Global Ocean-Atmosphere Prediction and Predictability (GOAPP) Milestones for Themes I and II

Revised to remove Richard Greatbatch from GOAPP.
Revised to add projects led by Aaron Berg and Jinyu Sheng.

This document lists the revised milestones for all GOAPP projects, taking into account the comments of the CFCAS review panel and the level of funding provided by CFCAS.

The main changes are (i) two projects have been deleted (following the recommendations of the review panel) (ii) the research will now take place over 4 years (rather than the five years in the proposal). Milestones for individual projects have been adjusted accordingly.

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Theme I: Days to Seasons

Sub-Theme I.1 Ocean Modelling and Data Assimilation

I.1.1 Suppression of Bias and Drift in Ocean Model Components

Co-Investigators **D. Wright**, K. Thompson
Collaborators Youyu Lu, E. Demirov, P. Myers

Specific Objectives:

- Implement and test the spectral nudging technique in the basin-scale and global ocean models developed in Theme I.
- Make the developments available to project I.1.4 on ocean hindcasting and forecasting using basin-scale and global models, and also to sub-themes I.2 and II.3.1 focused on coupled global atmosphere-ocean modelling and data assimilation.

Schedule and Milestones:

Year 1: Implement spectral nudging in basin-scale and global models and test that it works similar to expectations from previous work.

Year 2: Evaluate the need for and feasibility of developing extensions to include spectral nudging in the equatorial region (within a few degrees of the equator). Complete model developments and testing, and make the modified code available to other projects and sub-themes. This project will be largely completed in the second year, but evaluation of modifications suggested by other elements of the proposal will continue at a reduced level of effort.

I.1.2 Statistics of Observed Variability for Model Testing and Improvement

Co-Investigators **K. Thompson**, M. Foreman and E. Demirov
Collaborator D. Wright

Specific Objectives:

Use statistics describing the mean state of the ocean and its variability to test the realism of eddy resolving models of the North Atlantic and North Pacific, and improve the models and their forcing functions. The observed statistics are (i) the mean sea surface topography based altimeter data and the most accurate regional geoids available, (ii) variance and skewness of sea level measured by altimeters, and (iii) mean, variance and skewness of surface drifter velocities.

Schedule and Milestones:

Year 1: Collate mean and variability statistics for the North Atlantic. Undertake numerical experiments to test sensitivity to variations in a small number of controls for the North Atlantic (using a ¼ degree OPA configuration). Extend the forward and the tangent linear/adjoint models of Yaremchuk and Nachaev (simplified OGCM) to include bottom topography.

Year 2: Collate mean and variability statistics for the North Pacific. Undertake numerical experiments to test sensitivity to variations in a small number of controls for the North Pacific (using ¼ degree OPA configuration). Continue development and testing of the tangent linear/adjoint models and use them to gauge sensitivity of the spectral nudges in the North Atlantic to changes in a "large number of controls" including surface forcing, lateral boundary conditions and bathymetry.

Year 3: Complete tangent linear/adjoint model development and sensitivity studies of the North Atlantic and initiate improvements to the model formulation, parameterizations and forcing functions for the ¼ degree North Atlantic model. Use the adjoint model to gauge sensitivity of the spectral nudges in the North Pacific to changes in a "large number of controls" including surface forcing, lateral boundary conditions and bathymetry. Use results from direct sensitivity runs and adjoint model to initiate improvements to the ¼ degree North Pacific model.

Year 4: Evaluate improvements of the ¼ degree North Atlantic and North Pacific models in forecast mode and adjust as necessary. Convey findings to the R&D group supporting operational ocean modelling at CMC and help with the implementation of any improvements.

I.1.3 Multivariate Assimilation of Altimeter and Argo Data for Ocean Forecasting

Co-Investigators: E. Demirov, K. Thompson and M. Foreman

Specific Objectives:

- Determine means and error covariance structure of the altimeter and Argo data to be assimilated into the global and basin models using 3DVar.
- Test and compare performance of new assimilation schemes for altimeter and Argo profile data.

Schedule and Milestones:

Year 1: (i) Calculate the background error covariance for the auxiliary variables (ξ_D, ξ_T and ξ_S) using the ¼ degree North Atlantic model developed in project I.1.2. The covariances will be estimated using the new maximum likelihood approach. (ii) Use these covariances to assimilate Argo and altimeter data for the North Atlantic using the new auxiliary variable- based scheme. (iii) Implement the SEEK filter for the North Atlantic (building on the SAM2 code to be provided by Mercator).

