Report of the

U.S. GLOBEC Georges Bank

2006 Phase 4B Scientific Investigators' Meeting

October 2 - 3, 2006

Woods Hole Oceanographic Institution's
Massachusetts

Edited and prepared by
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1. Introduction

A U.S. GLOBEC Georges Bank Phase 4B Scientific Investigators' meeting was held on October 2 - 3, 2006. This two-day meeting was held at the Woods Hole Oceanographic Institution's Quisset Campus, Clark Laboratory.

The purpose of the meeting was to bring together investigators early in this final synthesis phase of the GLOBEC NWA program in order to coordinate efforts and review program goals. The specific goals of the meeting were to: 1) have researchers present an overview of their Phase 4B project together with any early results, 2) establish communication links and needs among projects, and 3) discuss the phase 4B projects within the context of the overall goals of the GLOBEC NWA program.

The meeting began with Cabell Davis welcoming the group and presenting meeting logistics and goals, and program goals and interconnections.

Welcome, logistics and program overview.

Cabell Davis, WHOI

Davis presented the meeting goals and briefly reviewed the overall GLOBEC NWA program goal of quantifying biological-physical mechanisms controlling recruitment of cod and haddock and their dominant copepod prey species. He presented a circle plot of haddock biomass-at-age data, which clearly shows the large cohorts. He pointed out that our ultimate objective is to provide insights into the causes of those "bonanza" year classes. Davis stressed that it is not just fish populations that are impacted strongly by recruitment processes, but most animal species with planktonic phases of life as well as holozooplankton, including the target copepod species.

Davis then went over the interconnections between the different phase 4B projects, discussing how interdependent they are. The FVCOM-NPZD-copepod study (Davis et al) is focusing on understanding the internal biological and physical mechanisms controlling the lower-food web and copepod species dynamics in the GB/GOM region and the consequences of boundary forcing scenarios related to basin and global dynamics. It is necessary to understand the interior dynamics of the GB/GOM system in order to understand how the system responds to external forcing. The output of the FVCOM biophysical model will include concentration-based 3D abundances of dominant copepod species, which serve as prey for cod and haddock larvae. These copepod concentrations are critically needed in the larval fish modeling project (Werner et al.), which is combining individual-based models of cod and haddock with regional and basin physical models (ROMS) in order to compare the biological/physical processes controlling larval fish growth and survival in the GB/GOM region with that on the Norwegian shelf. The basin scale dynamics developed by Werner et al also can provide boundary forcing for the FVCOM model. The detailed analysis of mechanisms controlling diapause in *Calanus* (Runge et al) involves a combination of historical data analysis and IBMs and is critically important to the concentration based FVCOM copepod modeling (Davis et al) as well as to the basin-scale *Calanus* IBM study

(Gangopadhyay et al). The basin-scale *Calanus* study also uses ROMS and therefore has strong links to the ROMS-based basin-scale larval fish study. The synthesis work being done relating global, basin, and regional dynamics (Greene/Pershing et al) helps tie together the 4B studies. Although this last study is focusing on freshwater input into shelf regions of the NWA from the Arctic, the planned workshops provide an excellent venue for discussions of remote forcing of the GB/GOM region in general and are therefore an integral part of phase 4B synthesis efforts.

2. Individual Project Talks

Following this introduction and program overview, the individual project talks began. Four projects were presented in the morning session and two after lunch.

2.1. Davis et al. Project:

2.1.1. Project Overview

Davis presented an overview of the NPZD-copepod species FVCOM-modeling project, describing its main objectives, approach, hypotheses, and outputs.

Processes Controlling Abundance of Dominant Copepod Species on Georges Bank: Local Dynamics and Large-Scale Forcing: Project Overview

Cabell Davis, WHOI

The main objective of this project is to model the biological-physical mechanisms controlling the development of 3D spatial patterns of lower food web (NPZD) and dominant copepod species on GB/GOM over time scales of days to years during the GLOBEC period (1995-1999). This modeling effort will examine how local-dynamics and external physical forcing impact the abundance of the target species. The study will determine the relative importance of food-limitation, predation, and advection. The FVCOM will be used together with GLOBEC and other data sets, to conduct targeted numerical experiments examining such factors as sustainability of resident populations (in the absence of immigration), the effects of intrusions of Labrador water from the slope and Scotian Shelf, and scenarios of catastrophic warming. The general hypothesis of the study is that the characteristic distributional patterns of the dominant copepod species are determined by the interaction of their characteristic life-histories and the biological and physical environment. A state-of-the-art unstructured-grid model, FVCOM, driven by tides and meteorological forcings, provides the 3D physical fields and incorporates biological components including lower trophic level food web (NPZD), stage-structured copepod species models, and a Lagrangian tracking tool for incorporation of individual-based models of selected species. Thus, inputs to the model include local dynamics and large scale forcing, and distributions of nutrients, phytoplankton, and copepod species. The model outputs 3D distributions of temperature, salinity, currents, nutrients, phytoplankton, microzooplankton, and copepod species at time steps of minutes over the

1995-1999 GLOBEC field study. The website for this project can be found at http://www.whoi.edu/sites/G4Bcopepods.

2.1.2. FVCOM Physical Model

Following this overview, Changsheng Chen presented the overview of FVCOM physical model and the latest results, 1995-2005.

