitude of center of projection:	-165° 00' 00"
Latitude of center of projection:	90° 00' 00"
False easting:	2000000 m
False northing:	4000000 m

Table 4.1 Lambert Azimuthal Equal-Area Projection Parameters

The specific parameters were chosen with regards to the study area. The chosen radius of sphere of reference is the default radius in Arc/Info. The longitude of center of projection was chosen so that the extent of the study area is vertically symmetrical, while the North Pole was selected as the longitude of center of projection. False easting and northing were chosen so that all points in the study area have positive locations.

4.2 PREPARATION OF GIS LAYERS FOR ORIENTATION

The general frame of the study area gives the user a frame of reference, i.e. knowledge of what part of the world is being viewed. That general information consists of coastlines, a latitude/longitude grid, nautical charts etc.

4.2.1 Building a Frame and a Latlong Grid

The study area reaches from latitude 62° N to 75°N and 160°E to 128°W. The area encompasses the northern part of the Bering Sea, the Chukchi Sea, The

Beaufort Sea and the East Siberian Sea. It was selected so that it reaches from the continental shelf to the deeper basin of the Arctic Ocean.

On a sphere the 180°W longitude is the same as the 180°E longitude. However, when ArcView and Arc/Info handle geographic coordinates, 180°W is given the number -180 while 180°E is +180. Since the study area reaches over 180° E/W longitude the area is not spatially continuous in geographic coordinates. Layers for the study area in geographic coordinates are therefore divided up in two parts, one west of 180°E/W longitude and another east of the 180°E/W longitude. However layers in projected coordinate systems are spatially continuous.

When the study area has been defined, the relevant sections of maps have been chosen. A shapefile consisting of the outline of the study area was created by which other layers could subsequently be clipped. The coverage **frame** was created in Arc/Info using the *Generate* function. Two boxes were created in geographic coordinates, one for the eastern part of the study area (east of 180°W) and another for the western part. The **frame** layer was then projected to the Lambert Azimuthal Equal Area projection. The Arc/Info command sequence (AML) can be found in Appendix A.

The projection of all data into a projection different than geographic projection results in a loss of (longitude, latitude) references. However geographic coordinates are the most common way of position identification. Therefore, a net of five-degree cells was created and attributed with the geographic coordinates of the lower left corner of each cell. The layer, **fivedeg**,

was created in Arc/Info using the *Generate* function (details are given in Appendix A). The coverage was then converted to a shapefile in ArcView and its attribute table edited. The *lowerleft* field in the table has the geographic coordinate of each cell's lower left corner. Figure 4.1 shows the **fivedeg** layer overlying the land/ocean within the study area.

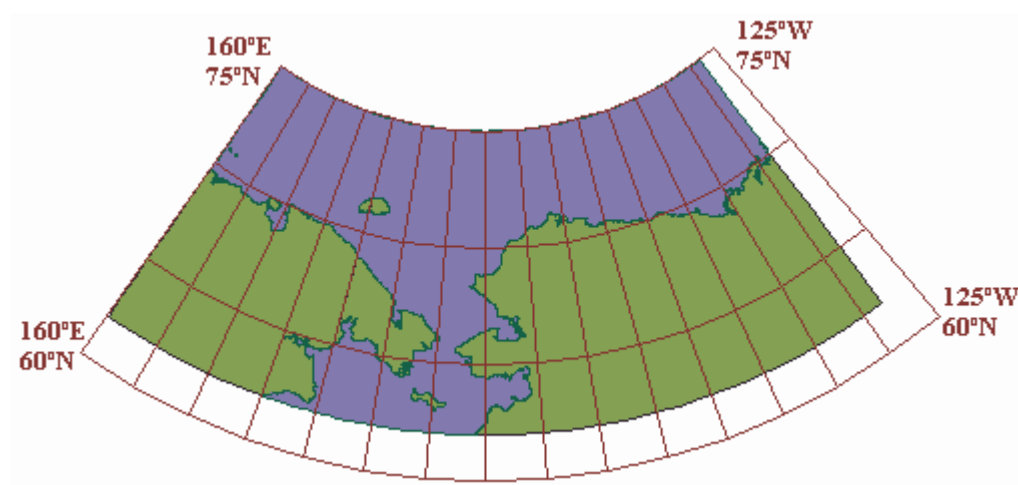



Figure 4.1 The **fivedeg** Layer Overlying the Study Area

4.2.2 Layers from Digital Chart of the World

Layers from the Digital Chart of the World were downloaded from their Internet site (PSU 2000). The layers selected were **ponet** and **rivers**, for the geographic regions of East Russia, Alaska, the Yukon Territory and the Northwest Territories. The files were in Arc/Info export format (.e00) and were imported with the Import71 utility. The layers were then projected to the Lambert Azimuthal Equal Area projection and merged in ArcView with the *mergethemes.ave* script (Appendix A).

The coastlines, **ponet**, from the DCW, define where the ocean ends and land begins. The **river** shapefile from the DCW only shows major rivers like the Yukon and Mackenzie rivers. The position of the mouth of those big rivers indicates where influences of freshwater inflow may be significant. Therefore this layer is included on most maps showing interpolated biomass surfaces.

4.2.3 NOAA Nautical Charts

The NOAA nautical charts provide valuable information in the form of place names and other landmarks. They are scanned versions of the paper maps and include all the details found in the paper maps. The files are in a BSB digital format, which is generally not a file format supported by ArcView. However an extension has been developed by NOAA Coastal Services Center, Maptech, Inc., and ESRI that allows the GIS users to read a BSB-formatted chart (NOAA, 2000). The extension, *chartviewer*, consists of two files, *chartview.dll* and *chartview.avx*. Those files have to be added to the ArcView's extension folder on the user's computer, *chartview.dll* to the *ArcView/Bin* directory and *chartview.avx* to the *ArcView/Ext* directory. Then the *chartviewer* extension becomes an available extension in ArcView. When the *chartviewer* extension is selected, the "Add a Nautical Chart" button  appears in the projects toolbar. The charts can be added to the view like any other ArcView layer by filenames.

The filenames of the charts do not provide information on the extent of each map. Therefore a more advanced method of adding the charts to the view was developed. A shapefile, **NOAAmesh**, containing the outlines of the charts was created. Along with the shapefile, the script *addnoaa.ave* was created. The

shapefile **NOAAmesh** (Figure 4.2) was created by using the Avenue program *get_extent.ave* to extract the outlines of every chart. Then the shapefile along with all the charts were projected to Lambert projection using the chart projection utility *chartreprojector* (NOAA, 2000). Finally the *addnoaa.ave* was written and used to activate the hotlink for **NOAAmesh**.

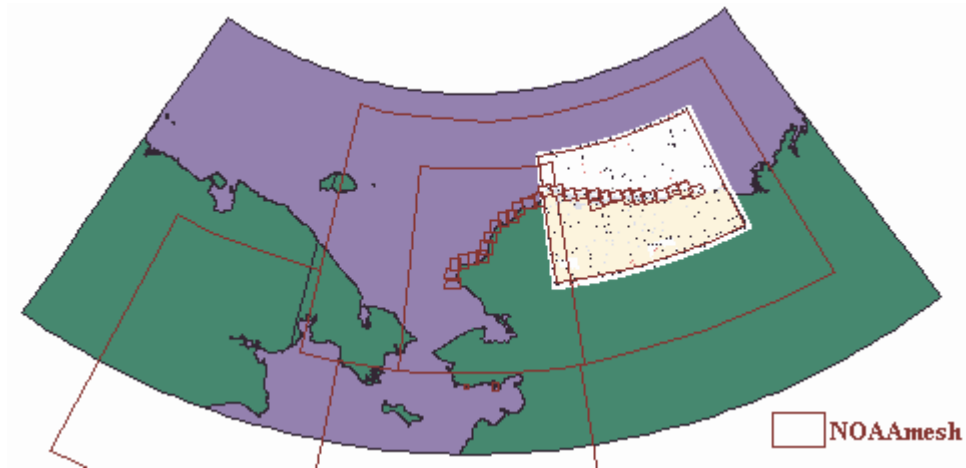


Figure 4.2 The **NOAAmesh** Shapefile

The products of the above procedure can be used in ArcView in the following way. The *addNOAA* script is added to the project and the name changed to *addNOAA*. The **NOAAmesh** is added to the view, and its attribute table opened. Then hotlink properties of the **NOAAmesh** are edited (Theme-> Properties-> Hotlink). The hotlink box should look like the one in Figure 4.3.

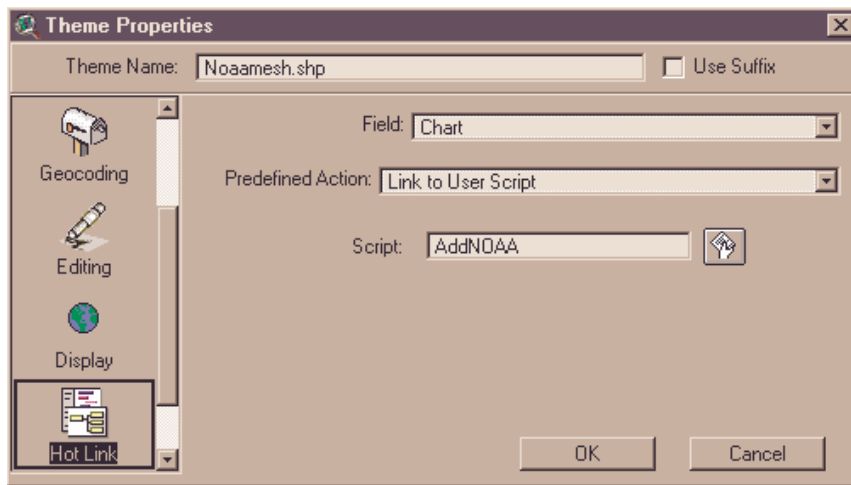



Figure 4.3 The **NOAAmesh** Properties Box

When the hotlink has been activated, charts can be added to the view by first selecting the hotlink button  and then clicking on a polygon in the **NOAAmesh** where a NOAA nautical chart is wanted.

4.3 DIGITAL BATHYMETRY/ELEVATION BASEMAP

Four sources of digital bathymetry/elevation were reviewed in this project. They were in different formats so procedures were developed to import the grids into ArcView. In ArcView the grids were compared and a decision was made about how to construct one basemap from these sources.

4.3.1 Importing the Bathymetry Grids

The ETOPO5 bathymetry grid was downloaded from an Internet site (NGDC, 2000) in an ASCII comma delimited text file format, (a XYZ list long, lat, depth/elevation). Grid points west of 180°E were downloaded separately from

those east of 180°E since the site server could not handle the total area all at once. The two files were merged in Notepad and added to the ArcView project as a table. From there, the data were added to the view as an event theme (View -> Add Event Theme) and converted to a shapefile. In Arc/Info the layer was projected to the Lambert Azimuthal Equal Area projection and a grid was produced using the *topogrid* function; the command sequence can be found in Appendix A. The resulting grid, **ETOPO5** is shown in Figure 3.11.

The gravity based bathymetric prediction grid was downloaded from an Internet site (Sandwell, 2000). The file format is an ASCII comma delimited text file format, a XYZ list. The same procedure was therefore used for this grid as the ETOPO5 grid, resulting in the grid shown in Figure 3.12.

The IBCAO Arctic bathymetry grid is only available in its complete version from an Internet site (Jacobson, 2000b). The whole file was downloaded and when it was unzipped the file proved to be 150 megabytes in size. Therefore, Notepad, Excel, Access and Wordpad were unable to open the file. However in Matlab, fractions of the ASCII file could be read and stored separately. The procedure conducted in Matlab is in Appendix A. The resulting six comma delimited text files were then imported into ArcView, added to a view as event themes, converted to shapefiles and merged with *mergethemes.ave*. The layer was projected using the *pol2lamb.txt* text file and a grid was interpolated from the layer using the *topogrid* function. The same command sequence was used as with the **ETOPO5** grid.

Three GTOPO30 zip files (E140N90, W180N90, and W140N90) were downloaded from the Internet site (EROS, 2000). The files were unzipped and their extension was changed from *.dem to *.bil. Then the files were processed in the Arc/Info according to the GTOPO30 *readme* file. The procedure can be found in Appendix A.

4.3.2 Assembling the Basemap

Comparison of the three bathymetric grids reveals a great difference between the one assembled from satellite gravity information and the other two, ETOPO5 and IBCAO. The difference between the gravity based grid and the IBCAO grid in the Bering Strait can be seen in Figure 4.4.

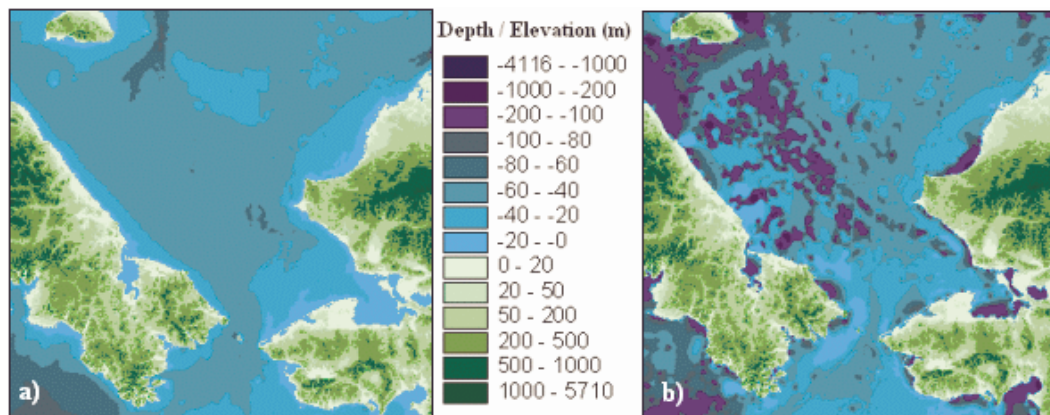


Figure 4.4 Comparison of the a) IBCAO and the b) Gravity Grids (Bering Strait)

Different cell sizes or interpolation algorithms cannot explain this major difference. The cause must be found in the data sources that lie behind the bathymetry models. The IBCAO is created only for the Arctic Ocean from ship soundings while the gravity-based grid is created from satellite information on

gravity and calibrated by sparse ship soundings. A choice of which bathymetry grid to use had to be made; therefore measured depth in the benthic data sampling was compared to the grid values of the three bathymetry maps. In the statistical program Minitab, the deviations of the grids from the measured values were analyzed. Figures 4.5, 4.6 and 4.7 show a dotplots of the deviations for each grid, the ETOPO5 grid, the gravity based grid and the IBCAO grid

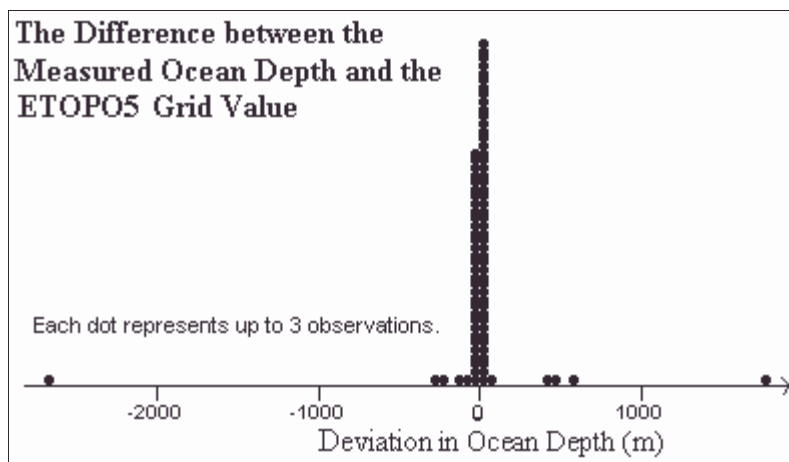


Figure 4.5 Difference Between Measured Depth and the ETOPO5 Grid Value

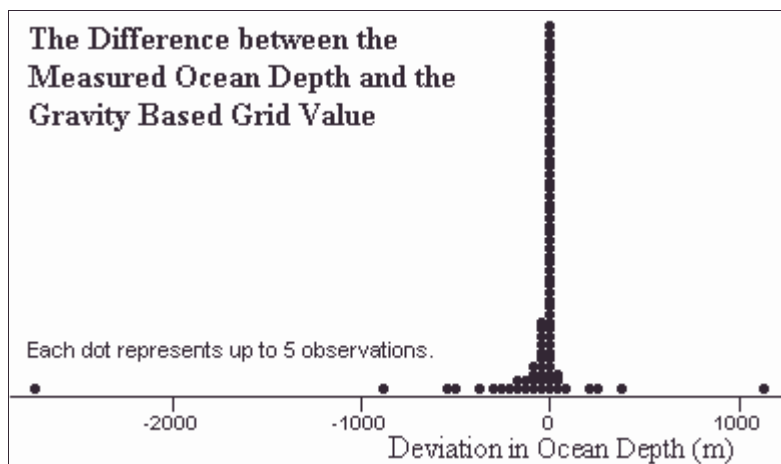


Figure 4.6 Difference Between Measured Depth and Gravity Based Grid

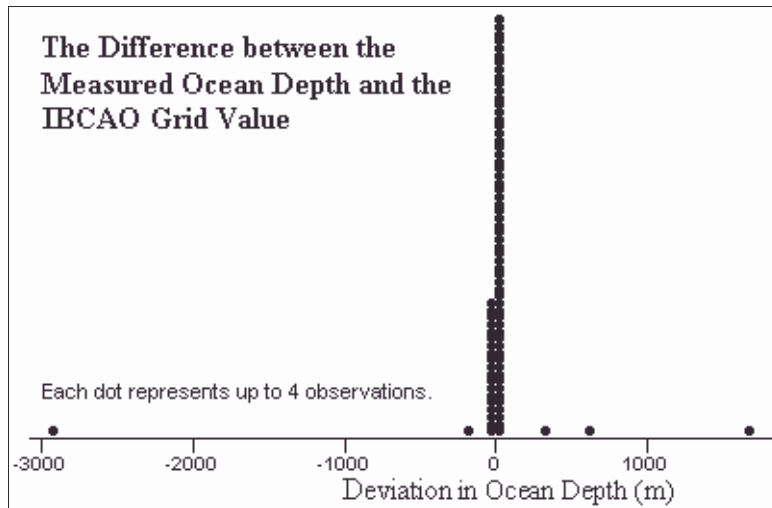


Figure 4.7 Difference Between Measured Depth and the IBCAO Grid Value

The three dotplots above show two outliers, one far to the right and another far to the left. These outliers were left out in the evaluation of the grids, since if they were included their values would dominate the calculated mean and standard deviation. The three grids are compared in Table 4.2.