Year 2: (i) Repeat steps (i), (ii) and (iii) from year 1 for the North Pacific. (ii) Continue assessment and improvement of the auxiliary-based assimilation scheme and SEEK filter applied to the North Atlantic. (iii) Assess the impact of better regional geoids, and other improvement stemming from project I.1.2, on the assimilation of altimeter and Argo data.

Year 3: (i) Assess performance of the auxiliary-based assimilation scheme and SEEK filter applied to the North Pacific. (ii) Compare performance of the auxiliary-based assimilation scheme and the SEEK filter with those used in existing operational centers. (iii) Combine the strengths of the auxiliary and SEEK based approaches in a new hybrid scheme.

Year 4: Evaluate new hybrid assimilation scheme in forecast mode in North Pacific and North Atlantic. Convey findings to the R&D group supporting operational ocean modeling at CMC for implementation there.

I.1.4 Ocean Reanalysis and Forecasting

Co-Investigators **D. Wright**, E. Demirov, M. Foreman, M. Stacey
Collaborators Y. Lu, I. Yashayaev, K. Thompson

Specific Objectives:

- Test the ability to hindcast and forecast variability in ocean conditions using the OPA model with various forms of data assimilation, including those developed in I.1.1-3.
- Use embedded finer resolution sub-domains in a NA basin model to investigate the possibility of improving specific aspects of model results through improved resolution in critical regions.
- Investigate the causes of variability where good agreement with observations is found.
- Provision of a test-bed and conduit for model improvements into the global coupled system for Theme I and, ultimately, to the operational coupled system.

Schedule and Milestones:

Years 1-2

- Implementation of global and basin-scale models. The global model will have a nominal horizontal resolution of 1 degree while the basin scale models will have nominal horizontal resolution of ¼ degree.
- Implementation of basic spectral nudging code in the OPA model.
- Perform initial prognostic ocean-only simulation covering the ECMWF reanalysis period using the 1 degree global model.

- Comparisons of prognostic model results with previous work in the North Pacific and the North Atlantic.
- Development of embedded finer resolution sub-domains for the regions around Cape Hatteras and the Grand Banks of Newfoundland.

Years 2-3

- Initial global (1 degree) simulation with spectral nudging included.
- Assess the influence of spectral nudging on basin-scale circulation and watermass properties.
- Inclusion of the "Neptune effect" in the OPA code and examination of influence on watermass properties. Does this reduce the need for spectral nudging?
- Evaluation of the need for spectral nudging to be extended into the equatorial region.
- Initial evaluation of the effects of embedded sub-domain(s) in the NA basin model.
- Provide current best estimate of ocean state to other GOAPP investigators.

Years 3-4

- Complete the evaluation of model results with and without embedded sub-domains.
- Perform ocean reanalyses and forecasts with data assimilation included.
- Evaluate the improvements over the results without data assimilation and make recommendations for inclusion in the CMC operational system.
- Examine dynamics of events that are well-represented by the model.
- Provide current best estimate of ocean state to other GOAPP investigators.

I.1.5 Modelling and Assimilation of Sea Ice

Co-Investigators: **P. Myers**, E. Demirov
Collaborators: M. Buehner, Y. Lu, T. Carrieres, A-M Treguier, G. Flato

Specific Objectives:

- Develop a version of the OPA coupled sea-ice ocean model for the North Atlantic incorporating data assimilation (both on the ocean and sea ice components)
- Validate the data-assimilative coupled ice-ocean model against observed sea-ice measurements and existing models used operationally
- Examine the representation of freshwater content and fluxes in a coupled sea-ice/ocean system with sea-ice assimilation.

Schedule and Milestones:

Year 1: Implementation and initial testing of assimilation routines in coupled ice-ocean OPA model.

Years 2-3: Evaluation of the coupled model with ice and ocean data assimilation, and comparison of different assimilation schemes.

Years 3-4: Further improvement and refinement of assimilation schemes; experiments with assimilating data into only one component of the coupled system; impact of improved sea-ice representation on the cross-shelf fluxes of freshwater and the hydrographic properties of the Labrador Sea.

