12th Arctic Ocean Model Intercomparison Project (AOMIP) Workshop
Woods Hole, Massachusetts, USA, 14-16 January, 2009

WORKSHOP REPORT

Introduction

Andrey Proshutinsky, the AOMIP Principal Investigator, opened the 12th AOMIP workshop by welcoming the participants (see Appendix A) and presented an overview of AOMIP history, major goals, tasks, strategy and tactics. Major goals and objectives for a new AOMIP development phase were also formulated (see Appendix D). The purpose of this workshop was to plan the next phase of the AOMIP program by identifying new scientific priorities, potential collaborations and deliverables. The workshop was planned to:

- Re-initiate AOMIP activities
- Identify the most important directions of model improvements
- Discuss and establish conditions for coordinated numerical experiments focusing on model improvements
- Discuss future AOMIP plans and strategy

Proshutinsky also provided an update on the status of the efforts to maintain AOMIP activities under new NSF funding recommendations. One major recommendation was to change AOMIP's operational mode (Appendix D).

Workshop Format

Each workshop day consisted of two types of activities, namely: (i) science talks and (ii) discussions focused on identification of key problems and formulation of conditions for coordinated AOMIP experiments. Science talks and discussions were organized under five major topics: 1) Fresh water and heat, 2) Sea ice, 3) Model development progress and results, 4) Exchanges/transports and ecosystem modeling, and 5) Long-term model integrations. One-hour breakout sessions were used to formulate the conditions for a set of coordinated experiments. These breakout sessions were followed by a plenary session on the last day of the workshop.

Workshop Overview

The workshop brought forty one AOMIP collaborators from Canada, Denmark, France, Japan, Germany, Russia, United Kingdom, and USA representing twenty four different federal, state and private organizations (universities, scientific institutions and centers). Thirty two scientific presentations were accompanied by more then five hours of discussions (not mentioning *tête-à-tête* interactions and fruitful *corridor* meetings during coffee breaks, reception and workshop dinner). The most important workshop result is a formulation of a set of coordinated experiments directed to improve AOMIP regional and global models and to investigate causes and consequences of Arctic climate change.

Scientific problems for coordinated experiments

A set of scientific problems was identified during the workshop. It is expected that the teams working on these experiments will be expanded after publication of this report via involvement of all interested scientists dealing with Arctic studies. Team leader names (PIs of experiments responsible for experiment formulation, activation, data collection, analysis and publications) are shown in bold. Also note that each of these experiments will possibly have a set of sub-experiments with sub-leaders.

1. ***Bering Strait volume, heat and salt fluxes:*** **M. Steele**, R. Woodgate. W. Maslowski

This is a collaborative model-observational study of volume, heat, and freshwater fluxes through Bering Strait, an important arctic gateway. This experiment focuses on this strait because of its physical importance for the Arctic Ocean ice and water dynamics and thermodynamics. A set of numerical experiments and model intercomparisons seeks to answer a series of important scientific questions, validate Arctic regional and global models using Bering Strait historical and recently collected data, and to recommend important model improvements allowing reproduction of the Bering Strait – related changes in the entire Arctic Ocean. The conditions of the desired model output from each participant/model, including (i) location, (ii) parameters, (iii) time period and resolution, and (iv) model description are discussed in Appendix C.1.

2. ***Canada Basin: shelf-basin exchange and mechanisms:*** **W. Maslowski**, E. Watanabe, G. Nurser

The major science questions for these experiments are: (1) How much of the heat and fresh water associated with the Pacific Water are transported from the Chukchi shelf to the Canada Basin across the Beaufort shelf break by meso-scale eddies? (2) What are the mechanisms controlling generation and development of meso-scale eddies which are thought to play an important role in the shelf-basin mass, heat and fresh water exchanges? Conditions for this experiment and model output parameters are presented in Appendix C.2

3. ***Pacific Water circulation (origin, forcing, pathways):*** **Ye. Aksenov**, R. Gerdes, A. Nguyen, E. Watanabe, A. Proshutinsky

The circulation of Pacific Water may be coherent with the surface currents but its pathways are not known from direct observations. Recently the vertical structure of this layer and its properties have been revised by Shimada *et al*., (2001) and Steele *et al.,* (2004) where the presence of two types of summer Pacific halocline water and one type of winter Pacific halocline water in the Beaufort Gyre were reported. According to the Environmental Working Group analysis, the total thickness of the Pacific layer in the Beaufort Gyre is approximately 150 m. This thickness is subject to temporal variability (McLaughlin *et al.,* 2003) depending on wind stress and circulation modes (Proshutinsky *et al*., 2002). Steele *et al.* (2004) found similar evidence in their examination of data from the 1980s and 1990s. Accordingly, it is important to investigate the variability of the different Pacific-origin water components, their circulation patterns and their role in stabilizing or destabilizing the Canada Basin and the Arctic Ocean climatic circulation.

Conditions proposed for this experiment and model output parameters are presented in Appendix C.3

4. ***Canada Basin: major mechanisms of halocline formation and variability:*** **A. Nguyen**, Ye. Aksenov, E. Watanabe

These studies will be focused on investigations of: How to better model the arctic halocline which creates the stratification necessary to insulate perennial sea ice from the Atlantic Water layer? and How to avoid restoring and flux correction procedures in numerical models? These studies will also answer scientific questions such as: what is the role of different mechanisms influencing heat fluxes in the ocean - sea-ice - atmosphere system? Other scientific questions and conditions of numerical experiments and model intercomparisons are presented in Appendix C.4.

5. ***Circulation and fate of fresh water from river runoff (pathways and seasonal transformation due to mixing and freezing)***: **Ye. Aksenov**, A. Jahn

A relatively recently published paper **"**Sensitivity of the thermohaline circulation to Arctic Ocean runoff" by Rennermalm et al (2006) investigates how changes in Arctic river discharge may control thermohaline circulation by a series of experiments with an intermediate complexity global climate model. The study does not, however, study how the arctic river runoff reaches the North Atlantic and how much time it takes for this water to influence the THC. This study will fill this gap and will answer a set of scientific questions about pathways of river water and its transformations. Conditions for intercomparison experiments are outlined in Appendix C.5.

6. ***Beaufort Gyre: mechanisms of fresh water accumulation and release (origin of the BG freshwater reservoir, sources and sinks, role of sea ice dynamics and seasonal transformations, Ekman pumping):*** **A. Proshutinsky** (ocean), **W. Hibler** (ice), R. Forsberg, A. Jahn, E. Watanabe, S. Hakkinen

Hydrographic climatology shows that due to a salinity minimum which extends from the surface to approximately 400m depth, the Canada Basin contains about 45,000 km^3 of fresh water. This value is calculated relative to a reference mean salinity (34.8) of the Arctic Ocean and specifies how much fresh water is accumulated in this region from different sources (ice melting and freezing, rivers, atmospheric precipitation and water transport from the Pacific and Atlantic Oceans via straits). Proshutinsky et al. (2002) hypothesized that in winter, the wind in the Canada Basin drives sea ice and ocean in a clockwise sense, accumulating freshwater in the Beaufort Gyre (BG) through Ekman convergence and subsequent downwelling. In summer, winds are weaker and the BG releases fresh water. At the same time, thermodynamic processes may also be important - in winter, ice growth and subsequent salt release reduce the FWC of the BG, and in summer, ice melt increases the FWC. The interplay between dynamic- and thermodynamic forcing is undoubtedly complex. This problem can be solved by AOMIP coordinated experiments specifically designed to understand the major mechanisms of fresh water accumulation and release in the BG Region. Appendix C.6 describes conditions of these experiments.