	Deviations			Squared Deviations		
	Mean (m)	Median (m)	Std. Dev.	Mean (m ²)	Median (m ²)	Std.Dev.
ETOPO5 Grid	5.5	1.1	58.8	3477	16	27290
Gravity Based Grid	-28.3	-1.58	91.8	9200	35	50066
IBCAO Grid	3.9	0.65	47.4	2252	4	24471

Table 4.2 Comparison of the Deviations of the Three Bathymetry Grid Values from Measured Depth

The comparison in Table 4.2 shows the statistics of the difference between the measured ocean depth and the depth according to the three bathymetry grids.

The mean of pure deviations reveals whether the deviations are biased, i.e. whether the grid values are consistently higher or lower than the measured depth. While statistics of the squared deviations indicate the overall deviations. The IBCAO grid has the smallest deviations, both when pure deviations are compared and in the case of squared deviations.

Since the IBCAO grid proved to be closer to the measured values than the other two grids, the IBCAO grid was used as a base map for the study area. Since the grid does not cover the entire area (Figure 3.4), data from another grid was used to fill in the gap. The ETOPO5 grid has the second smallest deviations after the IBCAO grid (Table 4.2) and was therefore used along with the IBCAO grid. Therefore the final base map is composed of the IBCAO grid for the most part of the ocean, the ETOPO5 when IBCAO does not exist and GTOPO30 for the land areas. There is a smooth transition between all three grids, no abrupt changes appear in elevation or depth.

The procedure of merging those grid sources, to create the **basemap** grid, was conducted in Arc/Info and the details can be found in Appendix A.

4.4 PROCESSING THE ARCTIC ICE-OCEAN MODEL OUTPUT


The output of the Arctic Ice-Ocean Model for the year of 1993 was downloaded. The 12 month average data files were in a NetCDF file format. Many ways of processing the NetCDF files were considered, most of which came from the Unidata reference Internet site (UCAR, 2000) that describes software for manipulating or displaying NetCDF data. Most of those methods appear to be

used in conjunction with UNIX computers, and were therefore not a feasible option for this research. However, the Noesys data visualizing software works in the Windows environment (RS, 2000). The software is not free but a trial version was used for the project.

The Noesys system allows you to import the Netcdf files into a new project (File -> Import) and a multilayer file shows up. The *ahl*, *atemp*, *asal*, *au* and *av* are 368x304 matrices that have information on sea surface height, temperature, salinity and the velocity vectors, respectively. The matrices can then be exported (File -> Export Object), with selecting the file type “Formatted text” and choosing a {space} for a column delimiter and a {CR} as a row delimiter. The output is a comma delimited text files with a matrix of numbers. The file can then be converted to a grid in Arc/Info and viewed in ArcView. Details are in Appendix A.

The only available information on the projection of the ice-ocean model grids was that they were in a rotated spherical coordinate system with the equator along 50°W and 130°E. To decipher the projection of the grids, the coordinates of the gridpoints were projected into several different projections. The only projection that showed the extent of the gridpoint collection as a rectangular was an Azimuthal Equidistant map projection. Therefore the Azimuthal Equidistant projection is regarded as the projection of the Ice-Ocean Arctic model. The longitude of the center of projection proved to be 140°W and the latitude of its center is the North Pole. The specific northing and easting parameters of the projection were defined by projecting a coastline shapefile into Azimuthal

Equidistant projection. This was done several times with different projection parameters. The projection parameters of the coastline coverage that fitted best were considered the right parameters. The grids were assigned the Azimuthal Equidistant projection and projected to Lambert projection using the `azi2lamb.txt` projection file (Appendix A).

The velocity vector grid image, u and v , does not give a representative image of the currents. Therefore a method of viewing the velocity vectors as arrows with the correct direction and a relative length was developed. Grid points with velocity values were extracted in Arc/Info from both velocity components for every month. One point layer, **flux_lamb**, was created from these grid points, with the velocity values for every month in the attribute table (Appendix A). Now all the velocity information for the entire year 1993, is in one attribute table. The scripts *findflux.ave* and *arrow.ave* (originally written by Ye Zichuan), were rewritten for these data. The scripts can now be executed from a *Draw Ocean Current Arrows* button  and the question boxes shown in Figure 4.8 appear. If more than one shapefile is in the view, the program asks you for which shapefile it is supposed to draw arrows. The program then lets you choose a month and in what projection the arrows should be drawn, the Lambert Azimuthal Equal Area projection or the original Azimuthal Equidistant projection. Finally, a relative length of arrows is chosen and the program draws the arrows for all the selected points in the layer.

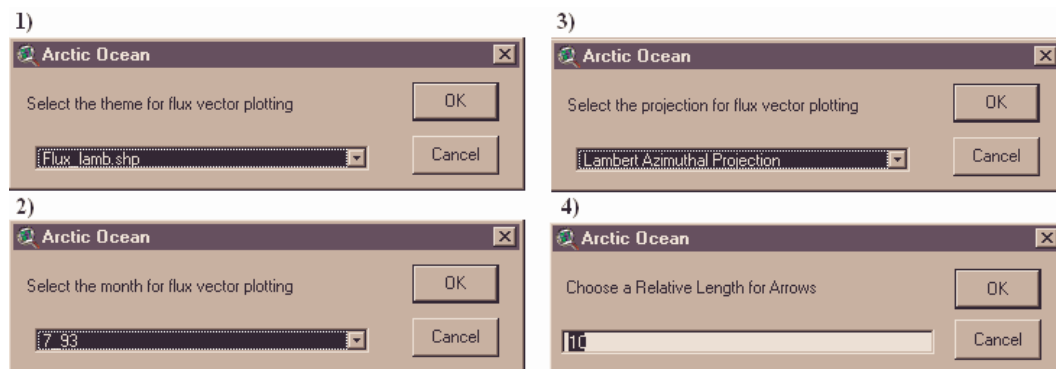


Figure 4.8 Question Boxes that Appear During Execution of *findflux.ave*

Figure 4.9 shows the current arrows for July 1993 in Chukchi Sea, overlying the temperature grid for the same month. A strong current appears to lie around Wrangell Island (Ostrov Vrangelya), and down through the Bering Strait as well as up by the Alaskan Coast.

Monthly averages of temperature, salinity, ocean height and velocity vectors for the year 1993 are available on the attached CD. The temperature, salinity and ocean height are in a grid format, while the velocity vectors can be viewed as flux arrows. The temperature and salinity conditions of the ocean influence which benthic species inhabit the ocean floor and their abundance. Information about the ocean currents is also essential to understand how nutrients are transported and where they may be in high concentrations. Regions with high nutrient concentration are likely to have high benthic productivity.

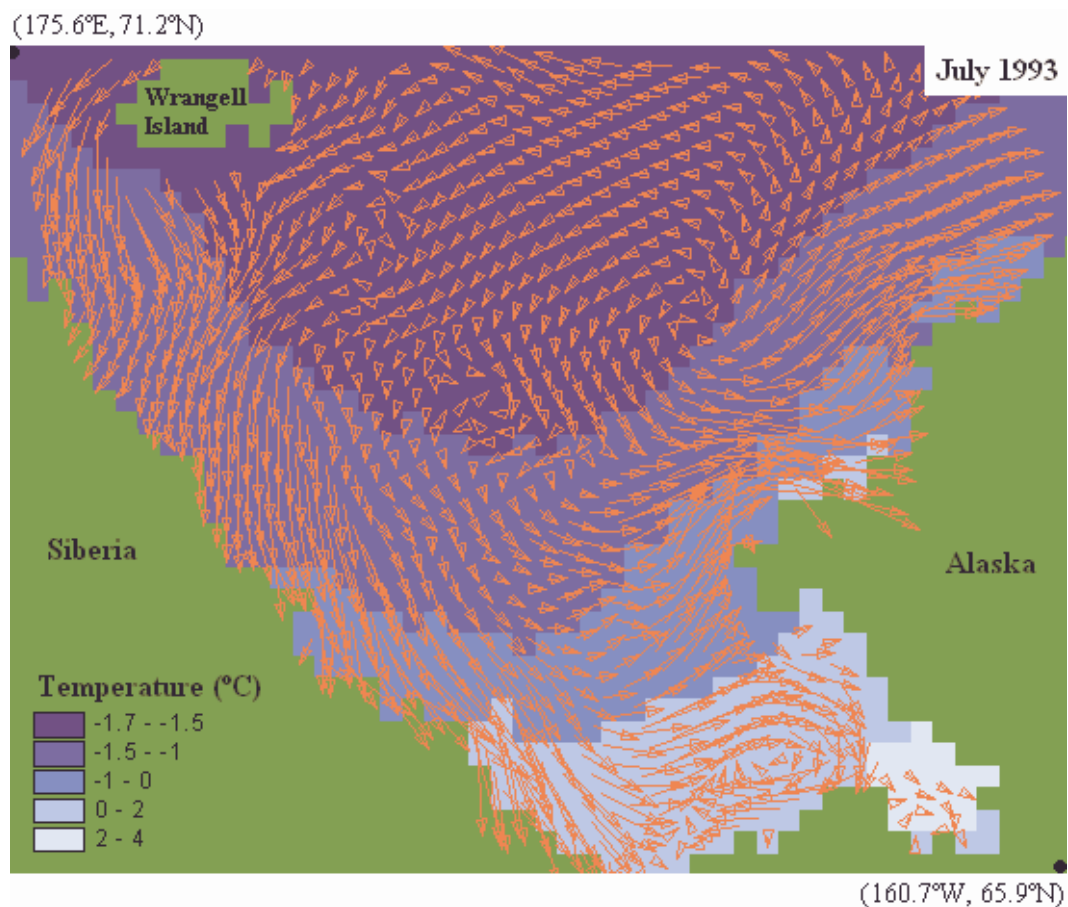


Figure 4.9 Currents in the Chukchi Sea Overlying a Temperature Grid, July 1993

4.5 THE BENTHIC RELATIONAL DATABASE

All the benthic data that was gathered for this research was assembled in a Microsoft Access database called *Arctic*. Data were set up in Excel worksheets and imported into Access, and then appropriate relationships between the tables were established as seen in Figure 4.10. In order to transfer the files into ArcView, append queries were used to create a table, *Benthos*, with all the information of interest from all the tables. A sample of the append queries can be

seen in Figure 4.11, while a few rows in the *Benthos* table are shown in Figure 4.12.

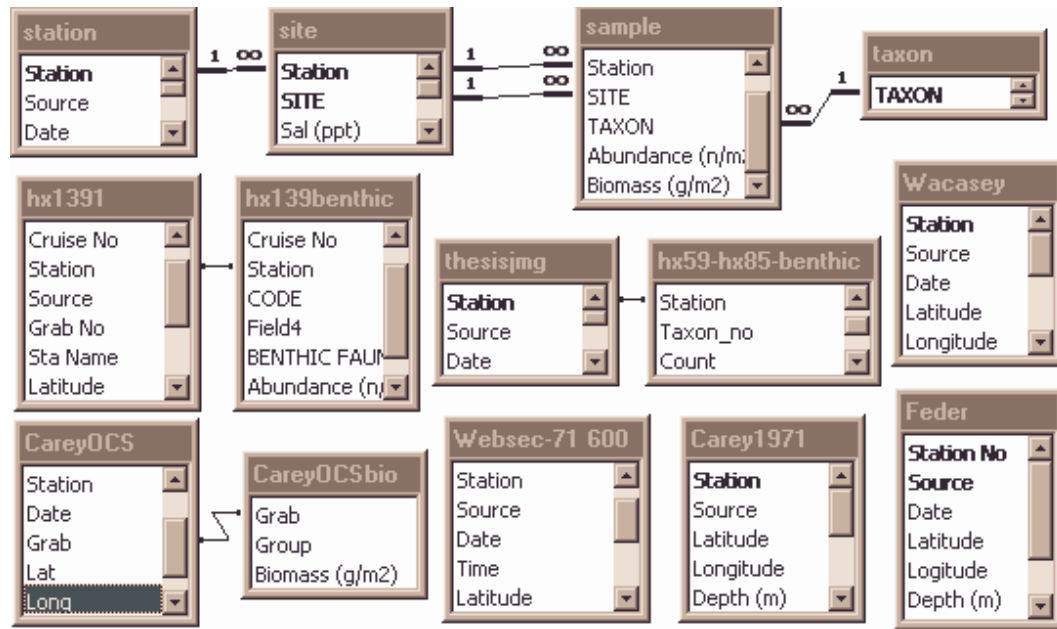


Figure 4.10 The Tables in the Arctic Database and Their Relationships

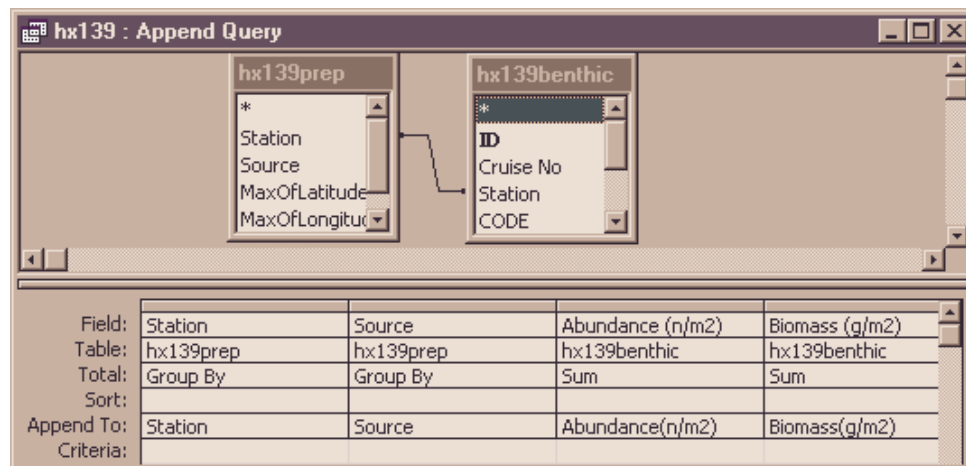


Figure 4.11 The Format of an Append Query

Station	Site	Source	Latitude	Longitude	Date	Depth (m)	Temp (C)	Sal (ppt)	Abundance	Biomass (g/m2)
1	1	Wacasey	69.24	-138.48	7/24/75	1.4	9.1	8	3367	0.36
100	1	Wacasey	69.11	-137.95	7/17/75	13	1	28	176	0.29
104	1	Wacasey	68.98	-137.35	7/15/75	3	0.3	26	576	1.13
107	1	Wacasey	68.97	-137.22	7/16/75	2.8	1.6	28	86	0.05
11	1	JMG_hx139	62.01	-169.01					5245	355
114	1	Wacasey	69.1	-137.98	7/29/75	2.6	9.7	38	180	1.08
12	1	JMG_hx139	62.01	-168.01					2118	58
13702	1	NODC	70.16	-143.14	6/8/70	10	0	26		
13703	1	NODC	70.16	-143.14	6/8/70	10	0	27		

Figure 4.12 The *Benthos*, a Table Containing All the Benthic Data

From this format, the table can be transferred to an ArcView project. Two methods were used for the transfer, exportation and database connection. The table was exported as a comma delimited text file and added to the project view in ArcView as an event theme. This method is simpler than the database connection. In order to establish a database connection between Access and ArcView an ODBC driver has to be set up. To set the driver up, the control panel of the computer is opened and the ODBC icon clicked. Under the User DSN tab, the Add button is selected and the driver is configured in the way shown in Figure 4.13.

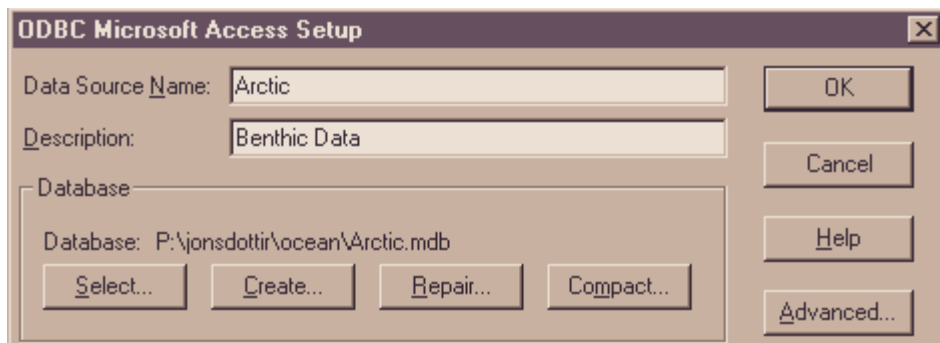


Figure 4.13 The Configuration of the ODBC drive

The Arctic database can now be connected to the Arc View project. With the project window active, the SQL Connect option is selected under the Project menu. The Arctic database is selected in the Connection box and the Connect button is pressed, then tables and field of interest can be selected (Figure 4.14) and the Query button pressed to create a table. The table created by the query can then be added to the view as an event theme.

