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Hypsometry and Volume of the Arctic Ocean and Its Constituent's Seas

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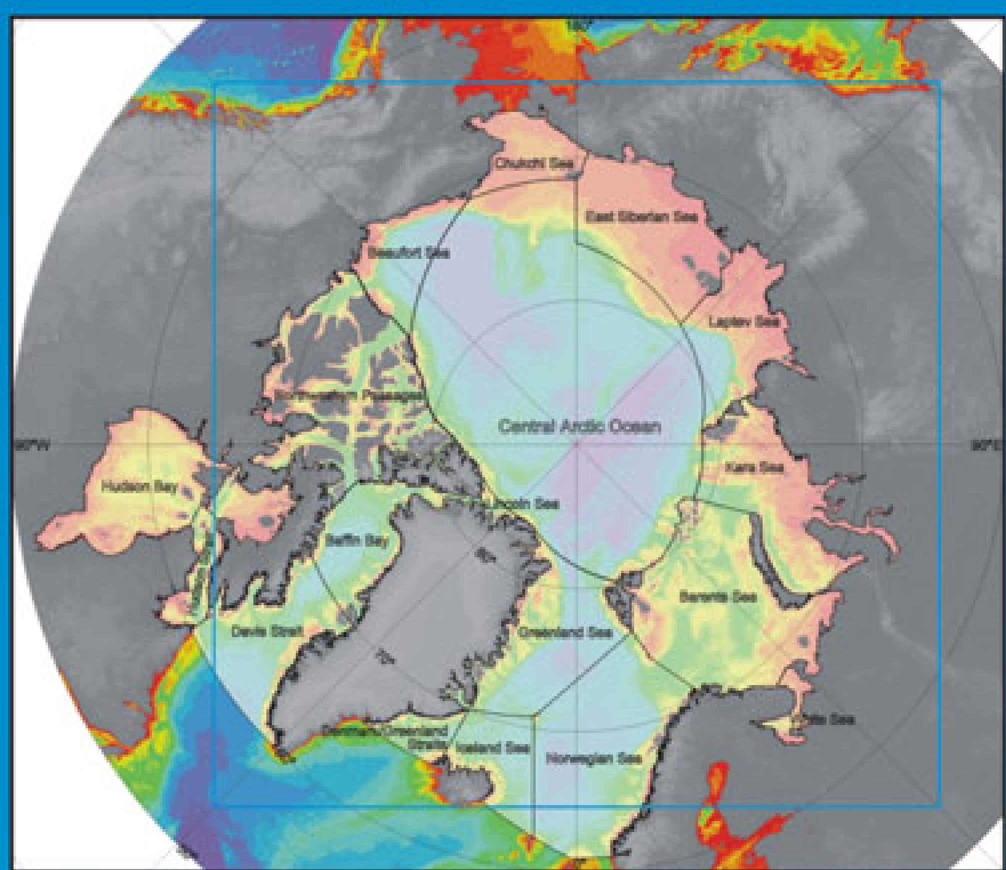

Figure 1. Limits for the Arctic Ocean and its constituent seas as defined by the International Hydrographic Organization (IHO).