I.1.6 Assessing the Capability of a Nested-Grid Shelf Circulation Model for the Eastern Canadian Shelf

Co-Investigators: **Jinyu Sheng**
Collaborators: D. Wright, K. Thompson, D. Brickman, Y. Lu, H. Ritchie

Specific Objectives:

- Develop a high-resolution (1/12 degree) shelf circulation model for the Eastern Canadian Shelf and embed it within a ¼ degree North Atlantic Ocean model developed by Theme I GOAPP researchers. The embedding will be achieved using a one-way nesting technique based on the semi-prognostic method developed by the applicant.

- Quantify the change in skill of the shelf model that results from nesting shelf model within the deep ocean model. The metric used to assess the model skill will focus on sea level, circulation and water mass changes on timescales of days to seasons. The model will be run in hindcast mode and the surface atmospheric forcing will be based on the best available analysis fields.

Schedule and Milestones:

Year 3: Complete development of a 1/12 degree regional shelf circulation model for the eastern Canadian shelf based on NEMO. The nested-grid ECS model will be run in hindcast model and forced by realistic astronomical and meteorological forcing.

Year 4: Couple the high-resolution ECS circulation model to the 1/4 degree North Atlantic circulation model and assess the capability of the nested-grid shelf circulation model in simulating circulation and temperature/salinity distributions on the ECS at timescales of days to seasons.

Sub-Theme I.2 Coupled Atmosphere-Ocean Modeling and Data Assimilation

I.2.1 Independent Assimilation into Coupled Models

Co-Investigators: **P. Gauthier**, H. Ritchie

Collaborators: E. Demirov, D. Wright, S. Bélair, P. Pellerin, F. Saucier, K. Thompson

Specific Objectives:

- Initially to achieve improvements in both atmosphere and ocean forecasts when driven by "off-line" analyses produced by uncoupled data assimilation cycles of the other component (this will provide benchmarks for examining the details of coupling behavior)
- To further improve atmosphere and ocean forecasts when the component models are coupled together during assimilation cycles, but not within the analysis step
- To provide coupled atmosphere-ocean fields from coupled atmosphere-ocean hindcast for sub-periods of 1993-2005, to be used in project I.2.2.

Schedule and Milestones:

Years 1-2:
- Perform atmosphere only data assimilation and medium range forecasts for periods during the ocean-only forecast being done in I.1.4.
- Establish atmospheric verification metrics to be used throughout this project.
- Use forcing fields from year 1 to drive the global ocean model and assimilation system.
- Compare results with those of I.1.4 using NCEP forcing.
- Establish ocean verification metrics for use throughout this project

Years 3-4:
- Redo analyses and medium range forecasts using independent assimilation.
- Compare results with those from steps above.
- Perform initial coupled system hindcasts for sub-periods of 1993-2005.
- Examine how the sensitivity to observations is affected by marine boundary layer parameterizations.

I.2.2 Exploratory Studies on Joint Assimilation into Coupled Models

Co-Investigators **H. Ritchie**, P. Gauthier
Collaborators E. Demirov, D. Wright, Y. Tang, K. Thompson, Wm. Merryfield

Specific Objectives:

To conduct exploratory studies to examine the use of atmosphere-ocean cross-correlation functions during the analysis step, i.e., joint atmosphere-ocean data assimilation.

Schedule and Milestones:

Years 1-2:

- Conduct diagnostic evaluation of atmosphere-ocean cross correlations based on long CGCM coupled run from project II.1.1 as outlined above.
- Set up and evaluate the coupled atmosphere-ocean modelling system consisting of the GEM atmospheric model and simplified ocean model. Perform the control simulation of the twin experiment and extract "synthetic observations" from both the atmosphere and ocean.

Years 3-4:

- For the simplified coupled system, use the "NMC method" to determine atmosphere-ocean "cross-correlation" and perform joint coupled assimilation of various combinations of synthetic observations from the atmosphere and/or ocean and evaluate the impact of cross-medium observations on the accuracy of the forecasts in each medium.
- Examine predictability as a function of variable, time-scale, season and region, in comparison with outputs from I.2.1.