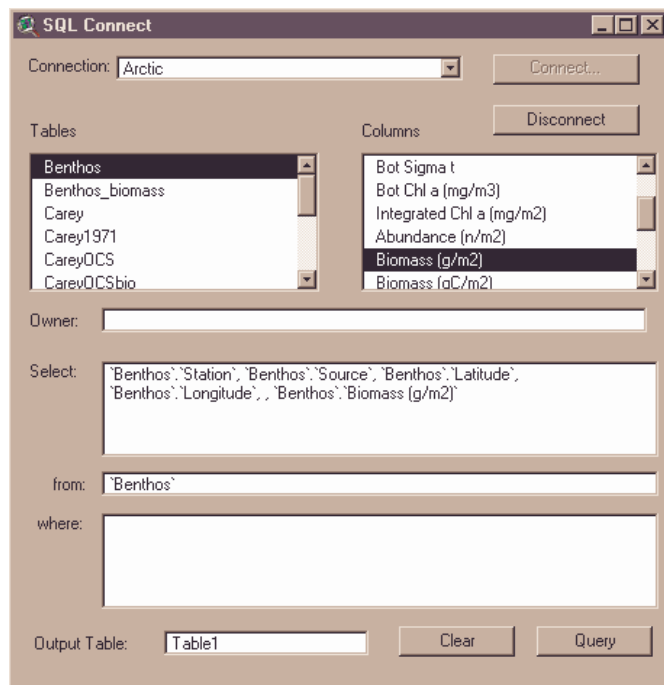


Figure 4.14 The SQL Connect Window

This database connection has the advantage that the table can always be refreshed (Table -> Refresh) to update the values after changes done in Access. The other option, exporting a text file, has to be done after every change in order to update the values. The event theme can then be converted to a shapefile and projected to Lambert projection using the *geo2lamb.txt* projection file.

Quantitative benthic data have been assembled in an Access Relational Database, titled *Arctic*, where appropriate relationships have been defined between data tables. Individual tables have been queried to incorporate all the benthic biomass data in one table titled *Benthos*. Information in the original tables on specific species found at stations is not included in the *Benthos* table. The species information can however be incorporated at later time with further queries. The *Benthos* table has been imported into ArcView and converted to the shapefile **samples**. The shapefile was used for further spatial analysis of benthic biomass in ArcView and Arc/Info.

Chapter 5: Results

This chapter discusses the results of the research. An orientation geodatabase has been assembled. It has layers that give quantitative benthic data a frame of reference, i.e. coastlines, rivers, nautical charts etc. A bathymetry basemap has been assembled of the study area. The output of an Arctic Ice-Ocean model has been adapted to the ArcView framework. Finally, quantitative benthic data have been assembled in a relational database for further analysis and interpolated surfaces of biomass have been produced. All final versions of shapefiles and grids produced in this research have been written to an attached CD.

5.1 DIGITAL BATHYMETRY MODEL

The **basemap** in Figure 5.1 is a bathymetry grid of 2.5 km cell size. It covers the study area and is assembled from three bathymetry/elevation data sources. A reliable bathymetry grid is essential to understand the relationship between ocean depth and benthic productivity.

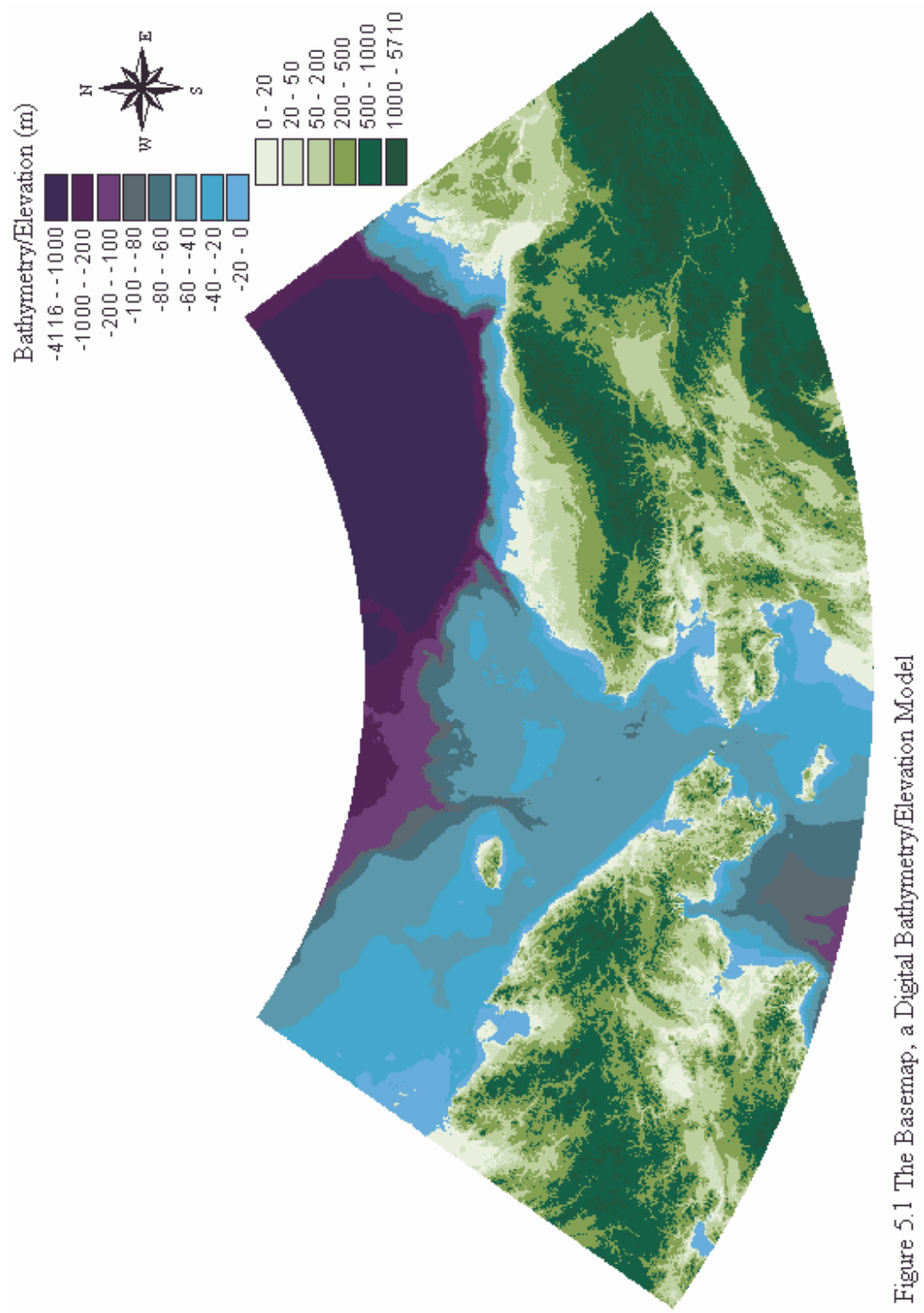


Figure 5.1 The Basemap, a Digital Bathymetry/Elevation Model

5.2 INTERPOLATION OF BENTHIC BIOMASS

The Arctic database has 641 records with measurements of benthic biomass. A dotplot in Figure 5.2 shows the distribution of the benthic biomass data while general statistics are shown in Table 5.1.

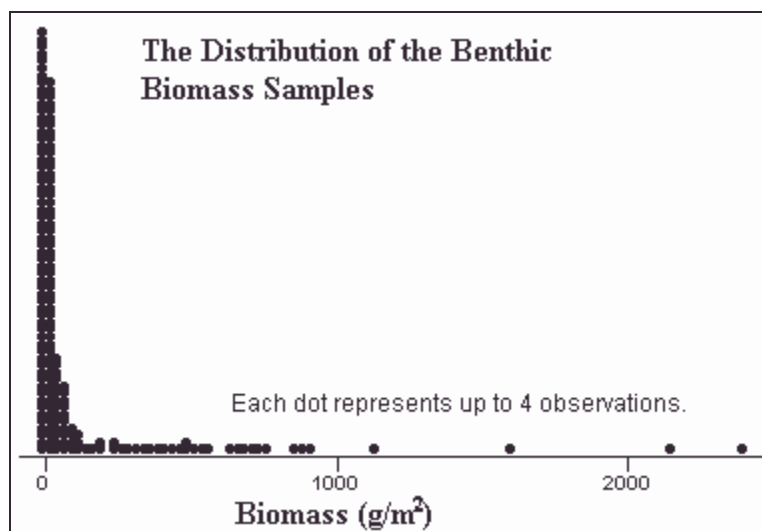


Figure 5.2 The Distribution of the Benthic Biomass Samples

Count	Minimum (g/m ²)	Maximum (g/m ²)	Mean (g/m ²)	Median (g/m ²)	Std. Dev.
641	0	2377	66.3	4.7	196.5

Table 5.1 General Statistics of the Benthic Biomass Samples

Benthic biomass is sampled at stations, i.e. point locations, whereas knowledge of the continuous benthic biomass pattern is desired. Therefore interpolation of the point data is important. Using interpolation, biomass at locations where biomass has not been sampled is predicted from neighboring biomass measurements. Two approaches were used to interpolate the biomass

data, the Arc/Info Workstation function *Topogrid* and the *Geostatistical Analyst* in ArcMap. The *Topogrid* function was developed with elevation data in mind, while the *Geostatistical Analyst* gives a variety of interpolation methods and is a great tool for the interpolation of all spatially continuous data.

The Geostatistical Analyst gives a variety of tools to analyze the data. The kriging interpolation technique predicts a surface based on the statistical characteristics of the data, and the reliability of the predicted surface can be estimated spatially. While other interpolation techniques cannot determine the reliability of the predicted surface on a spatial scale. Therefore kriging techniques were used in this study.

5.2.1 Interpolation Using *Topogrid*

The *Topogrid* interpolation function in Arc/Info was designed to handle elevation data. It uses a discretised thin plate spline technique that is intended to show surface continuity without losing the ability to follow abrupt changes in terrain (Wahba, 1990). The function is not designed for data such as the biomass data; however, this method of interpolation is simple and good for initial interpolation of the data. The interpolation was done for both the raw biomass data and for transformed data. The transformation involved taking the logarithm of the biomass data before interpolation and thereby reducing the range of the data. By reducing the variability less importance is given to very high biomass values, whereas in the raw data the influence area of high values is relatively larger than the influence area of a low value. The exact procedure is described in Appendix A, while the two resulting grids can be compared in Figure 5.3.

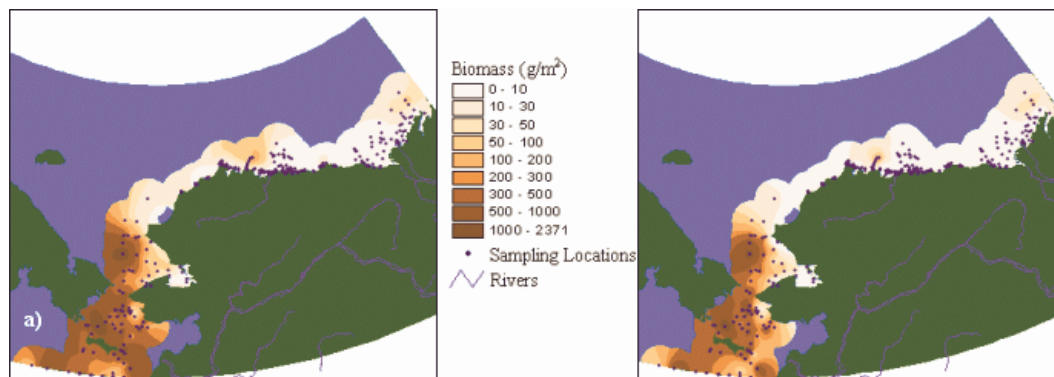


Figure 5.3 Interpolation of Biomass with *Topogrid*, a) Raw Data, b) Transformed Data

5.2.2 Interpolation Using the Geostatistical Analyst

The Geostatistical Analyst extension is a new package within the scope of ArcMap. It is intended for the interpolation of any continuous variable from point data. The user can analyze the statistical distribution of data before interpolation, select the interpolation method, and assess the quality of the results. The interface is well developed and a tutorial explains the procedures used by the program. Therefore the user has a good opportunity to evaluate which interpolation is appropriate and to understand the results.

The Geostatistical Analyst was used to analyze the benthic data by interpolation of the biomass. The use of the kriging methods was emphasized in the study; these methods use the statistical correlation between data points to predict a surface. Prior to the work in ArcMap the table *Benthos* was analyzed in the statistical program Minitab. By stepwise regression more correlation was found between the biomass and salinity, than between biomass and depth or temperature. An attempt was made to use the salinity output of the Arctic Ocean

model along with cokriging methods to predict biomass distribution. The cokriging attempts gave, however, a higher prediction error than the kriging models. Further study may reveal more valuable information on the relationship between variables.

The Geostatistical Analyst gives the user an opportunity to explore the dataset before interpolation; this can give an idea of what interpolation techniques may be applicable to the specific data. The tools available for exploration are shown in Figure 5.4 where a trend analysis of the biomass data shows a decrease in benthic biomass with higher latitudes. The apparent trend in East-West direction may be caused by the distribution of the sample points. Points in the Chukchi and Bering Sea are both west and south of those in the Beaufort Sea.

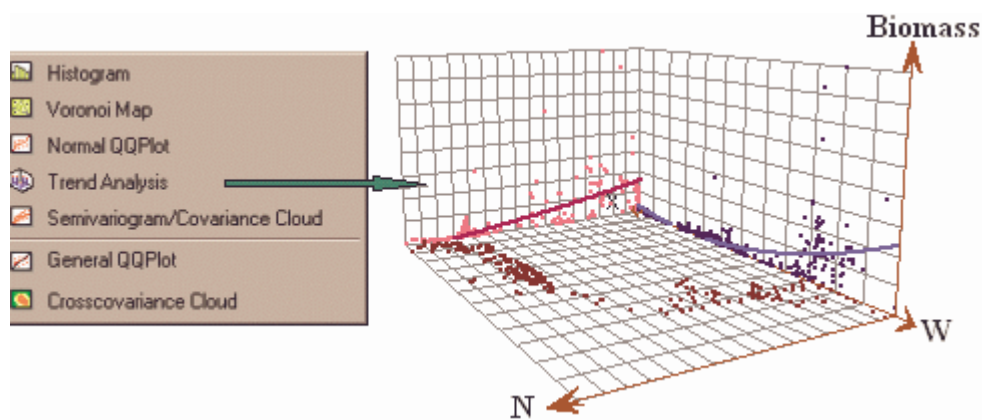


Figure 5.4 A Trend Analysis of the Benthic Biomass

Some of the interpolation methods require a normal distribution of data. The *Normal QQPlot* is a graph where quantiles from the distribution of biomass is plotted relative to a normal distribution. The graph gives an indication of the univariate normality while more general parameters of the distribution are

calculated by choosing *Histogram*. As seen in Figures 5.5 and 5.6, an assumption of normal distribution of the benthic biomass could not be established. However, the logarithmic transformation of the data gives a distribution fairly close to a normal distribution. Therefore, if univariate normality is required for a distribution, the logarithmic transformation may be a feasible option.

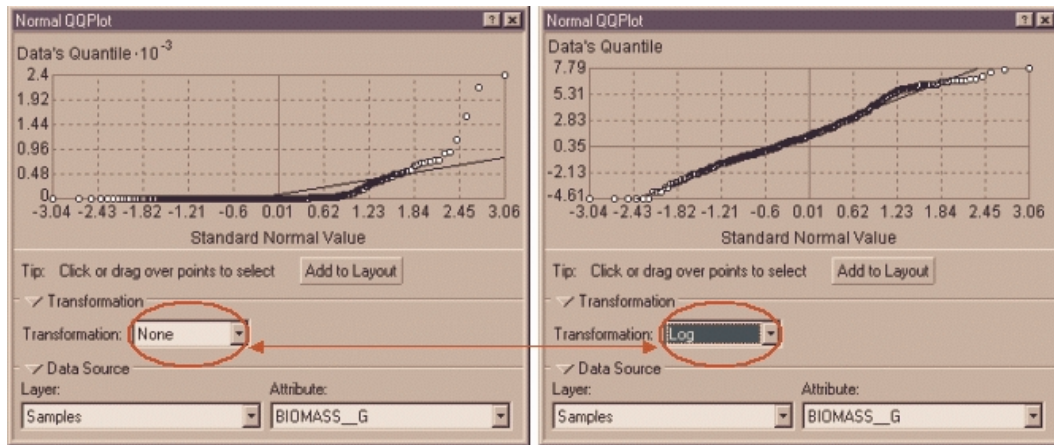


Figure 5.5 A Comparison of the Biomass Distribution to a Normal Distribution

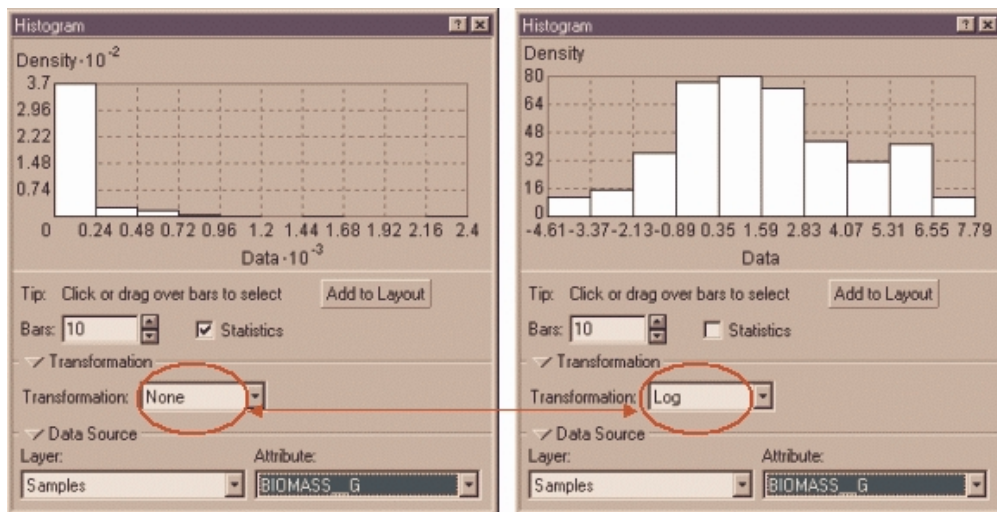


Figure 5.6 Histograms of the Biomass Samples, Raw Data and Log-Transformed

Different interpolation methods and parameters can give a variety of interpolated surfaces. For a selected dataset, trends can be removed and data can be transformed before interpolation, as seen in Figure 5.7. The data will then be untransformed and trends will be added before the final surface is produced. If a trend is removed from the data, the next screen will show the trend surface removed. Figure 5.8 shows a global first order detrending surface that is removed from the untransformed biomass data.