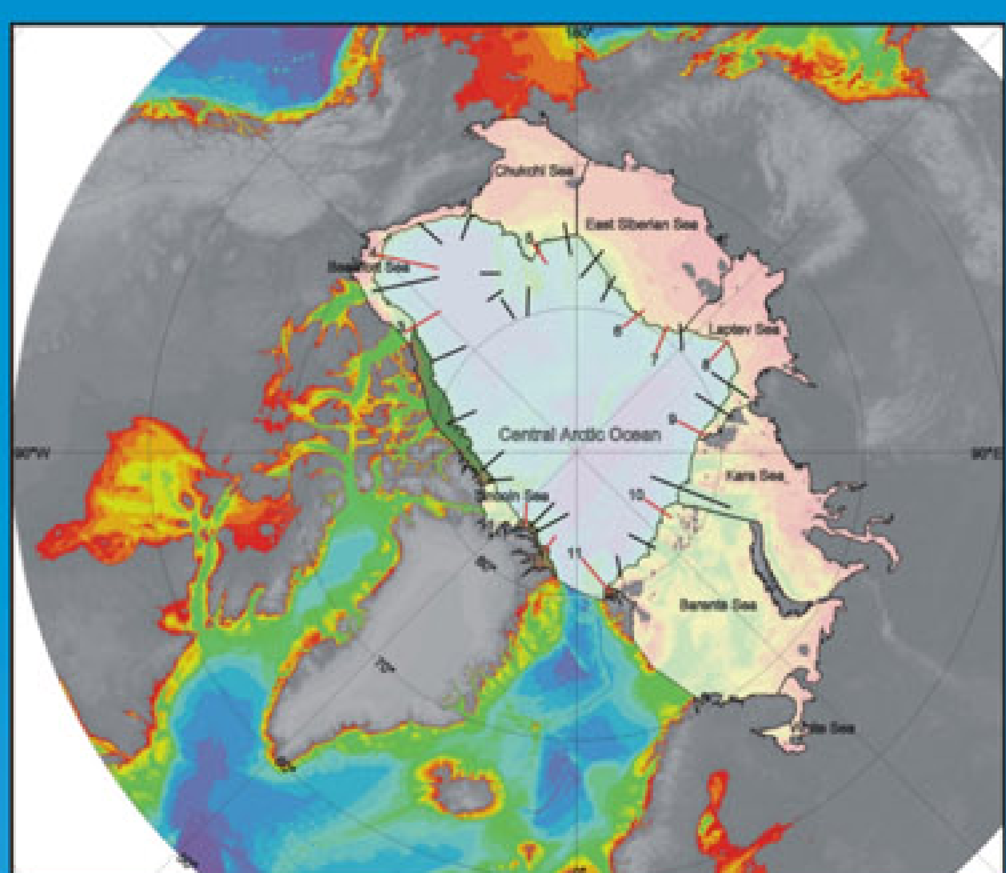

Figure 2. Redefined Limits for the Arctic Ocean and its constituent seas. The modifications from the IHO limits consists mainly of adjusting the shelf seas outer limits towards the deep Arctic Ocean so that they reach the shelf break. The shelf break have been defined using bathymetric profiles marked in this figure and the slope model in figure 3.

Bathymetric colors used in figures 1 and 2 [m]

Abstract
Researchers have for long been interested in the Earth's hypsometry -- the distribution of surface area at various elevations of land and depths of ocean. Menard and Smith [1966] published the first computer analysis of the hypsometry of the world ocean basin provinces, which provided a new perspective on large-scale seafloor morphology. They based their study on the most up-to-date (at the time) American and Russian bathymetric charts. However, the least known of the regions they studied was the Arctic Ocean, which, due to its thick perennial sea ice cover, had limited geophysical data available.

During the last decades icebreakers have been able to penetrate the pack ice to carry out geophysical measurements and, in addition, nuclear submarines have operated under the pack ice collecting geophysical data over large areas. Studies of these data have answered many questions about the history and evolution of the Arctic Ocean Basin and changed the understanding of the seafloor morphology. During the spring of 2000, a Beta version of the International Bathymetric Chart of the Arctic Ocean (IBCAO) was released which incorporated all the available bathymetric data at the time of compilation [Jakobsson et al., 2000]. Since the IBCAO is a digital grid model (2.5 x 2.5 km grid cell spacing) it is well suited for numerical analyses.

In this work the latest updated version of IBCAO, version 1.0 [Jakobsson et al., 2001], and the Global Seafloor Topography from satellite altimetry and ship soundings [Smith and Sandwell, 1997] have been used to estimate the hypsometry and volume of the entire Arctic Ocean and its constituent seas. An initial calculation of seafloor area and ocean volume was carried out by using the limits for the Arctic Ocean and its constituent seas as defined by the International Hydrographic Organization (IHO) (Figure 1). However, the main part of this work will be focused on the "high Arctic Ocean" constrained by the Fram Strait, western limit of Barents Sea, Berings Strait and the Canadian Arctic Archipelago (Figure 2). Since the IHO subdivision of the Arctic Ocean is merely political it is of limited use for oceanographic/geologic/geophysical discussions. Therefore, the IHO definitions within our area of interest (the high Arctic Ocean) have been modified to better reflect the seafloor provinces. These modifications consist of adjusting the shelf seas outer limits towards the deep Arctic Ocean so that they reach the shelf break instead of adhering to the IHO defined boundaries (Figure 2). The shelf break is here defined as the as the seaward extension of the continental margin along which were there is a marked increase of slope. Bathymetric profiles and a slope model based on the IBCAO model were used to delineate the shelf break (Figure 2 and 3). Finally physiographic provinces of the seafloor are classified using image processing and GIS techniques and their area relationship with the entire high Arctic Ocean will be analyzed.