US GLOBEC-IV-B: Interannual Variability of the Circulation in the Gulf of Maine/Georges Bank: A Hindcast FVCOM Experiment for 1995-2006

C. Chen (UMASSD), R. C. Beardsley (WHOI), C. Davis, (WHOI) and G. Cowles (UMASSD)

An integrated atmosphere-ocean-ecosystem model system was developed for the Gulf of Maine/Georges Bank/New England Shelf region. The core program of this system is the unstructured-grid, finite-volume coastal ocean model (FVCOM). With an improved heat flux algorithm, the modified fifth-generation community mesoscale atmospheric model (MM5) was used to construct mesoscale meteorological fields of surface wind stress, net heat flux, insolation, and precipitation minus evaporation over the Gulf of Maine and adjacent coastal ocean from 1978 to 2006. These fields were used to drive FVCOM for simulation and assimilation experiments covering the period 1995 to 2006. The model results show that both meteorological and oceanic fields exhibited significant interannual variability in heat flux, wind stress, water salinity and temperature, and subtidal currents. The subtidal circulation in the Gulf of Maine and on Georges Bank was directly influenced by interannual variability of the water properties and upstream transport of water from the Scotian Shelf. Ignoring the upstream flux condition directly affected the timing and intensity of the cyclonic gyre and thus the eastern Maine coastal current in summer as well as the on-bank transport in the spring. The simulation results compared well with long-term observational data of subtidal currents available in the region. The original ("first generation") horizontal grid used in the integrated model system has been upgraded to a "second generation" grid (with refined horizontal resolution around the coastal region and Nantucket Sound to resolve better the coastal currents, and to a "third generation" grid with additional horizontal resolution along the shelf break up to 300 m and inclusion of all estuaries, inlets, and intertidal zones up to a horizontal resolution of 10-20 m.

2.1.3. FVCOM Biological Model

Rubao Ji followed with a description of the NPZD-copepod species model and recent results.

Biological Models in the Gulf of Maine/Georges Bank region

Rubao Ji

(in collaboration with: Davis, Chen, Beardsley, Townsend, Durbin, Runge, Flagg, Tian, Qiao, Petrik)

In this talk, we present the current status and future plans for the biological-physical coupled modeling study in the Gulf of Maine and Georges Bank region. The food web model (Nitrogen-Phytoplankton-Zooplankton-Detritus, NPZD model) has been coupled on-line with the hydrodynamics model (FVCOM) and the whole year simulation for 1995 has been completed. The copepod population dynamics model (for *Pseudocalanus sp.*) has also been tested using a stage with mean age approach. The models were used to examine the local and remote forcings that affect nitrogen cycling/fluxes and phytoplankton bloom dynamics, as well as their impact on biological productivities in the Gulf of Maine/Georges Bank region. Specifically the impact of NAO related slope water intrusion on the seasonal nitrogen and phytoplankton dynamics was examined by initializing the model with different nitrogen concentrations in the deep waters. The NPZD model captures the spatio-temporal distribution of nitrogen and phytoplankton reasonably well. The model results suggest that high productivity on Georges Bank during summer is mainly supported by internal nitrogen recycling and tidal pumping processes along the tidal mixing front; and variation of nitrogen concentration in deep water (potentially associated with NAO) may not drive the interannual variability of phytoplankton productivity. Some critical issues regarding the application of coupled models in the Gulf of Maine/Georges Bank region were discussed, including the vital rates for copepod population dynamics model and the sensitivity of NPZD model to stratification and boundary conditions.

2.1.4. Canadian NWA Modeling

Bob Beardsley then gave a brief overview of the Canadian modeling efforts in the NWA, a result of discussions with Peter Smith (BIO).

Bedford Institute of Oceanography Operational Oceanography Projects

Robert Beardsley (WHOI)

In the last five years, Canada has begun a long-term R&D program to implement and improve an operational assimilation and prediction capability for the coupled global atmosphere-ocean-ice system. As part of the Canadian Operational Network of Coupled Environmental PredicTion Systems (CONCEPTS) program, the Bedford Institute of Oceanography has initiated several projects which incorporate numerical ocean modeling activities dealing with the western North Atlantic including the Canadian eastern shelf/slope domain and the Gulf of Maine. These slides provide a brief description of these modeling activities.

2.2 Runge et al Project:

Jeff Runge presented an overview and discussion of work on diapause mechanisms in *Calanus finmarchicus*.

Obey the LAW: Calanus finmarchicus dormancy explained

J.A. Runge, School of Marine Sciences, University of Maine and Gulf of Maine Research Institute
A. Leising, NOAA, Southwest Fisheries Science Center
C. Johnson, University of British Columbia

We seek to develop for inclusion in population dynamics modeling a mechanistic understanding of dormancy in the life cycle of *Calanus finmarchicus*. Our approach is to compile *Calanus* life cycle and environmental data sets across regions in the NW Atlantic, look for common patterns and cues and develop quantitative hypotheses using individual-based life-cycle models to explain the observed patterns. We compiled, with the assistance of colleagues (E. Durbin, R. Jones, S. Plourde, E. Head, P. Pepin), life history data sets, including ambient water temperature, food availability (measured as mean chlorophyll a concentration in the surface water column), photoperiod and life stage abundance cycles, from six areas spanning 9 degrees of latitude in the region. We use as proxies for dormancy entry and exit the proportion of stage CV (year day when the CV proportion is at one half of its climatological maximum proportion) and the proportion of adult females (yearday when adult females reach 10% of the population), respectively. Our first results show that no single observed environmental cue explains the range of dormancy patterns; rather, dormancy entry and emergence occur over a broad range of times, both among years and regions. We propose a "Lipid-Accumulation Window (LAW)" hypothesis, in which dormancy entry and exit involves interaction of multiple environmental factors with the copepod's physiological responses, including lipid accumulation and development rates. We postulate that an individual enters dormancy when it has accumulated ≥ 50% of its dry weight as lipid by the end of stage CV; if this condition is not met, it continues molting to adult. The lipid accumulation rate is dependent on ambient temperature and food availability. There is, therefore, a seasonal window in time of conditions that will allow dormancy. Upon entry, the length of the dormant period is a function of both ambient temperature during dormancy and the lipid level. Predation, especially at the early life stages, as well as advection, can significantly alter the demographic pattern of dormant individuals. We are presently testing this hypothesis using individual based models against the observed data. A similar approach is being carried out to examine dormancy of Pacific species of the genus, as part of the Northeast Pacific GLOBEC synthesis phase.