I.2.3 Simulation and Prediction of Variability Using a Coupled Tropical Pacific Global Atmosphere Model (Project removed)

Theme II: Seasons to Decades

Sub-Theme II.1 Analysis and Mechanisms

II.1.1 Tropical Modes: El Niño-Southern Oscillation and Madden-Julian Oscillation (Project removed)

II.1.2 Pacific Decadal Oscillation and Northern Annular Mode

Co-Investigators **J. Fyfe**, J. Derome, Wm. Merryfield
Collaborators B. Yu, G. J. Boer, H. Lin

Specific Objectives:

To understand and improve the representation of the dominant large-scale modes of tropical/extratropical variability in the CCCma coupled climate model (primarily), with a particular focus on the role these modes play in enhancing or limiting predictive skill at various time scales in the Northern Hemisphere.

Schedule and Milestones:

Years 1-2:

- Data collection to include observations, CCCma coupled model control simulations and a multi-model ensemble of results from IPCC models contributing to the AR4.
- Careful analysis and documentation of model behavior and errors in the simulation of mean climate and in the simulation of the key modes of Northern Hemisphere tropical/extratropical variability in the ensemble of model results, including the behavior of the "mean model".

Years 3-4:

- Investigate particular process affecting the key modes of Northern Hemisphere tropical/extratropical variability.
- Identify common deficiencies in the representation of the modes in the ensemble of model results and attempt to ascribe them to common model features.
- Guided by these results, to perform predictability experiments focusing on the predictability of the modes themselves.

Sub-Theme II.2 Predictability of the Coupled System

II.2.1 Potential Predictability of Current and Future Climates

Co-Investigators **G.J. Boer**, Wm. Merryfield
Collaborators S. Kharin, T. Murdock

Specific Objectives**:**

- Undertake a multi-model diagnosis of potential predictability of present-day climate using coupled climate model output (including that of CCCma CGCM3) submitted to IPCC Fourth Assessment.
- Extend the diagnostic study of potential predictability to include effect of climate change.
- Quantify regional influences on predictability in integrations in which ocean feedbacks are suppressed in key regions such as the tropical Pacific, the North Pacific, and the North Atlantic.

Schedule and Milestones:

Years 1 and 2: Collect data from IPCC data archive for multi-model potential predictability calculation for control and climate change simulations, transform to common grid, and perform multi-model potential predictability analysis.

Years 3 to 4: Undertake to identify regional ocean influences on predictability on a range of time-scales using methods such as “coupling surgery” guided at least in part by the results of the multi-model potential predictability study.

II.2.2. Prognostic predictability from ensembles of coupled model simulations

Co-Investigators **Wm. Merryfield**, G.J. Boer
Collaborators H. Lin

Specific Objectives:

- Obtain measures of prognostic predictability through “perfect model” predictability experiments based on large ensembles of coupled model integrations
- Investigate influence of initial climate regime on seasonal-to-decadal predictability

Schedule and Milestones:

Year 1: Set up computational machinery for constructing and running large ensembles for “perfect model” experiments. Begin computing large ensemble of 10 year runs starting from neutral ocean initial conditions.

Year 2: Complete computation of large ensemble of 10 year runs starting from neutral ocean initial conditions, continue subset of these runs to 50 years. Develop diagnostic tools and carry out analyses of prognostic predictability in these ensembles.

Year 3: Prepare publication on large ensemble results. Prepare initial conditions for regime-dependent, perfect model ensembles. Begin computations of these ensembles.

Year 4: Complete computation of regime-dependent perfect model ensembles, carry out prognostic predictability analyses. Prepare publication on regime dependence of seasonal to decadal predictability.

Sub-Theme II.3 Prediction

II.3.1 Coupled Model Initialization

Co-Investigators **G. Flato**, Wm. Merryfield
Collaborators J. Scinocca, Y. Tang, D. Wright

Specific Objectives:

- Investigate and implement several relatively simple ocean initialization schemes in a global coupled model.
- Evaluate the relative merits of these methods in terms of the realism of initialization products, the severity of initial "coupling shock", and the skill of bias-corrected coupled forecasts.
- Having established the fidelity of the methods and optimized them, to use them as a basis for generating an ensemble of initial conditions for the CHFP

Schedule and Milestones:

Year 1: Continue nudging experiments and test forecasts, following on from CliVar activity. Begin assembling 3-D data sets and initiate collaborative work on 2D-Var method.