7. ***Fresh water balance of the Arctic Ocean: seasonal and interannual variability (sources, sinks, pathways):*** **A. Jahn**, R. Gerdes, A. Nguyen, Ye. Aksenov, W. Maslowski, C. Herbaut

This research will attempt to answer the fundamental questions: How does fresh water enter the Arctic Ocean system? How does it move about including undergoing phase changes? How does it finally exit the system? First, groups responsible for this activity will evaluate how well models can reproduce pan-Arctic freshwater budget by comparison of model outputs budgets of Serreze et al. (2006). We anticipate that most (but perhaps not all) models will achieve freshwater balance in the upper layers including the AW after several decades. How these balances are actually achieved will provide insight into model physics. Zhang and Steele (2007) have shown how the magnitude of numerical vertical mixing can affect salinity structure within the Beaufort Gyre. More information about these experiments is available in Appendix C.7.

8. ***Atlantic Water circulation (circulation patterns, variability and heat exchange, model validation based on observations):*** **R. Gerdes**, Ye. Aksenov, A. Nguyen, W. Maslowski, C. Postlethwaite, R. Gerdes

The cyclonic pattern of Atlantic water propagation along the continental slope, proposed by Rudels *et al.* (1994) is supported by some numerical models (Holland, Karcher, Holloway, AOMIP, *pers. com.*). However other models (Häkkinen, Maslowski, Zhang, AOMIP*, pers. com.*) show anticyclonic rotation of this "wheel". McLauglin *et al.*, (2004) showed that Atlantic Water as much as 0.5^{o}C warmer than the historical record were observed in the eastern Canada Basin relatively recently. These observations signaled that warm-anomaly Fram Strait waters, first observed upstream in the Nansen Basin in 1990, had arrived in the Canada Basin. The mechanisms that drive the mean and time-varying Atlantic Water circulation require further investigation. The major experiments for these studies can be subdivided on three categories reflecting a) the general circulation of the Atlantic Water layer and causes of its variability; b) investigation the Atlantic Water inflow via Fram Strait in via St. Anna Trough (the Kara and Barents Seas), and c) model validations based on observations from NABOS project along the Siberian continental slope. Major details and conditions for these experiments are summarized in Appendix C.8.

9. ***Ecosystem experiments:*** **K. Popova**, M. Steele, F. Dupont, D. Holland, T. Reddy, C. Hill, E. Hunke

Recognizing that marine ecosystem modeling is complex and that the ecosystems come in many forms, even in the Arctic Ocean environment, the AOMIP has decided to formulate a set on coordinated experiments to incorporate a relatively simple ecosystem modeling in their regional models of the Arctic Ocean. These experiments are important to our understanding of the changing Arctic marine environment. The arctic ecosystems are often highly complex and are affected by both cyclic and stochastic influences. Computer models, combined with suitable data-collection programs, can help in deepening our understanding of these systems and how they will react to various influences (from climatologic to human). The first-order proposed set up experiments are outlined in Appendix C.9.

10.Observations, state estimation, and adjoint methods: **P. Heimbach,** F. Kauker and D. Stott

The major goal for this session was to discuss the role of observations for AOMIP, and the need of taking optimal advantage of them through rigorous estimation (data assimilation) methods. It was recognized that depending on the application, very different requirements are placed on the estimation/assimilation system which have to be recognized and respectively evaluated. Another problem was to identify the relevant data (both observational specifically organized for AOMIP model validation), and where and how to archive the data for better distribution among AOMIP collaborators and throughout the Arctic observational and modeling communities. The major conditions and recommendations are presented in Appendix C.10.

11. Sea-ice drift and changes in drag: **T. Martin,** V. Dansereau, B. Hibler, D. Huard, J.-F. Lemieux, M. McPhee, M. Steele, B. Tremblay,

A gradual increase in sea-ice drift speeds has been observed over the last 60 years (Hakkinen et al., 2008) raising the following questions: (1) Do numerical models capture this behaviour? (2) What causes/influences the speed change: a) in reality b) in individual models? (3) Does the description of momentum exchange in large-scale models need to be revised?

A large part of the observed increase in sea-ice drift speed can be explained by the increase in wind stress on the ice (Hakkinen et al., 2008). As most AOMIP model experiments included atmospheric forcing from reanalysis products, we expect simulated sea-ice drift speed to follow a positive trend. However, the current freshening of the Arctic Ocean's top layers also influences the drag between sea ice and ocean (M. McPhee, pers. comm.). Also, thinner, more deformable ice might explain part of the speedup.

A comparison of time series of monthly ice drift speeds averaged for the region north of 80N from various AOMIP models (output from coordinated experiments in 2006/2007) reveals that the response of the models to the increased wind stress in the forcing data differs in strength and even in the sign of the trend for the period 1979-2001 (T. Martin, pers. comm.). In order to answer the questions above, it is necessary to look into the individual components of the momentum balance in each model. And though monthly averaged output can be used to answer questions (1) and (2), high resolution output (e.g. daily) at least at reported buoy locations would be necessary to work on question (3), because the balance of forces in the momentum balance changes with the averaging period (Steele et al., 1997). More details are provided in Appendix C.11.

Next AOMIP Meetings

1. AOMIP collaborators were invited to organize a session in MOCA-09 (IAMAS, IAPSO and IACS Joint Assembly, to be held in July 19-29, 2009 in Montréal, Québec, Canada). Prior to that assembly, AOMIP collaborators are also participating in the modeling workshop “Arctic System Modeling Workshop III” (International Collaboration in Arctic System Modeling) to be held on July 16-17, at the University of Quebec at Montreal (UQAM) (http://www.iarc.uaf.edu/workshops/2009/arctic_system_model_09/)

2. The AOMIP participants agreed to meet again in fall 2009 (October 21-23, 2009), at Woods Hole Oceanographic Institution to report about numerical experiments and other project results

Action: Plan and coordinate 13th AOMIP workshop in fall 2009. *Andrey Proshutinsky, Michael Steele, David Holland*

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Zhang, J., and M. Steele (2007), Effect of vertical mixing on the Atlantic Water layer circulation in the Arctic Ocean, J. Geophys. Res., 112, C04S04, doi:10.1029/2006JC003732

APPENDIX A. LIST OF PARTICIPANTS

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APPENDIX B. AGENDA

Wednesday, January 14
Clark, 507

8:00 8:30 Andrey Proshutinsky: Introduction (welcome, AOMIP, and workshop major goals and tasks)

SESSION 1: FRESH WATER AND HEAT

8:30 9:00 Maslowski, Wieslaw (Naval Postgraduate School): Modeling Oceanic Heat Convergence into the Arctic Ocean
9:00 9:30 McPhee, Miles: (McPhee Research Company) Changes in Fresh-Water Content in the Arctic: Results from the 2008 Late Winter Survey
9:30 10:00 Proshutinsky, Andrey (WHOI): Arctic Ocean Freshwater observational and model results
10:20 10:50 Steele Mike et al. (University of Washington): Summertime upper Arctic Ocean warming and its impact on sea ice melt
10:50 11:20 Holland, David (NYU): Melting and Acceleration of Greenland Outlet Glaciers Triggered by Warm Subsurface Ocean Waters
11:20 11:50 Herbaut, Christophe and Marie-Noelle Houssais (LOCEAN): Role of arctic fresh water outflow in the North Atlantic subpolar gyre variability.
12:50 13:20 Forsberg, Rene (Danish National Space Center): Arctic Ocean dynamic topography from satellite altimetry and gravity (ICESat, GRACE and in-situ data)
13:20 13:50 Jahn, Alexandra (McGill University): Effect of the large-scale atmospheric circulation on the variability of the Arctic Ocean freshwater export
13:50 14:05 Berloff, Pavel (Woods Hole Oceanographic Institution): CABARET: new tracer advection scheme