2.3. Werner et al Project:

2.3.1. Project Overview

Greg Lough presented an overview of the larval fish modeling project comparing the NWA with the Norwegian Sea.

U.S. GLOBEC: NWA Georges Bank. Factors determining early-life-stage survival and recruitment variability in N. Atlantic cod: a comparison between NW Atlantic and Norwegian Sea Systems

R. Gregory Lough, NEFSC, NOAA

Basin-scale changes in North Atlantic ecosystems have been observed but the mechanisms and pathways between physical forcing and specific ecosystem responses have not been elucidated. Ecosystem shifts have been identified by proxies such as temperature, which can have direct and indirect effects on various trophic levels. For Arcto-Norwegian cod, there is a strong relationship between early larval survival to recruitment and temperature through effects on feeding, metabolism, and growth, or as a proxy for other climate parameters, such as the advection of zooplankton-rich Atlantic waters from the Norwegian Sea onto the adjacent shelves. For Georges Bank cod and haddock, recruitment can be more complex, but recent studies have indicated that growth and survival of larvae was related to low surface salinity, a proxy for the influx of fresh Scotian Shelf water, ultimately leading to an increase in copepod populations as prey for larvae.

The objective of the proposed study is to develop an understanding of the processes controlling recruitment of cod and haddock on Georges Bank and cod in the Norwegian Sea sufficient to parameterize useful recruitment models and to forecast likely changes in abundance under a range of climate change scenarios. We will use the detailed information and understanding gained from modeling, broad-scale and process studies completed for a limited number of years in both systems to develop recruitment models and a suite of proxies that can be used to recreate the patterns and trends of longer recruitment time series for cod and haddock.

As part of the synthesis phase of GLOBEC we propose to establish comparative biophysical coupled model studies for transport and growth of larval and early juvenile fish in the two marine ecosystems Georges Bank and the Norwegian shelf/Barents Sea (the northern and southern extremes of the distribution of Atlantic cod). The study will be carried out in collaboration with colleagues at the Institute of Marine Research. These comparative studies will contribute to basic understanding of the interactions between fish populations and zooplankton and how these interactions are influenced by climate variability and change. The joint efforts will include:

- Modeled basin-scale circulation fields with increased resolution within the regional domains of the two ecosystems
- Lagrangian (particle tracking) models for application within the regional domains
- Individual-based trophodynamic models for larval and early juvenile fish growth to be embedded in the regional circulation models
- Hybrid (full life-cycle) recruitment models that build on results and understanding gained from the detailed process studies and biophysical models.

2.3.2. Larval Fish Growth and Mortality

Larry Buckley then presented his latest work on the growth and mortality in larval cod and haddock on Georges Bank.

Seasonal trends in mortality and growth of cod and haddock larvae result in an optimal window for survival on Georges Bank

Larry Buckley, GSO, URI

In northern waters intra-annual trends in the abundance of fish larvae, their prey and predators are associated with strong seasonal trends in solar radiation, water temperature, water-column structure and circulation. With very few exceptions, any corresponding seasonal trends in the vital rates of fish larvae are poorly known, largely due to the scale of the sampling effort required. As part of the US GLOBEC: NW Atlantic Georges Bank Program, we were able to compile extensive data on weight-specific growth (G) and instantaneous mortality (M) rates of cod and haddock larvae each winter and spring over the period 1995 to 1999, along with data on the physical and biotic environment. M of young larvae was lowest in March, corresponding to the annual minimum in water temperature. G increased with larval size and Julian Day (photoperiod) between March and May. The M/G ratio, an index of stage-specific mortality, was lowest in March. The dependence of G on larval size resulted in an expanding temporal window of opportunity for fast growing cohorts when $M/G < 1$. Cohorts that grew rapidly remained within this window, while slow growing cohorts fell behind and rapidly lost biomass. Both cod and haddock exploit a brief period early in the seasonal cycle when, in some years, there is sufficient prey to support good larval growth, while the abundance and activity of their predators are still at low levels. Annual and climate induced changes in minimum water temperature, the rate of warming and cooling, the timing and intensity of the production cycle and the migration of mobile predators will affect recruitment through either an expansion or contraction of this temporal window of opportunity.

2.4. Green et al. project:

Pershing presented an overview of their synthesis project which examines the impact of remote forcing of the NWA by intrusions of low salinity water derived from the Arctic.

Response of the Gulf of Maine Ecosystem to Remote Climate Forcing

Pershing, Andrew, U. Maine, GMRI

This project continues the retrospective analysis of physical and biological changes in the Gulf of Maine region begun by Greene, Pershing, and colleagues under Phase III. Much of these efforts will focus on understanding the causes and consequences of the influx of relatively fresh water during the 1990s. Analyses to date have attributed widespread shifts in the Gulf of Maine and Georges Bank ecosystem to this freshening. By increasing stratification, the freshwater allowed for stronger and more persistent autumn phytoplankton blooms. The increased phytoplankton production supported larger populations of zooplankton that, in turn, contributed to the recovery of herring stocks. The increase in herring likely contributed to a decline in the older life history stages of the dominant copepod species, with adverse impacts on reproduction in the endangered right whale. These results highlight the importance of autumn, a season that has received little attention from the oceanographic community, and demonstrate a novel mechanism by which climate change can impact marine ecosystems.