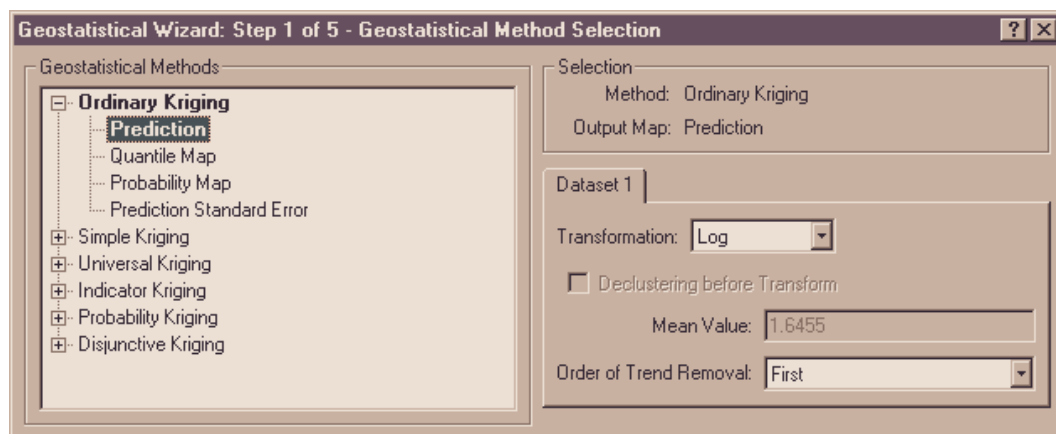


Figure 5.7 A Geostatistical Method Selection

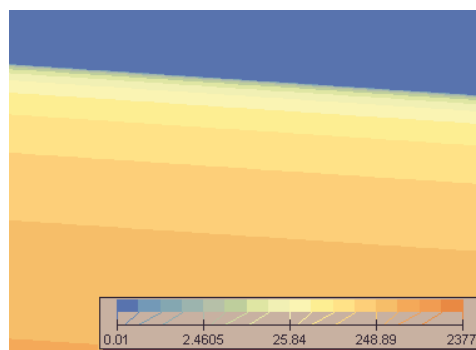


Figure 5.8 A Detrending Surface

After detrending the biomass data, the program calculates the autocorrelation of the data and fits a model to the results. The Semivariogram in Figure 5.9 shows the squared difference in biomass, γ , between points separated by a certain distance, h . The yellow line presents the statistical model fitted to the measurements.

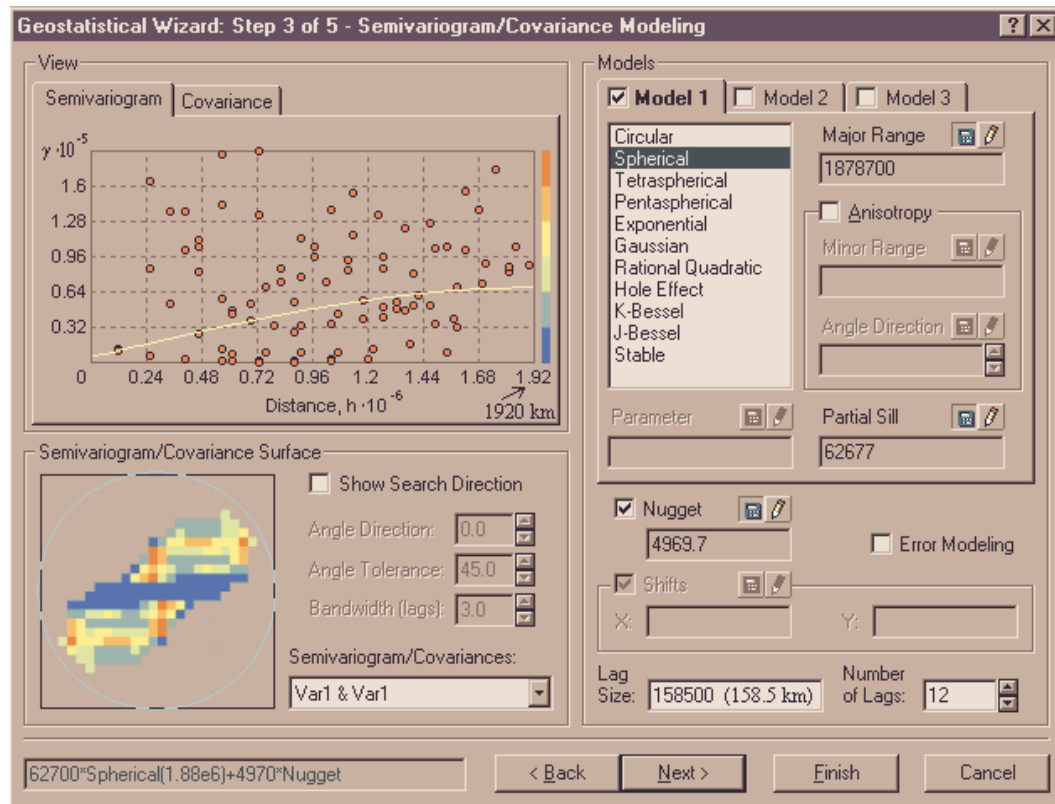


Figure 5.9 A Semivariogram

Not every pair of points is shown; each point on the graph stands for a group of pairs. The grouping is called binning; each bin spans a distance range (lag size of 158.5 km in Figure 5.9), while anisotropy also divides pairs of point in bins according to the angle between them. The model above is not anisotropic but

anisotropic models then create separate models for each direction interval, which can be useful in accounting for the directional characteristics of the data. However, if data are sparse, empty bins can exist and bins with few points for averaging may create undesirable variations.

The *nugget*, *range* and *sill* along with a shape function define the semivariogram model. The *nugget* describes spatial variations on the scale of sampling or measurement error, i.e. the difference in results one should expect from two samples at the same station. The *range* is the distance at which the model flattens out, i.e. at what distance samples stop being spatially autocorrelated. The *sill* gives the variations one should expect from samples separated by a distance beyond the *range*.

For every point in the analysis area, the program assigns neighboring points a weight based on the semivariogram model and takes a weighted average. A calculation of standard error contours (Figure 5.10) gives an indication of where the model may be trusted, while Figure 5.11 shows a statistical evaluation of the general quality of the surface.

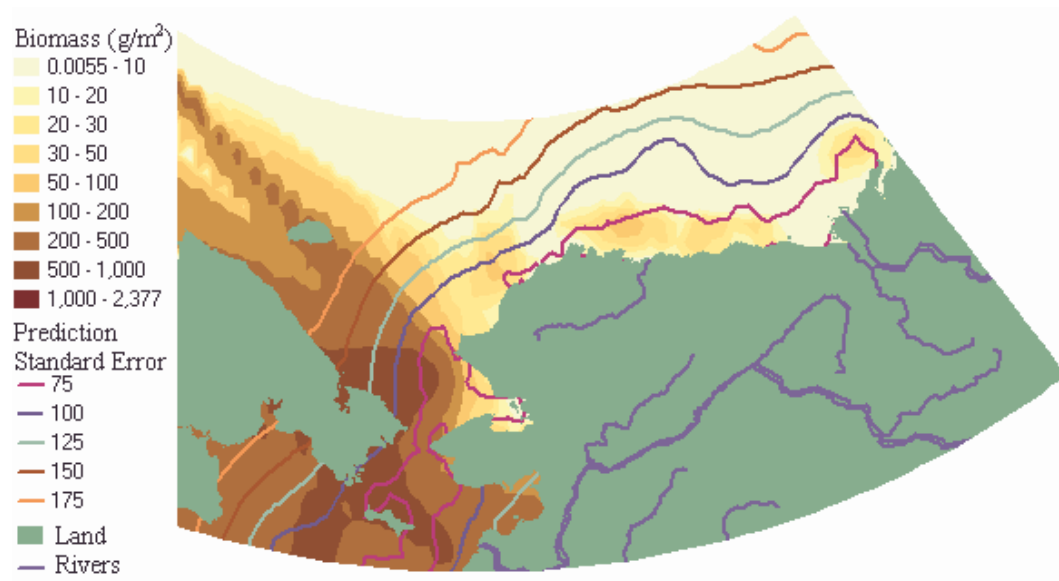


Figure 5.10 Biomass Interpolation and Standard Error Contours

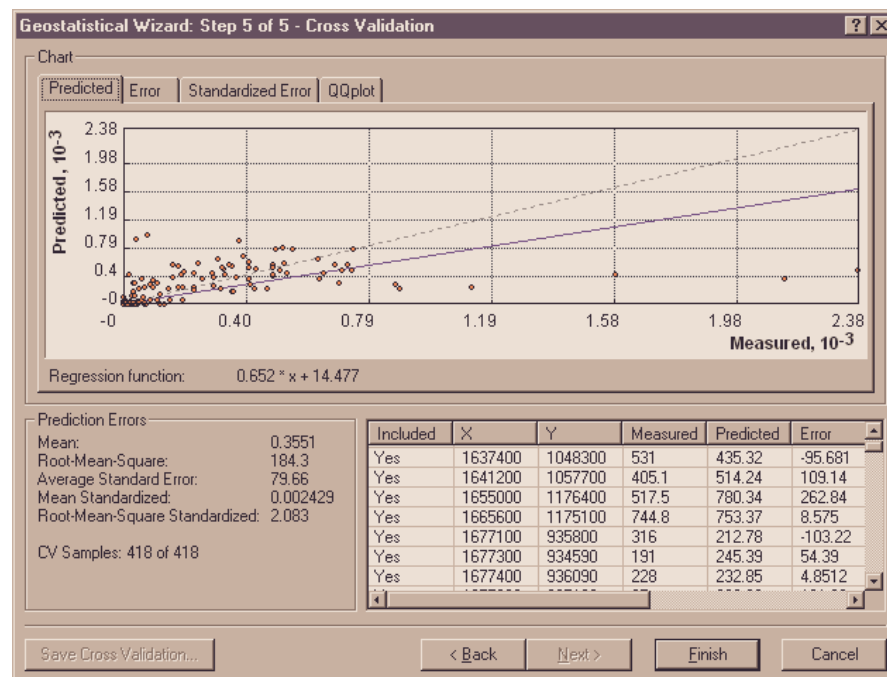


Figure 5.11 Cross Validation of Model Output

The Geostatistical Analyst was used to interpolate the benthic biomass. When the entire data set was analyzed, three ordinary kriging models appeared to have the smallest prediction error. One of them had no trend removed, another had a first order global trend removed and the third had the same trend removed and an anisotropy accounted for. The range of biomass values is large (Table 5.1), higher values are generally in the Bering and Chukchi Sea while biomass in the Beaufort Sea is significantly lower. Therefore, the benthic biomass dataset was also analyzed in two parts; one model was created for the Chukchi and Bering Sea and another for the Beaufort Sea.

5.2.3 Interpolation of the Entire Benthic Biomass Data Set

Three biomass surfaces were created for the entire benthic biomass data set with an ordinary kriging technique. One model with default parameters, another where a first order north-south trend was removed and a third one where anisotropy was also accounted for. These models give similar results, as seen in Figure 5.12, while a model where data were logarithmically transformed gave a huge standard error. An attempt to model the biomass by connecting it to the salinity concentration from the ice-ocean model, using cokriging, did not give lower prediction error than with the biomass data alone. Therefore the choice of models came down to the aforementioned three ordinary kriging models.

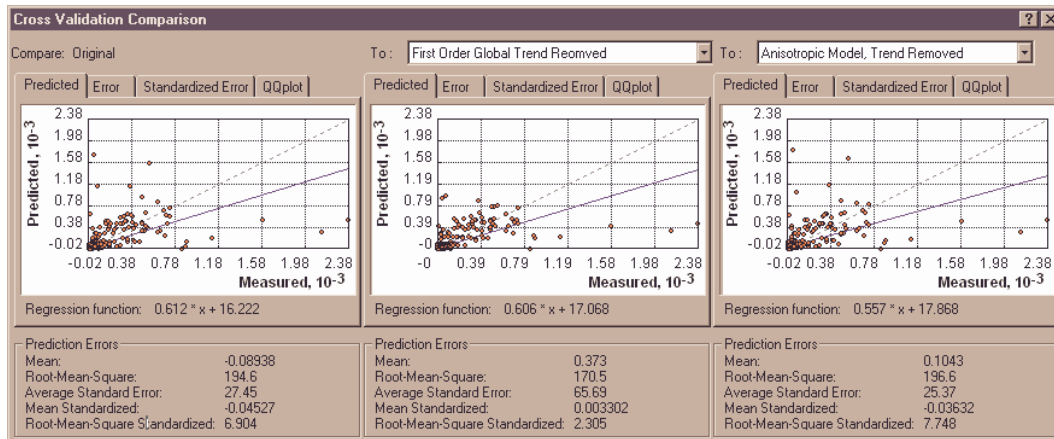


Figure 5.12 Prediction Error Comparison of Three Ordinary Kriging Models

If $Z(s_i)$ is the predicted value and $z(s_i)$ is the observed value and $\sigma(s_i)$ is the prediction standard error for location s_i , the mean prediction error is defined as shown in Equation 5.1. The root mean-squared prediction error is defined in Equation 5.2, the average standard error in Equation 5.3 and standardized prediction errors in Equations 5.4 and 5.5.

$$\frac{\sum_{i=1}^n (Z(s_i) - z(s_i))}{n} \quad (5.1) \text{ Mean Prediction Error}$$

$$\sqrt{\frac{\sum_{i=1}^n (Z(s_i) - z(s_i))^2}{n}} \quad (5.2) \text{ Root Mean-Squared Prediction Error}$$

$$\sqrt{\frac{\sum_{i=1}^n \sigma(s_i)}{n}} \quad (5.3) \text{ Average Standard Error}$$

$$\frac{\sum_{i=1}^n (Z(s_i) - z(s_i)) / \sigma(s_i)}{n} \quad (5.4) \text{ Mean Standardized Prediction Error}$$

$$\sqrt{\frac{\sum_{i=1}^n [(Z(s_i) - z(s_i)) / \sigma(s_i)]^2}{n}} \quad (5.5) \text{ RMS Standardized Prediction Error}$$

The comparison of the three interpolation models shows that the second model, where first order trend was removed, has a smaller mean error and the root-mean-square prediction error is also smaller than the other two models. The average standard error in all three models is a lot smaller than the root mean square error, which indicates that the models underestimate the variability of the biomass. The second model does however account for more variability than the others and seems to be the best model. The second model (Figure 5.13) is on the attached CD; it is an ArcMap layer titled **biomass**. Prediction standard error contours for the **biomass** model is also on the CD, titled **bio_standerr**.