14:05 14:30 Discussion: FRESH WATER AND HEAT COORDINATED EXPERIMENTS (Moderators: W. Maslowski and A. Proshutinsky)

SESSION 2: SEA ICE

14:40 15:10 Tremblay, Bruno (McGill University): Sediment transport by sea ice
15:10 15:40 Hunke, Elizabeth (Los Alamos National Laboratory): Age characteristics in a multi-decadal Arctic sea ice simulation
15:40 16:10 Lemieux, Jean-Francois (McGill University): Improving the nonlinear convergence properties of VP models with the Jacobian free Newton Krylov method
16:10 16:40 Heimbach, Patrick (MIT): Adjoint sensitivities of sea-ice export
16:40 17:10 Hibler, Bill (International Arctic Research Center): On Modeling Tidal and Inertial Variability in Sea Ice Drift and Deformation

Thursday, January 15
Clark, 507

SESSION 2 cont. SEA ICE

8:00 8:30 Huard, David (McGill University, Canada): Forcing an Arctic Sea Ice Model with NARR Surface Winds: How to Stitch Two Datasets
8:30 9:00 Martin, Torge (Geophysical Fluid Dynamics Laboratory, Princeton University): Impacts of Interactive Icebergs on Ocean and Sea Ice in a GCM

9:00 9:30 **Discussion: SEA ICE MODELING AND COORDINATED EXPERIMENTS** (Moderators: E. Hunke and T. Martin)

SESSION 3: MODEL PROGRESS AND MODEL RESULTS

9:30 10:00 Holloway, Greg (Institute of Ocean Sciences, Canada): Progress from a new-to-AOMIP model from Bedford Institute of Oceanography, Canada
10:20 10:50 Dukhovskoy, Dmitry, P. Posey, J. Metzger, A. Wallcraft and Eric Chassignet (Florida State University, Navy Research Laboratory): Validation analysis of the 0.72 degree HYCOM/CICE 4.0 2003-2006
10:50 11:20 Panteleev, Gleb (International Arctic Research Center, UAF): Reconstruction of the Chukchi Sea water circulation 1990-1991
11:20 11:50 Nguyen An T (Jet Propulsion Lab, California Institute of Technology): Improved modeling of the Arctic halocline with a sub-grid-scale brine rejection parameterization
12:50 13:20 Dupont, Frederic et al. (The Bedford Institute of Oceanography and Dalhousie University): Performance of NEMO-ORCA1 and NEMO-ORCA025 in the Arctic
13:20 13:50 Model improvement coordinated experiments (Moderators: D. Holland and G. Holloway)

SESSION 4: EXCHANGES/TRANSPORTS AND ECOSYSTEM MODELING

13:50 14:20 Hill, Chris (Massachusetts Institute of Technology): Exchanges between Arctic and outside in eddying global runs
14:40 15:10 Spall, Mike and Robert Pickart (Woods Hole Oceanographic Institution): Wind-driven circulation and exchange across the southern Beaufort Sea shelfbreak
15:10 15:40 Watanabe, Eiji (International Arctic Research Center): Pacific water transport in the Arctic Ocean simulated by an eddy-resolving sea ice-ocean model
15:40 16:10 Zhang, Jinlun et al. (Polar Science Center, University of Washington): 3D physical-plankton modeling of the arctic seas
16:10 16:40 Reddy, Tasha (Calgary University and New York University): Arctic Ocean Ecosystems: A Comparison of the Alaskan and McKenzie Shelves (SBI and CASES)
16:40 17:10 Semiletov, Igor and Natalia Shakhova (International Arctic Research Center, UAF): Some specific features of carbon fluxes over the East Siberian Shelf: from monitoring to modeling

17:10 17:40 Aksenov, Yevgeny, Katya Popova, and Steve Alderson(National Oceanography Centre, Southampton, UK): High-resolution global coupled sea ice-ocean-ecosystem modeling: focus on the Arctic

Friday, January 16
Clark, 507

8**:00 8:30** **Discussion:** **ECOSYSTEM MODELING IN AOMIP FUTURE AND COORDINATED EXPERIMENTS** (Moderators: D. Holland and M. Steele)

SESSION 5: OTHER RESULTS

8:30 9:00 Gerdes, Ruediger (Alfred Wegener Institute, Germany): Long term perspective on Arctic sea ice from AOMIP hindcasts and coupled climate models
9:00 9:30 Hakkinen, Sirpa (Goddard Space Flight Center): Comparison of POM models with SODA ocean reanalysis
9:30 10:00 Postlethwaite, Clare (Proudman Oceanographic Laboratory, UK): Arctic modeling at the Proudman Oceanographic Laboratory, UK
10:20 10:50 Kauker, Frank and Michael Karcher (O.A.Sys - Ocean Atmosphere Systems): S4D/DAMOCLES modeling/assimilations activities in the ocean and sea ice

10:50 11:20 Discussion: MODEL IMPROVEMENTS AND COORDINATED 100-YEAR EXPERIMENTS (Moderator: R. Gerdes and A. Proshutinsky)

11:20 14:50 GROUP MEETING TO DETERMINE THEMES, GOALS AND CONDITIONS OF COORDINATED EXOERIMENTS

14:50 15:00 Workshop adjourn and final remarks

APPENDIX C. CONDITIONS FOR COORDINATED EXPERIMENTS

C.1 Bering Strait volume, heat and salt fluxes: **M. Steele**, R. Woodgate. W. Maslowski

This is a study of volume, heat, and freshwater fluxes through the Bering Strait, an important arctic gateway. We focus on this strait because of (1) its physical importance and (2) the relatively abundant observational database in the area. The following outlines the desired model output from each participant, including (i) location, (ii) parameters, (iii) time period & resolution, and (iv) model description.

<u>Location</u>: Your model section should be as close as possible to this section (in decimal degrees):
From: **65.980** degN**,** **169.643** degW
To: **65.625** degN, **168.177** degW

- Please provide:
    - Model **lat/lons** for your section across the strait that most closely match these endpoints
    - Model **bathymetry** at each position

Also, (for comparison to the "climate" mooring site A3 just north of Bering Strait), the lat/lon and ocean depth of your model point nearest to **66.33** degN, **168.965** degW

<u>Parameters</u>:

Properties for comparison along the Strait and at mooring site A3:

- **<u>Ocean temperature</u>**, **<u>salinity</u>**, and **<u>velocity</u>** at all points across your Bering Strait section (for example, for each time, an array of points in x and z (depth).
- Ocean T, S, and v for the model point closest to mooring site A3 (see "Location" section)
- Mean **<u>ice thickness</u>**, **<u>concentration</u>**, and **<u>velocity</u>** at all Bering Strait points

Fluxes for comparison: (if you do not have these, we will compute them from the properties)

- Net ocean **<u>volume flux</u>** across the strait
- Net ocean **<u>heat flux</u>** - relative to -1.9°C
- Net ocean **<u>freshwater flux</u>** – relative to reference salinity of 34.8
    - If possible, please also provide separate northward and southward fluxes for the above
- **<u>Ice area flux</u>** and **<u>ice volume flux</u>** across your Bering Strait section

<u>Time period & resolution:</u>

<u>Period</u>: As long as available but ideally covering at least **1990-present** (the period of intensive observations)

<u>Resolution</u>: We encourage at least **monthly mean** resolution, although more frequent data will be considered if available. We discourage the use of "snapshot" data.