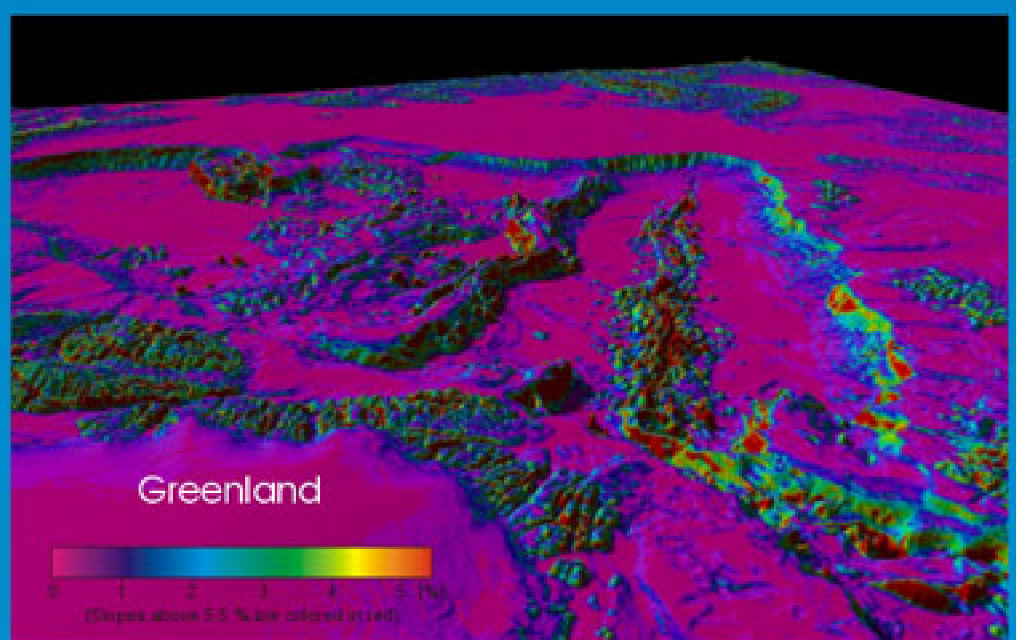

Figure 3. Slope model draped on the bathymetry.