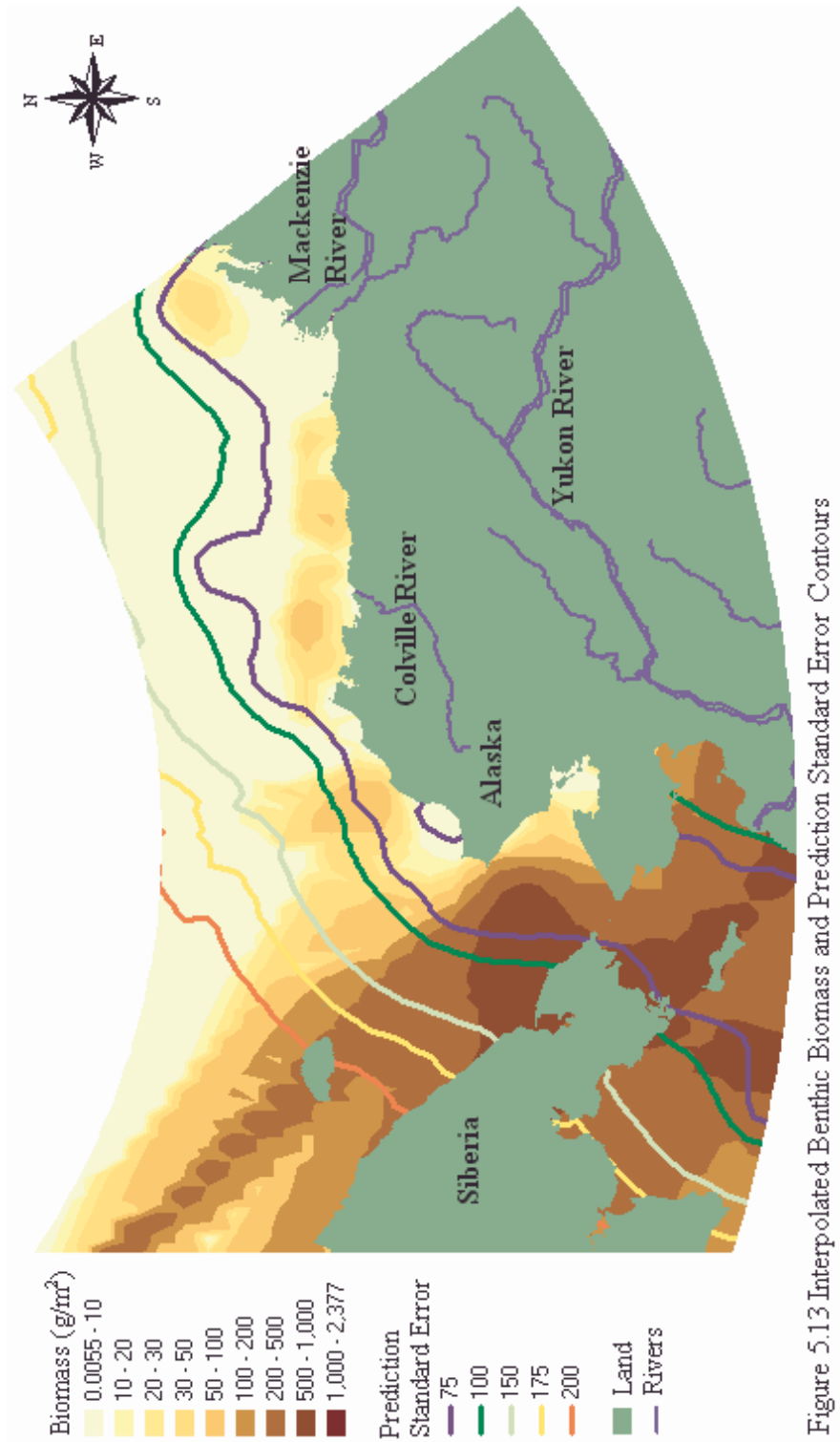


Figure 5.13 Interpolated Benthic Biomass and Prediction Standard Error Contours

Areas of high benthic productivity can be identified by an evaluation of where the benthic biomass is higher than a certain value. A probability map was created with the same method as the biomass layer was constructed. The probability layer shown in Figure 5.14, **bio_prob50**, shows the probability of biomass exceeding a value of 50 g/m². The probability layer is only visible in areas where the mean prediction error is expected to be less than 100 g/m². In areas of a high prediction error the reliability of the probability layer is smaller.

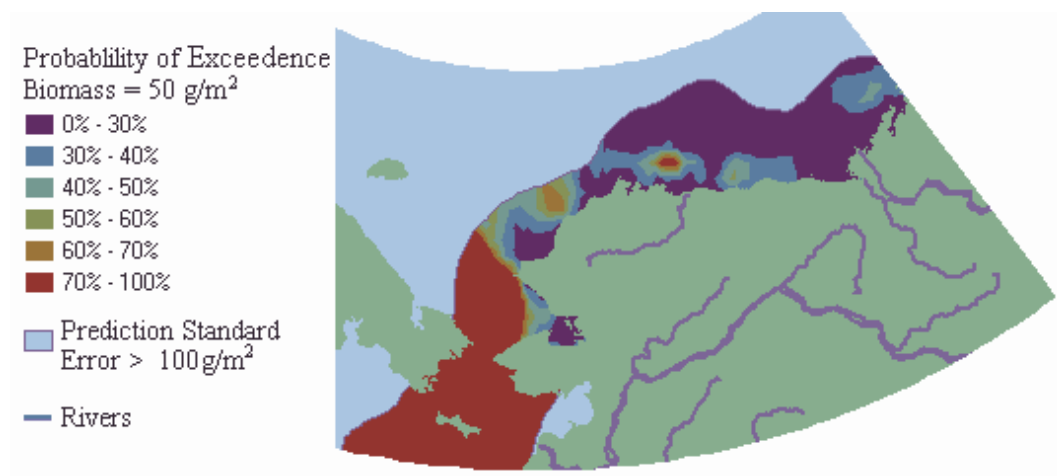


Figure 5.14 Probability of Biomass Exceeding 50 g/m²

5.2.4 Interpolation of the Benthic Biomass Data in Two Sets

The range of the benthic biomass data is large; the biomass in Chukchi and Bering Sea is significantly higher than the biomass in the Beaufort Sea. The interpolation of the entire dataset results in a good evaluation of the biomass in regions where the biomass is high. However, the standard error of prediction is very high relative to the biomass values in areas of low biomass. Therefore a separate kriging model was produced for the Beaufort Sea alone. A separate

model for the Chukchi and Bering Sea did however give higher prediction error than the model for the entire area as seen in Figure 5.15. The model for the entire area is therefore more practical for the Chukchi and Bering Sea.

An ordinary kriging model for the Beaufort Sea alone, with a second order global trend removed proved to have the lowest prediction error for the Beaufort Sea. The default parameters in the Geostatistical Analyst were used, and a statistical evaluation of the model is shown in Figure 5.15. The model for Beaufort Sea, **bio_beaufort** (Figure 5.16) shows more details in the distribution of benthic biomass in the Beaufort Sea than the model for the entire study area (Figure 5.13). The standard error of prediction is also significantly lower in the Beaufort Sea model and the results are therefore more dependable in the Beaufort Sea than the results from the model for the entire area.

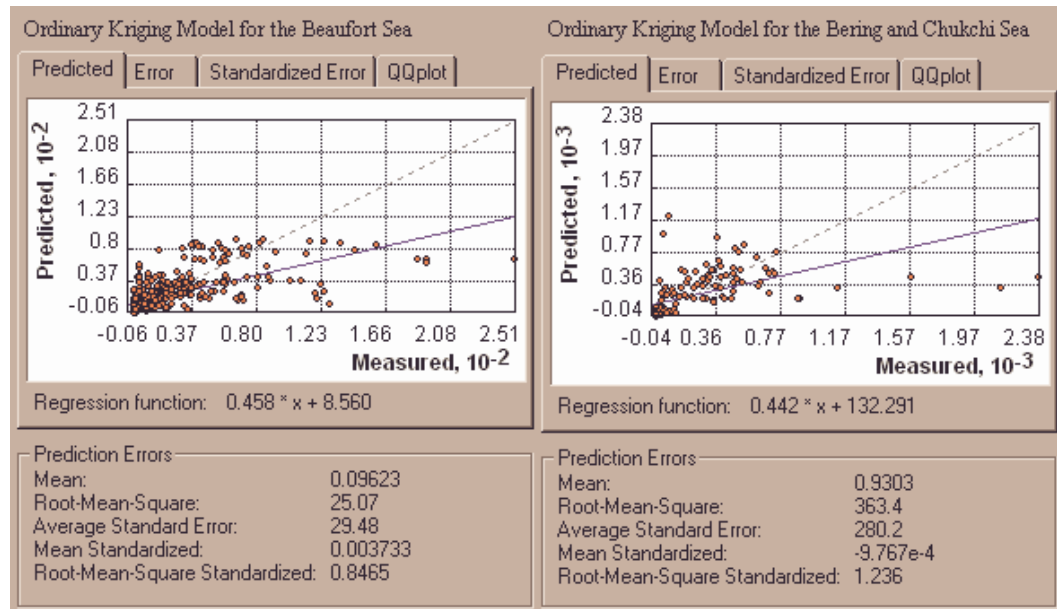


Figure 5.15 The Ordinary Kriging Model for the Beaufort Sea

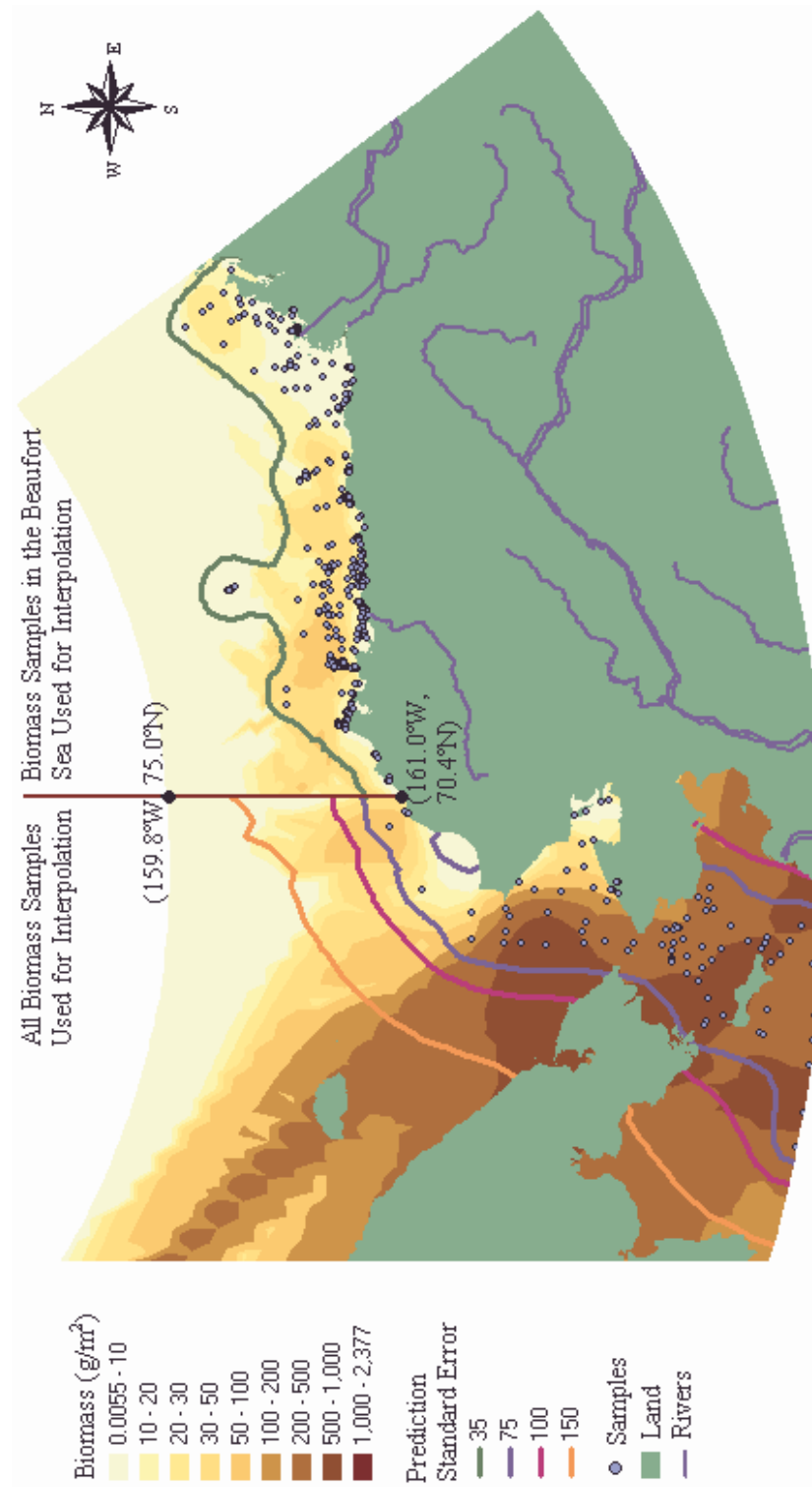


Figure 5.16 Interpolation of Benthic Biomass in Two Sets and Standard Error Contours

A probability map, **beaufort_prob30**, was produced for the Beaufort Sea to identify areas of high benthic productivity from the shapefile **beaufort**. The map (Figure 5.17) shows the probability of benthic biomass to succeed 30 g/m^2 . The standard error contours are saved as **beaufort_standerr**. The map only shows the probability evaluation where prediction is very reliable. The predicted standard error in the area shown in Figure 5.17 is lower than 35 g/m^2 .

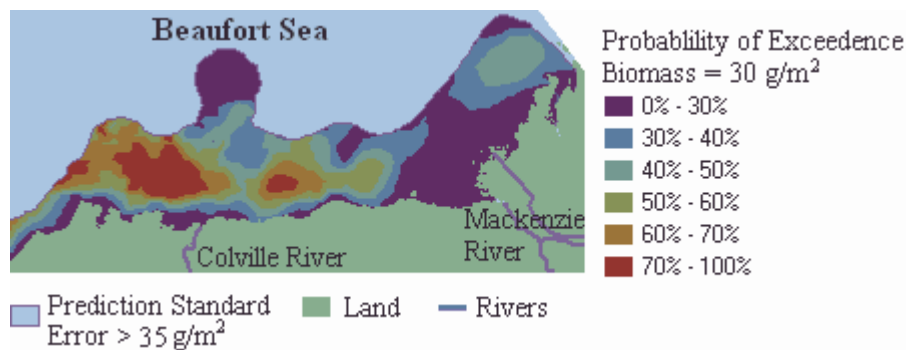


Figure 5.17 Probability of Biomass in Beaufort Sea Exceeding 30 g/m^2

The Chukchi and Bering Sea have much more benthic biomass than the Beaufort Sea. The probability map in Figure 5.18, **chukchi_prob250**, shows the probability of benthic biomass to exceed 250 g/m^2 . The probability evaluation is only visible in areas where the predicted standard error is lower than 100 g/m^2 .

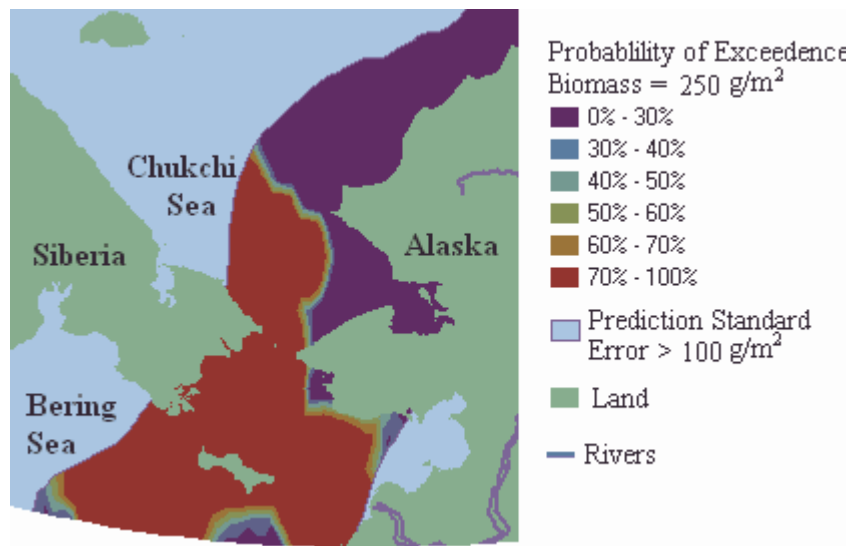


Figure 5.18 Probability of Biomass in Chukchi and Bering Sea Exceeding 250 g/m²

5.2.5 Interpretation of the Interpolated Benthic Biomass Maps

The prediction standard error contours give important information of the dependability of the benthic biomass interpolation. Examples of how well the maps can predict the benthic biomass were taken at four locations in the study area. The locations of the example points are shown in Figure 5.19. One of the samples, A is in the middle of the Chukchi Sea. Point B is further out to the west, where no benthic biomass samples were close by. Point C is in the middle of an area of high benthic biomass in the Beaufort Sea and Point D is in a region of very low biomass in the Beaufort Sea.

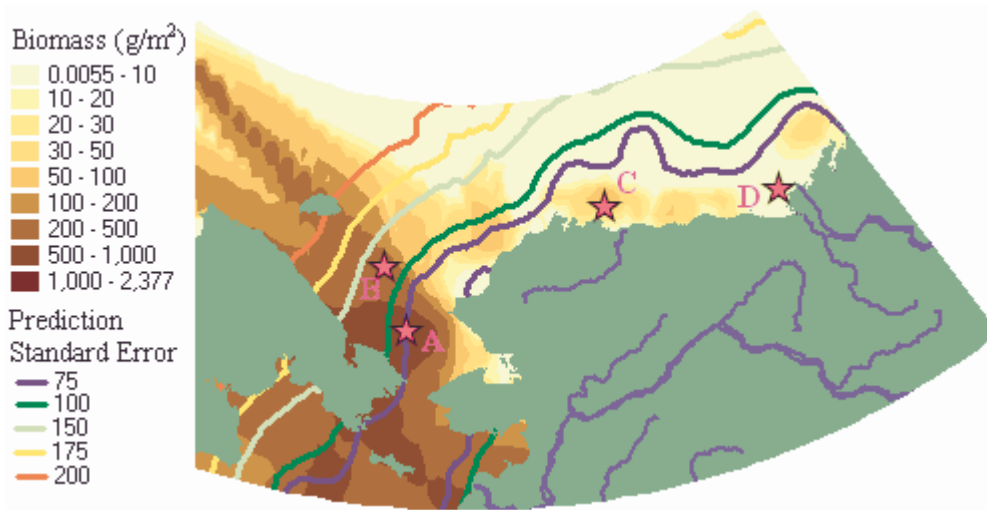


Figure 5.19 The Location of the Example Points, A, B, C and D

Table 5.2 shows the predicted values at the four locations and their standard errors. Values from both the model for the entire area and the model for the Beaufort Sea are shown for points C and D. The following figures show the probability density of benthic biomass in the example locations. A normal distribution is assumed at the point locations, the mean of the distribution is the predicted value and the standard deviation is the evaluated standard error.

ID	Model for the Entire Dataset			Model for the Beaufort Sea		
	Predicted Biomass, μ (g/m ²)	Biomass Standard Error, S_e (g/m ²)	$t = \mu/S_e$	Predicted Biomass, μ (g/m ²)	Biomass Standard Error, S_e (g/m ²)	$t = \mu/S_e$
A	800	87	9.2			
B	322	135	2.4			
C	83	67	1.2	75	30	2.5
D	3.4	68	0.1	3.3	30	0.1

Table 5.2 Predicted Benthic Biomass and Standard Error for Selected Locations

A t-statistical test shows whether the biomass is significantly different from zero. If $t = \mu/S_e > 2$ the biomass is significant, otherwise not. According to

the model for the entire dataset, the biomass is only significant for points A and B. While according to the model for the Beaufort Sea, the biomass is also significant for point C.