<u>Model description</u>:

As in Holloway et al., "Water properties & circulation in Arctic Ocn models," JGR vol 112, 2007:

- Tables A1, A2, A3, A4, A6, A7, A8, A9, A10, A14, A15, A16
- what ocean and sea ice model was used
- what forcing prescribed (including timescale of the forcing – hourly, monthly, etc)
- any particular forcing/adjustments/tuning of the Bering Strait inflow (e.g., local or far field relaxing to a known transport or seasonal cycle or temperature and salinity field, bottom or sidewall friction, "digging out" of channel to give expected transport)

C.2 Canada Basin: shelf-basin exchange and mechanisms: W. Maslowski, E. Watanabe, G. Nurser

a. Questions :
   i. How much of heat and freshwater associated with PW are transported from Chukchi shelf to Canada Basin across Beaufort shelf break by mesoscale eddies ?
   ii. What is mechanisms controlling generation and development of mesoscale eddies which play a great role in the shelf-to-basin transport ?

b. Experiments :
   - Drive eddy-resolving or eddy-permitting sea ice-ocean model by climatological or interannually varying atmospheric forcing
   - Horizontal model resolution should be less than 10 km (W. Maslowski's NAME : 9 km or 2 km?; E. Watanabe's COCO : 2.5 km; G. Nurser's model : global OCCAM 1/12 °, ~ 8 km resolution in the Arctic)
   - Compare the simulation results with some observations (e.g. Pickart, 2004; Pickart et al., 2005) and idealized model experiments (e.g. Spall, 2008)

c. Which fields :
   - Monthly mean time series of shelf-to-basin transport of PW tracer provided at Bering Strait, heat (referenced to seawater freezing point ?) and freshwater (referenced to 34.8 psu) across Beaufort shelf break
   - Vertical section of PW, temperature, salinity and velocity across Barrow Canyon and Beaufort shelf break
   - Mean and eddy kinetic energy in Canada Basin

C.3 Pacific water circulation (origin, forcing, pathways): Ye. Aksenov, R. Gerdes, A. Nguyen, E. Watanabe

a. Questions :
   i. How PW crosses the Arctic Ocean during cyclonic and anti-cyclonic regimes of the circulation?
   ii. How much of FW associated with the PW is in the CAA/Fram Strait outflow; what caused the recent decline of the PW fraction east of Greenland?
   iii. How big was the change in the storage of the PW and associated FW in the

Arctic Ocean over the last 50 years?

b. Experiments :
   - Identify pathways of the PW out of the Chukchi Sea into the Arctic Ocean: ideally we should be able to detect the eastern route into the Beaufort Sea and the western route into the Makarov Basin. Relate the variability of the transports along the routes to the type of the circulation in the Western Arctic.
   - Assess variations of the PW fraction in the polar outflow west and east of Greenland. Compare simulated in models fractions of the PW and FW flux of PW on the main transects. Compare simulations with the observations where possible.
   - From sources and sinks of PW estimate the recent 2001-2008 change of the PW content.

c. Which fields :
   - The model experiments require the PW tracer release in the Chukchi Sea, as close as possible to the Bering Strait. If PW tracer could not be included, TS or density classification for PW might be considered.
   - The standard period for the model fields is 1948-2008, although for some model it will be shorter
   - Monthly-mean depth-averaged 10-250 m horizontal distribution of the PW fraction For the Arctic Ocean.
   - Monthly-mean TS and PW tracer vertical distributions, monthly-mean timeseries of the total and PW-associated FW transports through the sides of the 'box' bounded by meridional transects ~150°W and ~180°W, zonal ~75°N and ~80°N.
   - Monthly-mean TS and PW tracer vertical distributions, monthly-mean timeseries of the total and PW-associated FW transport for the transects across Fram Strait at ~79°N (coinciding with AWI transects) and Davis Strait at ~66.5°N.
   - Monthly-mean timeseries of the total and PW-associated FW transport for the transects across Nares Strait at ~81.5°N, Jones Sound ~80°W, Lancaster Sound at ~94°W, and Hudson Strait at ~70°W, provided the model resolution is high enough to resolve these passages.

C.4 Canada basin: major mechanisms of halocline formation and variability: A. Nguyen, Ye. Aksenov, E. Watanabe

a. Questions :
   1. Halocline represented in models? Changes over time? Compare station data with model output in Canadian Basin
   2. Sources of the Halocline waters in Canadian Basin

b. Experiments :
   - Compare simulated and observed depth and thickness of the halocline layer in Canadian Basin and investigate their variability.

  - Use passive tracers to detect regional sources of the halocline waters

  c. Which fields:
    - Monthly-mean mixed layer depth and depth of the Atlantic core (depth of Tmax for 34.5<S) in the Arctic Ocean.
    - Monthly-mean TS and fields of the passive tracers representing shelf waters, Pacific Water, ice melt, and ventilation tracer.
    - TS on the virtual model stations at the CTD locations or if we can construct/obtain transects from the data then we need co-located model sections: CTD data from SCICEX for 1993-2000, Beaufort Gyre Experiment Project 2003-2005 and ITP data (www.whoi.edu/itp) 2004-2007.

C.5 Circulation and fate of fresh water from river runoff (pathways and seasonal transformation due to mixing and freezing): Ye. Aksenov, A. Jahn

a. Questions :
    i. What is the contribution of the Siberian and American riverine water into the FW storage in the Arctic Ocean and into the export from it.

b. Experiments :
    - The experiments would need river tracers in models and depends on whether people are willing to include river tracers. Two following experiments will be analysed this year but we keep the door open for other simulations.
    - 1958-2006 simulations with mean annual runoff in NEMO-1/4° and river tracers for 6 major rivers, OB, Yenisey, Lena, Yana, Kolyma, Mackenzie rivers, and provisionally Yukon River, Hudson Bay rivers.
    - Fully coupled CCSM3.0 1990 equilibrium climate simulation with runoff tracers for inflow into the different shelf seas (Barents, Kara, Laptev, East Siberian, Beaufort Gyre)

c. Which fields :
    - Tracer fields for 6 major rivers (depth range needs to be specified, in our model we see some river signal below AW layer)
    - Monthly-mean river tracer vertical distributions, monthly-mean timeseries of the river FW transport for the transects across Fram Strait at ~79°N and Davis Strait.
    - Monthly-mean timeseries of the river FW transport for the transects across Nares Strait, Jones Sound, Lancaster Sound, and Hudson Strait, provided the model resolution is high enough.

C.6 Beaufort Gyre: mechanisms of fresh water accumulation and release (origin of the BG freshwater reservoir, sources and sinks, role of sea ice dynamics and seasonal transformations, Ekman pumping): **A. Proshutinsky** (ocean), **W. Hibler** (ice), R. Forsberg, A. Jahn, E. Watanabe, S. Hakkinen

C.6a Beaufort Gyre fresh water transformations: accumulation and release mechanisms

a. Questions:

   i. How well do models reproduce the variability of the FW storage in the Arctic, compared to observed FW content and SSH variability (interannual and seasonal time scale)?

   ii. What % of freshwater in the Beaufort Gyre is due to ice melt, precipitation, river runoff from different rivers, and Pacific inflow?

b. Experiments (following the experiment Andrey designed last year):

- Compare model simulated FW content and SSH variability with observations and among each other to understand FW content variability from seasonal to decadal time scales
- Analyze the contribution of FW from these different sources to the FW in the Arctic Ocean using Pacific water, river runoff, ice melt, and precipitation tracers. Compare with observational data on this subject.
- Compare model outputs from 1948-2008, as well as shorter recent sub periods which can be extended if forcing data is available

c. Which fields:

