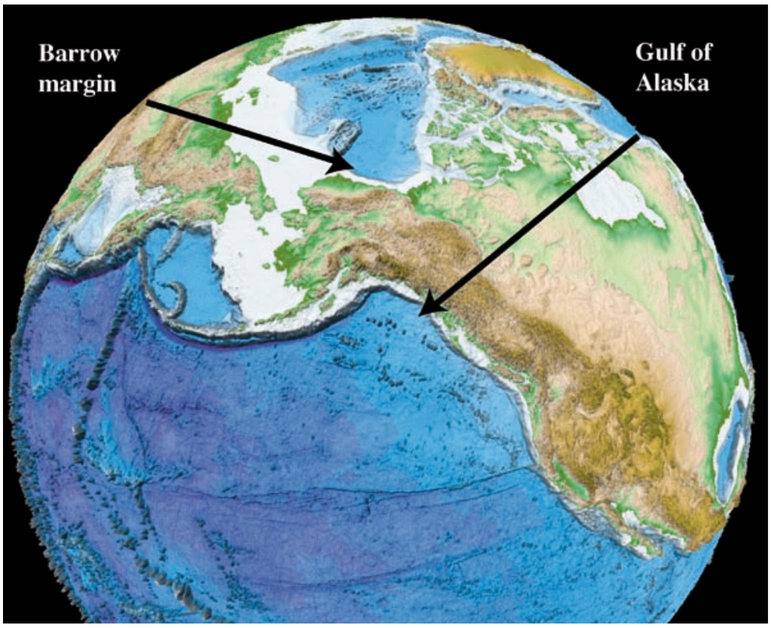


Figure 1: Location of Barrow margin and Gu lf of Alaska.

US UNCLOS Multibeam Data

The Processing of Multibeam Bathymetry and Backscatter

Processing bathymetry and backscatter from four different multibeam echosounder systems for US Law of the Sea concerns has required careful thought to ensure the highest quality and uniform treatment of the data. Special attention has been applied to the backscatter because it represents the acoustic response of the geology of the seafloor.

Luciano Fonseca, CCOM-JHC, University of New Hampshire (NH, USA) et. al.

THE CENTER FOR COASTAL & Ocean Mapping-Joint Hydrographic Center (CCOM-JHC), University of New Hampshire is in charge of acquiring multibeam bathymetry of US margins for any potential claims of extended continental shelves under Article 76 of the UN Convention on the Law of the Sea. The data have been collected using Simrad EM120 and EM121A, Reson 8150, and SeaBeam 2112 multibeam echosounders (MBES). More than a million square kilometres have been mapped in the Atlantic, Gulf of Mexico, Arctic, Bering Sea, Gulf of Alaska and in the western Pacific. Although bathymetry is the primary objective of each cruise, acoustic backscatter is readily available from each of the MBES systems, so these data are also processed. Processing this immense amount of data has required careful thought, resulting in standardised processing streams. The discussion below is a synopsis of those processing streams.

Bathymetry Processing

Quality control is maintained by running a calibration patch test prior to each cruise. Static offsets in sensor locations and timing are checked against those already in the MBES system. A cross-line is a first run perpendicular to the planned survey lines so that each survey line crosses it and a cross-line analysis is made at each crossing. Each cross-line analysis is a comparison of interpolated depths in the digital terrain models (DTMs) of the cross-line with corresponding measured soundings from the raw MBES file of the survey line. If the comparison of depths shows a difference greater than 1%, the survey is halted and a determination is made on why this precision has not been achieved. Invariably, the problem is minor errors in the static offsets and/or the sound-speed profile.

A suitable mixture of software is important for mapping missions. In particular, the availability of multiple tools for processing deep-water data provides the means to compare processing for flaws, to check on operator actions and to utilise the unique aspects of the various components of the processing to improve the quality control of the data. For example, for Simrad EM120 and EM121A data we employ *SwathEd* and *SAIC/SABER*, Reson 8150 and SeaBeam 2112 data are processed using *CARIS/HIPS* and all initial derivative products are processed using *IVS3D* software. A primary concern is to preserve effort at all stages, maintain single reference copies for the data and provide the required files for subsequent backscatter processing.

The lack of reliable uncertainty estimates for deep-water mapping systems has resulted in a fairly conventional processing approach based on inspection of point data, rather than the use of a more automated method. However, because the data densities are low, the processing cost can be readily absorbed into collection time and, particularly in the Arctic, the interpretation of features observed at the limits of the data can be a significant part of extracting the best from the available information, necessitating a manual approach.

