Final U.S. GLOBEC Symposium and Celebration

by Harold (Hal) Batchelder, Dale Haidvogel and David Mountain

More than 20 years ago, forward looking members of the U.S. ocean science community held a series of workshops to achieve a consensus on the core elements of a science plan for a U.S. Global Ocean Ecosystems Dynamics (hereafter U.S. GLOBEC or GLOBEC) program (http://www.usglobec.org). For additional history of the workshops leading to GLOBEC see the Appendix, "*History of Planning Efforts for GLOBEC*" in GLOBEC Report 1 (U.S. GLOBEC 1991; http://www.usglobec.org/reports/isp/isp.appendixa.html). It is clear from review of the early GLOBEC reports, that hints of the scale of the variability and the potential linkages between climate forcing, physical processes and population and ecosystem variations were there, but the magnitude of the variability, the existence of abrupt regime shifts (state transitions), and the complexity of the process linkages were unknown. Using the Northeast Pacific regional U.S. GLOBEC program as an example, the implementation plan (U.S. GLOBEC, 1996) identified four concrete benefits of U.S. GLOBEC:

(1) **improved knowledge of the impact of climate variability on marine ecosystems**;
(2) development and refinement of **coupled biophysical models** that would enable integration of biological, physical, and climate observations in coastal ecosystems;
(3) collection and analysis of **data sets** during the program that will provide the basis for future research activities;
(4) the generation of information to provide **a new basis for resource management** that will enable those responsible for managing living marine resources to move beyond the traditional fisheries management approach to a new paradigm that integrates environmental, fisheries and ecosystem data.

The context of ocean science in the early 1990s when U.S. GLOBEC was being created was one where large programs were being emphasized, developed mostly through bottom-up community initiatives. The World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JOGFS) had begun, focused on physical characterization and carbon dynamics at oceanic (global) scales, respectively. JGOFS was quantifying the vertical carbon flux that results from oceanic chemical and biological uptakes of CO_2, and determining how much of the production in the upper ocean was due to new nitrate *vs*. the magnitude of the total primary production and its role in the global carbon budget. GLOBEC's interest was to understand what controls the biotic (especially zooplankton) population dynamics in the sea. At the time, JGOFS was a balanced mix of process studies, large-scale ship and satellite surveys, time-series observations, models, and database activities predicated on improved documentation of the ocean carbon cycle and budget and predictive models to understand oceanic response to change. JGOFS' focus was on nutrient use, phytoplankton production and carbon transport and sequestration (mostly in oceanic regions); GLOBEC focused on zooplankton and fish in (mostly) coastal ecosystems.

On October 4–5, 2011, a Final U.S. GLOBEC Symposium was held at the American Association for the Advancement of Science Auditorium in Washington, D.C. to highlight and celebrate the scientific progress achieved by the program over the past two decades. Approximately 80 scientists, program managers and invited guests attended this event. The symposium consisted of invited talks, an evening reception and a poster session. Talks were intended to be retrospective views of the U.S. GLOBEC program and to synthesize results from the multiple GLOBEC regional scientific studies. Posters were shown from each of the ten Pan-Regional U.S. GLOBEC Synthesis projects which concluded this year. The talks given at the symposium are listed in Table 1, and the PDFs of these presentations will be available through the U.S. GLOBEC web site. In this article it is not possible to summarize all of the presentations; thus, below is a highly selective summary of some of the research done by U.S. GLOBEC as reported at the meeting. Many of the presentations highlighted attributes of the program that contributed to its success, and identified legacy products. These are summarized in Table 2 and Table 3.

While the presenters were proactive in coordinating their talks to avoid repeating similar messages or graphics in multiple presentations, a few graphics/publications got "lots of air time" at the symposium. This reflects how those papers were particularly successful in achieving a broader scale synthesis by focusing on larger-scales or mechanisms linking climate to ecosystem structure and function. Figures 1 and 2 show two such examples from the Georges Bank and Northeast Pacific systems, respectively. Both of these were considered by David Mountain as "fundamental discoveries" as they were integrative, big picture research that provided new insights on the coupling of climate to physics and ecosystems. Significantly, neither discovery would have been possible had not extensive pre-GLOBEC data existed for the regions. A lesson that emerged from the U.S. GLOBEC experience is that careful selection of study sites that had extensive prior sampling of the physical and ecosystem conditions (*e.g.*, time-series) was critical to the discoveries that link climate, physics and the ecosystem over large space and time scales. Investigations during the GLOBEC decades continued or expanded time-series measurements for *ca.* 7 years (more in some regions where NOAA or NPRB continued sampling programs after GLOBEC field work ended). Pre-existing data sets coupled with new data

Table 1 Talks given at the symposium.