- Monthly mean model output of the following fields for the region north of 60N including 60N (in original model grid):
  - Freshwater content in m. Please calculate freshwater content (FWC) as: FWC=Integral[(34.8-S)/34.8]dz, where dz is thickness of water layer from surface to bottom (including SSH elevation in case of free-surface models and also partial bottom cells' depth, if it is used) with salinity S. If salinity is greater than 34.8 you will have negative freshwater content and in this case do not take these negative numbers into account and do not sum them up in you total FWC (no negative FW allowed)
  - SSH field
  - sea ice thickness and concentration, snow depth, sea ice, snow and reference water densities, sea ice salinity
  - precipitation minus evaporation fields
  - passive tracer fields, if available
  - Monthly sea ice and snow melt
- Information about SSH in model: rigid lid or free surface
- Information about river runoff: sources, method of introduction into model (reference salinity if virtual salt flux is used), seasonal and interannual variability, if any

C.6b Role of Ekman pumping for FW storage changes in the Beaufort Gyre B. Hibler

a. Questions :
    i Has Ekman pumping played a major role in the recent freshening of the Beaufort Gyre?
    ii To what degree has weakening ice interaction played a significant role in this increased Ekman convergence over the last several decades?

b. Experiments :
    i Comparative experiments with ~30-40 year runs (e.g. 1970-2008)
    ii It is also possible to do some of these comparisons with only a barotropic ocean model
    iii We need to agree on an average region roughly defining the Beaufort Gyre. Then intetrate the stress curl delivered to the ocean system from the various models as a time series over this region over the last several decades. How has this changed and are they comparable?

c. Which fields :
    i For 'imbedded' models whereby the convergence of ice is included in the region as well as water, the relevant term is the curl of the wind stress less the gradient of the ice stress.
    ii For levitated models, you will have to just take the drag on the bottom of the ice.
    iii Fields of sea ice thickness and area coverage and of freshwater storage for the agreed Beaufort Gyre region

C.7 Fresh water balance of the Arctic Ocean: seasonal and interannual variability (sources, sinks, pathways): A. Jahn, R. Gerdes, A. Nguyen, Ye. Aksenov, W. Maslowski, C. Herbaut

C.7a FW export variability

a. Questions :
    i What is forcing FW export variability? Role of atmospheric forcing? Is NAO/AO suitable for comparison with FW export variability?
    ii What controls changes in the phase shift between the Fram Strait and CAA FW export?
    iii What is the mean model FW export through CAA and Fram Strait?

b. Experiments :
    i Assess variability of FW exports in different models, and determine which role atmospheric forcing and SSH fields play in forcing this variability in different models and in the model mean
    ii Investigate how and why the phase of the FW export through Fram Strait

and the CAA changes, and how this might depend on the CAA resolution in models

iii Compute model mean FW exports, and compare with observational budget of Serreze et al. 2006.

c. Which fields :

- Simulation from 1948-2008, or if not possible shorter recent sub periods
- Monthly mean liquid and solid FW flux (relative to 34.8, over full depth of Strait, negative FW allowed) through CAA, Fram Strait (~79°N), Barents Sea (Svalbard to Norway, i.e. along 20 degree E?), and Bering Strait for 1948 – 2008.
    a. Fluxes should be calculated over full depth of straits, relative to 34.8, negative FW allowed (i.e., include all salinities, not just salinities under 34.8)
    b. Need information how fluxes were calculated (with monthly means, daily, instantaneous values?)
    c. Need total fluxes, as well as the fluxes in and out of Arctic Ocean
    d. In high resolution models, needs fluxes for individual straits in CAA: Nares Strait, Jones Sound, Lancaster Sound, Davis Strait and Hudson Strait.
- Monthly mean fields of river runoff and net precipitation FW fluxes
- Need information on whether restoring is used, and details on restoring procedure
- Need details on how river runoff is added (virtual salt flux? If yes, which reference density is used?), sea ice density, sea ice salinity, snow density
- Need information on model resolution and grids (bi-polar, tri-polar, etc.) and forcing (NCEP, ERA-40, etc?)
- Monthly SLP (from the forcing used) and SSH fields

C.7b Solid and liquid FW export □ diversion of liquid FW north of Fram Strait and impact of this on sea ice □ M. McPhee

Questions:

i. How does a phase change in the export of FW affect sea-ice in the Arctic through recirculation?
ii. What vertical model resolution is required to realistically track liquid FW from summer melt?
iii. How is liquid FW partitioned between wind-driven boundary layer transport and ocean geostrophic flow?
iv. How much FW is Ekman pumped to levels below the IOBL direct stress-driven transport?

Experiments:

v. Impact of model vertical resolution on IOBL FWT

    vi. Impact of early season melting (e.g., high IAF in June) on distribution of ice and liquid FW.
    vii. Impact of Ekman pumping on liquid FWT

Which fields:

    viii. Liquid FW transport: FWT=Integral[v*{(34.8-S)/34.8}]dz
    ix. Ice FW transport
    x. Ice/ocean interface fluxes

C.8 Atlantic water circulation (circulation patterns, variability and heat exchange, model validation based on observations): R. Gerdes, Ye. Aksenov, A. Nguyen, W. Maslowski, C. Postlethwaite, G. Holloway

C.8a AW circulation sense and variability: G. Holloway

a. Questions :
    i. Right direction of circulation? Build of previous papers on this topic

b. Experiments :
    - Compare basin-scale AW circulation and topostrophy in the models (Greg Holloway might be interested in pursuing this.)

c. Which fields :
    - Monthly-mean stream functions 1948-2008
    - Model topography
    - Wind curl 1948-2008
    - Momentum balance terms
    - Topostrophy

C.8b Model validation of AW circulation along Siberian Shelf □Ye. Aksenov, A. Nguyen

a. Questions :
    i. How well the AW flow along the shelf is simulated in the models?
    ii. What are routes of the AW flow into the Eurasian and Makarov basins?

b. Experiments :
    - Assess strength, position/depth, TS of the AW flow along the shelf and estimate associated heat/salt fluxes and their variability for 1948-2008. Compare model results with observations.
    - Estimate partitioning of the flow along the Gakkel and Lomonosov ridges and inflow into t he Makarov Basin,

c. Which fields :
    - Monthly-mean timeseries of the total and AW-associated volume/heat/salt transports across specified sections (provisionally ~105°E, ~125°E, ~140°E,

~155°E), and through sides of two 'boxes', around the Siberian end of the Lomonosov Ridge and around the Eurasian end of the Gakkel Ridge. AW is specified with S>34.8 and T>0°C. Additionally, AW fraction, defined from tracers released in the Barents Sea and Fram Strait will be used.

- CTD data and current meter data from moorings from the NABOS transects 2002-2008.

C.8c AW inflow: **W. Maslowski**, A. Nguyen, Ye. Aksenov, C. Postlethwaite, R. Gerdes

a. Questions :

  i. How well represented? Dependence on resolution and/or parameterizations. Effect of circulation of AW in the Arctic Ocean?
  ii. Change of the heat storage of the AW layer
  iii. How do tides affect Barents Sea Branch of AW inflow?
  iv. Relative contribution of AW inflow through Fram Strait and the Barents Sea; their dependence on atmospheric forcing, sea ice state, and upstream oceanic conditions
  v. Relative role of buoyancy and wind forcing over the Arctic Ocean for the AW inflow

b. Experiments :

  - Assess strength, position/depth, TS of the AW inflow through Fram Strait and estimate associated heat/salt fluxes and their variability for 1948-2008, compared model results to the published observational estimates.
  - Assess the contribution of heat and salt of the Barents Sea Branch of AW inflow 1948-2008.
  - Estimate heat content of the AW layer in the Arctic ocean
  - Assess impact of including tides in model on AW transport through Barents Sea
  - Compare model versions of different resolution and parameterizations regarding their representation of the AW inflow
  - Calculate time series of AW volume flux north through Fram strait and through the Barents Sea; relate timeseries to atmospheric forcing fields and sea ice fields
  - Modify atmospheric forcing over the subpolar North Atlantic and the Nordic Seas to assess impact of upstream oceanic conditions
  - Modify wind and buoyancy forcing over the Arctic Ocean to assess their respective role for the AW inflow.
  - Idealized experiments to elucidate the cause of AW flow into the Arctic Ocean

c. Which fields :

  - Monthly-mean timeseries of the total and AW-associated volume/heat/salt transports across specified sections in Fram Strait and Barents Sea (provisionally AWI transect, Norway-Bjornaya transect, St Anna Trough section, Spitsbergen - Franz Josef Land and Franz Josef Land - Novaya

Zemlya sections). AW is specified with S>34.8 and T>0°C. Additionally, AW fraction, defined from tracers release in the Barents Sea and Fram Strait will be used.