Under Phase IVb, Greene et al. will conduct a review of conditions in the Labrador Sea and Arctic Ocean and examine the hypothesis that the 1990s freshening in the Gulf of Maine is a manifestation of Arctic climate change. This project will hold a workshop in November 2006 to consider these questions as well as the relative importance of top-down vs. bottom-up processes in structuring the Gulf of Maine ecosystem. This project will also extend the retrospective analysis downstream to the Middle Atlantic Bight, and will use the *Oleander* CPR data to compare ecosystem changes in this region with those in the Gulf of Maine.

2.5. Gangopadhyay et al. project:

2.5.1 Project Overview

Avijit Gangopadhyay presented the overview and status their project on basin scale modeling of *Calanus finmarchicus* distributions.

Basin-Scale Simulations for the North Atlantic - A Status Report

Avijit Gangopadhyay (UMASSD)

In this project, our goal is to probe the connections between *Calanus finmarchicus* distributions and the physical oceanographic properties, climate variability, and basin-scale circulation changes that are likely to affect the copepod's transport onto Georges Bank. We will do this using a combination of numerical model simulations and observational data. Our initial focus is on completing the basin-scale simulations for the North Atlantic, which was started as part of an ongoing NASA-IDS project. We presented the initial results from the NASA project first.

A major development in our current NASA-funded work is the systematic computation of a heat flux product for the low-NAO period (1958-1971). The NCEP reanalysis product was shown to be overestimating the heat loss in the high latitude regions by Josey, 2001 and by Visbeck et al., 2003. Comparison of the NCEP reanalysis during 1980-1993 with the Southampton Oceanographic Center's (SOC) product during the same period resulted in a regression model for the high NAO period. These regression model coefficients were then used to calibrate the low-NAO period NCEP data to generate realistic low-NAO heat flux climatology. To the best of our knowledge, this product is unique and will be very valuable for forcing our eddy-resolving simulations.

Preliminary results with these new fields are encouraging with realistic Gulf Stream and eddy activities. It is expected that these simulations for 1990s will be completed by December, 2006. High resolution field generation via multi-scale synthesis of GOMGB feature model derived synthetic profiles (FORMS, Gangopadhyay et al., 2003) and basin-scale simulated fields (from ROMS) for the GLOBEC years will then begin. An example of this synthesis methodology was presented.

Our proposed biological simulations will then utilize the high-resolution fields with individual-based models to investigate the Lagrangian pathways for zooplankton behavior in different climatic conditions. The biological IBM simulations will be analyzed for understanding impact of climate and BSV on *calfin* seeding and production.

2.5.2 Bisagni – Scotian Shelf Water cross-overs

Jim Bisagni presented SST and mooring data revealing Scotian Shelf Water cross-overs during the GLOBEC years.

Scotian Shelf Water Cross-Overs During the GLOBEC Years

James Bisagni (UMASSD)

The focus of this study is the small region along eastern Georges Bank and Northeast Channel within the Gulf of Maine. Earlier studies conducted with US GLOBEC - Georges Bank program show the importance of the circulation pattern in and near the NEC for the Georges Bank ecosystem. Model studies have shown, that the basic flow on the western Scotian Shelf and in the NEC would rather follow the bathymetry rather than crossing the NEC. Evidence of episodically occurring Scotian Shelf Water "Crossover" (SSWC) events, in which Scotian Shelf Water (SSW) crosses the NEC directly from Browns Bank to Georges Bank have been observed using moorings, drifters and satellite-derived sea surface temperature. Here, a comprehensive study of satellite-derived SST was performed to study the occurrence of SSWC events in time and space during 1985 through March 2001, with special emphasis on the US-GLOBEC Georges Bank focus period of 1995-1999. Five-day composite SST anomalies were computed to eliminate influence of the weather band and the seasonal cycle. SST data were binned in 34 11km2 boxes along the eastern and western side of the North East Channel. SST anomalies are highly correlated with NDCP buoy 44011. Results show a five year periodicity of years with high counts of SSWC suggesting a strong interannual variability of SSWC events. Findings indicate that surface SSWC events depart on the southern most tip of Browns Bank and arrive between 41.4^{o} – 42^{o} N along the western side of the Northeast Channel, but not further to the northwest.

2.5.3 Brunner – Satellite SST analysis 1985-1999

Anne-Marie Brunner presented a nice description of the interannual variability of satellite SST in the NWA from 1985-1999, showing the 1998 low salinity intrusion passing along the edge of the slope from the Scotian Self to the Mid-Atlantic Bight (MAB).

Interannual Variability of Satellite-Derived Sea Surface Temperature in the Western North Atlantic Shelf and Slope, 1985-1999

Anne-Marie Brunner (UMASSD)