A normal distribution probability density function describes the prediction dependability. If μ is the mean (predicted value) and σ is the standard deviation (standard error) the probability density is described by Equation 5.6.

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(\frac{-(x-\mu)^2}{2\sigma^2}\right) \quad (5.6) \text{ The Probability Density}$$

Figures 5.20 through 5.23 show the probability density for points A, B, C and D, according to the model for the entire study area, while Figure 5.24 shows the probability functions for A, B, C and D on one graph for comparison.

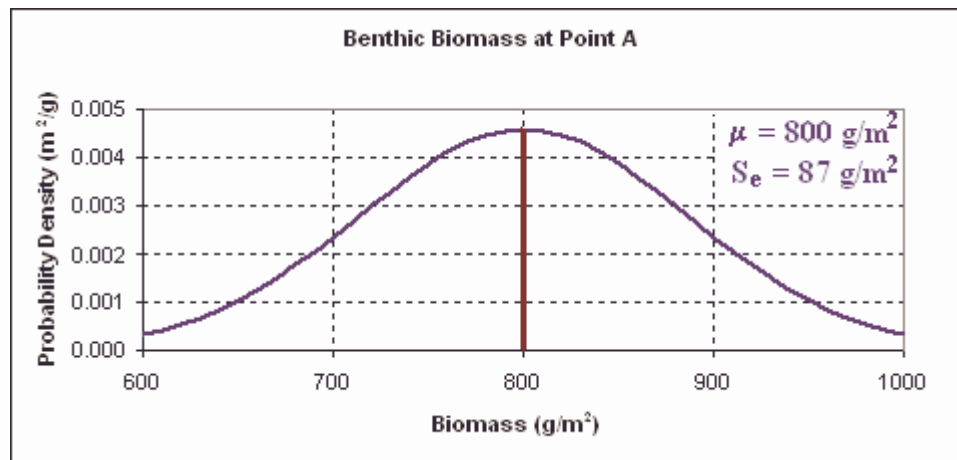


Figure 5.20 The Benthic Biomass Prediction at Point A

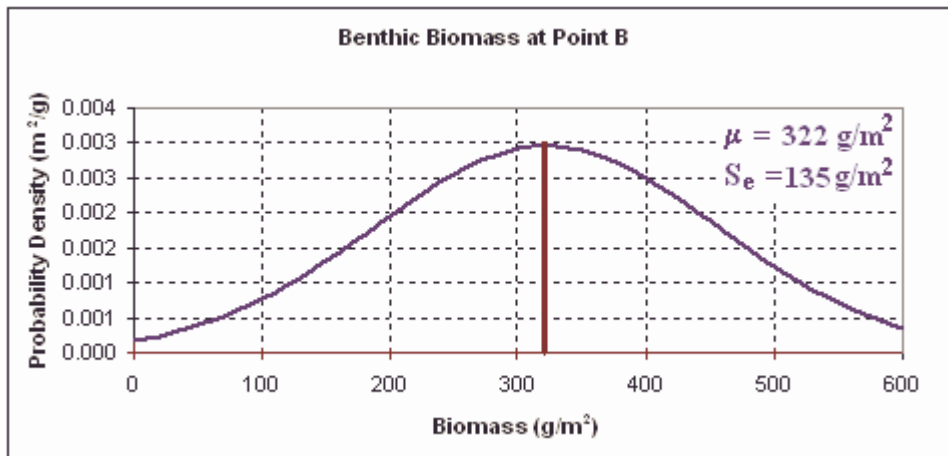


Figure 5.21 The Benthic Biomass Prediction at Point B

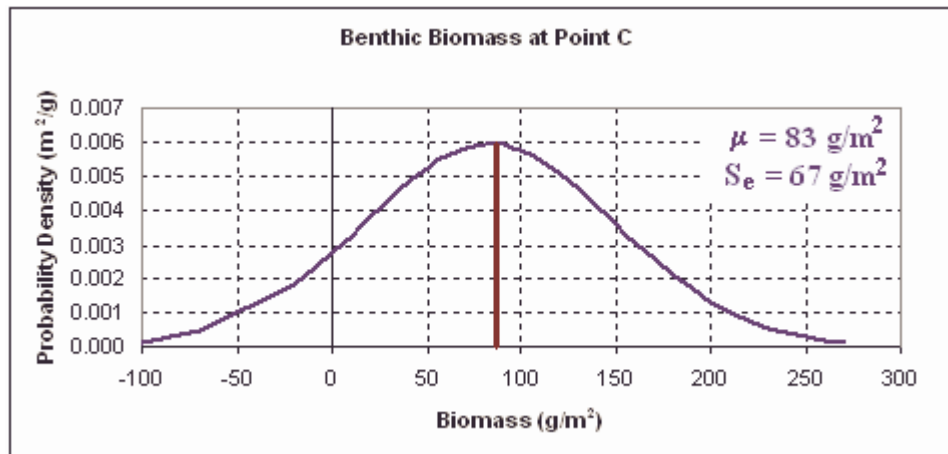


Figure 5.22 The Benthic Biomass Prediction at Point C

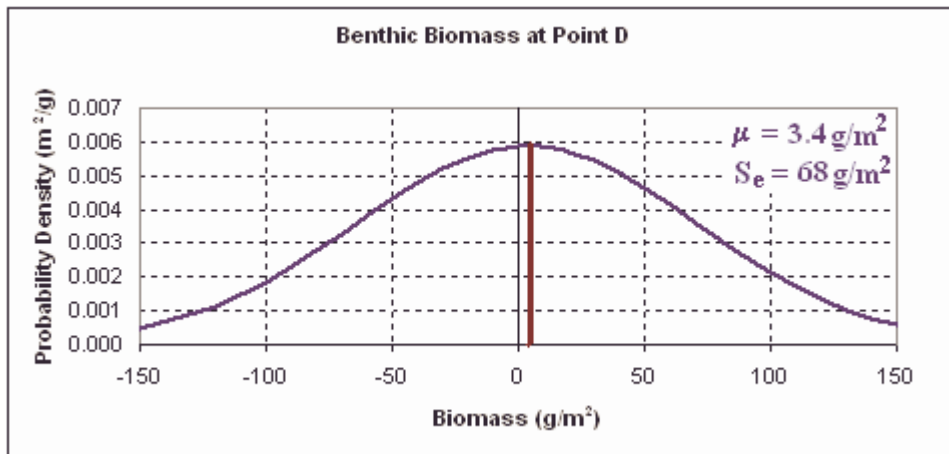


Figure 5.23 The Benthic Biomass Prediction at Point D

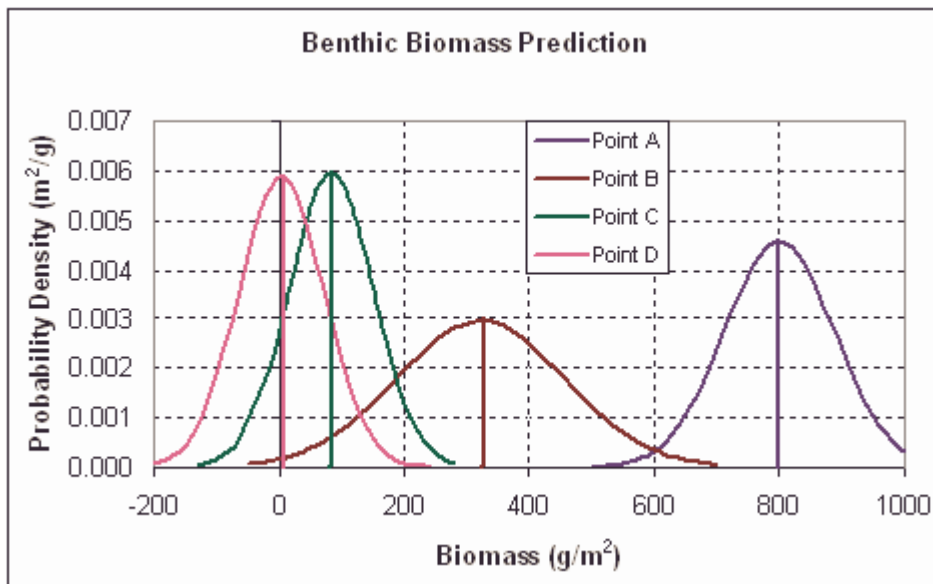


Figure 5.24 The Benthic Biomass Prediction at all Four Points

The first graph, Figure 5.20, shows the benthic biomass at point A, in the Chukchi Sea. The predicted value at point A is $800 g/m^2$ and the probability density curve shows that the benthic biomass is well determined. The uncertainty

is in the range of $\pm 100 \text{ g/m}^2$. The second graph, Figure 5.21 shows the benthic biomass at a point B in the Chukchi Sea. Point B is fairly far from any benthic measurements and the biomass is in the range of $320 \pm 150 \text{ g/m}^2$, the uncertainty of the prediction is larger than for point A. The biomass at the points C and D (Figure 5.24) is not well determined. The predicted value at C and D is low compared to the standard error that results in large uncertainty in benthic biomass evaluation. The model for Beaufort Sea does however predict the biomass in the Beaufort Sea area better than the model for the entire area. The probability density of benthic biomass at points C and D according to the Beaufort Sea model is shown in Figure 5.25 and 5.26.

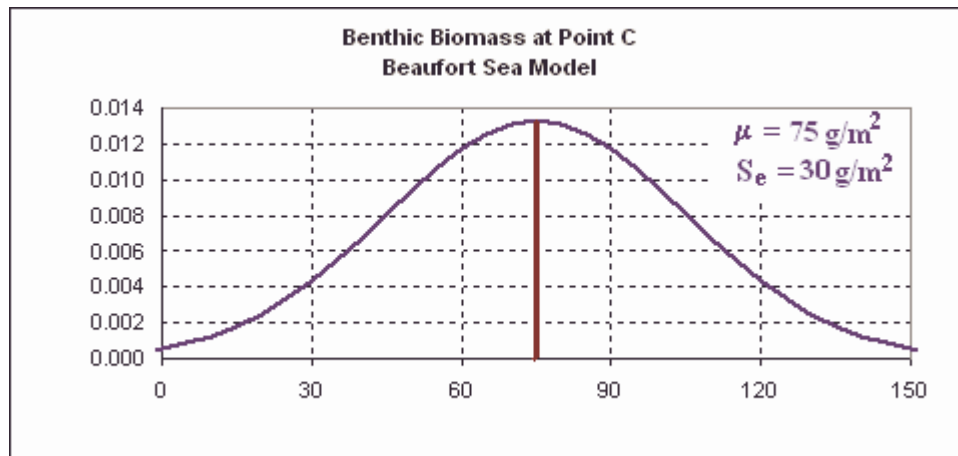


Figure 5.25 The Benthic Biomass Prediction at Point D, Beaufort Sea Model

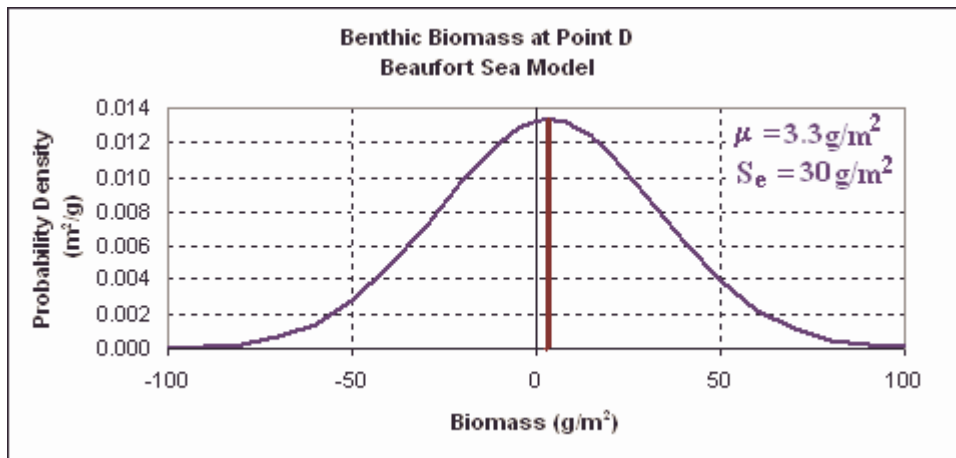


Figure 5.26 The Benthic Biomass Prediction at Point D, Beaufort Sea Model

Figure 5.25 shows the probability density for point C according to the Beaufort Sea model. The benthic biomass is predicted with more confidence than in the model for the entire area (Figure 5.27). According to the t-statistics the prediction for point C in the first model is not significantly different from zero. While in the Beaufort Sea model, $t = 2.5 > 2$, shows that the benthic biomass at point C is significant. According to the Beaufort Sea Model the benthic biomass at point C is in the range of $75 \pm 30 \text{ g/m}^2$. The biomass at point D is very low and cannot be predicted well since the standard error is high compared to the predicted value ($t = \mu/S_e = 0.1 < 2$). The biomass at point D is $3 \pm 30 \text{ g/m}^2$.

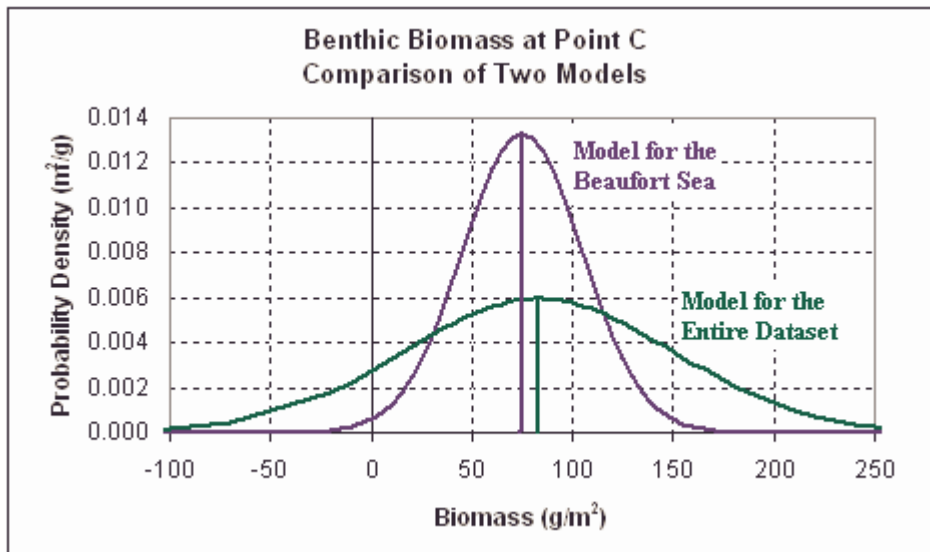


Figure 5.27 Comparison of the Two Models at Point C

The model for the entire area appears to predict biomass well in areas with high biomass. A comparison of the standard error contours to the predicted biomass indicates how well the biomass is predicted. The Beaufort Sea model appears to predict the low benthic biomass in the Beaufort Sea significantly better than the model for the entire area. The model gives lower standard error values and shows regions with high benthic biomass in more detail than the model for the entire area.

Both of the benthic biomass models (Figure 5.13 and 5.16) show areas of high benthic biomass in the Southern Chukchi Sea and the Bering Sea, where the predicted biomass exceeds 700 g/m^2 . Beaufort Sea has in general low biomass, less than 10 g/m^2 except in the vicinity of the mouth of large rivers. In the vicinity of Colville River the biomass reaches $50\text{--}100 \text{ g/m}^2$ and east of Mackenzie River the predicted biomass reaches 30 g/m^2 .

Chapter 6: Conclusions

6.1 INTRODUCTION

This research focuses on a GIS Analysis of the Western Arctic Ocean. The objective is to establish extensive knowledge of the spatial and temporal characteristics of the benthic community in the Beaufort, Chukchi and Northern Bering Sea. Available quantitative benthic data for the area were assembled in a relational database and analyzed in the ArcView and Arc/Info geographic information systems. Various other geographical data in digital format were also assembled to be viewed and analyzed along with the benthic data. Benthic productivity is strongly dependent on the existence of nutrients and physical factor such as ocean depth, temperature and currents.

This study shows that GIS is an effective platform for the analysis of the benthic community in the Western Arctic Ocean. The visualization and analysis of spatially distributed data can reveal clear relationships between physical and biological factors such as inflow of fresh water and areas of high benthic productivity

6.2 PREPARATION OF GEOSPATIAL DATABASE

The objectives of the study were to assemble geographically referenced data and develop methods for further analysis of the benthic community in the Western Arctic Ocean. A variety of information has been assembled and

preliminary analysis of benthic biomass has been performed. A detailed description of original data, methods and products can be found in this report. The description can therefore be used as a guide through further analysis with additional benthic data.

Various sources of digital geographical data were explored and data extracted. Data such as NOAA nautical charts, coastlines and rivers from the Digital Chart of the World, now serve as orientation files for physical and biological variables. The coastlines and rivers give a general reference system, while the detailed nautical charts include valuable information of landmarks and other details.

Several digital bathymetry/elevation models were studied and a bathymetry grid, **basemap**, with a cell size of 2.5 km was successfully assembled for the study area. The **basemap** grid is based primarily on the International Bathymetric Chart of the Arctic Ocean (IBCAO).

Methodology was developed to import the output of a grid based Ice-Ocean Arctic Model into ArcView. The model has a cell size of 18 km and gives information on ocean temperature, salinity and currents, as monthly averages for the whole Arctic Ocean. Twelve monthly files for the year of 1993 have been processed so temperature and salinity as grids, and velocity vectors as flux arrows can be viewed in ArcView.