All of the MBES lines are processed at sea in near real-time. At the end of each survey line, the raw datagram file is copied from a server to a processing computer. The cleaned soundings are used to populate submap DTMs at the highest resolution allowed by the sounding density. Initially, the submaps are assembled in Mercator (or Polar Stereographic for the Arctic) projection; however, ASCII XYZ (longitude, latitude, depth) values for each sounding from each line are extracted and gridded into non-projected georeferenced maps. Later, these maps can be projected as needed.

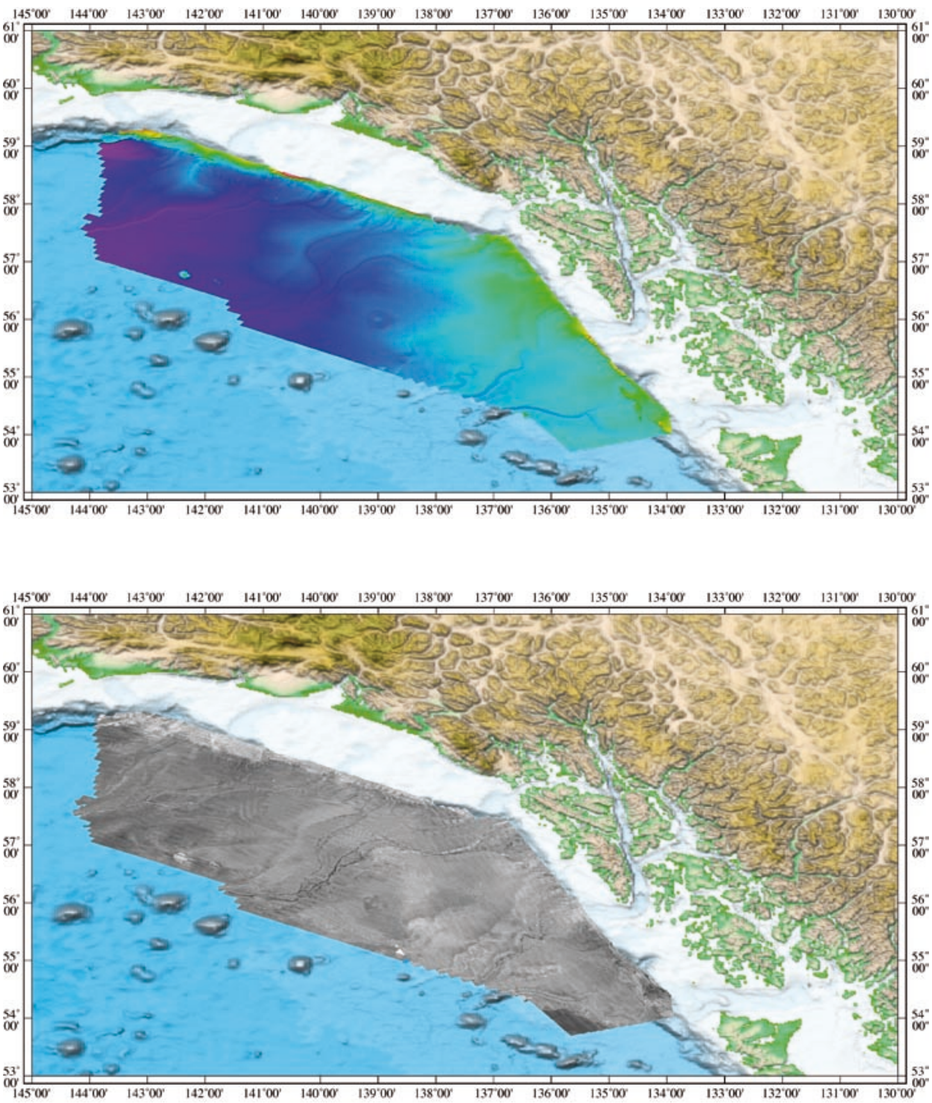


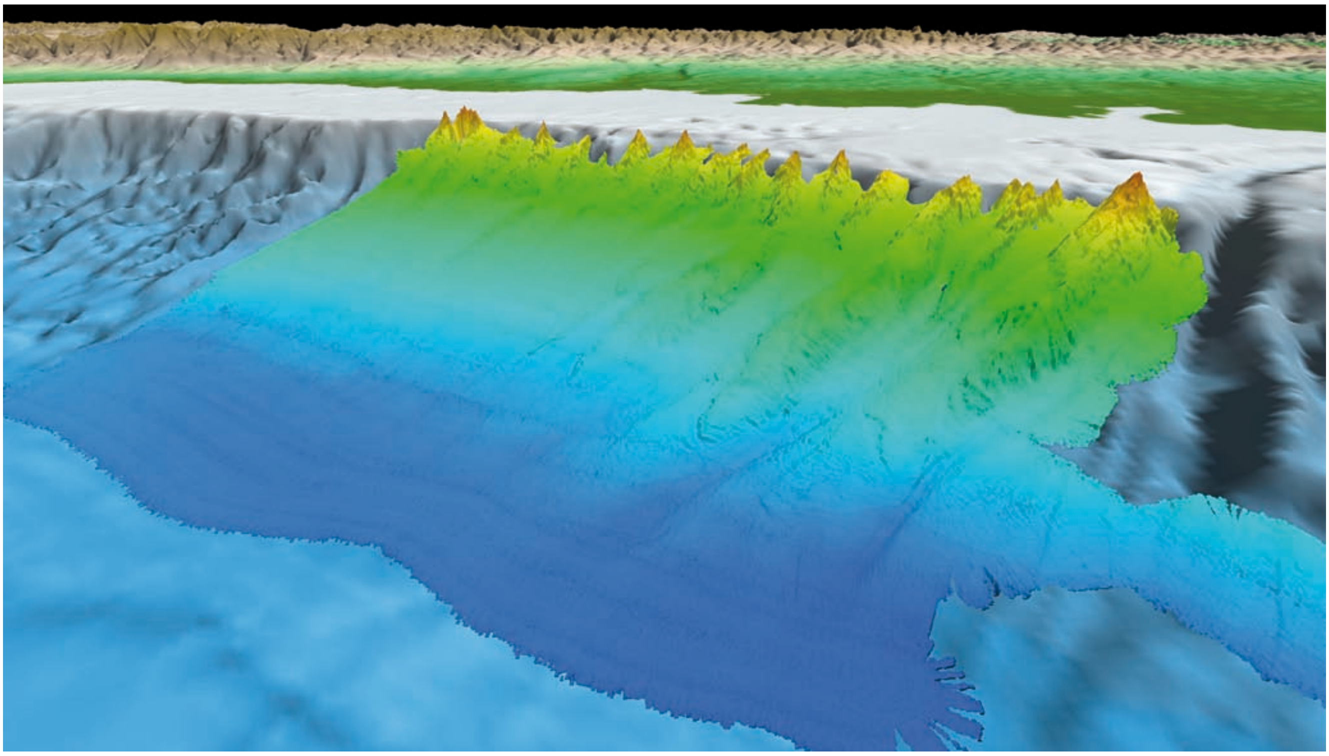
Figure 2: A regularly spaced (a) gridded DTM and (b) gridded backscatter mosaic of the Gulf of Alaska bathymetry data. The area mapped exceeds 162,000km2. Grid-cell resolution is 100m and water depths range from 237 to 4138m. Background topography and bathymetry from ETOPO2.

Acoustic Backscatter

Acoustic backscatter is acquired as an integral part of the MBES surveys. Backscatter contains important information about the seafloor morphology and geology. If the two-way travel time of the transmitted acoustic pulse is the primary observation from which bathymetry is derived, the intensities of the received time series are the starting point for the backscatter processing. Simrad EM120 and EM121A and Reson 8150 MBES record one complete time series of received intensities per acoustic beam, normally referred to as beam-time-series or snippets. The SeaBeam 2112 system only records one average value of intensity per beam, which is referred to as beam-average backscatter.

Backscatter processing uses *Geocoder* software, developed at CCOM-JHC, designed specifically for backscatter analysis. The main objective of the backscatter processing is to convert the raw intensity observations into estimates of seafloor backscatter strength per unit area in decibels. Initially, all the gains that were applied during acquisition are removed from the raw intensity observations. The observations are corrected based on the terms of the sonar equation, which include transmission loss, area of insonification, transducer source level and transmit and receive beam patterns. The acquisition geometry is taken into account by correcting the position of all beams based on the navigation, transducer attitude and sound-speed profiles and by correcting the backscatter values for changes in seafloor slope, calculated from the bathymetric model generated during the bathymetry processing.