Interannual variability of monthly-mean sea surface temperature is examined for the western North Atlantic continental shelf and slope between Cape Hatteras, North Carolina, and the southwestern Labrador Sea using fifteen years (1985-1999) of declouded, full-resolution, Advanced Very High Resolution Radiometer (AVHRR) data. All SST retrievals were computed using the NASA/NOAA Pathfinder SST algorithm. A spatial bathymetry-following grid was developed to focus on shelf and slope. We tracked the documented advection of cold Labrador Slope Water along the outer shelf during 1997 and 1998 as SST signal in the monthly gridded SST anomalies. The role of local forcing (net heatflux and wind) on observed IAV of SST is examined using monthly-mean winds and net heat flux for the same period using National Center for Environmental Prediction (NCEP) gridded reanalysis products. An empirical orthogonal function (EOF) analysis of monthly SST anomalies reveal that modes 1, 2 and 3 account for 22%, 14% and 8% of the variance respectively. Spatial EOF mode 1 shows a pattern of decreasing values over the shelf and slope towards both Cape Hatteras, and Hamilton Bank in the western Labrador Sea, forming a standing wave. Spatial EOF mode 2 shows a standing wave with increasingly positive values northeast of the Laurentian Channel and increasingly negative southwest of it. Spatial EOF mode 3 reveals an onshore-offshore standing wave throughout the Middle Atlantic Bight and Scotian Shelf region. Summing the first three modes and applying a 3month triangular filter removes the effects of eddies and small scale noise from the original SST dataset, more clearly revealing IAV of SST over the study domain. Correlations between corresponding EOF temporal amplitudes of wind strength, net heat flux, SST and the North Atlantic Oscillation monthly were computed. Only low correlation and significance levels were found suggesting that other mechanisms, including horizontal and vertical advection, may play a major role controlling IAV of SST over the region. Further the grid was divided in onshelf and offshelf sections using the 200m isobath as dividing shelf break. Correlation of offshore SST sections and the Gulf stream north wall anomalies at different longitudes shows generally high correlation, decreasing towards the Laurentian Channel. However, offshore SST anomalies are negatively correlated with the GSNW position at 50W, suggesting co-variation of the subpolar and subtropical gyres.

2.6. Groman et al. Data Management:

Bob Groman presented the status of the data management office activities. He described the inventory and the new interfaces developed to access and display these data using a geospatial interface.

Data management: JGOFS/GLOBEC geospatial interface

Robert Groman (WHOI)

The U.S. GLOBEC Data Management Office is responsible for managing the data collected by the Georges Bank, Northeast Pacific and Southern Ocean programs of the U.S. GLOBEC project and making these data available on-line. Currently, we have over 775 Georges Bank data sets, 157 Southern Ocean data sets and 437 data sets from the Northeast Pacific programs. The US JGOFS/US GLOBEC data management system is used to serve these data via the and is accessible to anyone having access to the Internet and any stand Web browser, such as Internet Explorer, Mozila, Netscape, Firefox and Safari. We encourage scientific investigators to serve their own data but will serve their data from the central data server, globec.whoi.edu, if they prefer. Current activities included on-going quality control, adding new data and modeling results to the data system, adding data reports and presentations to the web sites, and improving overall access to the data.

Currently, the interface to the system is a table or directory, organized by project, program and/or year depending on the preferences of each of the programs. (See http://globec.whoi.edu/) But there is interest in making the interface to the data geographically based and we have begun to implement this interface using MapServer software. For a preliminary view of this interface, showing the data from the Georges Bank program, see http://mapservice.whoi.edu/maps-bin/globec/map. By the end of November we hope to have all three projects accessible via this interface. In addition, we are adding interoperability enhancements to the data management system to facilitate access to these data from other sites and portal. To accomplish this, we are converting our human readable metadata records to machine readable, XML encoded, files using the FGDC metadata standard. Also, we are adding to our ability to download data. Currently, people can download data in ASCII comma and tab separated files, flat files, Matlab binary files, and as ZIP and tar files. We are adding the ability to access these data using the Open Geospatial Consortium's Web Map Service and Web Feature Service protocols.

To help analyze data, we recently released version 3.0 of the EasyKrig Matlab based kriging software. The EasyKrig program package uses a Graphical User Interface (GUI). It requires MATLAB 5.3 or higher with or without the optimization toolbox and consists of five components, or processing stages: (1) data preparation, (2) variogram computation, (3) kriging, (4) visualization and (5) saving results. It allows the user to process anisotropic data, select an appropriate model from a list of variogram models, and a choice of kriging methods, as well as associated kriging parameters. One of the major advantages of this program package is that the program minimizes the users' requirements to "guess" the initial parameters and automatically generates the required default parameters. In addition, because it uses a GUI, the modifications of the initial parameter settings can be easily performed. Another feature of this program package is that it has a built-in on-line help library that allows the user to obtain the descriptions of the use of parameters and operational options easily. Although this software package lacks some abilities such as Co-kriging, it does provide a convenient tool for geostatistical applications and should also help scientists from other fields.

Finally, we continue to develop our interface to the GeoZui3D 3-dimensional visualization software. GeoZui3D is a highly interactive 3D visualization system to support a number of different research projects. The GeoZui3D software is being developed at the Center for Coastal and Ocean Mapping, University of New Hampshire. It is a Zooming User Interface - hence 'Zui'. It is georeferenced - hence GeoZui. It emphasizes interactive 3D solutions - hence GeoZui3D. Our current efforts are focused on improving and simplifying access to the data stored in the US GLOBEC data system since our experimental data are not regularly spaced nor formatted in a way that GeoZui3D is prepared to handle.

3. Intra-interproject communications:

Following the afternoon coffee break, "free" time was allotted for intra- and inter-project communications as needed.

4. Plenary discussion of themes

The group reconvened in plenary session at 1600 to discuss major themes of the GLOBEC NWA program. The goal of this session, and of the working groups the following morning, was to place the individual 4B projects within the larger perspective of the project as a whole.

4.1. Introduction to themes

Davis led off this plenary session with an overview of the major themes up for discussion:

1. What are the key mechanisms controlling recruitment success the target species? e. g., the bonanza year classes of haddock (1998, 2003)
2. What are the key ecosystem indicators
3. What are the physical and biological processes that link global/basin and the GB/GOM region? e.g. intrusions, warming, winds
4. What is the relative importance of top-down vs. bottom-up forcing of GOM/GB ecosystem?
5. What are the big ideas to come out of GLOBEC NWA?
6. What are the products/transitions of GLOBEC NWA? e.g. operational products, lead-ins to new scientific programs.