- Monthly-mean timeseries of the AW heat content calculated from aforementioned AW definition.
- Monthly-mean TS and velocity fields in the Barents Sea for 2000-2001. Monthly timeseries of the cross-section velocity, T, S, volume, heat and salt transports for the same period across the frequently visited observational transects in the Barents Sea (e.g. Norway-Bjornoya, Vardo, Kola, Wilkitsky Strait, Spitsbergen- Franz-Josef Land, and Franz-Josef Land - Novaya Zemlya sections).
- Monthly-mean sea ice fraction, thickness and sea ice melt fields
- Monthly-mean wind, precipitation less evaporation, SSH

C.9 Ecosystem experiments: K. Popova, M. Steele, F. Dupont, D. Holland, T. Reddy, C. Hill, E. Hunke

Suggestion from Ecosystem Modelling working group

Participants:

Katya Popova (NOCS, UK)
Mike Steele (UW, USA)
Frederick Dupont (BIO, Canada)
David Holland (NYU, USA)
Tasha Reddy (Calgary University, Canada & NYU, USA)
Chris Hill (MIT)
Elizabeth Hunke (LANL)

The proposed plan for intercomparison of ecosystem models is split into two phases. The first phase involves participants with fully coupled physical and biological models. The second phase is based on the results of the first one and aims at the whole AOMIP community.

Phase 1 (Leading author: K. Popova, NOCS)

The working group included representatives from six pan-Arctic or Global modeling projects with fully coupled ecosystems of various complexity (see separate table). All the participants acknowledged potential problems with intercomparison of different ecosystem models embedded into different physical models of different resolution forcing by different atmospheric fields.

In discussion it was decided that three physical factors were likely to play a disproportionate role in Arctic productivity, and that the collation and intercomparison of these with primary production should provide a focus for the research:

1. Maximum penetration of the winter mixing (maximum UML depth during the year whenever it happens, 2D field, discontinuous).

    Justification: winter mixing provides the main mechanism of the nutrient supply to the photic zone; combined with deep nutrient distribution (either from Levitus climatology or from model output) provides a good estimate of amount of nutrients available for the phytoplankton primary production

    Potential problems: estimating maximum on the base of different average period of the standard output (e.g. monthly means vs 5 days means); difference in definitions of the UML depth between the models

    To be discussed: do we need to use unified definition of the UML depth?

2. Upwelling rate (annual average vertical velocity at 100m(?) depth, 2D field)

    Justification: In some areas (mostly on the shelf break) upwelling provides additional significant source of nutrients

    Potential problems: Not usually included into the standard model output; will require recalculation from horizontal velocity fields

    To be discussed: what is the optimal depth to analyse vertical velocity at (100m?)

3. Short-wave radiation at the ocean surface (taking into account cloud cover and ice cover) integrated over the period when UML depth is shallower than 80m(?) (2D field)

    Justification: primary production is limited by light availability especially in the areas with permanent or seasonal ice cover. Integration over the period when UML is shallow will take care of the Nordic Seas where deep convection prevents Primary Production no matter how much of the short-wave radiation is available [Strictly speaking instead of 80m or any other fixed depth we should use a depth of the photic zone, however it is variable and a function of phytoplankton which seems to be an unnecessary complication]

    Potential problems: ecosystem models are probably substantially different in their calculation of the photosinthetically active radiation in a grid cell with a fractional ice cover.

    To be discussed: is 80m (see above) a good estimate of the photic zone?

Synthesis:

1. The working hypothesis of the Phase 1 is that 60-80% of the variability of the primary production can be explained by the variability in the three physical factors mentioned above. Thus we can have a constructive way forward for comparison of the various

ecosystem models by comparing the relevant physics first. Then we can proceed by explaining the rest by difference in our ecosystem models or additional physical factors (e.g. horizontal nutrient transport).

2. Provided that (1) is correct all models can train a regression model using three 2D fields described above and Levitus nutrient climatology to estimate *2D annual mean primary production*.
3. On the basis of model comparison with observations, the best model will be selected, and its regression will be used in phase two.

Timescales (dates to be identified):

Deadline1: participants are providing 3 physical fields identified above (UML, w, short-wave rad) as well as mean annual primary production. Additional fields of interest (to be discussed): grazing, f-ratio, Chlorophyll (or biomass), nutrients.

Deadline 2: analysis of the fields and attempt at creating regression models

Deadline 3: validation(*) of the models; selection of the best one (if at all possible) to use its regression model in Phase 2.

(*)Model validation [was not discussed by the working group, please add your suggestions]

- UML depth climatology (monthly means)
- Satellite-derived Chl-a (monthly means)
- Satellite derived primary production (?) and synthesis by Carmack et al. (2006)
- Nutrient climatology

Phase 2 (Leading author: M.Steele, UW)

The aim of phase 2 is to estimate Primary Production based on regression model of Phase 1 (including "best performing regression" and "regression of best performing model") using as many physical models as possible. Comparison of these estimates should give a clear indications of the following:

- which geographical areas are the most sensitive to the errors in the physical models
- how sensitive ecosystem model to the errors in the physical fields
- what level of ecosystem model complexity in Arctic is appropriate in the climate modelling

*Phase 3 (*was not discussed during the working group, leading author was not identified)

During the final discussion a number physical modellers expressed an interest to include a simple identical "black box" ecosystem model. Such a model can be developed by participants with fully coupled ecosystem models.

C.10 Breakout session on observations, state estimation, and adjoint methods. Memo prepared by P. Heimbach (heimbach@mit.edu), F. Kauker (frank@oasys-research.de) and D. Stott (stott@ucar.edu)

The session discussed the role of observations for AOMIP, and the need of taking optimal advantage of them through rigorous estimation (data assimilation) methods.

It was recognized that depending on the application, very different requirements are placed on the estimation/assimilation system:

(1) extrapolation: data assimilation in the often-used context of forecasting;

(2) interpolation: state estimation, directed at understanding the system through provision of a model trajectory which is consistent with model equations as well as available observations within prior error bars, and from which closed budgets can be calculated.

Our session was mainly concerned with (2), in recognition that AOMIP's primary goal is understanding the system. Moreover, the development of the adjoint or Lagrange Multiplier Method by several groups (NAOSIM, ECCO) was recognized as a novel tool within AOMIP. Discussion focused on ways in which this tool could be best deployed in support of AOMIP.

(A) Use of the adjoint method for sensitivity calculations:

- Calculate adjoint sensitivities of key Arctic diagnostics/metrics,
- to the extent possible, compare sensitivities between the two currently existing systems (NAOSIM, ECCO),
- increase calculations in resolution and extend in time,
- ask AOMIP groups to test adjoint sensitivities via "guided" perturbation experiments to ascertain whether "robust" features or model artifacts.