Presentation Title	Presenter/Organization
Introduction and History of GLOBEC	Phillip Taylor/NSF and Elizabeth Turner/NOAA
The View from NOAA	Larry Robinson/NOAA
The View from NSF	Margaret Cavanaugh/NSF
Regional Perspectives in a Global Context	Thomas (Zack) Powell/University of California, Berkeley
Before and After	Eileen Hofmann/Old Dominion University
Fundamental Discoveries and Surprises	David Mountain/NOAA (retired)
Synthesis—Climate Impacts on Ecosystems	Frank Schwing/NOAA-OSTP
Two Decades of Progress in Physical-Biological Modeling and Prediction	Dennis McGillicuddy/WHOI
Synthesis—Population Dynamics in an Ecosystem Context	Jeffrey Runge/Gulf of Maine Research Institute
A View from the International Partners	Ian Perry/Fisheries and Oceans Canada
Contributions to Education and Training: Overview and Introduction	Dale Haidvogel/Rutgers University
Young Scientist—Confessions of a 'Young' Scientist: Krill Predator Ecology and the SO GLOBEC Experience	Ari Friedlaender/Duke University
A View from Ocean Leadership—Challenges Ahead in Washington	Robert Gagosian/The Consortium for Ocean Leadership
Young Scientist—What the Zooplankton Taught me about Climate	Julie Keister/University of Washington
Did US GLOBEC Meet the Tough Challenges and Promises on Climate and Ecosystems?	Ed Houde/University of Maryland
A Top-Down Perspective on Ecosystem Dynamics and Food Webs	Dan Costa/University of California, Santa Cruz
Young Scientist—The Odyssey of a GLOBEC-ian	Enrique Curchitser/Rutgers University
An Outsider's View of what GLOBEC Brought	Mimi Koehl/University of California, Berkeley
Taking the Legacy of US GLOBEC and Building Progress in Science and Management	Cisco Werner/NOAA and Steve Murawski/University of South Florida

Table 2 Attributes that enabled a successful U.S. GLOBEC program.

Consensus development of the initial science ideas through a series of workshops to achieve buy-in from ocean science community and federal funding agencies.
Multifaceted approach of complementary studies that included process-based, long-term observations, retrospective examinations, technology innovation, modeling, integration and synthesis.
Clear focus: few target species in specific regional ecosystems, but with considerations at larger (basin-to-global) scales; worked up and down the trophic levels only so far as needed (or could be afforded).
Long-term funding commitment: originally a 10 year program; eventually a 20 year program as different regions phased in sequentially.
Many partnerships: across scientific disciplines; across federal and academic sectors; across multiple federal agencies; internationally (SO was an international project, and the NEP and Georges Bank studies were U.S. contributions to PICES' Climate Change and Carrying Capacity and ICES' Cod and Climate Change regional programs, respectively).
Specific funding phases for regional synthesis AND pan-regional synthesis.

Table 3 The U.S. GLOBEC legacy.

Promoted a multi-, inter-disciplinary culture within the ocean sciences community that is needed to address big problems like the effects of climate change on marine ecosystems.
Documented and provided process-level understanding of ecosystem variability resulting from shifts in ocean physics driven by climate change.
Increased our understanding of the population dynamics and recruitment of zooplankton and fish populations.
Advanced the capabilities of coupled bio-physical modeling.
Fostered the development of new sampling and observing technologies.
Produced a new generation of interdisciplinary trained ocean scientists.
Generated and archived extensive, multi-disciplinary data sets and model outputs to support future investigations.
Developed integrated indices and model products in support of ecosystem-based management needs.

collected by U.S. GLOBEC, including spatial surveys, process studies and focused modeling, enabled these “fundamental discoveries”.