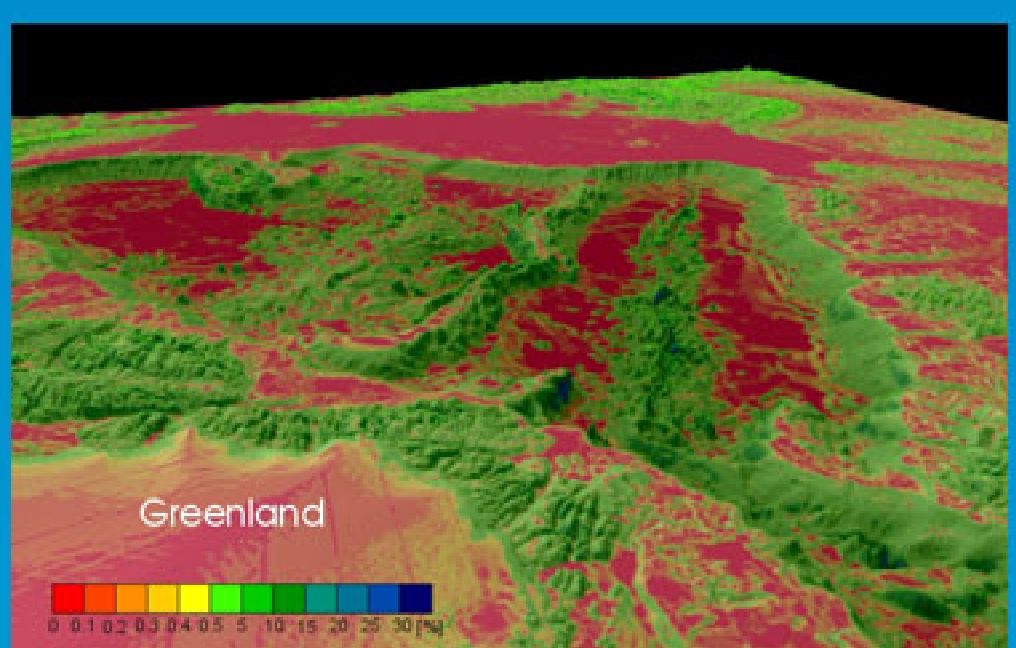

Figure 4. The slope model from figure 3 color coded by grouping slope values in order to perform an initial segmentation of the seafloor. This result will be used as a base for a subsequent classification of the Arctic Ocean into physiographic regions.

Defining Physiographic Regions

Menard and Smith's [1966] study analyzed the ocean floor classified into physiographic regions -- that are groups of features with distinctive topography, characteristic morphology and relations to other provinces. For the Arctic Ocean no physiographic provinces had previously been defined and Menard and Smith used information from the Russian Tectonic Chart of the Arctic Ocean for their classification. Classification of seafloor morphology is a large and complex topic in itself and it is not the focus for this present study. Therefore, a very simple approach has been taken to perform an initial segmentation of the seafloor by using a slope model (Figure 3 and 4). The results from the segmentation are used for a subsequent classification of the Arctic Ocean seafloor into physiographic regions. However, this is work in progress and the final classification is not presented here.

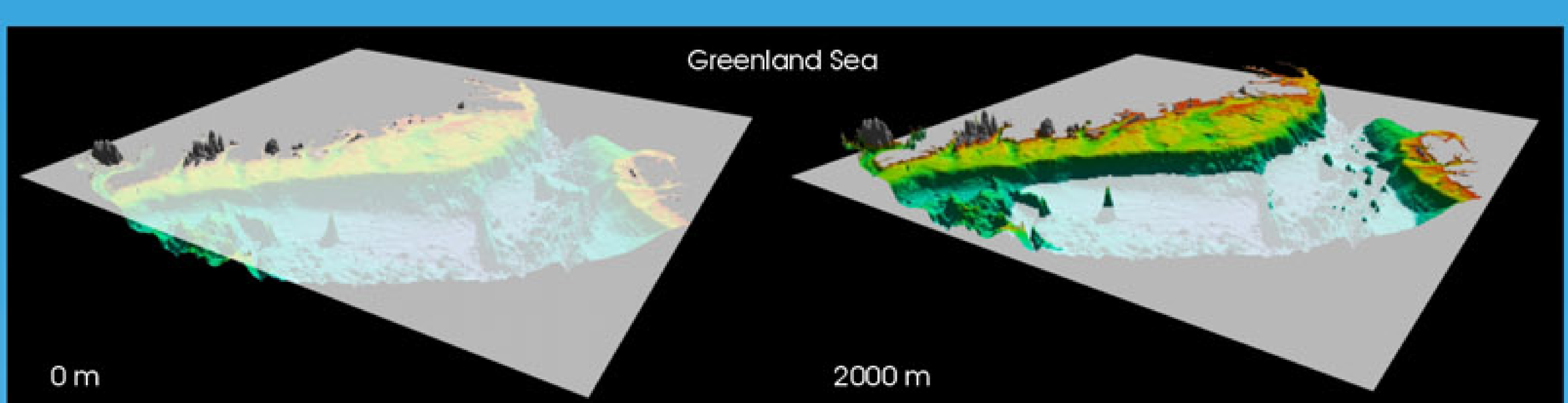

Figure 5. 3D visualization illustrating how the area and volume calculations were carried out. Models of each of the Arctic Ocean constituent seas were extracted from the merged IBCAO/Global Seafloor Topography model by using clipping polygons that defined the extensions of the individual seas. Subsequently, the area and volume was calculated on each side of a plane, which was lowered from the sea level in increments of 10 m, from 0 m to a depth of 500 m, and in increments of 50 m from 550 m down to the deepest depth within the enclosed polygon. The reported maximum areas for each ocean (0 m) in figure 6 does not include the areas above the plane and, thus, represents the actual ocean area with all islands excluded. All calculations were carried on Lamberts Equal Area projection. The example in this figures shows the Greenland Sea.