Once the backscatter strength has been calculated, the next step in the processing involves the removal of the backscatter angular response (the variation in backscatter strength with the angle of incidence). The angular response is an intrinsic property of the seafloor, so different seafloor types have different angular responses. However, the mosaic should be uniform across the swath if the seafloor is uniform. This angular variation is compensated by the use of algorithms for angle-varying gain corrections. *Geocoder* implements several approaches for this processing and suggests a default algorithm, which reduces the normal-incidence artefact. Finally,



the artefacts due to the overlap among adjacent lines are minimised by the use of a feathering algorithm. This algorithm blends the overlapping lines by choosing the highest priority sample, giving lower priority to samples that are close to the normal incidence or are on very shallow grazing angles.

Geocoder automatically applies the proper adjustments to the backscatter observations, so only minimum user interaction is required. The processing starts with the raw acquisition files and the result is a comprehensive analysis of the acoustic returns.

Full-resolution DTMs and Mosaics

The processed bathymetry and backscatter data are assembled at the completion of each cruise into full-resolution DTMs and co-registered backscatter mosaics. The DTMs and mosaics can be projected and re-projected by standard GIS packages (*ESRI*, *Geomedia*, *PCI*, etc.) as well as specialised software (*IVS3D Fledermaus*, *Global Mapper*, etc.). The DTMs and mosaics allow easy visualisation and interpretation of each dataset.

A primary issue is to determine which grid-cell resolution provides the highest resolution, justified by the sounding density. Invariably, a completed survey spans a large range of water depths, often from less than a few hundred metres to 4000m or deeper. For instance, the Arctic surveys range in water depths of 38–3970m. Consequently, the highest grid-cell resolution for an overview DTM ranges from 6m (the 38m depths) to 100m (the 3970m depths), depending on what part of the area is being gridded into a DTM. For a regularly spaced grid DTM, an overview of the entire area must use the coarsest grid-cell resolution for the entire DTM, thus creating a lower resolution in the shallower areas. Although not used in the US UNCLOS surveys, one could use an irregular array of points (i.e. TINs) <!Should TINs be defined?>for gridding the data. The pros and cons of regularly spaced grids versus TINs is beyond the scope of this paper, but should be considered before a decision on the type of grid is made.

An example of a regularly spaced grid of the Gulf of Alaska bathymetry is shown in Figures 1 and 2a. The measured water depths in the dataset ranges from 237m to 4238m indicating that the data resolution allows grid resolutions of 12m (shallow) to 100m (deepest). Figure 3a is an example from the Barrow margin, Arctic Ocean. In practice, the mapping project subdivides each region to be mapped into smaller submaps of various pixel resolution based on the expected water depths. Each submap is gridded at its optimum grid-cell resolution determined from the sounding densities. These provide archives of submap DTMs with the highest resolution allowed for each submap.

Once the optimum grid-cell resolution is determined for the overview map (100m in the Gulf of Alaska example), the acoustic-backscatter mosaic is draped over the bathymetry as a geo-referenced texture map (Figs. 2b and 3b) using IVS3D software. The optimal resolution for the backscatter mosaic is normally higher than the grid-cell resolution for the bathymetry. The optimum backscatter resolution is calculated based on the bathymetric model, transmit and receive beam widths, transmit pulse length, and on the