4.2. Georges Bank GLOBEC low salinity anomaly

Davis' overview was followed by an introductory presentation, related to theme 3, by Dave Mountain on the low salinity event that characterized GLOBEC years 1996 and 1998.

The Low Salinity Event - a Unifying Theme for Synthesis?

David Mountain, NEFSC, NOAA

The five years of the Georges Bank GLOBEC program were characterized by relatively low salinities - compared to comparable measurements from the1970's through the early 1990's. The cause of this low salinity event was a greater inflow of water from the Scotian Shelf, as documented in current meter measurements by Peter Smith. The temporal pattern of the salinity variation was reflected in many of the biological observations – with lower salinity associated with higher chlorophyll, higher copepod abundance, higher larval growth rates and lower larval mortality rates. A process-based understanding of the possible dynamic connections between these series should be an important focus of the synthesis phase of our program. The low salinity event appears related to large-scale variability in the Northwest Atlantic, including movement of the north wall of the Gulf Stream and transport of the Labrador Current. Isotope measurements suggest the low salinity is of high latitude origin. An important and intriguing question is whether the salinity variation on Georges Bank, and the biological variability that appears associated with it, are associated with the changes that have recently been documented occurring in the Arctic Ocean. Do the changes on Georges Bank represent the downstream, ecological effects of climate-scale changes in the Arctic and the North Atlantic Basin?

4.3. Transitioning GLOBEC to Operational Products

Andy Pershing then presented an introduction to theme 6 on transitioning the findings of GLOBEC NWA program to operational tools of use to managers.

Operational Products from GLOBEC

Andrew J. Pershing, U. Maine/ GMRI

To motivate discussion, Pershing presented a conceptual diagram of how data, knowledge, and information interact. Information is something we would like to know, for example, cod recruitment on Georges Bank. Data is something we measure, for example wind speed on Georges Bank. In this context, knowledge acts to transform data into information, for example, strong northerly winds would lead to poor larval retention on Georges Bank. The main role of the GLOBEC program has been to provide knowledge, and our task is to identify the information this knowledge can provide from the data we have available.

Knowledge is an abstract concept. In an operational setting, knowledge is replaced by models. The GLOBEC NWA program has produced a wealth of models that could be appropriate for operational use. These models fall into three categories: conceptual, statistical, and dynamical. Conceptual models tend to be qualitative; however, they could be useful for identifying ecosystem indicators. Statistical models, for example the relationship between the NAO and slope water type, and the relationship between slope water and *Calanus*, are quantitative and are typically derived from historical data. Their main limitation is the potential for non-stationarity. For example, the relationship between slope water and *Calanus* seems to have become weaker during the 1990s. There is evidence that the presence of large numbers of herring during the 1990s reduced the *Calanus* population and masked the relationship with the slope water. Non-stationarity will be especially challenging in a warming world; however, statistical models could provide a way of detecting unusual changes and events in the system. Dynamical models are the gold standard. They attempt to represent completely the interrelationships among state variables. Physical models such as FVCOM are the quintessential dynamical models, although the various biological models (NPZ, copepods, larval fish) would also fall in this category. However, it is worth recognizing that all of these models employ some kind of underlying statistical model to parameterize relationships that are unknown (for example, copepod mortality) or are impractical to compute from first principles (e.g. surface heat flux). The main disadvantage of dynamical models is their complexity. They typically require huge amounts of data for initialization and boundary forcing, and given their complexity, they are hard to validate.

Data is simpler and can be classified based on time. Historical data, for example the GB Broadscale survey can be useful for validating dynamical models, but can't be used as an input into an operational model. At the opposite end sits the real-time observational programs, for example, GoMOOS buoys and the various satellite systems. These would be the ideal data source to drive an operational system. Their main limitation is that they collect largely physical data. Between these two extremes we have various on-going sampling programs. Many of the monitoring programs managed by NOAA, for example the CPR and trawl surveys, would fall in this category. Although these surveys are on going, there is a considerable delay, often several months, between when the samples are collected and the data becomes available. Identifying high-value data for priority analysis would be a valuable service that GLOBEC could provide.

Pershing's introduction sparked a discussion, one that came up again the next day, on who should fund operations and the role that academic science should play. The general consensus was that actual 24x7 operations should be conducted under a NOAA modeling center. Academic scientists would fill the role of developing and validating models.

5. Working group discussion of themes

In the morning of day 2, a two-hour period was used for working groups to discuss the themes presented in plenary the previous afternoon. Participants were divided arbitrarily into two working groups. Each group was charged with discussing all the themes in order to obtain insights from all meeting participants on all the topics.

6. Working group reports on themes

6.1. Report of working group 1.

Present: Davis (Rapporteur), Beardsley, Runge, Lough, Buckley, Ji

This working group had a general discussion with a large amount of overlap between themes.