6.3 INTERPOLATION OF BENTHIC BIOMASS IN THE WESTERN ARCTIC OCEAN

Quantitative benthic data were assembled in a relational database, where their distribution can be viewed in ArcView. A GIS layer with the benthic biomass data was analyzed with a Geostatistical Analyst in ArcMap where areas of high benthic biomass could be identified with a kriging interpolation technique.

An ordinary kriging model was developed for the entire study area. Along with benthic biomass values the prediction standard error was evaluated. The prediction standard error maps show that the model predicts benthic biomass well in the vicinity of benthic measurements in the Chukchi and Bering Sea. The range of benthic biomass measurements was high; the benthic biomass in the Beaufort Sea is significantly lower than the biomass in Chukchi and Bering Sea. The kriging model does not predict the biomass with as much certainty in areas with low benthic biomass. Regions with high biomass had greater influence on the structure of the kriging than regions with low biomass.

Since the model for the entire area does not predict biomass with much certainty in the Beaufort Sea, a separate model was created from benthic biomass measurements in the Beaufort Sea. Regions of relatively high biomass can be well identified in the Beaufort Sea model. Prediction standard error is on the order of 30 g/m^2 , therefore, the model does not give much information for very low benthic biomass values. This model does not determine well whether benthic biomass is on the order of 1 g/m^2 or 10 g/m^2 . Further analysis of log-transformed data may give more information of areas with low benthic biomass.

Regions of high benthic biomass (above 700 g/m²) are apparent in the Southern Chukchi and Bering Sea where the warm waters of the Pacific Ocean mix together with the colder Arctic Ocean. The biomass is in general lower in the Beaufort Sea (below 10 g/m²) while fresh water inflow from major rivers appears to result in increased biomass in the vicinity of the rivers mouths. The biomass west of Colville River reaches 50-100 g/m² and east of Mackenzie River the biomass reaches 30 g/m².

6.4 RECOMMENDATIONS FOR FUTURE WORK

This research was directed primarily towards preparation of a geospatial database of the study area, Western Arctic Ocean, whereas a further study could aim at a more intensive analysis. The next steps would then be to find more quantitative benthic data, research the temporal variability in the benthic data, analyze the distribution of specific species in the study area and research the relationship between benthic biomass and physical or chemical variables.

Quantitative benthic data have been assembled from various sources, however more data would give more reliable results. The search for other data sources is important.

Benthos are often considered integrators of the productivity in the water column above the ocean floor. They show little seasonal variation in abundance or biomass, and are good indicators for long term variation. In this research no attempt has been made towards quantifying long-term changes. A study of the

time trends of the data may reveal important information on long-term changes, which may be connected to global climate changes.

The quantitative benthic data often include information on what specific benthic species inhabit the ocean floor. In this research the cumulative biomass has been studied while a visualization of spatial distribution of specific species reveals interesting patterns.

Spatially distributed information of physical and chemical variables may be used to model the benthic biomass. The relationship between different variables may be explored either with further use of the Geostatistical Analyst or other statistical programs. Knowledge of links between benthic biomass and physical/chemical factors may then be used to establish a good understanding of the effects of global climate change on the benthic community of the Western Arctic Ocean.

Appendix A: Scripts/Programs and Procedures

AML Projection Files:

Geo2lamb.txt

Pol2lamb.txt

Azi2lamb.txt

Command sequences, AMLs etc.:

Arc/Info commands for the creation of the **frame** coverage

Arc/Info commands for the creation of the **fivedeg** coverage

Arc/Info commands for the creation of the **ETOPO5** grid

Matlab commands for the creation of the **IBCAO** grid

Arc/Info commands for the creation of the **basemap** grid

Commands for converting the output of the ocean model data to grids

Procedure for creating **findflux_lamb** for the ocean model

Procedure for interpolation with Topogrid, creating the **biomass** grids

Scripts:

Mergethemes.ave

Get_Extent.ave

Addtopo.ave

Findflux.ave

Arrow.ave

AML Projection Files:

Geo2lamb.txt

- Was used to project various layers from geographic projection to Lambert Azimuthal Equal-Area projection

Azi2lamb.txt

- Was used to project the Ice-Ocean Arctic model output to Lambert Azimuthal Equal-Area projection

Pol2lamb.txt

- Was used to project IBCAO grid from Polar Stereographic projection to Lambert Azimuthal Equal-Area projection

Geo2lamb.txt:

```
input
projection geographic
units dd
parameters
output
projection
lambert_azimuth
units meters
parameters
0
-165 00 00
90 00 00
2000000
4000000
end
```

Azi2lamb.txt

```
input
projection azimuthal
units meters
parameters
0
-140 00 00
90 00 00
2233051
2566645
output
projection
lambert_azimuth
units meters
parameters
0
-165 00 00
90 00 00
2000000
4000000
end
```

Pol2lamb.txt :

```
Input
projection polar
units meters
parameters
00 00 00
75 00 00
0
0
output
projection
lambert_azimuth
units meters
parameters
0
-165 00 00
90 00 00
2000000
4000000
end
```

Arc/Info commands for the creation of the **frame** coverage (AML):

Most of the layers and grids in the project are clipped to the extent of this frame; Figure 3.1 shows layers clipped by the frame.

Arc: *&run framegeo.txt*

Framegeo.txt:

```
generate framegeo
polygons
1,170,70
160,62
160,75
180,75
180,62
160,62
end
2,-170,70
-180,62
-180,75
-128,75
-128,62
-180,62
end
end
quit
```

Arc: *clean framegeo*

Arc: *project cover framegeo frame geo2lamb.txt*

Arc: *clean frame*

Arc/Info commands for the creation of the **fivedeg** coverage (AML):

The **fivedeg** coverage is shown in Figure 4.1.

```
Arc: Generate fivedeg_geo  
Generate: fishnet  
Origin Coordinate (X,Y): 160, 60  
Y-Axis Coordinate (X,Y): 160, 5  
Cell Size (Width, Height): 5, 5  
Number of Rows, Columns: 3, 15  
Generate: quit  
Arc: build fivedeg_geo  
Arc: project cover fivedeg_geo fivedeg geo2lamb.txt  
Arc: build fivedeg
```

Arc/Info commands for the creation of the ETOPO5 grid (AML):

The ETOPO5 grid is shown in Figure 3.11

```
Arc: Shapearc etopopt_geo etopopt_geo  
Arc: Project etopopt_geo etopo_point geo2lamb.txt  
Arc: topogrid etopo 5000 (5 km)  
Topogrid: datatype spot  
Topogrid: point etopo_point Z  
Topogrid: enforce off  
Topogrid: end  
Arc: Grid  
Grid: etopo2 = selectpolygon(etopo, frame, inside)  
Grid: etopo_floor = floor(etopo2 + 0.5)  
Grid: ETOPO5 = int(etopo_floor)
```

The topogrid commands are the same as for the other bathymetry/ elevation grids discussed in Chapter 3.2. The except cell size does however vary, it is 5 km here but 2.5 km otherwise. Also the name of the elevation fields may have been different for some of the other grids.

Matlab commands for the creation of the **IBCAO** grid:

The IBCAO grid is shown in Figure 3.13.

DLM = '/'

- The delimiter between numbers is tab

RNG = [7 0 1000005 0]

- Range set to start at row 7 column 0 to row 1000005 column 0

A1 = DLMREAD('IBCAO.asc',DLM,RNG)

- Read the part of the ASCII file IBACAO.asc that is within the range of RNG into A1

A2 = rot90(reshape(A1,3,333333))

- The numbers were read into one long column, here they are divided up into three columns again, X, Y and Z and stored in the matrix A2

DLM2 = ','

- The delimiter of the output file is a comma (,)

dlmwrite('A3',A2,DLM2)

- A file A3 is written from the matrix A2, it has 333333 records.

This was done for the first 1.8 million records, which span the study area, i.e. the area above 64 N and to some extent somewhat below, since the extent is a square in Polar Stereographic coordinates, which does not translate to an exact circle in Geographic coordinates.

Arc/Info commands for the creation of the GTOPO30 grid (AML):

The GTOPO30 elevation grid is shown in Figure 3.14.

Arc: imagegrid E140N90 e140

Arc: grid

Grid: ee140 = con(e140 = 32768, e140 - 65536, e140)

Grid: kill e140 all

Grid: e140 = setnull(ee140 == -9999, ee140)

Merge the three files:

Grid: gtopo30_geo = merge(e140, w180, w140)

Grid: quit

Arc: project gtopo30_geo gtopo30_lam geo2lam.txt # 1000 232293.734
916932.875

Grid: setcell 1000

Grid: setwindow flamb165

Grid: gtopo30_1 = selectpolygon(gtopo30_lam, flamb165, inside)

Grid: *gtopo_floor* = *floor(gtopo2 + 0.5)*

Grid: *GTOPO30* = *int(gtopo_floor)*

Arc/Info commands for the creation of the **basemap** grid (AML):

Creating a grid from the **IBCAO** grid and the part of the **ETOPO5** grid that the **IBCAO** grid does not cover. The point coverages are already in a Lamberts projection.

Arc: *topogrid ibcao+etopo 2500 (2.5 km)*

Topogrid: *datatype spot*

Topogrid: *point ibcao_point z*

Topogrid: *point etopo_selpoint z*

Topogrid: *enforce off*

Topogrid: *end*

Arc: *grid*

Grid: *ibcao_etopo = selectpolygon (ibcao+etopo, frame, inside)*

Grid: *ibet_floor = floor(ibcfive + 0.5)*

Grid: *ibet_int = int(ibet_floor)*

Merge the bathymetry grid with the GTOPO30 elevation grid.

Arc: *grid*

Grid: *setcell ibet_int*

Grid: *setwindow ibet_int*

Grid: *basemap = merge(gtopo30, ibet_int)*

The final **basemap** is shown in Figure 5.1.

Commands for converting the output of the ocean model data to grids:

Add the following header to the text files and save as, for instance, salt_1.txt:

```
ncols 368
nrows 304
xllcorner 0
yllcorner 0
cellsize 18532
nodata_value 1e+030
```

Convert to an ArcInfo grid by typing the following:

Arc: Ascii2grid salt_1.txt flipsalt_1 float

The resulting grid is a mirror image of what it should be; therefore flip it:

Arc: grid

Grid: salt_1 = flip(flipsalt_1)

Now the grid can be viewed in ArcInfo/ArcView as shown in Figure 3.17.

Procedure for creating **findflux_lamb** for the ocean model:

For every u component grid (u_1) and the v component (v_1) extract the point coverages.

Arc: *Gridpoint u_1 u1_pt U*

Arc: *Gridpoint v_1 v1_pt V*

From one of the velocity component coverages extract the coordinates of the model points.

Arc: *Ungenerate point u1_pt modelpt.txt*

The modelpt.txt file comes out as a “tab” delimited file but by importing it into Excel, adding header, “*Point_id, X, Y*”, saving it as a comma delimited file “.csv” and in notepad resaving it as a “.txt” file it is formatted for ArcView.

Now in ArcView add the text file modelpt.txt as a table and add it to the view with “*View->Add Event Theme*” Convert to a shapefile with “*Theme->Convert to shapefile*” and save as modelpt.shp

Now add the u_pt and v_pt files to the view and open the attribute tables of all the themes. Start editing the modelpt table by “*Table->Start Editing*” Add fields for the u and v components by “*Edit->Add Field*” and name them u1_93 and v1_93 (according to the date of the files) Then join the attribute table of modelpt with the velocity component tables through their ID fields by “*Table->Join*” and with the u1_93 field active select the “*Field->Calculate*” and set the field equal to the U field of the u1_pt field, and the same for the v components. Then save the table and remove all joins.

Add the scripts plotflux.ave, arrow.ave and findmod.ave to the project and compile them. Execute the script plotflux.ave on either the whole set of point or a selected set of points. And the arrows appear as shown in Figure 4.9.

Procedure for interpolation with Topogrid, creating the **biomass** grids:

Add a field to the **samples** layer, with the logarithm to base 10 of the biomass data. Then create a 100 km buffer around the biomass sample data. In Arc View set distance and map units to meters. Then select the **samples** shapefile and chose Theme -> Create buffers. Set the specified distance at which the buffers should be to 10,000 meters, click next and save the buffer in a new theme, **buffer100km**. Create polygons, **land**, from the coastline layer, **ponet**, in ArcInfo (**Arc: build ponet**). Intersect the outline polygon of the study area, **frame**, with the land layer using the Geoprocessing wizard in Arc View. Select the ocean parts of the resulting file and convert to shapefile, **ocean**.

In Arc Info create the two biomass grids:

Arc: *shapearc buffer100km buffer100km*

Arc: *build buffer100km*

Arc: *shapearc ocean ocean*

Arc: *build ocean*

Arc: *topogrid biomass 2500*

Topogrid: *bio1 2500 (2.5km cell size)*

Topogrid: *datatype spot*

Topogrid: *point biomass_l biomass__g*

Topogrid: *enforce off*

Topogrid: *boundary ocean*

Topogrid: *xyzlimits # # # # 0 #*

Topogrid: *end*

Arc: *topogrid biolog 2500*

Topogrid: *datatype spot*

Topogrid: *point biomass_l log_biomass*

Topogrid: *enforce off*

Topogrid: *boundary ocean*

Topogrid: *end*

Arc: *grid*

Grid: *setcell bio1*

Grid: *bio2 = selectpolygon(bio1,ocean,inside)*

Grid: *biomass = selectpolygon(bio2,buffer100km,inside)*

Grid: *biolog2 = selectpolygon(biolog, ocean,inside)*

Grid: *biolog3 = selectpolygon(biolog2,buffer100km,inside)*

Grid: *biolog10 = exp10(biolog3)*

- Now the grids biomass and biolog10 are both interpolated benthic biomass as shown in Figure 5.3.

Mergethemes.ave

This Avenue script merges two or more shapefiles in ArcView

```
'MergeThemes

theView=av.GetActiveDoc
theThemes=theView.GetThemes

if (theThemes.Count<2) then
    MsgBox.Error("Must have at least two themes in a view to merge.", "")
    exit
end

themesToMerge=List.Make
while (true)
    t=MsgBox.Choice(theThemes, "Choose themes in view to merge:" + NL + "(Click Cancel to
end):", "Merge Themes")
    if (t<>Nil) then
        themesToMerge.Add(t)
    else
        break
    end
end

if ((themestoMerge=Nil) or (themesToMerge.Count<2)) then
    MsgBox.Error("Not enough themes to merge.", "")
    exit
end

checkType=themesToMerge.Get(0).GetFTab.FindField("Shape").GetType
for each i in 1..(themesToMerge.Count-1)
    t=themesToMerge.Get(i)
    if (checkType<>t.GetFTab.FindField("Shape").GetType) then
        MsgBox.Error("Theme feature type mismatch -- unable to merge.", "")
        exit
    end
end

outFName=av.GetProject.MakeFileName("theme", "shp")
outFname=FileDialog.Put(outFname, "*.shp", "Output Merged Shapefile")
if (outFName=Nil) then
    exit
end

fieldList=List.Make
for each f in themesToMerge.Get(0).GetFTab.GetFields
    if (f.GetName="Shape") then
        continue
    else
```

```

        fCopy=f.Clone
        fieldList.Add(fCopy)
    end
end

shapeType=themesToMerge.Get(0).GetFTab.FindField("Shape").GetType
if (shapeType=#FIELD_SHAPELINE) then
    outClass=POLYLINE
elseif (shapeType=#FIELD_SHAPEMULTIPOINT) then
    outClass=MULTIPOINT
elseif (shapeType=#FIELD_SHAPEPOINT) then
    outClass=POINT
elseif (shapeType=#FIELD_SHAPEPOLY) then
    outClass=POLYGON
else
    MsgBox.Error("Invalid shape field type.,"Merge Themes")
    exit
end
mergeFTab=FTab.MakeNew(outFName,outClass)

if (fieldList.Count>0) then
    mergeFTab.AddFields(fieldList)
end

for each t in themesToMerge
    av.ShowMsg("Merging"++t.GetName)
    inFTab=t.GetFTab
    if (inFTab.GetSelection.Count=0) then

        theRecordsToMerge=inFTab
        numRecs=inFTab.GetNumRecords
    else
        theRecordsToMerge=inFTab.GetSelection
        numRecs=theRecordsToMerge.Count
    end
    for each rec in theRecordsToMerge
        av.SetStatus((rec/numRecs)*100)
        newRec=mergeFTab.Addrecord
        inField=inFTab.FindField("Shape")
        outField=mergeFTab.FindField("Shape")
        mergeFTab.SetValue(outField,newrec,inFTab.ReturnValue(inField,rec))
        if (fieldList.Count>0) then
            for each f in fieldList
                fName=f.GetName
                inField=inFTab.FindField(fName)
                if (inField<>Nil) then
                    outField=mergeFTab.FindField(fName)
                    aValue=inFTab.ReturnValue(inField,rec)
                    mergeFTab.SetValue(outField,newRec,aValue)
                end
            end
        end
    end
end
end

```



```

        end
    end
end

av.ClearMsg
av.ClearStatus

if (MsgBox.YesNo("Add shapefile as theme to view?", "MergeThemes", true).Not) then
    exit
end

viewList={ }
for each d in av.GetProject.GetDocs
    if (d.Is(View)) then
        viewList.Add(d)
    end
end

viewList.Add("")
addToView=MsgBox.ListAsString(viewList, "Add Theme to:", "Merge Themes")

if (addToView<>Nil) then
    if (addToView="") then
        addToView=View.Make
        addToView.GetWin.Open
    end

    mergeTheme=FTheme.Make(mergeFTab)
    addToView.AddTheme(mergeTheme)

    addToView.GetWin.Activate
end