Volume and area calculations

The area and volume calculations have been carried out using batch tools available in Intergraph's software Terrain Analyst on a triangulation model (TIN model) of the merged IBCAO and Global Seafloor Topography. This TIN model was simply constructed by Delaunay triangulation of the grid model. The reason for using a TIN model rather than a grid model for these calculations is to be able to estimate the surface area of the topography in addition to the projected surface area. The volume and area of each of the Arctic Ocean seas was calculated within the constructed polygons defining the seas in increments of 10 m, from 0 m to a depth of 500 m depth and in increments of 50 m, from 550 m down to the deepest depth within the enclosed polygon. The 3D visualization in Figure 5, made using the software Fledermaus, illustrates how the area and volume calculations were carried out.

See the Results for figure captions

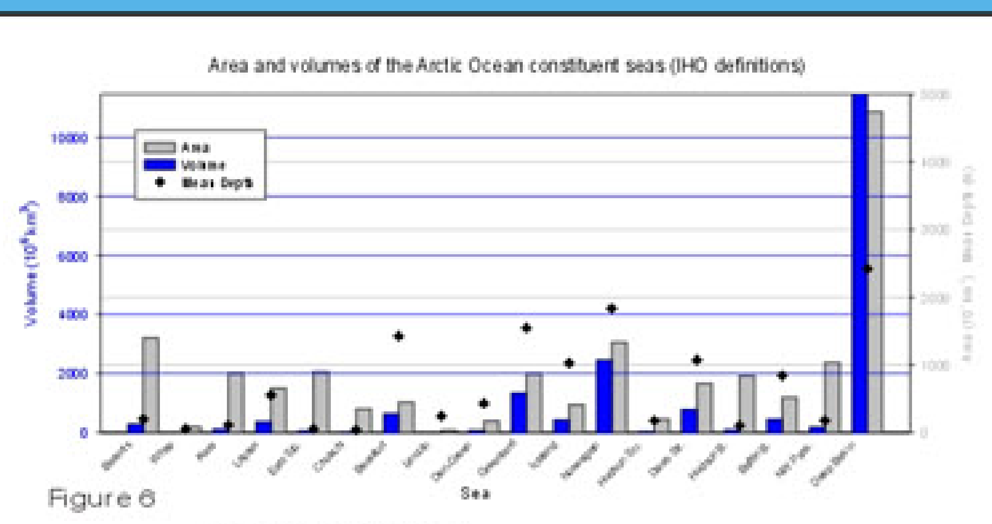

Figure 6

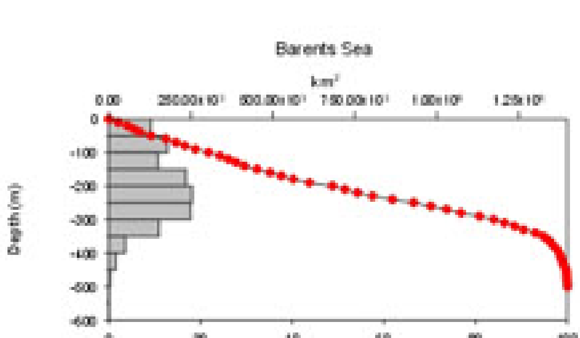

Figure 8

References
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Smith, W.H.F., and Sandwell, D.T., 1997, Global Seafloor Topography from Satellite Altimetry and Ship Depth Soundings, Science, v. 277, p. 1956-1962.