We first discussed the role of top down versus bottom up control of the ecosystem and target species. Two independent GLOBEC studies, Pershing et al (submitted) and Steele et al. (submitted), and a related study by Heath and Lough (in press) all have found strong support for the dominance of bottom-up control of the GB/GOM ecosystem. Pershing et al. compared the 1980s and 1990s, the so called MARMAP and GLOBEC decades, respectively, and found that the mean surface salinity of the GOM was lower during the 1990s than during the 1980s. This lower salinity was associated with higher fall phytoplankton, high abundance of small copepods during spring, higher herring stocks, and higher recruitment of haddock. Steele et al. used a combination of historical data and modeling to compare decadal scale changes in the Georges Bank ecosystem over the past 40 years. They concluded that, during the last three decades fish food requirements balanced lower trophic level production, whereas, during the 1960s, intrusions of low-nutrient Labrador Slope Water reduced primary and secondary production and overall fish yields. Heath and Lough (in press) found that CPR phytoplankton color index for the Gulf of Maine had both spring and fall peaks in the 1960s and 1970s but only a spring peak in the 1990s. This shift corresponds with the collapse of the cod spawning stock on Georges Bank in the 1990s. In the earlier period when stocks were high, significant spawning spanned the period from November to May, whereas in the 1990s spawning started about two months later, although peak activity still took place in February-March. Despite the apparent discrepancies in the fall phytoplankton bloom during the 1990s, the studies all suggest a strong bottom-up effect on fish production. The working group felt that both bottom up and top down processes operate on the system as a whole and different species may be affected in different ways. Bottom up effects do appear to strongly affect variability at the system level.

In considering the effects of remote (climate/basin) forcing on the GB/GOM system, it was felt that, in keeping with the approach of the GLOBEC NWA, we need to understand the interior dynamics of the GB/GOM system in order to understand how the system will respond to external forcing. We felt that the proposed process oriented modeling is the right approach, i.e., conducting targeted numerical experiments to examine different forcing scenarios. Setting up boundary conditions for warm and cold regimes will be examined with respect to their influence on lower food web and copepod species production.

By modeling the GLOBEC years, in which we have a rich data set, we will be able to examine the factors leading to "good" and "bad" years in terms of plankton production. The good years, like 1998 and 1999 provide necessary food conditions for outstanding year classes but are not a guarantee, e.g., haddock recruitment was high in 1998 but not in 1999. (Other factors like post-pelagic juvenile survival and cannibalism, not studied in GLOBEC, may contribute to recruitment success.)

Such production estimates can be used as indices for ecosystem based fisheries management. The models we are developing provide abundance estimates for dominant copepod species (*Calanus, Pseudocalanus, Oithon*a) which can be reduced to simple estimates, such as low, medium, high levels of large and small copepods. These indices can be compared in hindcast with good and bad year classes of cod and haddock.

Other indicators include the biological state variables in the model, including nutrients and phytoplankton. The model variables can be combined into multivariate indices or principal components. Model variables to consider include wind, temperature, N-P-Z levels, copepod species abundances, larval fish growth and survival.

From GLOBEC data, Buckley, Lough, and Mountain have found that ~50% of the variability in larval growth can be accounted for by seasonal effects and ontogeny (i.e. photoperiod and size), and another ~15% is due to a year effect. Thus we can account for a significant proportion of the total variance in larval growth and survival. The cause of the year effect is not yet known, but will be examined using the modeling studies. The remaining percentages are critically important to determine since a small change in mortality rate can have such a large impact on recruitment.

A major finding of the GLOBEC program was that larval cod and haddock at times are food limited in nature, even in the food rich region of Georges Bank. Using the extensive

GLOBEC data set, Buckley, Lough, and Durbin found a strong relationship between abundance of *Pseudocalanus* and larval fish growth, which is also related to survival (Mountain, in prep). This finding clearly indicates that bottom up effects are critical for these species.

Thus using the model, we can identify the mechanisms leading to good and bad years of *Pseudocalanus* which will serve as a proxy index for larval fish growth and survival. Since survival, as well as growth, is affected by copepod abundance, this index may be very powerful.

Historical data analysis indicates that remote forcing has a strong effect on bottom up processes though stratification, nutrient input, and wind driven flows. We will use the models to conduct numerical experiments to gain insight into these mechanisms. The modeling approach is needed to examine year to year effects of winds, warming, and stratification.

One issue raised is that Pershing *et al*, found a relationship between low salinity and system production, and in another study found a relationship between NAO and *Calanus* from the CPR GOM transects. Although there is a relationship between NAO and Labrador Slope Water intrusions in the GOM, intrusions of low salinity water from the Scotian Shelf do not appear to be related to NAO (Mountain pers. comm.). Thus, if the enhanced system production in the GOM is in fact caused by low salinity intrusions from the Scotian Shelf, this enhanced production must not be related to NAO, but may be due to a longer term effect, probably polar ice melt. The relation of CPR-derived *Calanus* abundance to NAO then may be due to intrusions of Labrador Slope Water into the GOM and not to enhanced productivity from Scotian Shelf intrusions.

Numerical experiments need to be done to compare the influence of salinity versus other aspects of remote forcing (global and basin), including wind forcing and surface heating. NAO effects do not appear to impact local meteorological conditions in the GB/GOM region (Beardsley cited Joyce study), but the influence of longer term global trends in warming and wind forcing on the GB/GOM ecosystem need to be examined.

In terms of transitioning the GLOBEC findings and models for use by managers, it was felt that it is not the role of GLOBEC scientists to run operational models, but it certainly is our responsibility to provide models that can be transitioned to operational groups such as NOS. The models we are developing will be tested in hindcast mode and can be run in nowcast and in the end, in forecast mode. The models will provide estimates of lower food-web and copepod species production as well as recruitment of fish through the larval stage. In this way, the models will provide indices of system productivity and good and bad years for larval fish survival as a function of local and remote forcing. The models are not expected to provide high-frequency (e.g., daily) forecasts, but are likely to provide indicators of value for 1-10 years into the future. The models are being calibrated on the GLOBEC years (1995-1999) and extended to present time.