```

Get_Extent.ave

This Avenue script extracts the extent of selected themes in ArcView and creates a rectangle with the same extent. The program was used to build the NOAAmesh shown in Figure 4.2.

```
'Get extent of selected layers

theView = av.GetActiveDoc

for each t in theView.GetActiveThemes
'theTheme2=theView.getactivethemes.get(0)
theval=t.getname
msgbox.warning(theval,"Warning")
' Change the extent of the DRG, i.e. cut the edges off.
    r = Rect.MakeEmpty

r = r.UnionWith(t.ReturnExtent)
'r = theView.ReturnUserRect
theTheme = theView.GetEditableTheme

if (r.IsNull) then msgbox.warning("r does not work","Warning")

' return nil
else
if (theTheme <> nil) then
    p = r.AsPolygon
    thePrj = theView.GetProjection
    if (thePrj.IsNull.Not) then
        p = p.ReturnUnprojected(thePrj)
    end
    theTheme.getFTab.BeginTransaction
    theField = theTheme.GetFTab.FindField("Shape")
    rec = theTheme.GetFTab.AddRecord
    theTheme.GetFTab.SetValue(theField, rec, p)
    theTheme.GetFTab.EndTransaction
    theTheme.GetFTab.GetSelection.ClearAll
    theTheme.GetFTab.GetSelection.Set(rec)
    theTheme.GetFTab.UpdateSelection
else
    gr = GraphicShape.Make(r)
    theView.GetGraphics.UnselectAll
    gr.SetSelected(TRUE)
    theView.GetGraphics.Add(gr)
end
av.GetProject.SetModified(true)
end
end
```

AddNOAA.ave

This Avenue script is used with the Hotlink button in ArcView to select a NOAA nautical chart and add it to the view as discussed in Chapter 4.2.3.

```
' Name: addnoaa
' Title: Adds a topographic map to a view (Noaa) and zooms in...
,
' Topics: Views
,
' Autor: Jona Finndis Jonsdottir jonafinndis@mail.utexas.edu, 12/18/1999
,
' Instruction: - replace the noaamesh.shp name with the name of your mesh
'             - change f:/noaa/ to the path of where the NOAA Nautical Charts are

theVal = SELF

theView = av.GetActiveDoc
if (not (theVal.IsNull)) then
  theVal2 = "f:/noaa/" + TheVal + ".kap".AsString

lookupname = "Attributes of noaamesh.shp"

lookuptab=av.getproject.finddoc(lookupname)
if (lookuptab=nil) then
  msgbox.info("Can't find Attribute noaamesh.shp","")
  exit
end

lookupvtab=lookuptab.getvtab

theField = lookupvtab.FindField("chart")

found = false
p = theView.GetDisplay.ReturnUserPoint
for each t in theView.GetActiveThemes
  if ((t.HasAttributes) and (t.GetHotField <> nil)) then
    recs = t.FindByPoint(p)
    for each rec in recs
      found = true
      theVal3 = t.ReturnValueString(theField.GetName, rec)
    end
  end
end
if (not found) then
  System.Beep
end
```

```

if (not (File.Exists(theVal2.AsFileName))) then
MsgBox.Info("Insert " +theVal3+ " CD", "" )
end

if (File.Exists(theVal2.AsFileName)) then
' Create the SourceName...
theSrc = SrcName.Make(theVal2)

' Use the SourceName to make a theme...
aTheme = Theme.Make(theSrc)

' Add the theme to the view...
theView.AddTheme(aTheme)

' Set a new name for the theme...
aTheme.SetName(theVal)

' Draw the theme...
aTheme.SetVisible(true)

' Make txmesh unactive
for each t in theView.GetActiveThemes.clone
t.SetActive( false )
end

aTheme.SetActive(true)

' Zoom
av.GetProject.SetModified(true)
theThemes = theView.GetActiveThemes
r = Rect.MakeEmpty
for each t in theThemes
r = r.UnionWith(t.ReturnExtent)
end

if (r.IsEmpty) then
return nil
elseif ( r.ReturnSize = (0@0) ) then
theView.GetDisplay.PanTo(r.ReturnOrigin)
else
theView.GetDisplay.SetExtent(r.Scale(1.1))
end
else
MsgBox.Warning("File "+theVal2+" not found.", "Hot Link" )
end
end

```

Findflux.ave

This Avenue script is used to create the current flux arrows shown in ArcView from the Ice-Ocean Arctic Model data, as shown in Figure 4.9.

```
'-----  
'--- Creation information ---  
'-----  
'Name: findflux.ave  
'Date: 9/95  
'Author: Ye Zichuan  
'   Center for Research in Water Resources  
'   The University of Texas at Austin  
'   ye@crwr.utexas.edu  
'Revisions:  
'1. 9/16/96 by Ferdi Hellweger  
'   - cosmetic changes  
'   - added comments in code  
'2. 6/12/2000 by Jona Finndis Jonsdottir  
'   - Changes to fit Arctic Ocean Data  
'-----  
'--- Purpose/Description ---  
'-----  
'This program plots flux vectors for data computed from Arctic Ocean data  
'-----  
'--- Input ---  
'-----  
'1. Theme of the region boundary.  
'   - point shape file.  
'   - 'point_id' field storing the point's id.  
'   - 'X' and 'Y' fields storing the point's coordinates, x and y.  
'   - 'U' and 'V' fields storing velocity components  
'-----  
'--- Output ---  
'-----  
'1. Flux vectors as graphics in view frame.  
'-----  
'--- Get general parameters ---  
'-----  
'--- Get project ---  
theproject=av.getproject  
'--- Get view ---  
theview = av.getactivedoc  
'--- Get graphics ---  
vgraphics=theview.getgraphics  
orgn=vgraphics.count  
'--- Get theme ---  
thethemes=theview.getthemes
```

```

if (thethemes.count = 0) then
  msgbox.error("No themes found", "Arctic Ocean")
  exit
end
if (thethemes.count = 1) then
  thetheme = thethemes.get(0)
  msgbox.info("Using " + thetheme.asstring + " as theme for flux vector plotting", "Arctic Ocean")
end
if (thethemes.count > 1) then
  thetheme=msgbox.choiceasstring(thethemes,"Select the theme for flux vector plotting","Arctic Ocean")
end
if(thetheme = nil)then
  exit
end

monthlist = { "1_93", "2_93", "3_93", "4_93", "5_93", "6_93", "7_93", "8_93", "9_93",
"10_93", "11_93", "12_93" }
themoth=msgbox.choiceasstring(monthlist,"Select the month for flux vector plotting","Arctic Ocean")

projectionlist = { "Lambert Azimuthal Projection", "Equidistant Azimuthal Projection" }
projection=msgbox.choiceasstring(projectionlist,"Select the projection for flux vector plotting","Arctic Ocean")

if (projection = "Lambert Azimuthal Projection") then
  proj = "lamb"
else
  proj = "azi"
end

'--- Get display extent ---
ext = theview.getdisplay.returnextent
ox = ext.returnorigin.getx
oy = ext.returnorigin.gety
ex = ext.getwidth
ey = ext.getheight
pt = point.make((ox+(ex*0.66)),(oy+(ey*0.872)))
len = (theview.getdisplay.returnextent.getwidth)/80
'-----
'--- Set date format ---
'-----
date.setdefformat("M_yy")
'-----
'--- Set up input data ---
'-----
'--- point theme ---
lftab=thetheme.getftab
if (lftab = nil) then
  msgbox.error("Can't open point theme", "Arctic Ocean")

```

```

        exit
    end

    lshapef = lftab.findfield("shape")
    if (lshapef = nil) then
        msgbox.error("Can't find point shape field", "Arctic Ocean")
        exit
    end

    lcx = lftab.findfield("X_" + proj)
    if (lshapef = nil) then
        msgbox.error("Can't find center x field", "Arctic Ocean")
        exit
    end

    lcy = lftab.findfield("Y_" + proj)
    if (lshapef = nil) then
        msgbox.error("Can't find center y field", "Arctic Ocean")
        exit
    end

    llidf = lftab.findfield("point_id")
    if (llidf = nil) then
        msgbox.error("Can't find point_id field in point theme", "Arctic Ocean")
        exit
    end

    lrecs = lftab.getnumrecords
    lftabsel = lftab.GetNumSelRecords
    if (lftabsel = 0) then
        selectlist = { "No", "Yes" }
        select=msgbox.choiceasstring(selectlist, "Do you want flux plotted for every point in the
layer", "Arctic Ocean")
        if (select = "No") then
            exit
        else
            lftab.GetSelection.SetAll
            lftab.UpdateSelection
        end
    end
end
'-----
'--- Set scale factor for vectors ---
'-----
relarrow=msgbox.input("Choose a Relative Length for Arrows", "Arctic Ocean", "10")
maxflux = 0
utime = lftab.findfield("U" + themonth)
if (utime = nil) then
    msgbox.error("Can't find time field in attribute table", "Arctic Ocean")
    exit
end
for each lfrec in lftab.getselection

```

```

    if (lftab.returnvalue(utime, lfrec) > maxflux) then
        maxflux = lftab.returnvalue(utime, lfrec)
    end
end

scalefactor = theview.getdisplay.returnextent.getwidth / (100 * maxflux / relarrow.asnumber)
'@msgbox.error("Scalefactor= "+ scalefactor.asstring, "Arctic Ocean")
'-----
'--- Flux vector plotting loop ---
'-----
mydate = date.make(themonth, "M_yy")
firsttime = true
plot = true
while(true)
    if (firsttime.not) then
        plot = false
    end
    firsttime = false
    if (plot) then

        '--- Cut old graphics --
        mglist = theview.getgraphics
        gfcnt = mglist.count-1
        if (gfcnt > orgn) then
            for each g in orgn..gfcnt
                mglist.get(g).setselected(true)
            end
            mglist.clearselected
        end

        '--- Plot flux vectors ---
        error = false
        for each lrec in lftab.getselection
            av.setstatus(lrec / lrecs * 100)
            lidfstr = lftab.returnvalue(lidf, lrec).asstring
            if (lidfstr = nil) then
                msgbox.error("Can't read from point_id field in point theme", "Arctic Ocean")
                exit
            end
            mydateu = lftab.findfield("u" + mydate.asstring)
            mydatev = lftab.findfield("v" + mydate.asstring)
            quq = lftab.returnvalue(mydateu, lrec)
            if (quq = nil) then
                msgbox.error("Can't read flux from u flux table", "Arctic Ocean")
                exit
            end
            qvq = lftab.returnvalue(mydatev, lrec)
            if (qvq = nil) then
                msgbox.error("Can't read flux from v flux table", "Arctic Ocean")
                exit
            end
        end
    end
end

```



```

lshape = lftab.returnvalue(lshapef, lrec)
if (lshape = nil) then
    msgbox.error("Can't read point shape", "Arctic Ocean")
    exit
end
partlist = lshape.asmultipoint.aslist
pcnt = partlist.count - 1
fpt = partlist.get(0)
tpt = partlist.get(pcnt)
cx = lftab.returnvalue(lcx, lrec)
cy = lftab.returnvalue(lcy, lrec)
fpt = point.make(cx,cy)
tpt = point.make((cx + (quq * scalefactor)),(cy + (qvq * scalefactor)))
appoint = polyline.make({ {fpt,tpt} })
apshp = graphicshape.make(appoint)
apsym = apshp.getsymbol
apsym.setcolor(color.getred)
avpoint = av.run("arrow.ave", {fpt,tpt,(15.0).asradians,len})
vgraphics.add(apshp)
avsym=avpoint.getsymbol
avsym.setcolor(color.getred)
vgraphics.add(avpoint)
end
textstr = mydate.asstring
mytext = graphictext.make(textstr,pt)
vgraphics.add(mytext)
av.setstatus(100)

end
'
'--- No more plotting ---
'
if (plot.not) then
    av.setstatus(100)
    exit
end
end
'-----
'--- End ---
'-----

```

Arrow.ave

This Avenue Script is used along with the findflux.ave script to plot the flux arrows in ArcView. The findflux.ave script will not work if this script is not included in the ArcView project.

```
'-----
'--- Creation information ---
'-----
'Name: arrow.ave
'Date: 9/95
'Author: Ye Zichuan
'   Center for Research in Water Resources
'   The University of Texas at Austin
'   ye@crwr.utexas.edu
'Revisions:
'1. 9/16/96 by Ferdi Hellweger
'   - cosmetic changes
'-----
'--- Purpose/Description ---
'-----
'This program creates an arrow.
'-----
'--- Input ---
'-----
'1. From point.
'2. To point.
'3. Angle.
'4. Length.
'-----
'--- Output ---
'-----
'1. Arrow.
'   -polygon graphic
'-----
'--- Code ---
'-----
fp  = self.Get(0)  ' from point
tp  = self.Get(1)  ' to point
theta = self.Get(2) ' angle
length = self.Get(3) ' length
x1 = tp.GetX
y1 = tp.GetY
x2 = fp.GetX
y2 = fp.GetY
xshift = length * (theta.cos)
yshift = length * (theta.sin)
totLength = (((y1-y2)^2)+((x1-x2)^2)).Sqrt
' point along the line
p1 = ((1.0 - (xshift/totLength)) * x1) + ((xshift/totLength) *x2)
p2 = ((1.0 - (xshift/totLength)) * y1) + ((xshift/totLength) *y2)
pi = Number.GetPI
```

```

if (x2<>x1) then
  slope = (y2-y1)/(x2-x1)
  slant = (slope/(((slope^2)+1).Sqrt)).ASin
else
  slant = pi/2.0
end
a1 = p1 - (yshift * (slant.sin))
a2 = p2 + (yshift * (slant.cos))
b1 = p1 + (yshift * (slant.sin))
b2 = p2 - (yshift * (slant.cos))
lpnt = Point.Make(a1,a2)
rpnt = Point.Make(b1,b2)
aPolyLine = PolyLine.Make({lpnt,tp},{tp,rpnt},{rpnt,lpnt})
gr = GraphicShape.Make(aPolyLine)
return(gr)

'-----
'--- End ---
'-----

```

Appendix B: Data Dictionary

Unless otherwise noted, the data are in ArcView 3.2 shapefile format.

Data	Description	Class	Attribute	Units
*.kap	NOAA nautical charts	BSB images		
addnoaa	Avenue script that works with noaamesh in ArcView	Text file		
Arctic.apr	ArcView project with extensions and data produced in this research	ArcView project		
Arctic.mdb	Benthic data relational database	Microsoft Access database		
arrow.ave	Avenue script that works with findflux in ArcView	Text file		
azi2lamb	Arc/Info projection file	Text file		
basemap	Bathymetry / Elevation	Grid	Value	Meters
basemap.avl	ArcView legend for basemap	Legend		
Beaufort	Benthic data sample points in the Beaufort Sea	Point	Same as samples.shp	
Beaufort_prob30	Probability of benthic biomass exceeding 30g/m ² in the Beaufort Sea	ArcMap layer	Probability Map	
Beaufort_standerr	Standard error contours of the bio_beaufort interpolation	ArcMap layer	Prediction Standard error	g/m ²
bio_beaufort	Interpolated biomass from beaufort.shp with ordinary kriging	ArcMap layer	Prediction	g/m ²
bio_standerr	Standard error contours of the biomass interpolation	ArcMap layer	Prediction Standard error	g/m ²
bio_prob50	Probability of benthic biomass exceeding 50g/m ²	ArcMap layer	Probability Map	

Data	Description	Class	Attribute	Units
biomass	Interpolated biomass from samples.shp with ordinary kriging	ArcMap layer	Prediction	g/m ²
buffer100km	100km buffer around samples.shp	Polygon	bufferdis	Meters
chartreprojector	Program that projects the NOAA nautical charts	EXE		
chartview	Chartviewer ArcView extension for viewing NOAA nautical charts	AVX, DLL		
chukchi_prob250	Probability of benthic biomass exceeding 50g/m2	ArcMap layer	Probability Map	
findflux	Avenue script that translates velocity vectors to flux arrows, works with flux_lamb	Text file		
fivedeg	Five degree boxes with coordinates of their lower left corner	Polygon	lowerleft	Degrees
flux_azi	Ice-Ocean model, average monthly ocean surface velocity vectors (1993) in original projection	Point	X_azi, Y_azi, U*_1993, V*_1993	Meters, cm/sec
flux_lamb	Ice-Ocean model, average monthly ocean surface velocity vectors (1993)	Point	X_lamb, Y_lamb, U*_1993, V*_1993	Meters, cm/sec
frame	Outlines of the study area	Polygon		
geo2lamb	Arc/Info projection file	Text file		
Geostatistics	ArcMap project, works with a Geostatistical Analyst extension	ArcMap project		
h1_*	Ice-Ocean model, average monthly ocean height (1993)	grid	Value	cm

Data	Description	Class	Attribute	Units
land	Land coverage of study area	Polygon		
mergethemes	Avenue script that merges themes	Text file		
noaamesh	Outlines of NOAA nautical charts	Polygon	Chart	
oc-buffer	Ocean coverage of the study area except for 100km buffer around samples.shp	Polygon		
ocean	Ocean Coverage of the study area	Polygon		
pol2lamb	Arc/Info projection file	Text file		
ponet	Coastlines and political boundaries	Polyline		
rivers	Major rivers	Polyline	Name System	
salt.avl	ArcView legend for salt_*	Legend		
salt_*	Ice-Ocean model, average monthly ocean surface salinity (1993)	grid	Value	
samples	Benthic data extracted from Arctic.mdb	Point	Station, Source, Latitude, Longitude, Date, Depth(m), Temp(C), Sal(ppt), Biomass(g/m ²)	
t.c6.93-*.cdf	Ice-Ocean model, original output	NetCDF		
temp.avl	ArcView legend for temp_*	Legend		
temp_*	Ice-Ocean model, average monthly ocean surface temperature (1993)	grid	Value	°C

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