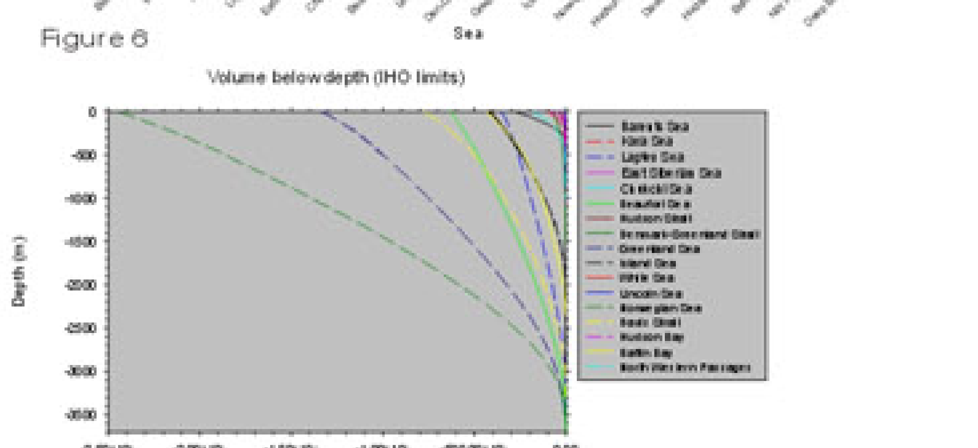

Figure 7

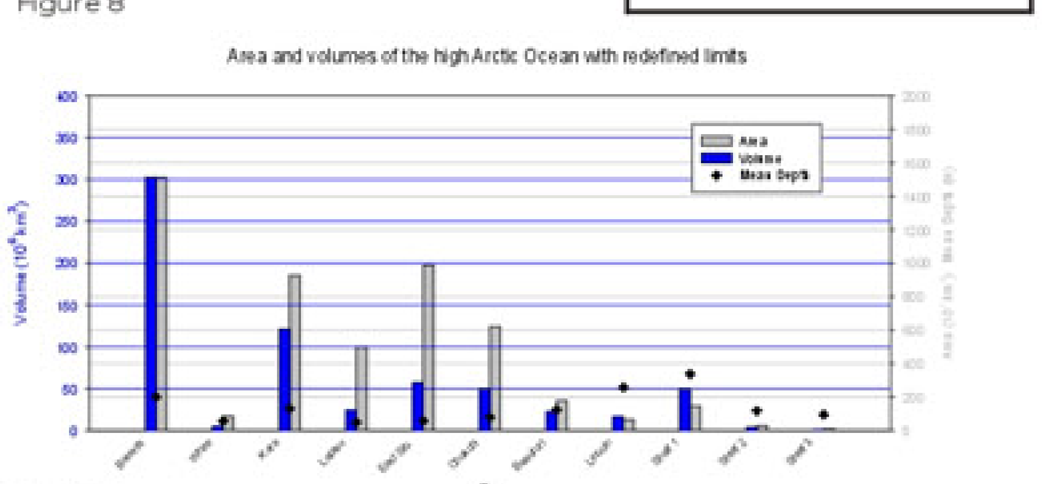

Figure 9. (Note the vertical scale difference to figure 6 and that the central Arctic Ocean deep basin not is included)

Results

The results from the area and volume calculations of the IHO defined Arctic Ocean constituent seas are summarized in Figure 6 and 7. Figure 8 shows the hypsometry of the Barents Sea as an example. An Excel spread sheet with the result from the calculations at each depth interval of all the constituent seas will be available. Aside from the central Arctic Ocean Basin the Barents Sea has the largest seafloor surface area and the Norwegian Sea the greatest volume. The entire Arctic Ocean as defined by IHO makes up ca 4 % of the entire world ocean area (Area of the entire World Oceans from Menard and Smith, 1966). With its mean depth of 1201 m it is the shallowest of all the major Oceans (Pacific Ocean, Atlantic Ocean, Indian Ocean with adjacent seas). The results from the redefined "high Arctic Ocean" and its constituent seas area summarized in Figure 9. In the high Arctic Ocean the portion of shelf compared to the entire area is as large as 53 %, which is significantly larger than for the rest of the Worlds' major oceans. This is work in progress and the results from analyses of the physiographic provinces are currently undergoing processing.