(B) Model-data synthesis or state estimation:

- NAOSIM currently focussing on period 2006 to 2008, ECCO attempting 1992 to 2008 (current prototype system in Labrador Sea),
- adjusted atmospheric state and/or parameter may potentially provide useful alternatives to existing atmospheric re-analysis products,

(C) Observations:

Estimation system should use ALL available observations to the extent practicable (the purpose being that the coupled ocean/sea-ice model serves as dynamical interpolator).

To this end, the observation community ought to be made aware of the importance of distributing existing data sets. Collection in unified data format and at centralized data archives would be highly desirable (but will probably not be achievable). Categories of observations may be (and may provide a unifying structure for data servers): (a) remotely-sensed ocean, (b) in-situ ocean, (c)remotely-sensed sea-ice, (d) in-situ sea-ice, (e) atmospheric state and (f) air-sea fluxes in the Arctic or/and the Southern Ocean.

(D) Uncertainty/error estimates:

A key ingredient for formulating a least-squares model vs. data estimation problem, besides models and observations, are error or uncertainty estimates which should be attributed to each (!) observational element. These include mainly instrument errors, representation errors, and correlations among uncertainties in individual data streams. Without such quantitative estimates no useful estimation system can be put in place.

(E) Distribution & archiving of observations and AOMIP model results

Various data servers already exist (e.g. NSIDC for sea ice, Damocles, etc), and questions are, how to best harness existing servers, facilitate data gathering for modelers, harmonize data formats, and encourage (or enforce?) provision of error estimates and their correlations for each data set.

1) AOMIP is an ARCSS funded project within the NSF Office of Polar Programs, and archiving of metadata for the AOMIP project results would be through the NCAR ARCSS Data Archive, see: http://www.eol.ucar.edu/projects/arcss/

2) The archiving of AOMIP model files – for setting up the model runs and also the output when desired – should be centralized, in order to facilitate data exchange during the experiments and for data stewardship when the project is completed. Metadata records in other archives should point to the data at the centralized archive.

3) NCAR/EOL will work with AOMIP to investigate and pursue the higher level of support for its data management needs. see: http://www.eol.ucar.edu/

C.11 Sea-ice drift and drag coefficients: T. Martin et al.

a) Questions:
   - a.1) Do numerical models capture this behavior?
   - a.2) What causes/influences ice drift speed changes in the individual models?
   - a.3) Does the description of momentum exchange in large-scale models need to be revised?

b) Experiments:
   No coordinated experiments are necessary in first place. It would rather be useful to have

output from a run of the models 'best setting'. If models were run with different atmospheric forcing it would be desireable to have output from all these runs.

c) Which fields:
   This study focusses on the momentum balance of sea ice and thus we seek output of all forces affecting sea-ice velocity. When the model uses a rotated grid please provide components of vector fields in geographical orientation.
   - c.1) Sea-ice velocity (u- and v-component).
   - c.2) Sea- ice thickness and concentration. Please provide information whether thickness is h or h' of h = h' * A, where A is the fraction of the grid cell covered by sea ice, I.e. The sea ice concentration.
   - c.3) Atmospheric and oceanic stress. If stresses are derived in the model code from atmospheric or oceanic velocities, please also provide these equations and the respective input quantities (e.g. wind, ocean current, drag coefficents).
   - c.4) Internal ice force. Please also provide equations used for its derivation and necessary parameters.
   - c.5) Coriolis force.
   - c.6) Pressure gradient force.

d) Temporal and spatial resolution:
   - d.1) monthly averages at every grid point of the model
   - d.2) daily averages at prescribed buoy locations. The buoy locations will be provided including instructions and fortran code on how to read the data file and how to interpolate to the buoy location.

Appendix D. AOMIP operational modes and work scope

1. Current state

Participants or supporters:
More than 60 from Australia, Belgium, Canada, France, Germany, Norway, Russia, Sweden, United Kingdom, and USA

Modeling/observational groups:
There are 25 AOMIP modeling and data processing groups/institutions

Project goals:
- Validate and improve Arctic Ocean models in a coordinated fashion.
- Investigate variability of the Arctic Ocean and sea ice at seasonal to decadal time scales, and identify mechanisms responsible for the observed changes.

Methods:
Coordinated experiments with repetitive/iteration loops including:
- > Coordinated model runs ->
- > Coordinated model validation and intercomparison ->
- > Model improvements -> (back to coordinated model runs)

Current operational mode:
A. Carry out:
Numerical experiments; validate models; inter-compare model results for parameters or processes for which group is responsible; introduce model improvements and test them; provide recommendations for other groups and repeat coordinated experiments with improved models

B. Collect and organize:
Observational data archives suitable for AOMIP model validation and share these data with other modeling groups. Major parameters include: hydrography (T&S), sea ice (concentration, age/thickness and drift), sea level including bottom pressure data, water transports through major straits, chemistry and active and passive tracers

C. Participate in:
AOMIP virtual workshops and discussions and attend an annual workshop at WHOI to report on findings, discuss future experiments, prepare recommendations for the modeling community and decide on publications and future project developments

D. Prepare:
AOMIP reports, manuscripts for AOMIP special issues of peer-reviewed journals, talks at national and international meetings

E. Provide:
Consultations and recommendations to modeling groups, individual modeling projects, other MIPs on AOMIP experience and model results.

Note:
PIs from group "A" (see Table 1 below) use partial NSF support but most of the model experiments are done with support from other projects; PIs from group "B" use their own internal resources.

2. Future operational mode and work scope

2.1. Introduction and basic operations

A new operational mode will be developed during the next 3 years under the current project. The major idea of this operational mode is to establish a virtual international AOMIP institution as an umbrella for all arctic modeling activities listed above. Under the institutional umbrella the AOMIP will carry out the following operations:

- Perform the basic AOMIP activities described in section 1 and at AOMIP web site Transfer to the new operational mode, with a work scope as outlined below.

It is expected that after 3 years of reorganization activities, the AOMIP will be linked with many activities of regional climate models (CARCMIP), GCSMs, and IPCC efforts in Polar Regions and possibly will be renamed to "ARCtic System MIP" (ARCSMIP) and will focus on the modeling of specifics of arctic processes, their mutual coupling and model improvements.

2.2. AOMIP Departments

The virtual AOMIP departments are shown in the table below. These departments will operate under AOMIP coordination but will acquire funds from national and international agencies to support core activities, organize meetings, and publications. During transformation to the new operational mode some of these institutions (marked A) will receive financial support from NSF under currently funded project. It is expected that AOMIP activities will be recognized by both the international community and funding agencies and will keep this institution working based on multi-national financial support.