Figure 1 summarizes one of these fundamental discoveries from the Georges Bank regional study. Time-series records show links between low salinity anomalies in the NW Atlantic, and phytoplankton production, zooplankton species composition and size structure, and survival of targeted larval fish species. The postulated mechanism for the link between climate and fish survival is described in the caption to Figure 1, but has not yet been examined through dynamical modeling (Mountain and Kane, 2010).

Figure 2 illustrates the findings from spatiotemporal patterns of sea surface temperature anomaly and sea surface height anomaly in the Northeast Pacific (Di Lorenzo *et al*., 2008, 2009). As in the Georges Bank example, the availability of long-term observations of salinity, nutrient upwelling and chl-a from the repeated surveys done by CalCOFI (Southern California) and Fisheries and Oceans Canada (Line P) enabled the recognition of the NPGO as an important climate mode of the Pacific. Subsequently, Di Lorenzo and colleagues demonstrated connections between climate modes and western North Pacific ocean conditions, especially in the Kuroshio-Oyashio extension region.

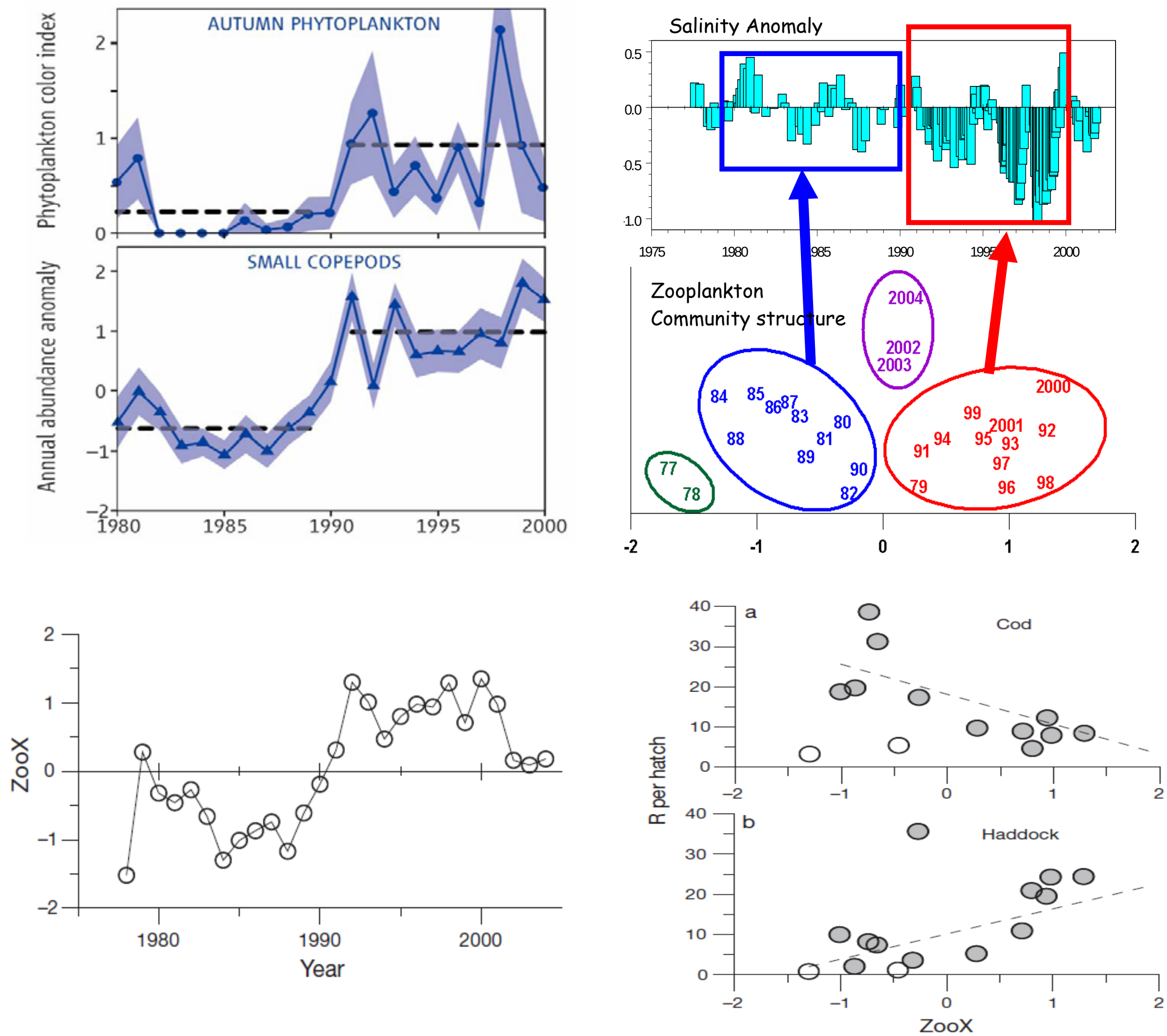


Fig. 1 Retrospective analysis of time-series (zooplankton size/species composition; cod and haddock recruitment; physical data) data collected prior (NEFSC MARMAP) and during GLOBEC on Georges Bank shows the following sequence of events from the late 1980s: Arctic Warming led to increased inflow of low salinity water (upper right) promoting enhanced stratification, allowing greater autumn and winter phytoplankton production (upper left) that altered the community structure of zooplankton, favoring small copepods (middle left, middle right) which increased (decreased) survival of haddock (cod) larvae on Georges Bank (lower right two panels). ZooX is an arbitrary index scaled from –2 to +2 on the x-coordinate axis of the non-metric multi-dimensional scaling of the zooplankton community composition (2nd panel down on right), and is used as an axis in the three lowermost panels. R per hatch in the lower right figures are the number of 1 yr old fish (recruits) per million hatched eggs. The above sequence is considered a plausible mechanism for the observed time-series data, but confirmation of the sequence requires additional sampling and especially dynamical modeling. From Durbin et al., 2003; Greene and Pershing, 2007; Kane, 2007; Mountain and Kane, 2010.