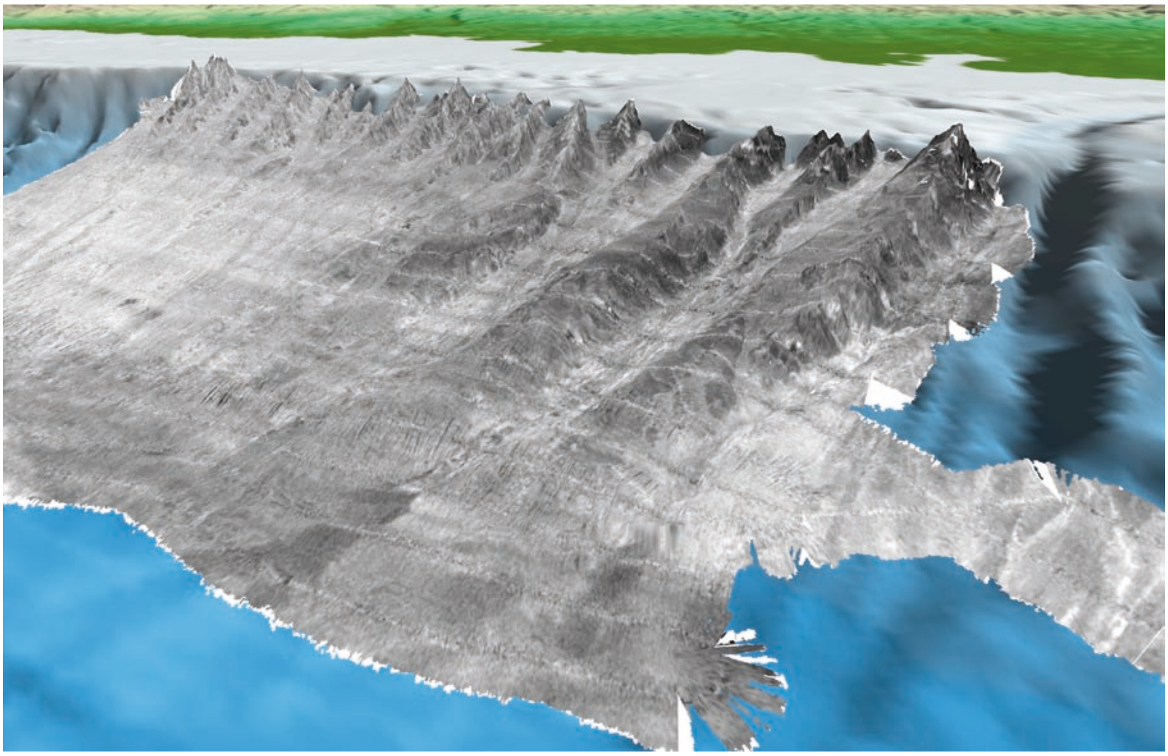


Figure 3: Perspective view of (a) gridded DTM and (b) regularly spaced gridded backscatter mosaic from the Barrow margin data. The area mapped exceeds 25,500km2. The grid-cell resolution is 100m and water depths range from 650 to 3800m. Background topography and bathymetry from ETOPO2.

choice of beam average or beam time series backscatter. The advantage of this approach is that each pixel on the computer screen has a longitude, latitude, depth and backscatter value and the data can be visualised in 3D at any desired vertical exaggeration and at any viewing resolution or view angle. An interpreter can therefore simultaneously investigate the bathymetry and backscatter to better understand the nature of the seafloor.

Metadata
Metadata is critically important for this project because it is likely that there will be years between the time of data collection and processing and the time the data will be analysed to develop an extended continental shelf submission. Consequently, each survey line of raw multibeam data has a complimentary metadata file that follows the Federal Geographic Data Committee (FGDC) metadata standard (1). The raw multibeam data and metadata are archived at the National Geophysical Data Center of NOAA as well as at the University of New Hampshire CCOM-JHC. The archives provide secure storage for the raw data, and are available to the public.

Summary
Vast amounts of new multibeam bathymetry and associated acoustic backscatter are being collected to support potential US extended continental shelf claims under Article 76 of the UN Convention on the Law of the Sea. The new data have been and are continuing to be collected from US continental and insular margins. The processed bathymetry and backscatter data, together with associated metadata, are posted on the web (2) within a few weeks of the completion of each cruise in a variety of data formats so that the marine science community, and any other interested party, has access to them in a timely fashion. The raw multibeam data and associated metadata are archived at the NOAA National Geophysical Data Center where they are also publicly available.

1 www.fgdc.gov/metadata
2 http://ccom.unh.edu/law_of_the_sea.html

The Authors

Dr Luciano Fonseca joined the University of New Hampshire's CCOM in 2003 after 12 years of experience in research and development in the oil industry. His research is focused on developing tools for extracting quantitative seafloor property information from multibeam backscatter and on modelling acoustic backscatter response.

Dr Jim Gardner spent 30 years with the Marine Geology Branch of the US Geological Survey, the last 10 years as Chief of Pacific Seafloor Mapping. He joined the University of New Hampshire's CCOM in 2003, where he is in charge of the collection and processing of new bathymetric data for the US Law of the Sea efforts.

Dr Brian R. Calder is a Research Associate Professor at CCOM-JHC. Here, his research interests revolve around data processing issues for hydrographic data and technology for improved survey systems.

Dr Larry A. Mayer is the Director of the Center for Coastal and Ocean Mapping and Co-Director of the NOAA/UNH Joint Hydrographic Center at the University of New Hampshire. At UNH, Mayer leads research on mapping and remote characterisation of the seafloor as well as advanced applications of 3D visualisation for ocean mapping problems.

Capt. Andrew A. Armstrong is the NOAA Co-Director of the Joint Hydrographic Center and is the NOAA program manager for the research and educational programs. He has over thirty years of hydrographic and ocean mapping experience with NOAA.

jim@ccom.unh.edu