Table 1. List of AOMIP departments

Institute, PI(s)	Country	Abbreviation	Type
1. Arctic and Antarctic Research Institute, A. Makshtas	Russia	AARI	B
2. Alfred Wegener Institute, R. Gerdes and C. Koeberle	Germany	AWI	B
3. Florida State University, E. Chassignet and D. Dukhovskoy	USA	FSU	A
4. Geophysical Fluid Dynamics Laboratory, S. Griffies, M. Winton	USA	GFDL	B
5. Goddard Space Flight Center, S. Hakkinen	USA	GSFC	B
6. International Arctic Research Center, B. Hibler, G. Panteleev	USA	IARC	B
7. Institute of Marine Sciences, UAF, M. Johnson	USA	IMS	A
8. Institute of Ocean Sciences, G. Holloway	Canada	IOS	B

9. Jet Propulsion Laboratory, R. Kwok, A. Nguyen	USA	JPL	B
10. Los Alamos National Laboratory, E. Hunke	USA	LANL	B
11. Massachusetts Institute of Technology, C. Hill	USA	MIT	A
12. Naval Postgraduate School, W. Maslowski	USA	NPS	A
13. National Center for Atmospheric Research, M. Holland	USA	NCAR	B
14. National Oceanographic Center, Southampton, Y. Aksenov, K. Popova	UK	NOCS	B
15. New York University, D. Holland	USA	NYU	A
16. Norwegian Polar Institute, Ole Anders Nøst	Norway	NPI	B
17. Ocean and Atmosphere Systems, M. Karcher and F. Kauker	Germany	OASYS	B
18. Proudman Oceanographic Laboratory, M. Maqueda	UK	POL	B
19. Russian Academy of Science, Moscow, N. Yakovlev	Russia	RASM	B
20. Russian Academy of Science, Novosibirsk, E. Golubeva	Russia	RASN	B
21. Swedish Meteorological and Hydrological Institute, M. Meir	Sweden	SMHI	B
22. University College London, S. Laxon	UK	UCL	B
23. University of Massachusetts, Dartmouth, C. Chen	USA	UMAS	A
24. University of Washington, M. Steele, J. Zhang	USA	UW	A
25. Woods Hole Oceanogr. Ins, A. Proshutinsky, P. Winsor, A. Condron	USA	WHOI	A

2.3 New operational mode specifics and work scope

A. Legacy:

The major project work scope of AOMIP (scientific goals, objectives, activities and products) will remain without change. The only changes to be introduced are to the project operational mode, project participation conditions and funding principals.

B. Reorganization:

Reorganization will be the major change in the project operational activity. Reorganization will encompass all items described below (*C-F*) and here we describe our major approach and work scope in general.
(a) The first step in the AOMIP operational mode reorganization will be an AOMIP virtual meeting to approve all changes proposed here. The goals of this meeting will be to: (i) inform the community about the AOMIP reorganization and (ii) collect new ideas and recommendations for the reorganization effort. Following this meeting we will develop a multi-functional web site allowing virtual communications, data exchange, data collection, and model intercomparison. This web site will serve as an instrument to provide project management, resource distribution, coordination, meetings, etc. simulating activities of a real institution but virtually. Additional financial resources will be required to design, develop and support this web site. We will establish this web site at WHOI and at least 2 months of

salary support for a web designer/research specialist are needed. We will obtain these financial resources from the internal WHOI sources or from other funding agencies.

C. Institutionalization:

(a) We propose to implement the AOMIP institution under the SEARCH program to provide SEARCH with its own modeling component and encourage and provide the means for broad interaction between SEARCH and the modeling community. We have received a message from John Walsh (see below) which clearly indicates that the SEARCH "Understanding Change Panel, UCP" unanimously supports this idea and is ready to endorse AOMIP under the SEARCH umbrella. One of the major goals of the work with SEARCH will be identification of the main SEARCH themes which must be addressed by AOMIP. In particular, through interactions with the "Observational Panel" AOMIP will formulate major activities to identify the most effective sampling strategy (parameters, intervals, locations) for a developing Arctic Observing Network. This will be done via numerical experiments employing AOMIP models and under coordination with the observational community. Similarly, AOMIP will coordinate its work with "Understanding" and "Responding" panels. In this regard, we will begin discussions with SEARCH (J. Walsh) and the European project DAMOCLES (J. C. Gascard) leaders to hold a joint SEARCH/UCP-AOMIP-DAMOCLES workshop in the next year. An important goal will be to better define the role of models in understanding arctic climate change. We note that the Climate Process Team on Gravity Current Entrainment (CPT-GCE, http://cpt-gce.org/) has been an extremely effective framework to link process-oriented research and model development.

(b) Our new project web site will promote both individualization of institutional departments (scientific groups) showing their personal tasks, ideas, accomplishments and recommendations and also will enhance coordination among these departments via solving community tasks and testing important ideas which cannot be carried out by individual groups. Proshutinsky, together with the AOMIP deputy directors will be responsible for this work. No additional funding is requested for this work because coordination is already budgeted for Proshutinsky in the AOMIP current proposal.

D. Enhanced Collaboration:

In addition to the traditional AOMIP collaboration and coordination partly described above, we will carry out specific collaborative activities with modeling groups and communities dealing with global models. This will be done to implement AOMIP findings and recommendations into their work. This work will include the following scope of activities:

(a) Enhance international activity to encourage scientists from other countries to plan AOMIP activities listed above and include financial support for these activities in their proposals, e.g. participate in the AOMIP institution membership and work. We will organize annual international virtual conferences (AOMIP has experience in the organization of such meetings via e-mail, and we will follow the lead of ARCUS for example who have made recent progress in this area with live webcasts from forums, message boards etc.). Our new web site will allow us to do this effectively; all presentations, subsequent discussions and recommendations will be posted in the "conference room" directory. David Holland will be responsible for the organization of these meetings.

(b) Increased collaboration with basic IPCC modeling groups (like GFDL, NCAR, MIT, UK, Australia, etc.) to enhance discussions and implementation of AOMIP recommendations in model improvements for Polar Regions. This work will be done based on personal relations between the AOMIP group and modeling groups listed above and specifically based on experience of the AOMIP "global" modelers. We plan to organize at least one special section at the AGU Fall meeting in San Francisco specifically dedicated to this theme "Representation of Polar regions in global models". Eric Chassignet and Chris Hill will be responsible for this work.

(c) Promote discussions with observers to work jointly on model improvements, process studies, and process parameterizations. The work scope for these activities will be two-fold: (i) Direct involvement of observers in AOMIP projects encouraging validation of AOMIP models, analysis of model outputs and preparing joint publications where observational results will be analyzed and explained using modeling technologies; (b) Presentations and discussions of data and modeling problems at annual AOMIP meetings and invitation of representatives of the observing community to these meetings. A special session will be organized at the AGU or EGU meetings "Polar data and modeling: ways to improve data analysis via modeling and model improvements". Mark Johnson and C. Chen will be responsible for this work. No additional funds are requested for this work.

E. Outreach enhancement

In addition to the outreach plans described in our basic proposal, AOMIP will:

(a) Before or after the annual meeting organize 2-3 day summer schools for young investigators who will present talks and have time to establish connections and form collaborations. Holland and Steele will be responsible for this work,

(b) Organize thematic annual meetings with broad announcements on ArcticInfo, in EOS, and of course on the AOMIP Institutional Web site. This will include organizing meetings at different institutions in order to entrain new/young scientists and to allow attendance by people who would not otherwise attend annual meetings. Proshutinsky will be responsible for these activities.

(c) Publish semi-annual AOMIP electronic newsletters to inform the community about AOMIP findings and exchange experience among different groups. Discuss funding opportunities and encourage collaborations among groups. Proshutinsky and all deputy directors will be responsible for this work. Some additional funds are needed for these activities. These funds could be obtained by partially redistributing travel funds (summer schools) and partially involving a web site designer and support person (publication of newsletters).

F. Funding diversification

This is clearly outlined in the AOMIP proposal, “our approach is to leverage the existing financial support of each participant for a comparative analysis of different models and scientific results.” AOMIP collaborators represent different institutions and different countries and different funding agencies and carry out AOMIP studies mainly utilizing their own support. Our funding diversification strategy is the major principle of the AOMIP organization and it will continue to be an important part of the new project operational mode. The AOMIP will continue implementing this approach in the future and will enhance this mode involving fund-raising activities to facilitate institutional development and AOMIP performance. In particular, outstanding issues regarding AOMIP support will be discussed at AOMIP annual meetings and we will attempt to obtain direct support for AOMIP from NASA, NOAA, ONR, DOE, and foreign funding agencies. AOMIP administration and leaders of departments will be responsible for these activities. No additional funding from NSF is requested for this work.