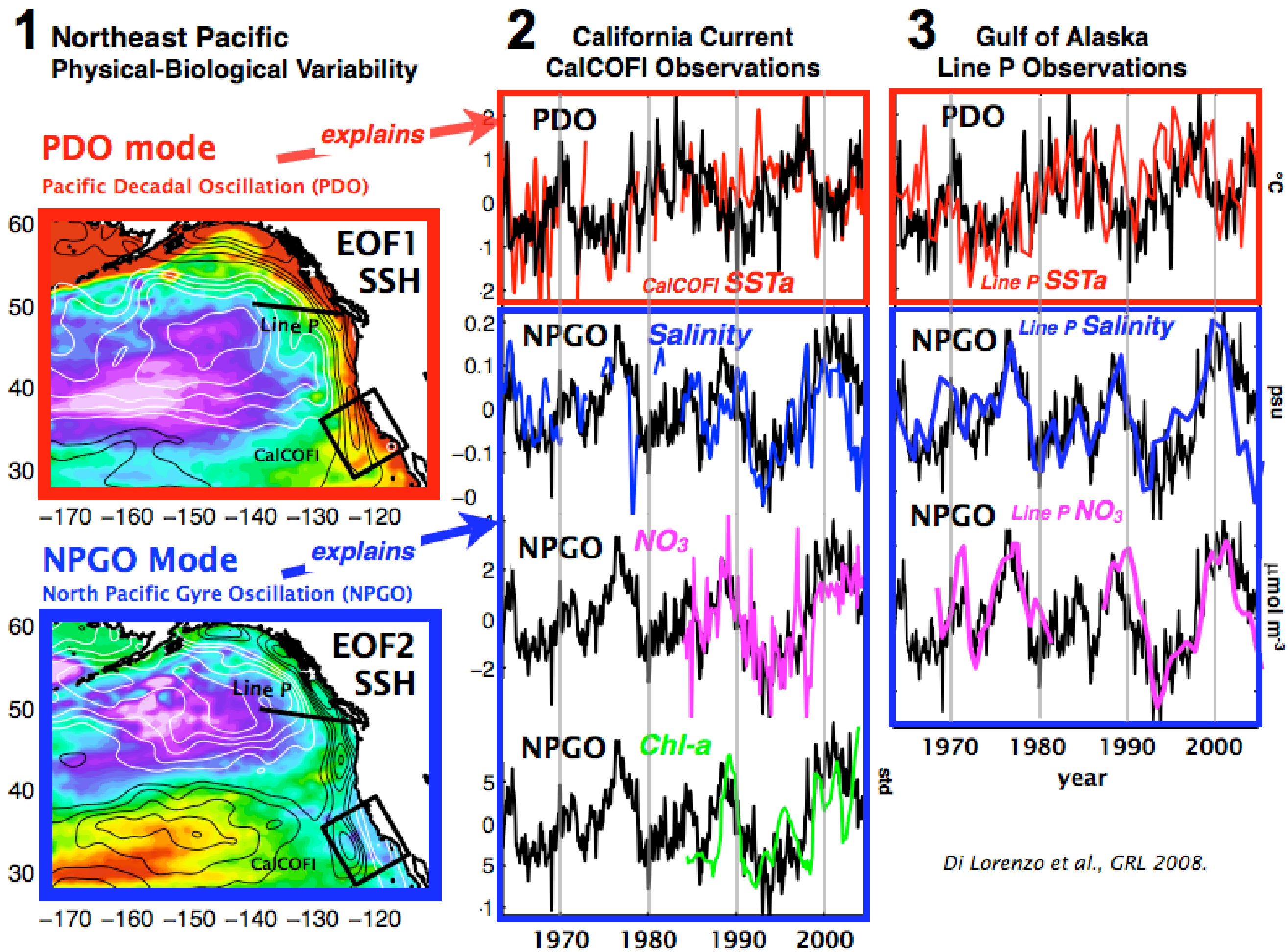


Fig. 2 *Two dominant patterns of climate variability in the North Pacific are the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO). The PDO emerges as the first EOF/PC of the spatiotemporal pattern of both sea surface temperature anomaly (SSTa) and sea surface height anomaly (SSHa). The NPGO index is the second EOF/PC of SSHa, and closely tracks the second EOF of the SSTa, which is known as the "Victoria Mode" (Bond et al., 2003). By definition of EOF analysis, the PDO and NPGO are statistically independent. Surface salinity, upper ocean nitrate concentration, and chlorophyll-a concentration in the California Current are strongly correlated with the strength of the NPGO.*

Several talks emphasized that physical oceanography and biological oceanography prior to GLOBEC were done largely independently, which led to difficulties in attributing causation to observed patterns in biological populations/communities. Early programs that did conduct interdisciplinary science, such as Warm Core Rings and SUPER, were of limited duration (3–5 years), which made it difficult to examine even temporal variability at interannual scales. During GLOBEC, it was assumed that variability in population recruitment and marine ecosystems results from the integration of many processes across multiple scales and include both direct and indirect interactions. The idea of alternate regional food webs, structured either through physical (*e.g.*, advection) or food web interactions emerged from GLOBEC studies in the Southern Ocean (krill, salp and copepod pathways to higher trophic levels [HTL]), Northeast Pacific (nitrogen *vs*. iron-limited regions and subtropical *vs*. subarctic species dominance in lower trophic levels [LTL]), and NW Atlantic (*Calanus* to cod and haddock connections).

Population dynamics were a cornerstone of the GLOBEC program. The dynamics of zooplanktonic populations are controlled by physical processes (immigration and emigration) and biological processes (birth and death rates). For larger organisms with greater swimming ability, immigration and emigration are controlled also by animal behavior. Many observations of species abundance, variability, vital rates and ecosystem connections were made in U.S. GLOBEC regional studies. Direct observations of behavior were fewer, as behavior was often inferred from distributional changes in field observations.