The use of our model-generated ecosystem indices can be used together with current spawning stock biomass estimates to help fisheries managers make better predictions.

These models also will serve as useful tools for determining what we need to measure in the future. In the case of observing systems, the models can be used for siting nodes and for determining what sensors are needed at each node.

6.2. Report of working group 2.

Pershing (Rapporteur), Mountain, Gangopadhyay, Bisagni, Brunner,

For the discussion, we considered the six thematic questions listed in Section 4. Our discussion ranged across these questions, but I've attempted to categorize the main points according to the six themes.

1. What are the key mechanisms controlling recruitment success in the target species? E.g. bonanza year classes of haddock (1998, 2003)

The general consensus was that the field program has provided good evidence linking feeding conditions with good larval recruitment, especially in haddock. The naupliar and early copepodid stages, especially in *Pseudocalanus*, were identified as the most important food items. Independent of food limitation, good recruitment years also coincided with years of reduced off-Bank transport and low egg mortality.

2. Ecosystem indicators

First, there was a general discussion of what a valuable indicator would be, with general agreement that simpler is better. We focuses manly on physical indices, as biological indices (for example, target copepod species) had been covered during the presentations and in the discussion of (1). Ideas for physical indicators that could be useful included:

- simple wind product for GB
- salinity (indicator for productivity)
- frontal positions (SSF, GS front)
- NAO--use as an integrated index, lagged
- maybe replace with wind stress info from Lab Sea
- NEC slope water index, for long-term system production a la Steele
- need flux, not just TS
- Gulf Stream rings impinging on Bank
- Zooplankton indices: Calanus, Ctyp, Oithona

3. What are the physical and biological processes that link global/basin and the GB/GOM region?

Many of our "big ideas" (e.g. 5) touched on this issues. We did address one link to the basin scale that was not covered during the presentations or other discussion. Specifically, the group was interested in David Townsend's observations on the silica cycle on Georges Bank and wondered how remineralization, which is important for continuing some diatom production in the summer, would be altered in a warmer world.

4. What are the relative importances of top-down vs. bottom-up forcing of GOM/GB ecosystem?

difference between mean state and variability
copepod models are entirely bottom up (no variability in predation)
this is an area for theory, definition

First off, we recognized the need to distinguish between forcing of the mean state vs. forcing of the variability and agreed to consider the later. The general tone of the discussion was that bottom-up processes were more important drivers on Georges Bank, in contrast with Frank et al's assertions for the Scotian Shelf. We noted that the copepod models being employed in Phase IVb only allow for bottom-up variability (e.g. changes in production) as mortality is assumed to be fixed. Finally, we concluded that this is a topic that would benefit from future theoretical treatment.

5. What are the big ideas to come out of GLOBEC NWA?

We were able to identify several ideas emerging from our program that were especially novel or that would apply to a wide range of ecosystems. First, we noted that we've established important linkages between GOM/GB and the basin scale. These include the NAO-*Calanus* relationships, the impact of low salinity intrusions on phytoplankton and zooplankton, and Wiebe's "three gyres" hypothesis for *Calanus* biogeography. Modeling is an important component of all GLOBEC studies, but the GLOBEC NWA program is unique in its development and use of models using unstructured grids (e.g. Quoddy, FVCOM). Related to question 4, we thought that Steele's identification of a strong bottom-up signal in Georges Bank despite intense fishing pressure was especially noteworthy. The group also thought that the possibility of alternate "regimes" in the GOM/GB ecosystem could be especially useful for management.

We also considered whether there were any conventional wisdoms that were disproved during our program. A major hypothesis at the start of the program was that stratified environments would provide better feeding conditions for larval fish (e.g. the Lasker hypothesis). Our program showed that other factors were more important, such as the duration of light required for efficient feeding. A major theme at the beginning of the program was the central importance of *Calanus* in the Georges Bank food web. Although *Calanus* is certainly important, it appears that variability in *Calanus* is of secondary importance for larval fish compared with smaller species such as *Pseudocalanus*. Due to the interest in early life history of cod and haddock, the program concentrated on the winter-spring period. However, recent work suggests that processes in autumn can lead to substantial variability in zooplankton abundance, and there is evidence that this variability can persist through winter and affect larval fish recruitment. Our group suggested that a fall study would be a good follow-up to the Georges Bank program.

6. What are the products/transitions of GLOBEC NWA? E.g. operational products, lead-ins to new scientific programs

Following from the last point above, there was considerable support for an intensive field program focusing on the fall-winter period in the Gulf of Maine. The group was also very interested in ensuring that the legacy of the NWA program be preserved and that it be communicated to the general public. We suggested a brochure capturing some of the main results would be an attractive option, as would a documentary of some kind. Along these lines, there was considerable enthusiasm for a COSEE program to bring GLOBEC and even JGOFS results into the K-12 curriculum.

Final Topics

After the working group reports were presented, the time-frame of the next meeting was discussed. It was agreed that meetings be held at 6 month intervals, since the 2-year time frame of Phase 4 is so short. The next meeting will be held in April 2006. The possibility of future publication in a volume of *Progress in Oceanography* was briefly discussed.

7. Meeting Summary

The Phase 4B meeting successfully accomplished its goals. Remarkable progress already has been made on the projects even though funding was received recently in many cases. Each group gave clear presentations of their project goals and progress. The interactions between groups were invaluable and established early-on a working relationship between groups. The group of 4B researchers is well-poised for the major synthesis work ahead. The results from these studies will contribute to a broad understanding of the effects of local and remote forcing on ecosystem and population dynamics of the target species. While the focus of the phase 4B research is primarily on scientific questions, this research is being done with consideration for transitioning results and models to operational tools useful to management.