Year 2: Analyze test forecasts made with nudging scheme; prepare paper on initial results. Begin experiments with 2D-Var method. Begin implementing sub-sea extension of SST assimilation. Consider atmospheric initial states constrained by analyses, assess impact on forecast skill.

Year 3: Develop an initial ensemble of ocean and atmosphere initial conditions for use in the CHFP (II.3.2). Continue experiments, analysis and skill assessment of model versions using variational assimilation schemes. Implement SLP assimilation. Prepare papers on variational schemes and their results.

Year 4: Begin using other assimilation schemes to provide ensemble initial conditions for the CHFP (II.3.2). Continue analysis and optimization of assimilation schemes implemented in latest version of CCCma coupled model.

II.3.2 The Coupled Model Historical Forecasting Project

Co-Investigators:	**G.J. Boer**, J. Derome, Wm. Merryfield, G. Flato
Collaborators:	J. Scinocca, B. Archambault, M.-F. Turcotte, H. Lin and Y. Tang.

Specific Objectives**:**

- Produce a sequence of retrospective multi-seasonal ensemble forecasts using the CCCma coupled atmosphere-ocean-land-ice model and to extend a subset of these forecasts to the decadal range.
- Investigate methods of generating ensembles of initial conditions and of forecasts, possibly including multi-analysis and multi-model approaches.
- Obtain basic skill measures of multi-seasonal forecasts produced in this way and some insight into the possible utility of predictions at longer times.
- Analyze and identify, to the extent possible, those aspects of the forecast system that impact on predictive skill.

Schedule and Milestones:

Years 1 and 2: Initial forecast experiments to assess and refine the CHFP approach to be adopted including ensemble generation, data assimilation, forecast production and initial verification methods.

Years 2 to 4: Initial decadal forecast experiments using a range of initialization methods plus forecasts of natural and anthropogenic forcing. Production of CHFP seasonal forecasts with careful quality control, data archiving, and assessment/verification. Results provided to CMC and to the COPES TFSP.

Years 4: Complete CHFP to the present if possible. Ongoing quality control and verification. Analysis of CHFP results. Participate in COPES TFSP analysis of current abilities in SIP. Provide forecast system to CMC for operational purposes if results warrant.

II.3.3 Forecast Combination, Calibration and Verification

Co-Investigators	**J. Derome** , G. J. Boer and W. Hsieh
Collaborators	S. Kharin, A. Shabbar , H. Lin and Y.Tang

Specific Objectives:

- Comprehensive and sophisticated analysis of the skill of CHFP forecasts at time scales of interest including the geographical distribution of skill and the connection to known dynamical modes.
- Development of sophisticated post-processing methods to improve skill of global coupled model forecasts including the development of probability forecasts and their calibration in single- and multi-model ensemble settings.
- Assessment of potential economic value in a cost-lost decision framework.

Schedule and Milestones:

Most of the tasks outlined above rely on the availability of the CHFP forecasts. Therefore, the schedule should be synchronized with II.3.2.

Year 2: Evaluate the true predictive skill of CCA forecasts in multi-century simulations with CGCM3 and other global climate models. Test post-processing techniques on available seasonal dynamical forecasts with the aim of improving their skill.

Year 3: Perform an initial skill analysis of CHFP forecasts.

Year 4: Test various skill improvement and calibration techniques as restricted time permits.

II.3.4 Sensitivity of Seasonal Climate Forecasts in the CCCma GCM to Initialization of Land Surface Hydrological States

Co-Investigators **A.Berg**
Collaborators G.J, Boer, Wm. Merryfield, V. Arora, S. Kharin

Specific Objectives:

To characterize the importance of accurate specification of the land surface hydrological state for seasonal prediction, with a particular focus on land surface initialization for drought prediction.

Schedule and Milestones:

Year 2: Adapt the Berg et al. (2005) hydrometeorological forcing data and perform offline simulations of the CLASS to produce initial hydrological states. An assessment of the realism of the initial states will be undertaken.

Year 3: Using the derived initial hydrological states, perform the drought sensitivity experiment to identify the sensitivity of the CCCma coupled GCM to this information for drought prediction.

Year 4: Perform a long-term retrospective forecast experiment in order to evaluate the sensitivity of the forecast system to the initialization of the land surface hydrology. Analyze the results in terms of changes to forecast skill of temperature and precipitation and in terms of the land/atmosphere mechanisms involved.