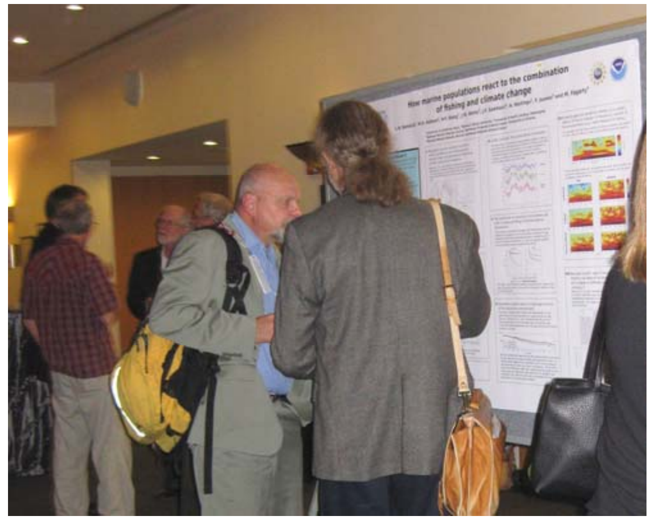
Modeling in U.S. GLOBEC included conceptual studies (Steele *et al*., 2007), prototype studies of biological processes in idealized flow fields (Batchelder *et al*., 2002), and site-specific models with realism (*e.g*., Dinniman *et al*., 2011; Hermann *et al*., 2009; Miller *et al*., 1998). Coupled biophysical modeling advanced greatly as the realism of circulation models improved. Physical–biological models evolved to systems of inter-connected models that included circulation, LTL dynamics, and individual HTL (especially fish) growth, and sometimes HTL population dynamics by inclusion of reproduction and recruitment. Transport pathways and controls on individual and population growth could be tracked, spawning areas identified, and spatial connectivity of populations estimated. For some of these (*e.g.*, connectivity), model-based estimates are difficult to validate because direct observations of connectivity are lacking.

The more powerful computers available during the GLOBEC decades had their most significant impact by enabling data-assimilative models of substantial complexity and high resolution. Data assimilation was greatly improved and applied to U.S. GLOBEC study regions to understand processes, to better estimate uncertain parameters, and to provide improved state estimates, particularly in regions subject to strong mesoscale variability. While to date the emphasis has been on assimilation of physical data, there is strong evidence that assimilation of physical data improves ecosystem state estimates in coupled bio-physical models (Fiechter *et al*., 2011).

U.S. GLOBEC significantly advanced the state of the field in linking regional ocean models with global climate models. Most global climate models do not represent continental shelves well, and the impact of continental shelf dynamics on the offshore regions, although important, is missing. Moreover, coastal regions are the sites of greatest anthropogenic change and greatest concern for the future. Climate-regional linking in the program was bidirectional, with both downscaling and upscaling. Accurate models of high resolution shelf dynamics, say in Eastern Boundary Current Regions, could have significant impacts on climate models both locally and remotely. Enrique Curchitser led this effort, working with the NCAR global climate model.

Just as important as the data sets and knowledge generated during the course of U.S. GLOBEC is the legacy of the next generation of scientists produced through their involvement in GLOBEC science. Hundreds of people participated as PIs, undergraduate and graduate students, postdoctoral investigators, technicians, program managers, and in many other ways. For many of them, the program was their introduction to science that was multi-disciplinary by design. Thus, these young scientists are trained in new ways that equip them to lead ocean and ecological investigations into new frontiers in the future. Many will have very successful careers and transmit the “GLOBEC way” to their own students, thus propagating the multi-disciplinary approach into the future. At the symposium three young scientists (two were graduate students and one a postdoc in GLOBEC) described their GLOBEC research and how it influenced their careers.

Dr. Ari Friedlaender did his doctoral research on the Western Antarctic Peninsula during the GLOBEC Southern Ocean program, receiving his Ph.D. in 2006 for his thesis,



Loo Botsford (back to camera) describing the significance of his salmon and cod research to Steve Murawski during the poster session (photo by Beth Turner).

Mark Ohman and Frank Schwing enjoying the poster session (photo by Ian Perry).

Jeff Runge, Beth Turner and Zack Powell enjoying tapas. Phil Taylor and Cisco Werner seated in background (photo by Ian Perry).

"*Spatial ecology of humpback and minke whales off the Western Antarctic Peninsula*". Before GLOBEC, Antarctic whale research was dominated by "whaling records" providing information on biology, life history and stock structure, and by coarse-scale surveys over broad regions. During Ari's research the emphasis shifted to quantitative studies of whales concurrent with their physical habitat and prey resources. This was feasible on Southern Ocean GLOBEC cruises because the large multi-disciplinary research teams provided environmental data to complement the whale studies. Dr. Friedlaender's work on cetaceans in the Southern Ocean continues with focused tagging of individuals to quantify underwater feeding behavior and prey patch selection.

Dr. Julie Keister received her Ph.D. from Oregon State University in 2008 for her dissertation, "*Variability in mesoscale circulation and its effects on zooplankton distribution in the Northern California Current*". Julie started with U.S. GLOBEC as a research technician working in the laboratory of William Peterson in Newport, Oregon, where she was responsible for sampling zooplankton during the Long-Term Observation Program and mesoscale survey cruises. Dr. Keister is now an Assistant Professor at the University of Washington, where she continues GLOBEC research as a co-PI with Dr. Manu Di Lorenzo and others in pan-regional synthesis.

Dr. Enrique Curchitser began working on GLOBEC physical modeling in the California Current System (CCS) and later the Coastal Gulf of Alaska (CGOA) as a postdoc. He produced the first GLOBEC physical model results in the CCS (*ca.* 2002), multi-decadal North Pacific Basin scale simulations and coupled biophysical models. Subsequently, Enrique linked high-resolution coastal ocean models to coarse-resolution climate models of the type used by the IPCC for long-range predictions of future conditions. Enrique is adding fish populations and fishing fleets, including behavior and economics into coupled ecosystem-circulation models. These three and others represent a new generation of GLOBEC trained scientists that not only links across disciplines within traditional natural sciences, oceanography and fisheries, but also links to social science (human activities).

As summarized by Ian Perry, the fundamental concepts of the GLOBEC way of doing science developed in the United States became a blueprint for other national GLOBEC studies undertaken worldwide. Moreover, U.S. GLOBEC approached SCOR, ICES, and IOC-UNESCO to develop an international program (IOC-SCOR Workshop, May 1991), which established the central themes of GLOBEC International. In 1995, the IGBP approved GLOBEC as a core project, with co-sponsorship by SCOR and IOC. As neither U.S. GLOBEC nor International GLOBEC were able to address all issues and provide answers to all questions, several challenges remain. A remaining task is to provide **meaningful** forecasts and projections of marine population variability and response to climate change and human influences. This will require continued sustained observations, large-scale meta-comparisons, improved integration of ocean observations and models, explicit inclusion of humans as drivers of change and recipients of ocean ecosystem services, better integrated scenario development and analysis that include uncertainty estimates, and improved communication of projections to policy makers and the public.

Final words

Although the October event was billed as the "Final GLOBEC Symposium and Celebration", we choose to believe that the event was not the final celebration of U.S. GLOBEC, but rather that 20 or 40 years hence a future generation of ocean scientists and managers, likely still confronting climate change and it impacts on coastal ecosystems, will be celebrating the foresight of NSF, NOAA and U.S. GLOBEC for having invested significant resources into the coupled physical, chemical and ecological investigations of the four target ecosystems: the Northwest Atlantic/Georges Bank, the Northern California Current, the Coastal Gulf of Alaska, and the Antarctic Peninsula.

Ed Houde concluded his talk on whether U.S. GLOBEC met the challenges and objectives it established in the early 1990s by posing the following question, *What are the three major contributions of U.S. GLOBEC that will insure the legacy of the program?* One is hard pressed to come up with only three major contributions (Table 3).

Postscript: One of us (HPB) as the coordinator for the GLOBEC Scientific Steering Committee (SSC) during 1992–1998 was responsible for recording the minutes of the SSC meetings, including notable quotes, the best of which became known as the Quote of the Meeting (QOTM). For the Final U.S. GLOBEC Symposium, the QOTM is from Loo Botsford for the statement, "*Dave Mountain is the George Carlin of GLOBEC*".

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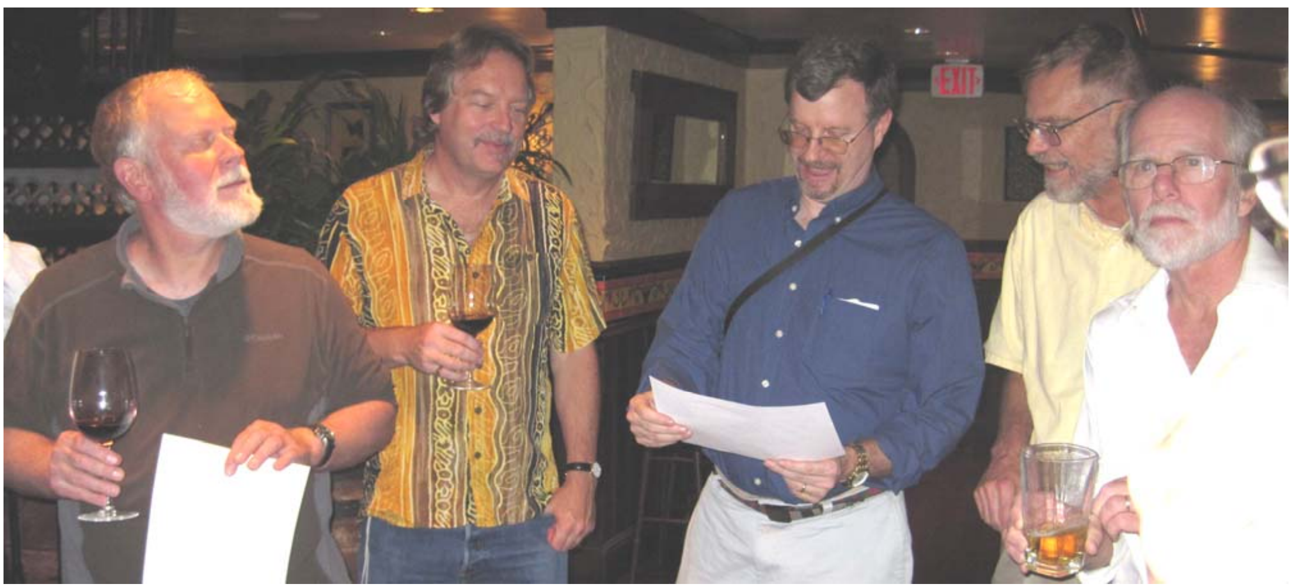

From left to right, Dale Haidvogel, Art Miller, Hal Batchelder, Bob Beardsley and Dave Mountain enjoy some of the "celebration" portion of the symposium (photo courtesy of Ian Perry).

Dr. Harold (Hal) Batchelder (hbatchelder@coas.oregonstate.edu) is a Professor in the College of Oceanic and Atmospheric Sciences at Oregon State University, U.S.A. His present research focuses on individual based modeling the biological–physical coupling of marine environments and marine populations, including studies on Calanus finmarchicus in the North Atlantic, and krill and juvenile salmon in the Northeast Pacific. In PICES, Hal served as Co-Chairman of the Climate Change and Carrying Capacity (CCCC) program and as a Science Board member from 2001–2009, and presently as a member of the FUTURE Advisory Panel on Status, Outlooks, Forecasts and Engagement. He is active in the PICES Marine Ecosystem Model Intercomparison Project (MEMIP). He was a Coordinator of the U.S. GLOBEC National Program for 6 years, and Executive Director of the U.S. GLOBEC Northeast Pacific regional program for 12 years.

Dr. Dale Haidvogel (dale@marine.rutgers.edu) is a Professor in the Institute of Marine and Coastal Sciences (IMCS) at Rutgers University, U.S.A. His research interests include the modeling of regional climate impacts, numerical and laboratory studies of fundamental earth system processes, and the development of advanced algorithms for geophysical modeling. Dale founded the IMCS Ocean Modeling Group which has as one of it foremost goals the implementation and distribution of interdisciplinary ocean modeling systems, including coupled models for atmosphere/ocean, biogeochemical, and ecosystem responses. Modeling software developed by the Ocean Modeling Group, and its colleagues, is now in world-wide application (www.myroms.org). Dale has served as Director of the U.S. GLOBEC National Office for the past 8 years.

Dr. David Mountain (dmountain@capecod.net) is an oceanographer who worked at the NOAA Fisheries laboratory in Woods Hole, MA, U.S.A. for many years before retiring in 2007. He was a Principal Investigator in the U.S. GLOBEC Georges Bank study and a member of the U.S. GLOBEC Scientific Steering Committee. He currently is an Adjunct Scientist with both the Woods Hole Oceanographic Institution and the University of Arizona in Tucson.